EIRLSBN: Twenty years of achievements in rice breeding

Edited by
B.C.Y. Collard,
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and B. Hardy

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IRRI

INTERNATIONAL RICE RESEARCH INSTITUTE

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Contents

Foreword

Eastern India is an area with a largely agrarian society and high poverty incidence. Rice is the dominant crop, but yields are low. Most of the rice is grown under rainfed conditions in which rainfall is highly unpredictable, and numerous abiotic and biotic stresses occur in combination during all growing seasons. Farmers have limited access to inputs such as fertilizer and good-quality seed. Despite these challenges, a progressive increase in rice production must be maintained, especially within the vast rainfed areas, if India and other Asian countries are to achieve food security.

Considerable progress has been made in developing new rice varieties for eastern India, although the literature on this topic is limited. Evidence for this is the development and release of many new improved varieties. At least 20 of these varieties have been released within the Eastern India Rainfed Lowland Shuttle Breeding Network (EIRLSBN). In addition to producing new varieties, this network has conducted considerable research on many high-priority traits and has identified new donor parents, key maturity groups for the region, elite lines that can be transplanted at normal or delayed times, and target variety profiles for eastern India. More importantly, the network has been an exemplary model for synergistic rice breeding partnerships. It demonstrates the benefits of regional and international scientific collaboration for working to overcome food insecurity. Indeed, it has influenced the formation and structure of many other breeding networks.

The EIRLSBN has now been in operation (in various forms) for more than 20 years and it has been a "quiet achiever." Therefore, it is high time that the history and accomplishments of this successful breeding network be formally documented, especially for the sake of the next generation of breeders and rice scientists. In the context of a rapidly rising population in India, decreasing land availability for rice production, and expected adverse effects from climate change, it is critical that the progress made by the network continue and proliferate in the decades to come. I congratulate the members of the EIRLSBN in commemorating their 20th anniversary, and I wish them further success in the future.

Robert S. Zeigler
Director General

Dedication

This book is dedicated to the late Dr. Sukumar Mallik (1955-2008).

Dr. Mallik was a distinguished rice breeder and scientist based at the Rice Research Station, Chinsurah, West Bengal, which he joined in 1978. As a founding member, he was one of the pioneers of the Eastern India Rainfed Lowland Shuttle Breeding Network (EIRLSBN), and was a key contributor to its success. He made an outstanding contribution to rainfed rice breeding in eastern India. He developed 16 varieties for upland, shallow, semideepwater, and deepwater areas that were released through a State Variety Release Committee or Central Variety Release Committee. One of his varieties, Sabita, is still the predominant variety in the rainfed lowland ecosystem in West Bengal, and it has been used as a national check variety since 1998. It is also popular in Odisha and Assam, and many breeders in India and abroad have used Sabita as a donor. Purnendu and Dinesh have also been national check varieties for the All India variety trials since 1999.

Another highlight was the development of breeding material adapted to stagnant flooding, a key trait for the region. Indeed, Dr. Mallik was one of the first scientists to describe stagnant flooding as an important trait. He published more than 150 articles in national and international journals or book chapters, including several seminal articles regarding rainfed rice breeding research (especially regarding stagnant flooding and on the EIRLSBN) that are very important today. He was a member of the Executive Council for the journal *Oryza*, and a regular reviewer for the journal since 1991, and for *Current Science* since 2006.

He was the recipient of many awards and distinctions. In 1985, he received the Young Scientist Award at the Indian Science Congress from the Indian Science Congress Association for the work “Breeding strategy for rainfed lowland rice.” He visited Thailand, India, and Bangladesh as one of the monitoring team members (International Rice Testing Program/United Nations Development Programme) in 1985, and actively participated in the International Deepwater Rice Workshop in Bangkok in 1987. In 2004, he received the prestigious Senadhira Award for lowland rice breeding, in the International Year of Rice, at the World Rice Research Conference in Tsukuba, Japan.

He is still fondly remembered during the annual shuttle breeding meetings held at CRRI, Cuttack.

Overview of and historical perspectives on the EIRLSBN

D.J. Mackill, B.C.Y. Collard, G.N. Atlin, A.M. Ismail, and S. Sarkarung

Background

The earliest breeding work at the International Rice Research Institute (IRRI) focused on the irrigated environments where quicker gains were expected. The results were spectacular and triggered the Green Revolution through the development and release of high-yielding semidwarf rice varieties (Khush 1999). This early success was limited to areas where irrigation was available or rainfall was sufficient to assure limited exposure of plants to water stress and to allow extensive use of inputs, including chemical fertilizers. However, beginning in the early 1970s, breeding for rainfed rice environments became an important priority. This started through IRRI's Genetic Evaluation and Utilization (GEU) Program, in which thousands of accessions from the collections in the IRRI Genetic Resources Center were screened for tolerance of various abiotic stresses through this program, including around 18,000 accessions evaluated under submergence and deepwater conditions (Khush and Coffman 1977). Subsequently, breeding programs were started on upland, rainfed lowland, and deepwater rice, with an emphasis on developing varieties tolerant of these abiotic stresses. These breeding programs also targeted a taller plant type than the typical semidwarf plant type developed for the irrigated environments.

From its beginning, the rainfed lowland breeding program at IRRI worked in collaboration with national agricultural research and extension system (NARES) partners in South and Southeast Asia. This usually involved sharing of advanced lines and segregating populations with breeders who were interested in obtaining new materials. F_2 populations provided a useful source of variability for breeders to select from under their local conditions, and several varieties were eventually released from these populations.

An early program for shuttle breeding started in 1982 in collaboration with the Rice Department of Thailand. In this program, crosses were made between Thai varieties and breeding lines with donors for specific traits such as high grain yield and tolerance of drought or submergence. In Thailand, the segregating populations were grown at six sites in the northeast and selected for local adaptation, and selections were advanced in the off-season nurseries at IRRI with minimal selection and screening for grain type and disease resistance. Anecdotal evidence suggests that this was an effective selection environment because numerous lines identified in this program were later released as varieties. These are recognized by the three-letter abbreviation of the Thai research stations in the IR designation (Chupae—CPA; Khon Kaen—KKN;

Surin—SRN; Ubon Ratchatani—UBN; Pimai—PMI; Sakon Nakorn—SKN). Some examples follow:

- IRRI 119 (IR57515-PMI-8-1-1-SRN-1-1), released as PSB Rc68 in the Philippines, and Ematta Latt in Myanmar.
- IR70213-9-CPA-12-UBN-2-1-3-1, released as INPARA 3 in Indonesia.
- IR43069-UBN-507-3-1-2-2, released as Thadokkham 1 (TDK1) in Laos.
- IR77924-62-71-1-2, released as RD 33 in Thailand (an aromatic, photoperiod-insensitive, and blast-resistant variety; alternative to KDML105).

This form of intense shuttle breeding was not readily sustainable due to increasing difficulties in moving seed across international borders, especially in the recent past, when countries became more protective of their germplasm resources. However, this did highlight the lack of arrangements for off-season nurseries in many rainfed areas, although such nurseries were technically feasible. A good example of the effective use of off-season nurseries is the Chinese program based on the southern island of Hainan, which services breeding stations throughout China. Off-season nurseries and the ability to make a large number of crosses are still constraints for many breeding programs in the region.

Research on rainfed lowland rice was strengthened in 1989 with the development of the programmatic structure at IRRI based on ecosystems. The rainfed lowland program included scientists from various disciplines, in particular plant breeding, agronomy, crop physiology, pest management, and social sciences. The research was first reported under the rainfed lowland program in the 1989 Program Report of IRRI (IRRI 1990). To facilitate the research work on rainfed lowland systems, IRRI and NARES formed the Rainfed Lowland Rice Research Consortium (Zeigler 1999). This later evolved into the Consortium for Unfavorable Rice Environments (CURE) in 2002, which combined work on upland, rainfed lowland, and deepwater rice (including salt-affected soils) into a single consortium structured in specific working groups focusing primarily on major abiotic stresses (drought, submergence and flood-prone, salinity/alkalinity, and other soil problems) and uplands.

Formation of a shuttle breeding network for eastern India

The Eastern India Rainfed Lowland Shuttle Breeding Network (EIRLSBN) was formally established in 1991 as an Indian Council for Agricultural Research (ICAR)-IRRI collaborative program. This program was funded by IRRI and was jointly coordinated by the Central Rice Research Institute (CRRI), Cuttack, and IRRI (Mallik et al 2002). CRRI was selected to represent flood-prone breeding environments and typical rainfed environments in eastern India, Bangladesh, and Cambodia (Sarkarung 1995). Initially, six centers in Assam, Bihar, Chhattisgarh, eastern Uttar Pradesh, Odisha, and West Bengal made up the network, but it subsequently expanded to include additional centers. For Odisha, Bihar, and Assam, two breeding centers were established within each state due to their diverse rice ecosystems.

The shuttle breeding concept was inspired by the International Maize and Wheat Improvement Center's wheat breeding progam, initiated by Nobel laureate Dr. Norman Borlaug. This system involved two contrasting field locations in Mexico (Ciudad Obregón and Toluca), which differed in rainfall pattern, temperature, elevation, and biotic factors, to screen breeding material so that two generations of wheat were grown each year. That breeding material was also screened against a broad range of different diseases and environmental conditions (Ortiz et al 2007). The result was the development of broadly adapted breeding lines with resistance to stem rust and other diseases.

Unfortunately, the external funding available to the network has been highly variable. Despite this, the breeders struggled to ensure that the core activities continued during the years of reduced funding. Starting in 2008, the network received funding from the STRASA (Stress-Tolerant Rice for Africa and South Asia) project, supported by the Bill & Melinda Gates Foundation. Currently, the network includes nine centers that represent different rice production environments in the region.

The network has historically focused more on submergence-prone, semideep environments, but the initial version of the network, although it included upper toposequence fields at Raipur, never stressed selection of drought-tolerant materials because only one drought-prone site was included, and the data were analyzed across deepwater and shallow-water sites. Several other breeding networks were influenced by the formation of the EIRLSBN. Similar networks on upland rice and drought began in 2002 and 2004, respectively, that were affiliated with the drought breeding program at IRRI, and the salinity breeding network started with the inception of the STRASA project in 2008. The upland rice shuttle breeding network is a network of about nine upland rice sites, for unbunded upland fields. The IRRI-India drought breeding network focuses on the very large area of bunded upper fields that are usually transplanted or managed by beushening, and that are prone to drought. Both the upland and drought networks were offshoots of the EIRLSBN and the Consortium for Unfavorable Rice Environments (CURE). The important variety Sahbhagi Dhan (IR74371-70-1-1) was identified through the drought breeding network. Thus, the EIRLSBN has been a highly influential model for the other more recently established breeding networks.

Activities and achievements

A major activity of the EIRLSBN has been germplasm development, exchange, and joint selection of segregating breeding material (Fig. 1). In order to broaden the genetic base of breeding programs, many of the traditional varieties such as Sabita, Rajshree, and Safri 17 from eastern India were used for crosses when the shuttle breeding program started. The main objective was to develop a broad range of new breeding lines that were suitable for the diverse rice ecosystems in this region. During the earlier stages of the network, and when timely exchange of germplasm across countries was feasible, segregating material used to be generated at IRRI and in Thailand and sent to participating institutions for advancement and further selection. This allowed the development of site-specific varieties adapted to local conditions and biotic/abiotic factors. However, as the movement of germplasm became more difficult, this activ-

Fig. 1. Breeders making selections during the annual meetings at CRRI: (A) November 2011 and (B) November 2012.

ity was decentralized by having most of the crosses made at CRRI for sharing of segregating material, while material from IRRI was shared as fixed lines. Typically, an annual meeting is held in India during which breeders participate in joint selection activities, and exchange ideas and discuss any relevant breeding matters. In the early years, a field tour to key sites was conducted for breeders to evaluate and select breeding materials likely suited to their own regions and conditions. Overall, IRRI has played an important organizational and advisory role in close collaboration with the program coordinator at CRRI (Reddy et al 2013).

Another important activity has been the free exchange of elite breeding lines or donor parents. Each year, the best entries from each center in eastern India and IRRI are included in a coordinated observational yield trial in which the same set of material (usually a total of approximately 100 entries) is tested at each site. The most promising lines are promoted to an advanced yield trial, which usually contains 20–25 entries. The most promising elite lines are then tested in on-farm or participatory varietal selection (PVS) trials. The Sub1 varieties developed for eastern India have also been tested in on-farm trials within the network (Reddy et al 2013).

In recent years, the experimental design of the trials has been prepared by an IRRI database specialist based in India, and the data are analyzed centrally and distributed to all partners. The results are reviewed at the annual planning meeting held before the planting season, usually in March or April. During the planning meeting, the participants decide which lines to advance for further testing (from the observation nursery to the yield trial or from the yield trial to PVS trials).

During the past 20 years, the EIRLSBN has made several notable achievements:

- The release of at least 20 varieties for eastern India.
- The production of hundreds of advanced breeding lines.
- The identification of three distinct maturity groups for states within the region.
- The development of elite breeding lines suitable for normal and delayed planting conditions.
- A compilation of target traits for the region.

Less tangible outputs are the interactions among breeders, physiologists, pathologists, socioeconomists, and other scientists due to the collaborative spirit of the participants made possible by the network. The network has also provided a framework for the efficient coordination and continuity of breeding efforts in the region and related research activities. Last but not least, the network has provided an invaluable support group for new scientists to join and young breeders to be trained. This has become even more important as the next generation of breeders is being trained while senior breeders are retiring.

The EIRLSBN has operated on the basis of free exchange of germplasm developed by the Indian partners and by IRRI, with the ultimate goal of helping the poorest farmers in the region. One of the future challenges is how to maintain this mode of collaboration in view of increased interest in the protection of germplasm and commercialization of seed distribution by publically funded breeding programs. Maintaining strong financial support for the network and its partners is also a continuing difficulty.

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Notes

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Rice breeding and an overview of the EIRLSBN at the coordinating center, CRRI, Cuttack

J.N. Reddy, R.K. Sarkar, and S.S.C. Patnaik

In India, rice is the staple food of the country, occupying 41.9 million ha, with a total production of 144 million tons (2010), with an average yield of 3.4 t/ha. Eastern India, comprising the states of Odisha, West Bengal, Bihar, Assam, Chhattisgarh, and eastern Uttar Pradesh, has a total rice area of 26.8 million ha, of which nearly 14.0 million ha are under rainfed lowlands. Rice area, production, and yield under different rainfed lowland rice ecosystems are presented in Tables 1 and 2. In Odisha, rice is the major food crop, covering more than 70% of the cultivated area and about 63% of the total area under food grains. Odisha's share in the country's rice production was more than 11% in the pre-high-yielding varieties (HYVs) era, which gradually declined to 7.9% in 2009-10. Rice is now grown over an area of 4.41 million ha, with total production of 6.94 million t. In Odisha, about 65% of the area is under rainfed rice, of which 52% is rainfed lowlands.

Rainfed lowlands

Surface-water hydrology in the cropping season had been taken as the main criterion for the classification of lowlands into different ecosystems. Starting with Khush (1984), most researchers had classified rainfed lowlands into four categories: shallow (0–30 cm), semideep (30–50 cm), deep (50–100 cm), and very deep (>100 cm). However, the depth of water proposed by various workers for each category differed in most cases. Since there is no unanimity in accepting any of the proposed classifications, it is desirable to specify water depth along with the ecosystem to avoid confusion in the nomenclature.

Scope for further improving productivity through better management is limited in the rainfed lowlands. Varietal improvement remains the main strategy to start with for improving production and productivity in this ecosystem. However, until recently, efforts for improving genetic yield potential of rainfed lowland rice remained confined to favorable lowlands, leaving the unfavorable lowlands for traditional agriculture, that is, using traditional methods and local varieties (Mallik et al 2009).

Varietal improvement

Until the 1950s, most of the rice varieties developed in different states of India were mostly pure-line selections from indigenous cultivars, exploiting genetic gains avail-

Table 1. Area, production, and yield under different rainfed lowland rice ecosystems.

Rice ecosystem	Area		Production		Yield (t/ha)
	Million ha	%	Million tons	%	
Drought-prone	4.0	9	6.0	7	1.5
Favorable	3.0	7	6.0	7	2.0
Stagnant flood-prone (medium/ semideep, waterlogged)	3.0	7	2.5	3	0.8
Submergence-/flood-prone	3.0	7	1.5	2	0.5
Subtotal (rainfed)	13.0	29	16.0	19	1.2
Deepwater	3.0	6	2.5	3	0.8
Floating rice	1.0	2	0.5	1	0.5
Subtotal (deepwater)	4.0	9	3.0	4	0.8

Table 2. Rice area (million ha) in different environments in eastern India.

State	Irrigated	Upland	Rainfed lowland		Deepwater	Very deep water	Total
			0–30 cm	30–50 cm	(50–100 cm)	(>100 cm)	
Assam	0.2	0.2	0.9	0.5	0.4	0.1	2.3
Bihar	1.5	0.5	1.7	0.5	0.4	0.7	5.3
Odisha	1.1	0.7	1.7	0.5	0.4	0.1	4.5
Chhattisgarh	0.6	1.3	2.7	–	–	–	4.6
Uttar Pradesh	1.0	0.7	1.9	0.3	0.2	0.5	4.6
West Bengal	1.3	0.9	1.7	0.5	0.4	0.7	5.5
Total	5.7	4.3	10.6	2.3	1.8	2.1	26.8

able in original populations. Many landraces selected by farmers for local adaptations were also grown in different lowland situations. These varieties were mostly tall, susceptible to lodging, and photoperiod sensitive, and had low yield potential.

During these early years, no rice variety could be identified that had been specifically bred for the rainfed lowlands of India. Mahsuri, an intermediate-stature, weakly photosensitive variety with short dormancy, was an introduction from Malaysia (Mayong Ebos 80/Taichung 65//Mayong Ebos 80). This variety was developed through the japonica × indica hybridization program started in 1952, and it was widely cultivated in the shallow and intermediate lowlands of Andhra Pradesh, Bihar, Assam, West Bengal, and Odisha. The most significant breakthrough in the varietal development program for shallow lowlands was the development of Jagannath and Pankaj in 1969. These three varieties (Pankaj, Jagannath, and Mahsuri), increasingly being used in breeding programs, subsequently led to the development of promising shallow lowland varieties such as Savitri, Dharitri, Mahalakshmi, and Gayatri.

In semideepwater lowlands, farmers grow either indigenous tall varieties with photosensitivity and late maturity or their improved pure-line selections. Local flood-/submergence-tolerant varieties such as Khajara, Dhusara, and FR13A have been used either directly (pure-line selection) or in hybridization programs. In general, these varieties are well adapted to stagnant flooding (waterlogging/semideep) and monsoon growing conditions, but they often lodge badly because they have weak culms. CRRI has developed many varieties and released them for different lowland situations in Odisha (Table 3). However, most of these varieties do not have adequate tolerance of typical lowland stresses such as submergence, early vegetative-stage and reproductive-stage drought, and stagnant flooding. Furthermore, most varieties are photoperiod insensitive, but photoperiod sensitivity is desired, and they do not possess cold tolerance during flowering. Therefore, current breeding efforts are directed toward incorporating tolerances of these stresses into new breeding lines.

Priorities and current constraints

Low productivity in the rainfed rice ecosystem is due to several biotic and abiotic constraints. The following are some of the traits needed to overcome these constraints limiting rice production in Odisha/eastern India:

1. Submergence tolerance for more than 2 weeks
2. Drought tolerance at the vegetative and reproductive stages
3. Tolerance of stagnant flooding
4. Tolerance of various soil problems (e.g., iron toxicity, zinc deficiency, salinity)
5. Resistance to stem borer, swarming caterpillers, cutworms, etc.
6. Resistance to common diseases such as bacterial blight, sheath blight, sheath rot, etc.
7. Photoperiod sensitivity
8. Adequate seed dormancy
9. Good grain quality

Table 3. Varieties released by the Central Rice Research Institute for different rainfed lowland situations in Odisha/eastern India.

Variety name	Designation	Parentage	Year	Recommended states	Duration (d)
Shallow lowlands					
Anamika	CR149-3244-198	MNP 36/CR12/Pankaj	1979	Assam, Bihar, West Bengal	145
Ramakrishna	CR44-122-1	TKM 6/IR8	1980	Odisha	130
Samalei	CR95-CRS-952-1	Leaung 152/IR8	1980	Odisha	150
Savitri/Ponmani	CR210-1009	Pankaj/Jagannath	1982	Odisha, Tamil Nadu, West Bengal	150
Dharitri	CR210-1017-607	Pankaj/Jagannath	1988	Odisha, West Bengal	150
Moti	CR260-136-321	CR151-79/CR1014	1988	Odisha	145
Padmini	CRM 25	CR1014 mutant	1988	Odisha	145
CR1002	CR213-1002	CR70-80-2/Pankaj	1992	Odisha, West Bengal, Bihar	145
Seema	CR211-1016	Jagannath Natural Crops	1992	Orissa	150
Pooja	CR629-256	Vijaya/T 141	1999	Assam, M.P., Odisha, Tripura, and West Bengal	150
Ketekijoha (aromatic)	–	Badshabhog/Savitri	2006	Odisha	145
Nua Kalajeera	IET 18393	Pure-line selection from Kalajeera	2008	Odisha	150, PS[a]
Nua Dhusara (CR Sugandh Dhan 3)	IET 18395	Pure-line selection from Dhusara	2008	Odisha	150, PS
Swarna-Sub1	IET 20266	Swarna* 3/IR49830-7-1-2-3	2009	Odisha	145
Nua Chinikamini	CR2580-7	Chinikamini	2010	Odisha	145
Reeta (CR Dhan401)	CR780-1937-1-3	Savitri/IR44	2010	Odisha, West Bengal, Tamil Nadu and Andhra Pradesh	145
Sumit	CR662-22-1-1-1-1	IR32/IR13246	2012	Odisha	145

(Cont.)

Table 3 continued

Variety name	Designation	Parentage	Year	Recommended states	Duration (d)
Poorna Bhog	CRM 2203-4,	Pusa Basmati-1 mutant	2012	Odisha	140
CRDhan 701	CRHR 32	CRMS 31A/CRL 22	2010	Bihar and Gujarat	142
Semideepwater					
Utkalprabha	CR221-1036	Waikyaku/CR1014	1983	Odisha	155
CR1014	CR563-1014	T 90/Urang Urangan	1988	Odisha	160
Kalashree	CR260-292	CR151-79/CR1014	1988	Odisha	160
Gayatri	CR210-1018	Pankaj/Jagannath	1988	Odisha, West Bengal, Bihar	160
Panidhan	CR260-30	CR151-79/CR1014	1988	Odisha	180
Tulasi	CR260-171	CR151-79/CR1014	1988	Odisha	170
Sarala	CR260-77	CR151/CR104	2000	Odisha	150
Durga	CR683-123	Pankaj/CR1014	2000	Odisha	155, PS
Varshadhan	CRLC 899	IR31432-8-3-2/IR31406-3-3-3-1// IR26940-3-3-3-1	2006	Odisha	160, PS
Hanseswari (CR Dhan 70)	IET 11904	Pure-line selection in composite cross	2008	Odisha	150 PS
CR Dhan 501	CR2008-111	Savitri/Padmini	2010	UP, Assam	152
Deep water					
CR Dhan 500	CR2285-6-6-31	Ravana/Mahsuri	2011	Odisha, UP	160
Jalamani	CR2080-169-3-2-5-2	Panikekoa/Ambika	2012	Odisha	160
Jayanti	CR2282-1-2-5-1	Samson Polo/Jalanidhi	2012	Odisha	160
Coastal salinity					
Lunishree	CRM 30	Nonasail Gamma irradiated mutant	1992	Odisha, West Bengal	145

(Cont.)

Table 3 continued

Variety name	Designation	Parentage	Year	Recommended states	Duration (d)
Sonamani	CR644	Velki mutant/Mahsuri	1996	Odisha	155
Luna Suvarna	CR2096-71-2	Mahsuri/Ourmundakan	2010	Coastal saline areas, Odisha	150
Luna Sampad	CR2095-181-1	Mahsuri/Chakrakanda	2010	Coastal saline areas, Odisha	140
Luna Barial	CR2092-158-3	Jaya/Lunishree	2012	Coastal saline areas, Odisha	150–155
Luna Sankhi	CR2577-1	IR31142-14-1-1-3-2/IR71350	2012	Coastal saline areas, Odisha (dry season)	105–110

[a] PS = photoperiod sensitive.

Breeding strategies

The major traits, essential for the stability of varieties under rainfed lowlands, as indicated above were identified and the following strategies are being adopted to incorporate them.

1. Submergence tolerance

In eastern India, rainfed lowland rice areas are generally submerged in the early vegetative stage for 5 to 7 days two to three times during the same season due to flash flooding. This stage, which is considered the most sensitive to submergence stress, has received more attention in breeding programs. A field screening has been developed for this purpose at CRRI, Cuttack, using artificial tanks to control water depth. Attempts were made, however, to find alternative donors because FR13A has poor combining ability, thus producing agronomically undesirable progenies. Though many improved varieties have been released for rainfed shallow lowlands in Odisha and eastern India (Table 3), none of these varieties possesses the required submergence tolerance. However, breeding line IR49830-7-1-2-3, which derives its tolerance from FR13A, has good agronomic characters and is resistant to bacterial leaf blight (BLB) and green leafhoppers (GLH) (Mackill et al 1993, Sarkarung et al 1995). This line has been used extensively in breeding programs for the improvement of submergence tolerance. To further enhance the adaptation of rainfed lowland rice varieties, the submergence tolerance gene *SUB1* has been successfully introduced into several popular high-yielding varieties in eastern India, including Swarna, Samba Mahsuri, and IR64, using marker-assisted backcrossing at IRRI (Mackill et al 2012, Collard et al 2013). Under submerged conditions, these lines showed 50–70% survival compared with only 10–15% survival by their original parents without *SUB1*. Swarna-Sub1 also showed its superiority over its original parent Swarna in on-farm trials in Odisha (Sarkar et al 2009, Singh et al 2013). After three years of thorough testing in flood-prone areas of Odisha, Swarna-Sub1 was released in 2009 for commercial use by farmers. Now, this variety is becoming popular with the farmers of Odisha and also in many flood-prone areas of eastern India.

2. Tolerance of stagnant flooding

Stagnant flooding of water is a chronic problem in semideepwater situations. Here, the plants are subjected to continuous waterlogging, usually to depths of 25–50 cm for most of the season, resulting in poor tillering, lodging, and occurrence of pests and diseases. Varieties and breeding lines need to be screened for tolerance of stagnant flooding (waterlogging) for better and more stable productivity. Many improved varieties such as Utkal Prabha, CR1014, Kalashree, and Phanidhan have been developed and released by CRRI for stagnant-flood conditions (Table 3). In addition, numerous improved lines, including CRLC 899 and CR2003-2, have been identified under the shuttle breeding network as suitable for waterlogged situations in Odisha and other eastern Indian states (Table 4).

Table 4. Breeding material (64 advanced breeding lines) nominated for different All India Coordinated Rice Improvement Program trials within the EIRLSBN.

Advanced breeding lines	IET no.	Parentage/IR number	Trial[a]	Year
CRLC 881	15653	BR 113/Swetha soke	IVT-SDW	1997
CRLC 882	15654	BR 113/Swetha soke	IVT-SDW	1997
CRLC 883	15656	BR 113/Swetha soke	IVT-SDW	1997
CRLC 884	15657	IR68/IR32720-138-2-1-1-2//IR36934-1-3-1-1	IVT-SDW	1997
CRLC 885	15658	KDML 105/RD 4//IR21848-65-3-2	IVT-SDW	1997
CRLC 899	16481	IR31432-8-3-2/IR31406-3-3-3-1//IR26940-3-3-3-1	IVT-SDW	1999
CR1000-1	17305	IR55789-B2-8-3-1-1/IR41431-68-1-2-3//IR53484-B2-10-2-2-2-3	IVT-SDW	2001
CR2001-1	17306	Abhaya/Sabita//CN1035-37	IVT-SDW	2001
CR2002-1	17307	IR57463-13-1-2-2/IR55008-8-1-2-2-3	IVT-SDW	2001
CR2003-1	17308	IR43342-10-1-1-3-3/IR53508-B2-4-1-3-3//IR57491-42-2-2-3-3	IVT-SDW	2001
CR2004-1	17309	IR48063-SKN-37-1-1-1-3/IR53508-B2-4-1-3-3//IR55030-B2-11-1-2-3-2	IVT-SDW	2001
CR2003-2	17393	IR57463-13-1-2-2/IR55008-8-1-2-2-3	NSDWSN	2001
CR2003-3	17394	IR43342-10-1-1-3-3/IR53508-B2-4-1-3-3//IR57491-42-2-2-3-3	NSDWSN	2001
CR2005-1	17390	IR41431-68-1-2-3/IR43450-SKN-506-2-2-1//IR49830-7-1-2-2	NSDWSN	2001
CR2006-1	17391	IR41431-68-1-2-3/IR43450-SKN-506-2-2-1//IR53508-B2-4-1-3-3	NSDWSN	2001

(Cont.)

Table 4 continued

Advanced breeding lines	IET no.	Parentage/IR number	Trial[a]	Year
CR2006-2	17392	IR41431-68-1-2-3/IR43450-SKN-506-2-2-1// IR53508-B2-4-1-3-3	NSDWSN	2001
CR2003-7	17738	IR67638-15-CR7-1-3-1	NSDWSN	2002
CR2003-9	17739	IR67638-11-CR3-2-5-1	NSDWSN	2002
CR2006-6	17740	IR67632-4-CR6-3-1-10	NSDWSN	2002
CR2019-1	17741	IR67623-29-CR1-1-2-3	NSDWSN	2002
CR2022-1	17742	IR67636-24-CR5-2	NSDWSN	2002
CR2023-1	17743	IR67637-2-CR1-3-1-1	NSDWSN	2002
CR2023-4	17744	IR67637-6-CR1-1-1-5	NSDWSN	2002
CR2035-2	17745	IR70149-TTB14-CR1-1-1	NSDWSN	2002
CR2042-1	17746	IR70843-NDR30-1-CR1-2-1	NSDWSN	2002
CR2042-2	17747	IR70843-NDR32-5-CR1-1-1	NSDWSN	2002
CR2019-3	18340	IR67623-29-CR1-1-1-1	NSDWSN	2003
CR2049-1	18341	IR72016-B-4-CR1-1-1	NSDWSN	2003
CR2057-1	18342	IR73233-74-CR1-12-2	NSDWSN	2003
CR2045-1	18343	IR72002-B-39-CR2-1-1-1	NSDWSN	2003
CR2030-1	18344	IR68087-78-CR1-1	NSDWSN	2003
CR2003-13	18769	IR67638-15-CR6-1-10-1	NSDWSN	2004
CR2006-7	18770	IR67632-4- CR1-3-3-2	NSDWSN	2004
CR2027-2	18776	IR67652-7-CR2-2-1	NSDWSN	2004
CR2056-1	18759	IR72723-TTB118-CR1-3-2	NSDWSN	2004
CRLC 899-2	19177	IR31432-8-3-2/IR31406-3-3-3-1// IR26940-3-3-3-1	NSDWSN	2005

(Cont.)

Table 4 continued

Advanced breeding lines	IET no.	Parentage/IR number	Trial[a]	Year
CR2027-3	19178	IR53508-B2-4-1-3-3/IR48063-SKN-37-1-1-1-3//IR52904-41-3-1-2-1	NSDWSN	2005
CR2047-1	19179	Banla Phdao/IR58306-80-B-3-1-1//Mahsuri	NSDWSN	2005
CR2048-2	19180	BKP 246/Sabita//IR55008-10-3-3-3-3	NSDWSN	2005
CR2052-3	19181	Neang Nary P10/IR55008-8-1-2-2-3//Sabita	NSDWSN	2005
CR2057-3	19182	IR57521-PMI-7-1-3-SRN-1-3/IR 55008-10-3-3-3-3//RPW 17	NSDWSN	2005
CR1000-4	19648	IR31432-8-3-2/IR31406-3-3-3-1//IR26940-3-3-3-1	IVT-DW	2006
CR2006-15	19649	IR41431-68-1-2-3/IR43450-SKN-506-2-2-1//IR53508-B2-4-1-3-3	IVT-DW	2006
CR2033-1	19650	IR61033-82-3-2-2/IR60243-CPA-7-1-1-1-1//IR55776-16-2-1-1-3	IVT-DW	2006
CR2059-1	19651	IR58895-PMI-5-1-3-3 /Rajshree//Sabita	IVT-DW	2006
CR2060-2	19652	Abhaya/Sabita//RD 15	IVT-DW	2006
CR2006-14	20057	IR41431-68-1-2-3/IR43450-SKN-506-2-2-1//IR53508-B2-4-1-3-3	NSDWSN	2006
CR2019-6	20058	IR31238-474-3-P1/IR41054-81-2-3-2//IR52555-UBN-3-2-1	NSDWSN	2006
CR2024-1	20059	IR48063-SKN-37-1-1-1-3/IR53508-B2-4-1-3-3//IR57530-UBN-9-1-2-3-1	NSDWSN	2006
CR2026-5	20060	IR53508-B2-4-1-3-3/IR46331-PMI-32-2-1-1//IR54071-UBN-1-1-3-1-2	NSDWSN	2006
CR2029-3	20061	IR56592-21-1-3-1-2/IR48120-49-5-3-2//IR55008-33-3-2-1	NSDWSN	2006

(Cont.)

Table 4 continued

Advanced breeding lines	IET no.	Parentage/IR number	Trial[a]	Year
CR2039-1	20062	CR673-475/IR55008-8-1-2-2-3//IR58306-80-B-3-1-1	NSNSDW	2006
CR2043-3	20063	Abhaya/IR57515-PMI-8-1-1-SRN-1-1//CN846-6-6	NSNSDW	2006
CR2057-17	20064	IR57521-PMI-7-1-3-SRN-1-3/IR55008-10-3-3-3-3//RPW 17	NSNSDW	2006
CR2058-2	20065	IR58895-PMI-5-1-3-3/CR753-29-9//Sabita	NSNSDW	2006
CR2061-1	20066	CN1035-60/CR753-29-9//Abhaya	NSNSDW	2006
CRLC 899-3	20394	IR31432-8-3-2/IR31406-333-1//IR26940-20-3-3-3-1	NSDWSN	2007
CR925-2	–	Gayatri/CN718-8-21-10	NSDWSN	2007
CR2539-1	20266	Swarna*3/IR49830-7-1-2-3 (IR82809-237)	IVT-L	2007
CR2026-5	21159	IR53508-B2-4-1-3-3/IR46331-PMI-32-2-1-1//IR54071-UBN-1-1-3-1-2	NSDWSN	2008
CR2059-1	21160	IR58895-PMI-5-1-3-3 /Rajshree//Sabita	NSDWSN	2008
CR2003-2-1	21350	IR43342-10-1-1-3-3/IR53508-B2-4-1-3-3//IR57491-42-2-2-3-3	NSDWSN	2009
CR2377-2-1-1-1	21351	Swarna/IR72077	NSDWSN	2009
CR2378-13-1-1-1	21352	Swarna/IR68552-100-1-2-2	NSDWSN	2009

[a] IVT-SDW = Initial Variety Trial-Semideepwater
NSDWSN = National Semideepwater Screening Nursery,
IVT-DW = Initial Variety Trial-Deep Water,
IVT-L = Initial Variety Trial-Late.

3. Drought tolerance

In eastern India, direct seeding in rainfed lowlands faces water deficit at the early vegetative stage and occasionally at the ripening stage due to delays in monsoon, uneven rain distribution, and early cessation of rains. Very little work has been done to develop drought-tolerant late-maturing varieties, particularly for eastern India. More emphasis needs to be given to vigorous screening of new breeding lines at the seedling stage, followed by flowering stage, to develop better adapted varieties. Varieties combining drought tolerance with submergence tolerance are most desired for rainfed lowlands, as both stresses could occur within the same season or in successive years.

4. Photoperiod sensitivity and thermo-insensitivity

Flowering time is one of the most important traits for farmers' acceptance of lowland varieties in different areas and states of India. Depending upon location and topography, the rainfed lowlands normally have standing water up to October, and in places such as coastal Odisha and West Bengal, up to the end of November. Hence, photosensitive types suiting local situations need to be developed to ensure adoption. Furthermore, rice varieties growing in rainfed lowlands usually flower between the second week of October and the first week of November, when the ambient temperature is fairly low. Therefore, incorporation of thermo-insensitivity characters or better cold tolerance during the reproductive stage is essential for stabilizing the duration of the crop and avoiding problems associated with late maturity.

5. Seed dormancy

In numerous cases, water remains in the fields through maturity due to stagnant flooding or late cyclones. Under such situations, the panicles come in contact with water and at times remain in the water for several days. For areas vulnerable to these types of problems, strong seed dormancy is essential to avoid seed germination on the panicle. Some of the Mahsuri derivatives (e.g., Swarna and Samba Mahsuri for shallow water; Sarala, Durga, and Varshadhan for semideep lowlands; and Lunishree and Sonamani for coastal saline areas) have reasonable seed dormancy and are widely grown by farmers.

6. Grain quality

Many of the traditional lowland cultivars, particularly those developed for semideep situations, have coarse long bold (LB) grains and red kernels. Improvement of grain quality, particularly long slender (LS) grains with linear elongation ability, will be useful for the development of quality rice that can also be suitable for export. Long slender grain types have the advantage of producing heavy panicles for increased yield. Some examples of varieties with good grain quality are Moti, Samalei Ketekijoha, Nua Kalajeera, Nua Dhusara, and Nua Chinikamini for shallow lowlands and CR1014 and Durga for semideep situations. The scope for improving grain quality, including the development of export-oriented scented rice grown under rainfed lowlands, needs to be further exploited.

7. Problem soils

Many lowland areas in India suffer from iron toxicity, Zn deficiency, and salinity. Varieties such as Mahsuri and Samalei, and some elite lines such as CR672-3 and CR617-16-10-2 bred at CRRI, had good tolerance of Fe toxicity. Very little information is available on lowland varieties suitable for Zn-deficient soils, and this is another area that needs more attention in varietal improvement programs.

In India, about 3.1 million ha of land are in coastal areas. These areas are generally less productive due to high salinity as well as stagnant flooding. Examples of salt-tolerant local cultivars grown in these coastal areas are Damodar, Dasal, Getu, Nonasail, and Nona Bokra, which have an average yield of around 1.5–2.0 t/ha. More recently, significant progress in developing modern salt-tolerant varieties has been made using hybridization and mutation breeding. Varieties developed include Sonamani (CR 644) and Lunishree. Recently, long-duration (150–160 days) varieties Luna Samplad, Luna Suvarna, and Luna Barial were released but have not yet become popular with the farmers in coastal saline areas of Odisha.

8. Biotic stresses

Major diseases such as BLB, sheath blight, sheath rot, and rice tungro virus (RTV) as well as insects such as stem borers, gall midge, GLH, brown planthopper (BPH), and cutworms are becoming serious problems in different rainfed lowland ecosystems. Among these, stem borers and bacterial blight are the most common problems occurring in all rainfed lowlands. Genetic resistance against some of the major diseases has been incorporated for some lowland varieties. CRRI has developed improved breeding lines with bacterial blight resistance genes (*xa5, xa13,* and *Xa21*) in the background of Swarna, IR64, Lalat, and Tapaswini. These new genotypes are being popularized with the farmers in shallow and irrigated ecosystems. Even though some limited success has been achieved in improving some lowland varieties with built-in tolerance of a few pests, no progress has been made for developing lowland varieties tolerant of stem borer. The search for better resistant donors is in progress. Efforts are ongoing at CRRI to develop varieties for these adverse situations in rainfed lowland areas of eastern India in general and in Odisha in particular, in collaboration with IRRI, Philippines.

The Eastern India Rainfed Lowland Shuttle Breeding Network

To improve the yield potential of the rainfed lowland rice varieties of eastern India (Assam, Bihar, Chhattisgarh, eastern Uttar Pradesh, Odisha, and West Bengal), an ICAR-IRRI Collaborative Shuttle Breeding Program began in the wet season (kharif) of 1992 (Reddy et al 2013). The program was funded by IRRI and jointly coordinated by CRRI, Cuttack, and IRRI, Philippines. The program initially started with six centers (Titabar, Pusa, Raipur, Masodha, Chinsurah, and Cuttack). Later, the program expanded with the inclusion of some more centers. The program is now in operation at nine centers. Each year, all breeders from eastern India and IRRI meet at CRRI for field activities and to discuss breeding matters (Fig. 1).

Fig. 1. Breeders from eastern India participating in the annual selection activity at CRRI, Cuttack, during 2010, 2011, and 2012 (from top to bottom, respectively).

The major objectives of the rainfed lowland shuttle breeding network program are (1) making available a diversified set of donors/improved breeding lines suitable for rainfed lowlands for the participating centers; (2) providing segregating populations with broad genetic background to all the centers for effective selection in their location-specific conditions; (3) evaluating elite breeding lines developed by the participating centers and IRRI especially for submergence tolerance, photoperiod sensitivity, thermo-insensitivity, yield potential, and adaptability in eastern India; and (4) on-farm testing of promising varieties to study their adaptability and acceptability. On the basis of these objectives, the following activities have been undertaken over the years at the key site, CRRI, Cuttack, under the EIRLSBN.

Generation, selection, and evaluation of breeding material

The breeding program uses material developed at IRRI, CRRI, and other centers participating in the network. In most cases, the pedigree method of breeding has been followed in the development of breeding material. At CRRI, about 50 crosses are made each year. A typical F_2 population size is about 2,000 plants per cross. Screening of breeding material and plant selection involve screening for agronomic traits (flowering time, plant height), yield-component traits (ear-bearing tillers/m^2, panicle weight, and panicle length), disease and insect resistance (stem borer, cutworm, bacterial blight, sheath blight), abiotic stress tolerance (submergence, drought, and cold), and quality parameters (head rice recovery, amylose content, kernel length). In some cases, modified bulk and single seed descent (SSD) methods were also followed. To transfer specific genes (e.g., *SUB1*, *xa5*, *Xa13*, *Xa21*), a marker-assisted backcross breeding approach was used.

Segregating breeding material developed at IRRI first comes to CRRI for seed multiplication or is sometimes directly distributed to different network partners. During the annual meeting at CRRI, breeders gather for selection activities in the field and during the flowering/maturity stage (during November) to select material for use in their own program (Fig. 2). Breeding material includes single, double, or multiple crosses involving parents selected from different network partners and donors tolerant of different biotic and abiotic stresses. The selected breeding material is then sent back to the concerned breeders for location-specific evaluation and selection.

Observational yield trials (OYTs)

Observational yield trials are conducted involving the breeding material developed at different participating centers within the network and also material developed at IRRI. Each center will nominate 10–12 promising lines in the OYT; the total number of entries in this trial is usually 80 to 100. After receiving the seed from all centers, CRRI will constitute the trial and send the seed material to the network partners/cooperating centers for conducting the trial and for evaluation. In general, the OYTs are conducted in an augmented block design with four standard checks and one local check. After the evaluation, the data are sent back to CRRI by all cooperating centers for compilation and analysis. Over the years (1992-2011), about 1,800 entries were evaluated in OYTs at CRRI.

Fig. 2. Breeders from eastern India participating in a selection activity at CRRI, Cuttack. (A) Breeders making field selections during 2011. (B) Dr. J.N. Reddy (left) and Dr. D.J. Mackill (right) are shown making selections from breeding material (2010).

All the entries included in an OYT are screened for submergence tolerance at CRRI under artificially controlled conditions. Twenty-one-day-old seedlings of a direct-seeded crop are completely submerged for 12 days under 80-cm water depth. After 10 days of de-submergence, plant survival is counted. All of the OYT entries are also evaluated for quality parameters such as kernel length, kernel breadth, length-breadth ratio, kernel length after cooking, volume expansion ratio, elongation ratio, water uptake, amylose content, and alkali spreading value at CRRI, Cuttack. Check varieties used in recent years have included Savitri, Sabita, Swarna, Swarna-Sub1, and Sarala.

Advanced yield trials (AYTs)

Advanced yield trials are being conducted with 20–25 entries selected from the OYT on the basis of their performance over locations and performance at a particular location, along with four standard checks and one local check. In general, the AYTs will be conducted in a randomized block design with three replications, at five locations. On the basis of the ecosystem at a particular location, the trial is conducted either in shallow or semideep lowland situations. During the last two decades, about 480 advanced breeding lines developed by different cooperating centers have been evaluated in AYTs. Check varieties used in recent years have included IR49830, Purnendu, Sabita, Jal-Lahari, and Varshadhan.

On-farm participatory varietal selection (PVS) trials

On-farm trials involving 10–12 promising lines selected from advanced yield trials along with other promising lines from each center are being carried out for yield and adaptability in farmers' fields under researcher-managed and farmer-managed PVS trials. Over the years, about 200 improved breeding lines have been evaluated in farmers' fields in different coastal districts of Odisha. Promising lines in on-farm trials have been nominated to state adaptive trials or National Coordinated Trials (All India Coordinated Rice Improvement Program; AICRIP) for multilocation testing.

Facilities and resources at CRRI, Cuttack

At CRRI, Cuttack, all the field and lab facilities are available for varietal improvement for different rainfed lowland ecologies. Very good screening facilities for different abiotic stresses, including submergence, drought (vegetative and reproductive stage), and salinity, and for different biotic stresses (bacterial blight, blast, rice tungro disease) are available.

During the last 20 years, many scientists have been associated with the EIRLSBN at CRRI, Cuttack. Dr. R.N. De (1992), a plant breeder, was the first coordinator of the Rainfed Lowland Shuttle Breeding Program, followed by Dr. J.K. Roy (1993-98), Mr. P.J. Jachuck (1999), D. Choudhary (2000), and Dr. J.N. Reddy (2001 to date). Dr. J.N. Reddy has been associated with the program since its inception (1992 to date). Dr. R.K. Sarkar, a plant physiologist, and Mr. S.S.C. Patnaik, a plant breeder, are also associated with the program (2003 to date). Currently, four technical staff are under the supervision of the breeder.

Salient achievements of the EIRLSBN

Genotypes identified for submergence tolerance. Submergence is one of the most important abiotic stresses affecting rice, second only to drought, which affects yield in rainfed lowlands. Over the years, more than 3,000 germplasm accessions/breeding lines from different participating centers have been screened for submergence tolerance in artificial cement tanks (21-day-old seedlings were submerged for 12 days with 80 cm of water) at CRRI. The flood-tolerant variety FR13A was found to have good submergence tolerance, but it has poor combining ability. Among the germplasm/improved breeding lines screened, local cultivars such as Gangasiuli, Khoda, Kadara, Kalaputia, Kusuma, and Ravana from Odisha and improved breeding lines such as IR38784-15-19, CR2003-13, CR2006-7, CR2056-5, CR2003-24, CR2033-1, NDR 9830116, NDR 9830125, NDR 9930025, NDR 9830109, NDR 9830123, NDR 9830131, NDR 9930070, NDR 8659, NDR 8588, NDR 8831, NDR 8820, IR76522-7-14-4-1, OR 1901-14-32, IR74601-17, TTB 225-2-138, and CN1266-6-3 were found to have good submergence tolerance and are being used in breeding programs.

Genotypes identified for late planting. Late planting with aged seedlings is a normal practice in eastern India due to unpredictable and erratic rainfall. Among the different lines tested in normal and delayed planting experiments, CR683-123 (Durga), CRLC 899-2 (Varshadhan), PSR 1119-13-3 (Kishori), NDR 96004, CR673-475, and CR780-1937 were identified as promising, under both normal and delayed planting conditions. Some of these lines were released/recommended for release by different state governments because of their good performance.

Generation of breeding material. The major objective of the shuttle breeding program is to make available improved breeding lines and segregating populations with a diverse genetic base to the participating centers for location-specific selection. Hence, a lot of breeding materials have been developed (by IRRI, CRRI, and cooperating centers) and exchanged among the cooperating centers under this network. Over the years (1992-2011), about 385 F_2 bulks and 27,130 F_3–F_8 progenies have been grown and about 24,000 single-plant selections were made (Table 4).

Participatory varietal selection. Promising entries selected on the basis of their performance in advanced yield trials under the EIRLSBN program along with other promising entries of the center have been tested in PVS trials, including researcher-managed (mother) and farmer-managed (baby) trials at all the participating centers, with the participation of selected farmers. Through on-farm testing/PVS under this program, numerous lines were identified as promising. Many promising lines were nominated to different trials (Table 4) under AICRIP. Among the different lines tested/identified under the program, many lines were found promising and some of them were released in the state of Odisha. Some noteworthy varieties/breeding lines are the following.

Variety Varshadhan (CRLC 899; IR54112-B2-1-6-2-2-2-CR1-2; IET 16481), identified under the EIRLSBN, was released in 2005 by the Odisha State Sub-Committee on Crop Standards, Notification, and Release of Variety, for cultivation in stagnant flood-prone semideep areas (0 to 75 cm) of coastal Odisha during the wet season

(Fig. 3). This photosensitive variety flowers during the second week of November and yields 3.5–4.0 t/ha. It is lodging resistant and is also moderately tolerant of neck blast, bacterial blight, sheath rot, and WBPH. It is also suitable for late planting with 50–60-day-old seedlings.

Swarna-Sub1 (CR2539-1; IR82809-237; IET 20266) was developed under an ICAR-IRRI collaborative program by incorporating the submergence tolerance gene *SUB1* into variety Swarna through marker-assisted backcross breeding at the International Rice Research Institute (IRRI), Philippines. It was released by the Odisha State Seed Sub-Committee on Crop Standards, Notification, and Release of Variety in 2009 after three years of rigorous testing in the target environment. It is semidwarf (105–110 cm) and matures in 140 days under direct-seeded conditions and in 145 days under transplanted conditions (Fig. 3). It has medium slender grain with 66.5% head rice recovery and elongation ratio of 1.76. It yields 4.5–5.5 t/ha under normal conditions and 3.0–4.0 t/ha under submergence stress.

CR2003-2 (IR67638-CR15-1-6-1-4; IET 17393), identified under the EIRLSBN, was identified as promising for semideepwater areas of Odisha and Bihar in the eastern region and was recommended for large-scale testing and release during 2005, after three years of testing in AICRIP.

Future needs and directions

There is a need to improve the tolerance of many abiotic stresses such as submergence and to also develop new varieties with combinations of abiotic and biotic stress tolerance prevailing in any particular region. This can be accomplished through the following:

1. The identification of donors/improved lines with submergence tolerance for more than 2 weeks and also at different crop growth stages.
2. The identification of donors for submergence tolerance mechanisms other than that conferred by *SUB1*.
3. Combining drought tolerance with submergence tolerance.
4. Combining submergence tolerance with tolerance of waterlogging/stagnant flooding.
5. Combining submergence tolerance with salinity tolerance, especially for varieties targeting coastal areas.
6. Combining salinity tolerance with waterlogging tolerance.
7. Incorporation of submergence tolerance and resistance to stem borer and bacterial blight in all the high-yielding rainfed lowland rice varieties in the region.

Fig. 3. Field photos of varieties Varshadhan and Swarna-Sub1.

Future requirements for continuation and improvement of the EIRLSBN

The EIRLSBN has made many significant contributions to rice production in eastern India that warrant an impact assessment to quantify this contribution and identify areas for improvement (Reddy et al 2013). Resources are needed to ensure that the network will continue well into the future, as there is considerable work to be done to improve rice varieties targeted to eastern India. The following improvements need to be considered in the future:

1. The generation of more breeding materials based on location-specific requirements to be made available to the cooperating centers.
2. Increased contribution of breeding material by participating and cooperating centers to the network.
3. Rigorous analyses and use of the large amount of data generated under the network to streamline target-specific breeding programs and for publication.
4. More resources to ensure regular monitoring of the trials at different locations and breeding tours for exchange of experiences.
5. Continuous financial support to the cooperating centers to expand their activities.

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Two decades of achievements of the EIRLSBN: contributions of Odisha University of Agriculture and Technology

S.R. Das and D.N. Bastia

In Odisha, rice is synonymous with food. Agriculture in Odisha generally means growing rice. Odisha is an agrarian state with agriculture and related sectors contributing nearly 22% of the state's gross domestic product in 2009-10. Nearly 70% of the total workforce is directly or indirectly employed by this sector. Rice is the major crop, covering about 63% of the total area under food grains. It is the staple food of almost the entire population of Odisha; therefore, the state's economy is directly linked to changes in rice production.

Age-old social customs and festivals in Odisha have strong connections to different phases of rice cultivation: *Akhyatrutiya* in May-June marks the seeding of rice, *Rajasankranti* in mid-June marks the completion of sowing, *Garbhanasankranti* in October symbolizes the reproductive phase of rice, whereas *Nuakhaee* and *Laxmipuja* coincide with the harvesting of upland and lowland rice, respectively. *Makarsankranti* in mid-January is celebrated as *Chaita Parab* by the tribal people, since by this time rice has been threshed and brought to the granary (Mohanty et al 1995).

Overview of rice production in Odisha

Despite the crop's economic, strategic, and cultural importance, rice productivity in Odisha is one of the lowest in the country. The state remained untouched by the effects of the Green Revolution since the mid-1960s, with rice yield hovering around 1.0 t/ha. This has resulted in a decline in the state's share in the country's rice production, from more than 11% in the pre-high-yielding variety (HYV) period to less than 8% in recent years. However, the past 15 years witnessed a rapid increase in rice yield, from 1.0 t/ha in the mid-1990s to the current more than 1.5 t/ha (milled rice). Despite this improvement, the average paddy yield in the state is still well below the national average of more than 2 t/ha (Mohanty et al 2012).

In the last four decades, rice area in the state has been stagnant at 4.5 million ha, with production growth completely dependent on increases in yield (Das 2012). Rice area accounts for 91% of the area under cereals and contributes about 94% of the total cereal production in the state. In fact, the introduction of HYVs did not have any significant impact on rice production and productivity for over two decades. Yield per hectare fluctuated between 800 and 977 kg; however, it showed an upward trend from 1986 onward, although productivity continued to remain far below the national average.

Geography and climate of the state

Odisha is located in the subtropical belt in the eastern region of India between 17°31′N to 20°31′N latitude and 81°31′ E to 87°30′ E longitude, and is surrounded by Jharkhand to the north, Chhattisgarh to the west, Andhra Pradesh to the south, West Bengal to the northeast, and the Bay of Bengal to the southeast. The mountain ranges of Eastern Ghats run from northeast to southwest in the middle of the state. These mountain ranges separate the eastern part of the state, which is a belt of 482 km of coastline, and the western part, which is an extensive plateau. The state has a geographic area of 15.5 million ha, and is divided into four geographic divisions: the Northern Plateau (25.5%), Central Table Land (24.1%), Eastern Ghat Region (29.2%), and Coastal Region (21.2%) (Pani and Patra 2004).

The state can be broadly categorized into hot and dry subhumid, warm and humid, hot and humid, and hot and moist subhumid regions, and it experiences four major seasons: winter (December-February), summer (March-May), rainy (June-September), and autumn (October-November). The monthly average minimum and maximum temperatures range from 14 °C in December to 38 °C in May, respectively. The mean maximum temperature is 32 °C in the coastal districts of the state; however, it sometimes reaches 42 °C in hilly areas. The relative humidity of the state varies from 36% to 98%; the average bright sunshine hours range from 3.7 per day during July-August to 8.8 per day during March to May.

The southwest monsoon affects the state for a 3–4-month period. It starts during the second fortnight of June and continues up to the first week of October. The annual normal rainfall of the state is 1,451 mm. More than 80% of the precipitation is received from mid-June to September. The rainfall pattern is highly unpredictable and therefore the state commonly suffers from either drought or flood. Agriculture in Odisha depends strongly on monsoon rains that largely determine crop yields: a lack of rainfall causes drought stress while excess rainfall causes flooding.

Agro-climatic zones and crops grown in Odisha

Depending on the physical features, soil types, and rainfall, the state is divided into 10 distinct agro-climatic zones with varied characteristics (Das 2012). Rice is considered to be the major crop in all the agro-climatic zones of Odisha (Gangopadhayay 1991). However, the state is broadly divided into two zones: the Plateau Region and coastal alluvial plain.

The Plateau Region comprises about 85% of the geographic area, with predominantly red and yellow laterite and lateritic soils. The soils are highly leached, acidic, low in organic matter, and low in nitrogen, phosphorus, and potassium. Soil texture is sandy, sandy loam, and loamy to clay soil depending on the topography. In the higher areas, soils are coarse textured and highly drought prone. The region has 2.75 million ha of rice lands, constituting about 62% of the total rice area of the state. This region is differentiated into eight distinct agro-climatic zones. The total rice production in this region is estimated to be 4.23 million tons, with yield of about 1.5 t/ha.

The Coastal Region comprises about 15% of the geographic area of the state and runs along the coastline, having a width varying from 24 km to 72 km from the sea coast. Soils are alluvial, both deltaic and coastal. The deltaic alluvial soils are generally fertile but low in N and P. The coastal alluvial soils within 10 km of the sea coast show high total soluble salts, mainly sodium chloride, due to tidal inundation. The coastal belt has about 1.70 million ha of rice land, constituting about 38% of the total rice area. Rice cultivated on these lands generally suffers from waterlogging problems and is flood prone. Total rice production in this region is estimated to be 2.68 million tons, with an average yield of >1.5 t/ha.

Rice ecosystems in Odisha

Rice is grown under diverse ecosystems and a wide range of climatic conditions in Odisha. Immense diversity in growth conditions makes classification and characterization of the rice ecosystems a challenging task. But, classification of rice land on the basis of some key descriptive factors influencing rice productivity is essential for variety development and the formulation of crop management practices (Das 2012). During 2009-10, rice was cultivated on 4.37 million ha, which can be classified into seven different categories: irrigated kharif (39.1%), rainfed upland (12.5%), medium land (10.2%), shallow lowland (22.5%), and semideep (6.9%), deep (2.9%), and irrigated rabi (5.9%).

Farmers have their own system of classification of rice ecosystems such as uplands, medium lands, and lowlands, primarily on the basis of land topography and water regime. Farmers have identified reasonably well-adapted varieties for specific rice-growing areas and have also developed appropriate cultural practices. Rice researchers nationally and internationally redefined the farmers' system of classification on the basis of the amount of water available to the rice crop, and water depth during the major part of the crop's life cycle. Although a broad classification of rice ecosystems in Odisha has been mentioned, the kharif paddy coverage of the state during 2009-10 revealed that uplands, medium lands, and lowlands constitute 23.3%, 40.3%, and 36.4% of the rice area, respectively.

Rice farmers in Odisha

The farming community of all social groups in Odisha can be divided into four different classes, based on government definitions:

1. Scheduled tribes constitute about 32% of the total population of the state and inhabit mainly the Plateau Region. They have confined themselves to the cultivation of dryland rice on the top and slopes of hills. They are small farmers or landless laborers. They have not yet given up *podu* or *jhum* cultivation, and the practice of collecting grains of wild rice (considered to be the earliest phase of domestication of rice) is still prevalent among certain tribes in the Jeypore tract.
2. Scheduled castes constitute nearly 15% of the total population. They are mostly landless or small farmers and constitute a high proportion of the agricultural labor force.
3. Middle-caste farmers constitute almost 50% of the population. They are small and marginal farmers and/or sharecroppers. This class of farmers constitutes the backbone of Odisha's agriculture.

4. High-caste farmers in general own relatively better areas of rice land, with inherent high soil fertility and productivity. They have medium- and large-size farm holdings. The benefits of high-yielding varieties have mostly been gained by this class. However, a large number of them are absentee landlords and they lease their lands to sharecroppers; this shift from owner-farming to sharecrop farming is increasing. The net profit is high for the landlord; in a way, it is unearned profit. Sharecroppers are not expected to make any land improvement or use better crop management practices involving investment in inputs. Thus, productivity remains low.

Because of the continuous fragmentation of landholdings, almost 70% of the rural households have holding sizes of less than 1 hectare. The majority of the rural households (about 86%) are small or marginal farmers or landless agricultural laborers and they are resource-poor (Table 1). Thus, they are unable to adopt modern rice production technologies such as high-yielding varieties, high-quality seeds, recommended doses of fertilizers and pesticides, and agricultural equipment for increasing rice productivity.

Farmers usually fail to recover the cost of paddy production in the existing market infrastructure. Because of poor procurement strategies of government organizations, farmers depend on traders and are exploited by mill owners to sell their marketable surplus at prices less than the minimum support price. A majority of farmers in rainfed areas are resource-poor and generally do not obtain institutional credit. They grow traditional rice varieties to overcome the risk associated with rainfed rice farming, resulting in low crop productivity. Thus, the poor performance of agriculture is the major cause of the low credit-deposit ratio in the state. This situation results in a poor credit flow to agriculture and per hectare credit in Odisha is lower than in other states. Therefore, the lack of dependable market support, poor flow of credit to agriculture,

Table 1. Group-wise distribution of the number of operational holdings for all social groups, scheduled caste, and scheduled tribes of Odisha (Agriculture Census 2005-06).

Class	Marginal (<1.0 ha)	Small (1–2 ha)	Semi-medium (2–4 ha)	Medium (4–10 ha)	Large (>10 ha)	Total
All social groups						
No.	2,597,164	1,156,162	472,129	119,529	11,408	4,356,392
%	59.6	26.6	10.8	2.7	0.3	100.0
Scheduled caste (14.5%)						
No.	453,408	133,304	38,482	5,654	318	631,166
%	71.8	21.1	6.1	0.9	0.1	100.0
Scheduled tribes (32.3%)						
No.	771,153	386,540	175,356	71,399	2,956	1,407,404
%	54.8	27.4	12.5	5.1	0.2	100.0

Source: Economic Survey, Odisha: 2011-12.

and failure to adopt modern rice production technologies (i.e., due to the lack of credit-market-technology) cause the low rice productivity in Odisha (Naik et al 2008).

Breeding objectives

Breeding objectives have changed over time because of changing climatic factors, biotic and abiotic stresses, quality preferences, agroecological conditions, and even the changing needs of growers and consumers. In the first phase of the breeding program during the 1960s and '70s, the primary objectives were high yield and adaptability to irrigated medium lands in both kharif and rabi, and also in favorable rainfed medium lands in the kharif season. During this period, insect pests and diseases were not a severe problem and quality was a secondary consideration.

However, the adoption of semidwarf high-yielding varieties coupled with improved management practices and continuous rice cropping with reduced genetic variability intended for increased production increased the vulnerability of the crop to major insect pests and diseases. Therefore, breeding for resistance to insect pests and diseases became the main objective in the '70s and '80s. In the second phase, emphasis was placed on developing early duration (100 days or less) for the rainfed upland ecosystem; resistance to gall midge and bacterial leaf blight (BLB), particularly in the mid season; and medium-duration rice varieties (110 to 135 days) suitable for medium and irrigated lands.

Furthermore, the newly developed semidwarf rice varieties were poorly adapted to specific ecosystems, and these varieties were found to be unsuitable in specific stress situations such as drought, waterlogging (or stagnant flooding), low light intensity, and salinity, and in some cases were susceptible to major pests and diseases and hence did not provide high yield.

Therefore, in subsequent phases of the breeding program, emphasis was given to developing varieties with tolerance of stresses such as drought, waterlogging, and salinity; resistance to diseases and pests; and better cooking and eating quality. Major research efforts concentrated on breeding varieties for unfavorable ecosystems such as drought-prone uplands, flood-prone lowlands, and coastal saline tracts. The development of hybrid rice was the next important rice breeding strategy to break the yield plateau in irrigated ecosystems.

Old and current varieties

Traditional cultivars/varieties grown in Odisha

Odisha has been considered as the center of origin and genetic diversity for cultivated rice. Thousands of rice varieties were cultivated in Odisha earlier, and, even after the spread of high-yielding rice varieties, farmers still cultivate hundreds of these traditional types.

The majority of these traditional cultivars had low yield primarily because of their tall stature, weak culms (making them susceptible to lodging), low tillering ability, and poor panicle features. These cultivars were grown for specific traits such as maturity duration, plant stature, panicle features, and tolerance of biotic and abiotic stresses, and other specific traits such as aroma, good cooking quality, and good grain quality. These traditional tall types are still favored by farmers in rainfed uplands, semideepwater and deepwater situations, and saline areas of the state. Despite their low yield potential, they are preferred because of a number of traits desired by farmers, such as early seedling vigor, rapid germination, deep root systems with a higher proportion of thick roots, superior grain quality, better yield stability, and tolerance of low moisture stress, submergence, and salinity.

However, in recent years, the development and spread of semidwarf high-yielding rice varieties resulted in replacing many locally adapted varieties developed by farmers over generations. Thus, the loss of diversity and genetic erosion are a serious concern, especially for breeders and rice scientists. The traditional varieties grown by farmers are likely to be completely lost in the near future if measures are not taken to protect these valuable genetic resources. The traditional rice varieties have been explored, collected, and conserved. The Central Rice Research Institute, under an ICAR project known as Jeypore Botanical Survey, collected about 1,745 accessions of cultivated rice and 150 accessions of wild rice from the Jeypore tract of Odisha. These are known as JBS varieties. In recent years, the CRRI and NBPGR had collected almost all the traditional rice varieties of Odisha, numbering about 2,000, which are conserved in medium-term storage at CRRI and in long-term storage at NBPGR (Pani and Patra 2004). Recently, the Directorate of Agriculture and Food Production, government of Odisha, has implemented a program to collect, evaluate, and characterize indigenous rice varieties that are still available to farmers from the different districts of the state.

Some traditional varieties are aromatic and it has been estimated that more than 50 traditional aromatic rice varieties with pleasant aroma are grown in various parts of the state. These scented rice varieties usually have small and round grains and do not elongate much after cooking. However, they have a strong aroma under the prevailing warmer climate during the grain maturity period in the kharif season. The small- and medium-grain aromatic rice varieties are regarded as a separate class of nonbasmati aromatic rice. A survey of rural and urban markets indicated that generally these small- and round-grain aromatic types are sold at a much higher price (Rs. 35–40 per kg), which is about double the price of normal nonaromatic fine-grain rice. Therefore, there is potential for the production and marketing of these indigenous scented rice varieties for the social and economic development of the farmers of Odisha (Das and Rout 2006).

Improved varieties of rice

Before the inauguration of the Indian Council of Agricultural Research and the Rice Research Schemes in India, the state agricultural departments routinely performed pure-line selection of popular landraces that were grown in the state during the early 1920s. Certain improved varieties, Benibhog for autumn rice, Cuttack-1 (early winter), Cuttack-2 (mid-winter), Cuttack-3 and -5 (late winter), and Kujang-1 and Kujang-2 for the saline tracts of the state, became available.

Rice research, namely, variety improvement, began in 1932 following the establishment of the Rice Research Station at the State Agricultural Farm in Cuttack. In 1938, ICAR (then Imperial Council of Agricultural Research) sponsored a rice breeding project, which was in operation with a paddy specialist subsequently redesignated as the economic botanist-I. Rice varietal development work was also in operation at two substations in South Odisha: one at Berhampur and the other at Jeypore. Research on agronomy, entomology, and pathology started in the 1940s with the appointment of an agronomist, entomologist, and mycologist, respectively (Chalam 1956).

In 1946, the State Agricultural Farm at Cuttack was handed over to ICAR for the establishment of the Central Rice Research Institute (CRRI). The Rice Research Station was shifted to the newly established State Agricultural Farm at Bhubaneswar. In 1963, following the establishment of the Orissa University of Agriculture and Technology (OUAT) in Bhubaneswar, the Rice Research Station along with the State Agricultural Farm were transferred to the university.

The development of improved varieties fulfilling the varietal requirements of the three broad rice ecosystems dates back to the late 1930s. The breeding method was limited to pure-line selection within the indigenous tall varieties or farmers' varieties. There was enormous variation in the cultivated rice varieties in Odisha, reflecting the great genetic diversity in the agroecological conditions under which the crop had been cultivated for hundreds of years. Many of these indigenous rice varieties are tall (more than 130 cm) and were selected by farmers on the basis of their adaptation to local conditions. In general, these indigenous varieties are poor yielders but have many other desirable traits. Through pure-line selection, a total of 30 different rice varieties were released in 1944 from the three research stations, Cuttack (T series), Berhampur (BAM series), and Jeypore (J series), for different ecosystems in Odisha. Most of these improved tall varieties are low yielding primarily because they are susceptible to lodging and are nonresponsive to improved crop management practices. They are not cultivated anymore, except for a few of them such as T 141, T 90, T 1242, BAM 6, SR 26, FR13A, and FR43B, which maintain their popularity for lowland ecosystems and as donor parents in breeding programs.

Popular varieties currently grown in Odisha

The Rice Research Station, Bhubaneswar, was responsible for the development and release of rice varieties for almost all of the ecosystems. A total of 59 high-yielding rice varieties were released during 1969-2012 for different ecosystems in Odisha. Some of the most popular rice varieties grown for different ecosystems are noted below (and in Table 2). Varieties Parijat, Pathara, Khandagiri, Udayagiri, Sidhant, Mandakini, and Jyotirmayee were suitable for uplands; varieties with multiple resistance such as Bhoi, Lalat, Konark, Kharavela, Gajapati, Surendra, Manaswini, and Pratikshya were suitable for medium lands; and Kanchan, Rambha, Ramchandi, Jagabandhu, Mahanadi and Upahar were suitable for lowlands. These varieties are still popular and grown widely in the state.

One lowland variety (OR 142-99) was released in Cambodia under the popular name of Santepheap-3 via the International Network for the Genetic Evaluation of Rice

Table 2. **Popular rice varieties currently grown in different ecosystems in Odisha.**

Name	Designation	IET no.	Cross combination	Days to maturity	Ecosystem^a	Yield (t/ha)		Grain type^b	Year of release
						Average	Potential		
Parijat	OR 34-16	2684	TKM 6/TN1	95	RUP	3.8	6.9	MS	1976
Pathara	OR 83-23	6639	CO 18/Hema	95	RUP	3.4	6.6	MS	1985
Khandagiri	OR 811-2	10396	Parijat/IR13429-94-3-2	95	RUP	3.2	6.1	MS	1992
Udayagiri	OR 752-38-1	12136	IRAT 138/IR13543-66	95	RUP	3.6	5.6	SB	1999
Sidhanta	ORS 102-4	15296	Jajati/Annapurna	90	RUP	3.4	7.3	SB	2005
Mandakini	OR 2077-4	17847	Ghanteswari/IR27069	103	RUP	2.6	4.6	MS	2010
Jyotirmayee	OR 1777-4	21106	P 677-50-103-2-9/Badami	95	RUP	4.4	8.1	MS	2012
Lalat	ORS 26-2014-4	9947	OBS 677 /IR2071//Vikram/W 1263	130	IRME	4.4	8.3	LS	1988
Konark	OR 1143-230	12734	Lalat/OR 135-3-4	125	IRME	4.6	8.6	MS	1999
Bhoi	OR 987-13	12443	Gauri/RP 825-45-1-3	120	IRME	3.9	6.2	MB	1999
Manaswini	OR 1912-24	19005	Swarna/Lalat	132	IRME	4.7	7.5	LS	2008
Jajati	OR 47-2	7284	Rajeswari/T 141	135	IRM	4.0	7.0	MS	1980
Gajapati	OR 820-29	13251	OR 136-3/IR13429-196-1-120	135	IRM	4.4	7.1	MS	1999
Kharavela	OR 815-3	13253	Daya/IR13240-108-2-2-3	132	IRM	4.4	8.1	MS	1999
Surendra	OR 447-20-P	12815	OR 158-5/Rasi	132	IRM	4.7	7.7	MB	1999
Pratikshya	ORS 201-5	15191	Swarna/IR64	140	IRM	4.8	7.2	MS	2005
Tejaswini	OR 1912-22	20005	Swarna/Lalat	135	IRM	4.9	9.0	MB	2010
Hiranmayee	OR 2329-44	20601	OR 1530-8/IR68181-B-49	135	IRM	5.5	12.5	MS	2012
Kanchan	OR 609-15	10016	Jajati/Mahsuri	125	RSL	4.0	5.5	MS	1992
Ramachandi	OR 912-10-190	13354	IR17494-32-2-2-1/Jagannath	160	RSL	4.2	6.0	MB	1999
Mahanandi	OR 1301-13	13356	IR19661-131-1-3-1/Savitri	155	RSL	4.4	7.0	MB	1999
Indravati	OR 1128-7-S1	13396	IR56/OR 142-99	150	RSL	4.1	7.0	MB	1999
Jagabandhu	OR 1206-25-1	14800	Savithri/IR4819 sel. //IR27301 sel.	150	RSL	4.4	6.8	MB	2002
Uphar	OR 1234-12-1	17318	Mahalaxmi/IR62	160	SDW	3.6	6.4	SB	2005
Mrunalini	OR 1898-18	18649	Mahalaxmi/OR 633-7	150	RSL	5.7	9.6	SB	2010
Nua Kalajeera	Kalajeera	18393	Pure-line selection	135	RSL	3.5	5.0	MS	2008
Nua Acharamati	Acharamati	19713	Pure-line selection	134	RSL	4.2	8.1	SB	2012

[a] RUP = rainfed upland; IRME = irrigated mid-early; IRM = irrigated medium; RSL = rainfed shallow lowland; SDW = semideepwater. [b] MS = medium slender, SB = short bold, LS = long slender, MB = medium bold.

(INGER). It is one of the most popular varieties in that country and covers a sizable area in shallow lowlands, improving the production and productivity of rice. Similarly, another lowland variety (OR 1128-7-1) was released in Tamil Nadu during 2000 called ADT 44. Rambha was identified as a promising variety for rainfed lowland areas in Myanmar, and Sarathi for irrigated areas in Bangladesh, China, Thailand, Vietnam, and Malaysia. Some of the varieties released during the period were cultivated on sizable areas of land in the state—constituting more than 70% of the area of the state—and were popular among Odisha farmers. It is worth mentioning that varieties such as Khandagiri in uplands and Lalat, Konark, Surendra, and Pratikshya in medium lands have spread to neighboring states such as West Bengal and Chhatisgarh. Pratikshya is a newly released variety with growth duration of 142 days combining high yield with multiple disease resistance and it has replaced the widely grown variety Swarna in medium lands due to its high yield, better resistance to prevailing diseases, and superior grain quality.

The project "Genetic yield enhancement of indigenous aromatic rice for economic development of the rural poor" led to the development and release of two varieties, Nua Kalajeera and Nua Acharamati. Their wide-scale cultivation and marketing would help all categories of farmers to earn more money, which would improve the socioeconomic conditions of farmers in the state and consumers would obtain quality scented rice at a reasonable price. These varieties are now widely distributed, covering more than 70% of the rice area, which helped in increasing rice production and productivity and this is directly linked with the state economy.

Brief description of the breeding program

The breeding program was conceptualized at the Rice Research Station, Department of Plant Breeding and Genetics, College of Agriculture, OUAT, Bhubaneswar, in 1970. In order to meet the varietal requirements for different rice ecosystems, the following project objectives were conceptualized:

1. Breeding for high yield, yield stability, higher disease and insect resistance, and better grain quality in irrigated systems.
2. Breeding rice varieties for rainfed shallow lowlands and semideepwater ecosystems.
3. Mutation breeding for short mutants and searching for alternative dwarfing genes.
4. Weed competitiveness in upland rice and the development of rice varieties for rainfed uplands.
5. Genetic enhancement of short-grain aromatic rice for higher productivity and for export.

The breeding program began to develop short high-yielding varieties at OUAT in 1957. A mutation breeding program produced a short-height mutant, BBS 873, from the popular lowland tall rice variety T 141. The mutant was photosensitive (while modern semidwarfs such as TN 1 and IR8, possessing the *sd1* dwarfing gene, are photoperiod-insensitive), moderately responsive to nitrogen fertilizer, with maturity duration of about 155 days, and it yielded about 50% more rice than the parent T 141 in shallow-water conditions. BBS 873 was released as Jagannath by the Central Variety Release Committee (CVRC) in 1969 for lowlands for the coastal districts of Odisha, West Bengal, and Andhra Pradesh. For a decade or so, Jagannath was the leading high-yielding variety in Odisha.

Breeding for short high-yielding varieties was accelerated after the introduction of two short varieties, TN 1 from Taiwan and IR8 developed at IRRI, into India in 1965 and 1966, respectively. These two exotic varieties ushered in a revolution in rice production, and were extensively used in the hybridization programs for indigenous development of high-yielding rice varieties, primarily for irrigated lands and for rainfed uplands and medium lands. Varietal improvement for lowlands was intensified in the late 1970s. Altogether, 59 rice varieties have been released during the last 40 years (Table 3). Some of these varieties that have gained popularity among the farmers in Odisha and in neighboring states are cultivated on large areas (Table 2).

Table 3. High-yielding varieties released since 1969.

Year of release	No. of releases	Variety
1969	1	Jagannath
1971	3	Hema, Kumar, Rajeswari
1976	2	Parijat, Suphala,
1980	3	Keshari, Subhadra, Jajati
1983	5	Shankar, Rudra, Sarathi, Daya, Pratap
1985	3	Pathara, Gouri, Rambha
1988	4	Shrabani, Lalat, Ananga, Bhuban
1992	12	Nilagiri, Khandagiri, Badami, Ghanteswari, Birupa, Bhanja, Samant, Meher, Manik, Urbasi, Mahalaxmi, Kanchan
1999	12	Lalitagiri, Udayagiri, Bhoi, Sebati, Konarka, Kharavela, Gajapati, Surendra, Prachi, Mahanadi, Indrabati, Ramachandi
2002	1	Jagabandhu
2005	4	Sidhanta, Jogesh, Pratikshya, Upahar
2008	1	Manaswini
2009	1	Ranidhan
2010	3	Mandakini, Tejaswini, Mrunalini
2012	4	Jyotirmayee, Hiranmayee, Tanmayee, Nua Acharamati

Besides applied research on rice breeding and varietal improvement, basic studies with relevance to a breeding program on high-yielding varieties have been ongoing since the 1980s. Some of the important findings or outputs follow:

- A competition study involving four established early varieties (Annapurna, Parijat, Suphala, and Bala) showed that when combinations of two varieties were mixed together (i.e., binary seed mixtures), Annapurna is the most competitive, followed by Parijat; there appears to be a relationship between competitive ability and adaptability.
- When F_1 plants (i.e., mid-parent value) display superiority over parents, these populations often generate better recombinants or superior breeding lines in advanced generations.
- Inheritance of short height in mutant variety Jagannath appeared to be multigenic.
- Both additive and nonadditive gene action are important in the inheritance of yield and its components—grain number and 100-grain weight.
- Selection response is higher for fertile grain number as a basis of selection than grain yield per se. Grain number is considered to be an important selection criterion for higher productivity in rice.
- Submergence tolerance is governed by a few dominant genes and considered as a typical quantitative trait; fast recovery, sturdy stem, tight leaf sheath architecture, and regeneration ability greatly improve the expression of tolerance.
- The use of rapid generation advance (RGA) is very effective for advancing generations in field conditions in lowland rice.

Breeding methods used for varietal development

The most commonly used breeding method at the Rice Research Station, Bhubaneswar, involves recombination breeding consisting of controlled crossing between carefully selected parents, followed by the pedigree method of selection in segregating generations for target traits. In order to breed for quantitatively inherited traits such as yield and tolerance of complex abiotic stresses and to combine a set of traits that make a variety unique or for a specific niche, the convergent breeding approach is used. This approach is also used to breed varieties for the major rice ecosystems that require step-wise improvement for target characteristics that would combine high and stable yield, adaptability, and acceptable quality.

The pedigree method is followed for improving both qualitative and quantitative traits. Because of the lack of land/laboratory facilities and labor, or when the selection environment is not appropriate to discriminate desirable genotypes from undesirable ones, particularly in breeding for biotic or abiotic stresses, judicious selection of parents tolerant of drought, submergence, or biotic stresses becomes necessary. Under such situations, the F_2 generation is raised under optimal conditions and F_3 populations are bulked for up to five generations and the segregating generations are advanced by the bulk method of breeding until the selection of elite breeding lines is made in later generations. The selected genotypes are then evaluated for yield and other component traits in the next season.

Single seed descent (SSD) for rapid generation advance is well suited for breeding long-duration photosensitive varieties and this approach is widely used by IRRI and NARES. Instead of harvesting one crop a year of a long-duration photosensitive variety with strong seed dormancy, three crops can be harvested using an SSD-RGA strategy under field conditions. In breeding for lowland and deepwater ecosystems, this strategy has been useful.

However, for advancing segregating populations of lowland late-maturity crosses, a method for RGA has been standardized at the Rice Research Station, Bhubaneswar. This involves growing photoperiod-sensitive populations during the rabi crop as described below:

- Single seeds are collected from each of the breeding populations of F_2 to F_5 generations and bulk seed samples are made by the last week of December.
- Seeds are oven dried at 55 °C for 5 days to break their dormancy, and then directly seeded at the latest by 10 January.
- In May-June, panicles are collected from the bulk population on the basis of visual selection for grain number and grain quality and used for raising pedigree lines in the next kharif season.
- Normal single-plant selection for plant type and agronomic features is done during the wet season.

Pedigree and mass pedigree, including single seed descent, methods of breeding have their own unique advantages. However, the relative effectiveness in terms of the frequency of elite breeding lines is yet to be ascertained. More than the selection method, it is the choice of parents, genotype × environment interaction, sample size, genetic drift, and changes in gene frequency due to inbreeding that determine the probability of producing improved elite breeding lines.

Number of crosses and population sizes

Some 35–40 crosses are made annually during both the wet and dry seasons. Generally, single crosses are made in the wet season and three-way crosses are made for selected single crosses and a third parent in the dry season. New crosses are made in every season by selecting promising parents from multilocation, national, and international trials conducted at the research station. Some promising elite breeding lines are also selected on the basis of breeding objectives, plant type, grain quality, and field tolerance of pests and diseases for hybridization. In case the number of cross combinations is more than 50, then some crosses are handled using the bulk method from the F_2 to F_6 generations; single-plant selections are made in the F_6 generation and evaluated for yield and other component traits in the next season.

As a rule of thumb, a population size of 1,500–2,000 is grown for each F_2 cross in every season. The population size is usually determined based on the availability of F_1 seeds, importance of a cross, land/laboratory facilities, available labor, and budget.

Screening for key traits

Plant height class is usually selected based on the target ecosystem (semidwarf to intermediate for upland areas, semidwarf for irrigated ecosystems, and short to intermediate height for lowland areas). Emphasis was given to moderate tiller number, high grain number with improved fertility, and better grain quality with short slender to medium slender grains for higher head rice recovery. Key attributes such as plant types with high grain number with improved fertility and field tolerance of major pests and diseases are used as criteria during visual selection.

For lowland late-maturity populations, F_2 populations are grown in the wet season and single-plant selections are made on the basis of short to intermediate plant height with maturity duration of 145–155 days, and panicles are selected with high grain number and high fertility. Plants are also selected based on their field tolerance of major pests and diseases such as stem borer, gall midge, leaffolder, bacterial leaf blight, sheath rot, and sheath blight. Since there were no facilities for artificial screening for tolerance of biotic stresses at the research station, only phenotypic evaluation for pests such as stem borer, gall midge, leaffolder, BPH, and diseases such as BLB, sheath rot, and sheath blight was carried out by visual selection. However, the elite breeding lines nominated to DRR, Hyderabad, for evaluation in the national network of testing are routinely screened for major pests and diseases under artificial epiphytotic conditions at DRR and field screening is carried out at endemic test sites during the wet season.

Screening for tolerance of abiotic stresses such as drought, submergence, and stagnant flooding is not done because of the lack of facilities at the research station. However, parents for population development were carefully selected based on their tolerance of such abiotic stresses based on screening results obtained within the EIRLSBN at CRRI and elsewhere. Tests for quality parameters were also not performed at the research station. Elite germplasm and fixed breeding lines are sent to CRRI and DRR for screening of quality traits in alternate years.

An overview of field trials

The ultimate aim of any breeding program is to develop improved varieties with superior yield performance, higher disease and insect resistance, and better grain quality. Various breeding and selection approaches have been employed to develop such superior varieties with enhanced yield and greater yield stability (Fig. 4). These strains are recommended to be released as new varieties by the Central or State Variety Release Committee and they should be notified by the Ministry of Agriculture, government of India, if they have been accepted for commercial planting. The release of an elite breeding line for use as a variety is based on the demonstration of its superiority over the best existing varieties (included as checks in evaluation trials) in terms of yield or some other traits of economic importance such as disease and pest resistance and tolerance of drought, submergence, and salinity.

Elite breeding lines are extensively evaluated for their relative performance in multilocation trials conducted under the All India Coordinated Rice Improvement Project (AICRIP) coordinated by DRR, which plays a key role in the testing, identification, and release of new varieties. Prior to the nomination of new strains to the national network for multisite testing, they are meticulously evaluated for their performance through various tests such as observation strips (OBS), station yield trials

(SYT), and multilocation trials (MLT) within the state to determine their superiority over the best existing varieties in yield and other agronomic traits. Some of these new strains developed in the lowland breeding program are also nominated for EIRLSBN trials and are evaluated for yield and yield-related traits in observational yield trials (OYT) and advanced yield trials (AYT) in shallow lowland situations. The various trial dimensions such as number of entries, replications, locations, and experimental designs used are presented in Table 4.

New elite breeding lines are nominated to the national network of multisite testing under the AICRIP coordinated by DRR, and are evaluated simultaneously for yield, pest and disease resistance, and quality in an initial variety trial (IVT) for 1 year and in an AVT for 2 years. Entries that are outstanding in both yield and disease resistance in the IVT are promoted to the AVT. After evaluation for 1 year in the AVT, the outstanding entries are included in agronomic trials. After evaluation for 2 years under an AVT, entries with superior performance in yield and disease resistance may be nominated in the annual workshop of the coordinated project for prerelease multiplication and for consideration for release as a variety by the Central Variety Release Committee.

A DOS-based computer software called SPAR-1 (special package for agricultural research) designed by the IASRI (Indian Agricultural Statistics Research Institute,

Table 4. Overview of the breeding scheme.

Population/stage size	Generation	Details
n = 1,500–2,000 plants per population	F_2	Single plants selected for short to intermediate plant height; appropriate maturity duration; dense, well exserted panicles with improved fertility; short slender to medium slender grains; and field tolerance of major pests and diseases
n = 150–200 lines per population	F_3	Promising lines are selected on the basis of phenotypic acceptability and single plants are selected from the selected lines. Single-plant selection for different traits varies with the breeding objectives.
n = 100–150 lines per population	F_4	Similar selection strategies are adopted as for F_3. Emphasis is made on selecting lines tolerant of major pests and diseases under field conditions with superior phenotypic acceptability.
n = 50–75 lines per population	F_5	Similar selection strategies with better phenotypic acceptability.
n = 10–15 lines per population	F_6	Augmented design, five checks in each block, unreplicated; evaluated for yield, maturity duration, and better grain quality.
OBS: 100–200 entries		
SYT: 25, 36, 49, 64, or 81 entries	F_7	Lattice design, three checks, two replications.
MLT: 25–30 entries	F_8	Randomized complete block design, three checks, three replications, four test sites within the state.

Pusa, New Delhi) is used for data analysis. The augmented design analysis is usually carried out by the procedures made popular by IRRI.

Facilities and resources

Since the establishment of the Orissa University of Agriculture and Technology (OUAT) at Bhubaneswar in 1962, the Rice Research Station, Bhubaneswar, was an integral part of the university and played a pivotal role in the development of rice varieties for almost all ecosystems. It continued functioning with an assistant professor as a full-time staff member and an associate professor in the Department of Plant Breeding and Genetics as a part-time researcher for rice varietal development. The rice breeders at the research station were supported by two research assistants and six field assistants for effective management of the research programs. Rice research in different disciplines was confined to different departments of the College of Agriculture, Bhubaneswar. The Rice Research Substation at Berhampur has been re-designated as a regional research substation to conduct research on crops other than rice. Since then, the station has become a location for rice varietal testing. Similarly, the Jeypore substation has become only a center for varietal testing with a junior rice breeder funded by DRR through AICRIP. Rice breeding received funding to improve the infrastructure for varietal testing with the establishment of regional research stations, one each in the ten agro-climatic zones of Odisha. The Rice Research Station, Chiplima, was established for conducting an AICRIP testing program on rice breeding, agronomy, entomology, and pathology. This station started functioning in 1970 with specialists in each of the above disciplines.

The rice research programs at the Rice Research Station, Bhubaneswar, are now being organized by an associate professor of the Department of Plant Breeding and Genetics, and are recently supported by an adjunct professor to concentrate on varietal improvement programs for rainfed lowland rice. Because of insufficient resources and personnel, the number of testing locations for varietal testing has declined drastically and multisite evaluation of promising lines under MLT within the state has gone down to only four locations. Similarly, the rice breeders at the rice research station are supported by only four field assistants for conducting the ongoing rice research program activities.

Rice varietal improvement programs within the university are carried out at the Rice Research Station, Bhubaneswar, Odisha, which is equipped with land for field trials and nurseries, a small field laboratory, a well-spaced threshing floor, two seed storage facilities, and a net house in which promising parents and elite germplasm are grown for systematic crossing work in every rice-growing season. Equipment, including weighing machines, grain counters, seed moisture meters, seed incubators, and germinators present in the field laboratory, is frequently used for all applied breeding research.

The university provides a research grant of Rs 200,000 (US$4,000) per annum for the ongoing varietal development program in rice. The Directorate of Rice Research at Hyderabad granted Rs 150,000 ($3,000) per annum for variety evaluation trials for different ecosystems. In addition, IRRI provides a research grant of Rs 100,000

($2,000) every year for the generation and evaluation of breeding lines suitable for rainfed lowlands under the EIRLSBN program.

Varietal improvement for rainfed lowlands and the EIRLSBN

The rainfed lowland rice area in the state is 1.41 million ha, which is more than 32% of the total rice area, and it comprises shallow, semideepwater, and deepwater areas. Shallow lowlands occupy a major area of 0.98 million ha (22.5%), followed by semideepwater area, comprising 0.30 million ha (6.9%), and deepwater area with 0.13 million ha (2.9%). Lowland rice is the major rice crop of the coastal region. Erratic rainfall and an uncontrolled water situation are the main constraints in these rainfed ecosystems. Photosensitive varieties of maturity durations varying from 145 to 165 days, with strong seed dormancy and plant height of 100 to >120 cm, are grown in the lowlands. The lowland direct-seeded crop often suffers from field problems such as poor seedling establishment due to weed competition, early drought or occasional submergence, suppressed tillering attributed to prolonged water stagnation, premature lodging favored by general wet conditions and reduced light intensity, and crop damage due to flash-flood submergence and postflood drought.

Because of the rice breeder's deep involvement in the improvement of high-yielding varieties for irrigated lands and rainfed medium lands, the lowland rice breeding program was delayed until 1980. In 1969, Pankaj (a sister line selection of IR5) was released by the CVRC along with Jagannath, and at a later date Mahsuri (developed from a japonica/indica cross) was released. These three varieties were used extensively in rice breeding work for rainfed shallow lowlands as well as semideepwater lowlands. One of the significant achievements in lowland breeding during the 1980s was the evolution of the short, photosensitive, late-maturing (about 155 days) variety Savitri (CR1009) developed from the cross Pankaj/Jagannath at CRRI. Similarly, the OUAT lowland rice breeding program was intensified in the late 1970s, with the program emphasizing short to intermediate plant height (90–100 cm), photosensitivity, maturity duration of 145 to 155 days, selection for panicle weight, and tolerance of submergence caused by flash-flooding.

For semideepwater areas, intermediate to tall plant height (110–130 cm), photosensitivity, maturity duration of 150–165 days, selection for panicle weight, and tolerance of submergence and stagnant flooding (via moderate elongation ability at the seedling stage) and also tolerance of drought at the early seedling stage were required. In both ecosystems, resistance to stem borer, gall midge, leaffolder, brown planthopper, bacterial leaf blight, sheath blight, and sheath rot is an important breeding objective.

With the increased area of high-yielding varieties such as Jagannath, Savitri, Gayatri, Mahsuri, Kanchan, Mahanadi, Jagabandhu, and Upahar, the productivity of the shallow-water lowlands has been showing a significant upward trend. However, the farmers continue to grow tall varieties such as CR1014, BAM 6, and T 1242 and common landraces on semideepwater lands, and the high-yielding varieties recommended for semideepwater areas have not yet gained popularity among lowland farmers. Thus, the lack of suitable rice varieties with high yield and resistance to stem borer and bacterial blight, and with submergence tolerance, is the major constraint to high productivity in the lowland areas of the state.

To improve the genetic yield potential of rainfed lowland rice in eastern India (Assam. Bihar, Chhattisgarh, eastern U.P., Odisha, and West Bengal), an ICAR-IRRI Collaborative Shuttle Breeding Program started in 1992. The program, known as the EIRLSBN, is funded through IRRI programs and jointly coordinated by CRRI, Cuttack, and IRRI, Philippines. The program began with six centers (Titabar, Pusa, Raipur, Masodha, Chinsurah, and Cuttack). Later, the program expanded with the inclusion of some more centers, including OUAT, Bhubaneswar. Reddy et al (2013) have extensively reviewed the major objectives, activities, and achievements of the EIRLSBN.

The Rice Research Station, Bhubaneswar, has been involved in the EIRLSBN since 1998. It provided improved breeding lines suitable for rainfed lowlands for evaluation within the EIRLSBN program in diverse lowland ecosystems of eastern India, and generated breeding material for genetic enhancement of the yield potential of rainfed lowland rice. The promising breeding lines identified from evaluation in field trials within the EIRLSBN are usually nominated for DRR multilocation and state multilocation trials for further evaluation. Elite breeding lines released as varieties, or recommended for release by the DRR network and state trials, are presented in Tables 5, 6, and 7.

Table 5. Shuttle breeding material released as varieties.

Name of the variety	Designation (IET no.)	Cross combination	Adaptability	Year of release
Jagabandhu	OR 1206-25-1 (IET 14100)	Savitri/IR4819 Sel.//IR27301 Sel.	For both shallow and semideep-water lowlands	2002
Upahar	OR 1234-12-1 (IET 17318)	Mahalaxmi/IR62	For both shallow and semideep-water lowlands	2005
Mrunalini	OR 1898-18 (IET 18649)	Mahalaxmi/OR 633-7	Shallow-water lowlands	2009
Tanmayee	OR 2339-8 (IET 20262)	Indravati/Kanchan	Shallow-water lowlands	2012

Table 6. Shuttle breeding material recommended for release by the DRR testing network.

Variety/ IET no.	Cross combination	Recommended for	Recommendation year
OR 1334-16 (IET 15206)	Mahalaxmi/IET 8892	Semideepwater areas in Odisha	2000
OR 1551-6-2 (IET 16472)	Savitri/OR 624-44	Lowland areas of eastern region and Assam	2001
OR 1898-8-21 (IET 17808)	Mahalaxmi/OR 633-7	Semideepwater areas of Odisha in eastern region	2004
OR 1898-18 (IET 18649)	Mahalaxmi/OR 633-7	Lowland areas of eastern region, Andhra Pradesh, and Gujarat	2006
OR 2119-13 (IET 19147)	Manika/Manosarovar	Lowland areas of eastern region and Gujarat	2007
OR 2339-8 (IET 20262)	Indravati/Kanchan	Lowland areas in Andhra Pradesh, Chhattisgarh, Maharastra, and Gujarat	2009

Table 7. Shuttle breeding material found promising in Odisha state trials.

Variety	Cross combination	Year of testing
OR 1898-2	Mahalaxmi/OR 633-7	2001
OR 1898-2-34	Mahalaxmi/OR 633-7	2002
OR 1884-9-23	OR 1301-7/IR49517	2003
OR 1898-18	Mahalaxmi/OR 633-7	2004
OR 1898-2-35	Mahalaxmi/OR 633-7	2005
OR 1898-32-69	Mahalaxmi/OR 633-7	2005
OR 2150-2	IET 11047/Ramchandi	2006
OR 2162-5	OR 142-99/Surendra	2006
OR 2328-5	OR 1206-26-2/OR 1534-129	2007
OR 2405-KK-5	OR 1206-26-2/IR62140	2007
OR 2166-3	IR72/Indravati	2008
OR 2339-8	Indravati/Kanchan	2008
OR 2330-1	OR 1530-8/NDR 8003	2009
OR 2407-KK-19	Indravati/IR62181-B-49	2009
OR 2331-14	OR 1301-32/IR52561	2010
OR 1878-4	OR 909-4-89/Pankaj	2010
OR 2310-4	Swarna/Birupa	2011
OR 2329-3	OR 1530-8/IR68181-8-49	2011

Future needs and directions

In Odisha, rice is grown under highly diverse ecosystems and a wide range of climatic conditions. However, rice production during the last four decades varied greatly from year to year (Das 2012). Thus, yield fluctuation is a serious concern for food security, and large-scale efforts are required to attain the targeted production of more than 10 million tons but also for stability of rice production in the state.

Since 55% of the total rice area is rainfed, priority should be given to improving productivity in rainfed rice systems to meet the growing food demand. The diverse ecosystems under which rice is grown within the rainfed system make it difficult to prescribe a single technology package for the entire region and careful evaluation is needed to develop a customized technology package for each ecosystem (Mohanty et al 2012). Unfortunately, no suitable package of practices for crop management, crop nutrition, and plant protection against diseases and pests for rainfed farming systems has been developed. It is therefore necessary to intensify or reorient the ongoing research programs to develop technologies for mostly rainfed rice, and this has so far been neglected. The development and adoption of an efficient technology for rainfed rice systems not only help to enhance production and productivity but also help maintain the stability of rice production in the state.

With the existing technologies, including suitable varieties and good-quality seeds, better water management practices, and by introducing resource-conserving production practices such as balanced fertilizer application, and integrated pest and nutrient management, productivity in irrigated lands, favorable rainfed medium lands, and shallow-water lowlands could be increased to reach the targeted rice production by 2020. Special emphasis should be given to shallow-water lowlands, because the inherent fertility of these lands is high. Thus, with suitable high-yielding rice varieties and better variety-input matching management, the productivity of these areas (more than 35% of the total rice area) could be increased from the present 1.3 t/ha to over 2.0 t/ha.

Socioeconomic problems and long-term strategies to improve production and productivity

Inadequate rural credit coupled with poor economic conditions of small and marginal farmers that account for 82% of the total farmers with small landholdings (half of the rural households own less than a hectare) due to continuous fragmentation make it difficult for farmers to adopt capital-intensive modern rice production technologies. More than 70% of the rice area in Odisha is used for growing high-yielding varieties (Directorate of Agriculture and Food Production 2012). Despite this, the state's rice productivity continues to remain far below the national average. Without drastic socioeconomic reforms with respect to the ownership of farmland and/or its management, exploitation of the full potential of the available technologies will continue to remain relatively low. A very important problem that needs immediate attention is "sharecropping," which is fast replacing "owner-farming." Fair agreements are needed for sharecroppers in terms of gaining a higher proportion of the produce, compared with the current 50:50 arrangement. This will require legislation, and it should be the responsibility of the landowner to make available necessary funds to the sharecropper for seeds of suitable varieties and inputs, which are subject to recovery at the time of sale or disposal of the produce.

The poor seed replacement rate, lack of marketing facilities and unfavorable pricing policy, high incidence of poverty, deterioration of the resource base, and declining profit margins contribute to low input use and a minimal use of capital-intensive technologies, leading to low rice productivity. Also, immediate government attention is necessary to have infrastructure developed for irrigation, drainage, transportation, and electricity. However, as a long-term strategy beyond 2020, it is imperative to maintain soil fertility and land development. For example, in the plateau regions, the productivity of uplands could be increased considerably through bunding, terracing, and land leveling. These would enhance the moisture retention of the soil. Similarly, in irrigated areas, better water management through field channels would enhance the economics of water and prevent land degradation; and the provision of effective drainage facilities would greatly improve the productivity of waterlogged lands with adverse soil conditions.

The role of IRRI

The major constraints limiting rice production in the rainfed lowlands have been tackled by the EIRLSBN program, which has been in operation in eastern India since 1992. The major achievements of the EIRLSBN have been described in this publication and by Reddy et al (2013). Many of the promising breeding lines generated and evaluated within the network combining high yield with moderate submergence tolerance and improved grain quality have been released as varieties in different eastern Indian states. However, the majority of these released varieties have very specific adaptation to either shallow or semideepwater situations, and therefore their performance is unstable in highly variable lowland conditions.

A large-scale marker-assisted backcrossing (MABC) program started at IRRI to incorporate *SUB1*, a major quantitative trait locus (QTL) conferring submergence tolerance, into popular mega-varieties in South and Southeast Asia (Collard et al 2013). Using MABC, *SUB1* was successfully introgressed into Swarna, Samba Mahsuri, and Savitri (CR1009) and it conferred very high submergence tolerance. These new Sub1 varieties have been or will be released in India and will be used as highly adapted donor parents in the EIRLSBN program to develop new breeding populations with *SUB1*. IRRI's breeding program for flood-prone areas integrates conventional and innovative molecular approaches for the development of new elite breeding lines tolerant of both submergence and stagnant flooding or anaerobic conditions during germination, and combines submergence tolerance with disease and insect resistance using a convergent breeding approach.

Both IRRI and EIRLSBN network programs should reciprocally exchange elite breeding lines, which would not only enrich the gene pool but would also be used to generate new improved breeding lines suitable for harsh and highly unpredictable rice-growing areas in the rainfed lowlands of eastern India.

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Twenty years of achievements of the EIRLSBN at the Rice Research Station, Chinsurah

Indrani Dana, Sitesh Chatterjee, and Chinmoy Kundu

The Rice Research Station belongs to the State Department of Agriculture, government of West Bengal. The station was established in 1932 with financial help from the Imperial Council of Agricultural Research & Empire Marketing Board, at 22°52´N latitude and 88°24´E longitude and at an altitude of 8.6 m.

Rice is an important staple food crop of West Bengal, and the state ranks first in the production of rice in India. The state's contribution is 15.8% of total rice production in India (Table 1). In West Bengal, rice is grown in three seasons: autumn (aus), winter (aman), and summer (boro). These three seasons are named according to the time of harvest of the crop: May/June to September/October for aus, July/August to October/November for aman, and November/December to April/May for boro. The boro area constitutes 27% of the total rice area, aus is only 4%, whereas aman/kharif (wet season) area predominates, covering 68% of the total rice area. Depending on the seasons, these three rice crops are cultivated under four different ecosystems: rainfed upland rice, irrigated rice, rainfed lowland rice, and flood-prone rice.

Geographic and environmental factors

The total area of West Bengal has been broadly divided into six agro-climatic zones depending on rainfall, temperature, soil type, and topography of the land:

1. Hill regions in the north
2. Terai and Teesta alluvial regions in the north
3. Red lateritic and gravelly undulating region in the west
4. Gangetic alluvial region in the east

Table 1. Rice area, yield, and production in West Bengal.

Rice	Years					
	2009-10			2010-11		
	Area (ha)	Yield (kg/ha)	Production (tons)	Area (ha)	Yield (kg/ha)	Production (tons)
Aus/autumn	214,062	3,271	700,150	212,132	3,206	680,159
Aman/kharif/ winter	3,986,330	3,612	14,396,952	3,362,122	3,761	12,643,982
Boro/summer	1,429,703	4,486	6,413,808	1,369,892	4,935	6,760,270
Total	5,630,095	3,821	21,510,910	4,944,146	4,062	20,084,411

Source: Joint Director of Agriculture Evaluation Wing, Government of West Bengal.

5. Vindhya alluvial region in the center
6. Coastal alluvial region in the south

In each region, rice has been the major crop for time immemorial. The practice of growing rice is believed to have originated in areas of eastern Asia, besides China, and southern Asia, at about 2000 BC. The climate of the state is tropical and humid, which is very conducive for growing rice. The temperature in the mainland normally varies from 24 to 40 °C during the summer and from 7 to 26 °C during the winter. The average rainfall in the state is about 1,750 mm. Maximum rainfall occurs from May to October (about 95%). Because of this uneven distribution of rainfall, flash flooding is a common feature in the shallow to lowland areas. In semideep to deepwater areas, stagnant flooding is a common problem.

The state covers an area of 8,875,200 ha, accounting for 2.7% of the total geographic area of the country, while its population of more than 90 million accounts for nearly 8% of the entire population of the country. This makes West Bengal the fourth most populous state in India (according to the 2011 census) after Uttar Pradesh, Maharashtra, and Bihar, but second most dense in population after Bihar (1,029/ km^2). The average literacy rate in the state is 68.6% (female literacy: 59.6%), which is higher than the national average of 65.4% (female literacy: 53.7%).

Agriculture is the predominant occupation of the state. It contributes nearly 24% to the state domestic product annually. For most rice production areas, farmers still depend on rainfall as only 27% of the rice land is irrigated aman area (Adhikari et al 2010). Most of the farmers are small and marginal, and generally do not have enough resources to access modern inputs and technologies for cultivation. About 84% of the state's agricultural lands are held by small and marginal farmers. More than 90% of the 5.7 million hectares of the state's arable land is cultivated by small and marginal farmers (< 1 ha of land) compared with 69.8% within the whole country. Large landholdings (>10 ha) are almost absent.

To help the small and marginal farmers, the state and central government initiated various schemes and projects. Examples are hubs for hiring farm implements for a fee and seed banks from which seeds are made available to farmers whenever required. The state government, through its agencies and agricultural universities, promotes agricultural machinery by demonstrating newly developed equipment. "Seed villages" are being formed where farmers are trained to produce high-quality certified seeds of paddy and other crops. Seed banks are also being formed and infrastructure is being developed to produce and distribute good-quality seeds. To insure poor farmers against crop losses due to aberrant weather, crop insurance schemes are being started.

Brief description of the breeding program

To tackle the deficiencies of these varieties of the lowland ecosystem and increase productivity, a shuttle breeding program, a joint collaborative initiative between the Indian Council of Agricultural Research (ICAR) and the International Rice Research Institute, began in 1992, mainly for the shallow to semideepwater or stagnant floodwater areas (up to 50 cm water depth). RRS-Chinsurah was one of the initial leading centers of this network. Activities carried out through the network include the following.

Hybridization, selection, and generation advancement

One-way, two-way, and three-way crosses were used. Some 30–40 crosses were made each year. F_1s were grown in shallow water or sometimes sent to IRRI and other collaborating breeders of the EIRLSBN of eastern India. From the F_2 generation onward, populations were grown in the field. In some cases, F_2s were also sent to IRRI and other collaborating centers. The segregating materials (mainly F_2 populations) received from IRRI were evaluated and advanced. RRS-Chinsurah also shared its own breeding material with IRRI and other participating centers.

Through a series of field tests or artificial screening, genotypes with desirable traits were identified, and used as parental material for crossing and for developing new breeding populations. A typical F_2 population size would consist of 2,500 to 3,500 plants. From F_3 to F_5, progenies were maintained following panicle-to-row selection. Selections were made in every generation for biotic and abiotic stresses. In the F_6 generation, seeds were bulk-harvested, and, for F_7 material, replicated yield trials were conducted.

Selections were based on: agronomic traits (plant height, flowering time, and responsiveness to low and high doses of fertilizer); plant type (plant stature, panicle length, grain number/panicle, and the density of grains in panicles); disease resistance (sheath rot, sheath blight, and bacterial leaf blight); and abiotic stress tolerance such as submergence and drought tolerance. Grain shape is the most important quality attribute that is used for selection.

Dry seeds were sown in the field from April onward prior to monsoon rains. Drought is common for about 1 month, as the monsoon generally starts in mid-June. Water starts accumulating in the field in mid-July and rises gradually, depending upon rainfall and surface runoff from neighboring fields, and may remain until harvest (i.e., stagnant flooding). As a result, breeding materials during generation advancement are exposed to severe abiotic stresses such as drought at the early vegetative stage, flooding of different depths and durations at different growth stages, and biotic stresses such as aquatic weeds, insects, and diseases.

After preliminary testing, promising entries were either sent to national nomination at the Directorate of Rice Research or sent for observational yield trials (OYTs). These OYTs were conducted in an augmented block design. Then, promising entries were sent for replicated yield trials (RYTs). RYTs were conducted following a randomized complete block design (RCBD). The promising breeding lines after RYTs are nominated to national trials via the Directorate of Rice Research (DRR). All trials were planted following 20 × 20-cm spacing.

Prior to or after the release of a variety on the basis of national performance and recommendation, it is important to ascertain the reaction of farmers to the agronomic performance and acceptance. Previously, a front-line demonstration (FLD) was used for this purpose. Currently, farmers' participatory varietal selection (PVS) is a more rapid and cost-effective way of identifying farmer-preferred cultivars and also for soliciting farmers' input into the selection and approval process.

Resources and facilities

One breeder has led the activities at RRS. Later on, scientists from entomology and pathology became associated with the program. One permanent field assistant and one field laborer work within this program. The late Dr. Sukumar Mallik was involved since its inception in 1992 until 2009, and he made an enormous contribution to rice breeding and research, and the overall success of the EIRLSBN.

Chinsurah has shallow (40 cm), semideep (40–75 cm), and deep (75–100 cm) lowland rice areas, and these sites are represented at the breeding station. RRS-Chinsurah hosts about 10,000 rice germplasm accessions. Of these, 5,000 have been sent to IRRI and 2,000 to the National Bureau of Plant Genetic Resources in Delhi for long-term storage. About 3,000 accessions are grown every year on the station farm. The site also has concrete tanks for artificial submergence screening.

Breeding objectives

Rice in West Bengal is mainly grown in the kharif or aman season. Aman rice area covers 68% of the area of West Bengal, accounting for 63% of total rice production. In order to feed the huge population of the state, the gap between the state's needs and current supply needs to be filled by increasing production. In the lowland ecosystem, mostly indigenous and traditional varieties were grown in the past. Their yield was very poor. To improve the yield potential of these varieties, research was undertaken in the late 1970s at the Rice Research Station (RRS), Chinsurah. A major flooding catastrophe in 1978 provided the impetus for developing rice varieties with flood tolerance. Afterward, selection and crossing of flood-tolerant rice varieties with high-yielding varieties began. Varieties having a long growth duration performed better in waterlogged areas. Extensive screening was therefore carried out to investigate this trait.
There are different mechanisms of adaptation for different flood-prone ecosystems. Elongation ability is needed for deepwater areas, where water depth exceeds 100 cm. Submergence tolerance and good regeneration ability are required for flash-flood situations where crops are submerged for 1 to 2 weeks.

Challenges in rainfed lowland rice areas such as drought, flooding, and intermittent submergence at different stages of crop growth depend upon the topography of the land and rainfall pattern. This affects rice yield substantially and the average yield of rice in these situations is approximately 1.5 t/ha. Sheath blight, sheath rot, and bacterial leaf blight are important diseases in lowland rice areas. Intermediate plant height (100–130 cm) and stiff culms are desirable characteristics. Low yields are mainly due to the lack of appropriate cultivars to cope with the risks associated with biotic and abiotic stresses. Regarding quality preferences in West Bengal, the desirable attributes of rice varieties are medium slender/long slender grain and intermediate amylose content (20–25%).

Old and current varieties

Old varieties

Many varieties have been developed for and released for different ecosystems in West Bengal (Samanta and Mallik 2004). The traditional flood-tolerant rice variety in the semideep situation of West Bengal was Jalaplaban, a selection from Gabura (maturity of 160 days). Varieties for deepwater areas were also released by RRS-Chinsurah. Other important varieties are listed below. Additional varieties that are very useful donor parents with specific traits are listed in Table 2.

Deepwater varieties:

- Jaladhi 1 (a selection from Kalakhersail)
- Jaladhi 2 (a selection from Baku)
- Jalaprabha (a selection from a composite)
- Neeraja (a selection from a landrace)
- Dinesh [CN570-652-39-2 (Jaladhi 2/Pankaj)]
- Hangseswari (a pure-line selection)

For semideep areas:

- NC 1281 (a selection from a local variety)
- OC 1393 (a selection from local material)
- Suresh [CN540 (IR262/Khao Nahng Nuey)]
- Biraj CNM539, mutant of OC 1393
- Bhagirathi [CN580-869-42-3 (Jhingasail/Patnai 23)]
- Sabita (CN492, a pure-line selection)
- Jogen [CN505-5-32-9 (IR26/SMI40-10-4)]
- Ambika [CN584-550-16-3 (Pankaj/Patnai 23)]

Table 2. Promising rice varieties for lowland situations developed or identified at RRS-Chinsurah during the early 1980s.

Characteristic	Variety[a]
Seedling vigor	NC492 (Sabita), NC493 (Amulya)
Drought tolerance at early vegetative stage	NC487, NC488, CN506-147-2-1, CN506-147-14-2
Stiff culm	CN506-147-14-2, NC496
Submergence tolerance	CN643, CN540
Resistance to stagnant flooding	Tilakkachari, NC490, NC492
Photoperiod sensitivity	NC492, CNM539
Seed dormancy	NC492, FR13A (introduced from Odisha)
Good grain quality	CN540 (Suresh), CNM539 (Biraj), CN691-1
Good basal tillering	CN499-160-2-1, CN499-160-13-6 (Mandira)

[a] CN = Chinsurah, NC = new collection.

- Mahananda [CN845-40-5 (IR36/Patnai 23)]
- Mandira [CN499-160-13-6 (IR34/KLG 6987-143-2-9//IR2070-2-5-6/HBJDW8)]
- Matangini (CN491, a pure-line selection from Kajallata)
- Saraswati [CN584-311-10 (Pankaj/Patnai 23)]
- Golak [CN578-190-7-4]
- Nalini [CN490 (a pure-line selection from Sindhur Mukhi)]
- Sunil [CN817-122 (OC 1393/BIO 476-PN 18-1-4)]
- Sudhir (CN718-8-21-10, another variety that has been developed from FR13A/Biraj)

Sabita is considered as a mega-variety in India for the semideep ecosystem. It is still the predominant variety in the rainfed lowland ecosystem in West Bengal, and has been used as a national check variety since 1998. It is also popular in Odisha and Assam, and many breeders in India and overseas have used Sabita as a donor.

The indigenous varieties that showed good survival after flooding but had lower yield included Kalawriji, Kaimsail, NC1281, Auskali, Nizersail, Meghi, Badrasail 2, Jabra, Motajata, Alakkachari, Asgo, Bhelki, Katiputur, and Kariwai 1. Varieties with higher grain yield but lower survival after flooding included Patnai 23, Pokkali, Kalamkati, Auspanjali, Sadakalma, Ghatakalma, Sitabhog, Peshwari, Bhimsail, Hamai, Bongota, and Begunbichi. In most of the shallow lowlands where flooding occurs once or twice in five years, farmers preferred high-yielding varieties such as Swarna, Savitri, and Pankaj, which are highly sensitive to submergence stress.

Current varieties released by the RRS

From 1992 to 1997, 13 entries were nominated to various DRR trials. Among them, CN1035-61 (IET 14496; Pankaj/IR38699-493-1-2//IR41389-20-5) was recommended by DRR because of its high yield of >4.0 t/ha in semideep situations. CN704-7-3 and CN570 652-39-2 ranked first and second, respectively, on the basis of overall performance in 1993. Similarly, CN505-5-32-9 (Jogen) and CN718-8-21-10 (Sudhir) ranked first and fifth in the 1996 International Rainfed Lowland Observational Nursery (IRLON) (Table 3).

From 1998 to 2003, 106 entries were nominated to various DRR trials. In 2002, CN1035-61 was released as Bhudeb for the semideep ecosystem (Mallik 2003). Bhudeb survived even after three floods in Assam during 2001 and the farmers named it Ban Vijay ("conquering the flood"). Bhudeb was used as a parent in many subsequent crosses and the crossed materials were evaluated in shuttle breeding trials. During 2002, 10 entries were identified through DRR trials. Their rankings in various trials are shown in Table 4.

During 2004 to 2009, 110 entries were nominated to DRR trials for various ecosystems, including shallow lowland, semideep, and deepwater areas. CN1039-9 (IET 17713), CN1231-11-7 (IET17791), CN1230-12-2 (IET 17684), and IR72035-CN 32-8 (IET 17686) were in the prerelease stage. CN1272-55-105 (Mohan/IET 4094) ranked first during 2008, 2009, and 2010 in India Variety Trials (IVT; late-maturity trial). During the All India Rice Workshop of 2010, it was recommended for release. In

Table 3. List of promising entries nominated to different INGER nurseries from 1993 to 1998.

Year	Nursery[a]	Outstanding entry[b,c]	Parentage[d]	Remarks
1993	IDRON	CN704-7-3 (1st), *NC490 (3rd), and *CN570-652-39 2 (2nd)	CN704 (Pankaj/CN 540), CN570 (Jaladhi 2/Pankaj)	Some of these entries were used by Myanmar, Cambodia, and Vietnam
1994	IDRON	CN705-18 (2nd) and *NC490 (5th)	CN705 (Mahsuri/CN643)	Among overall best five entries
		CN705-18 (2nd), *NC490 (5th), and NC488/77		Used as parents in Thailand and India
1995	IDRON	GS 302	Selection from Guskara	Among overall best five entries
		GS 302, CN570-570-18-1		Used as parents in Thailand, Myanmar, and India
1996	IRLRON	*CN505 (1st)		Top entry in <100 days flowering group
		*CN718-8-21-10 (5th)	CN718 (FR13 A/CNM 539)	Among best five entries in >100 days flowering group
	IDRON	*NC491		Resistant to sheath blight, bacterial blight, and neck blast
1997	IDRON	CN1027, *CN 578-190-7-4	CN578 (Jhingasail/HTA 108)	Among best entries in Myanmar
		CN1027, CN1035, *CN573-221-7-1	CN573 (Patnai 23/Jaladhi 2)	Among best entries in N. Lakhimpur, Assam
		*CN573-221-7-1, *CN578-190-7-4		Among best entries in Chinsurah, West Bengal

Cont.

Table 3 continued

Year	Nursery[a]	Outstanding entry[b,c]	Parentage[d]	Remarks
1998	IRLRON	CN721-5-2-28, CN 566-915-63-4	CN721 (CN496/CNM 539)	Among overall best five entries
		CN721-5-2-28		Resistant to bacterial blight, panicle blast, and rice tungro disease
		CN566-216-10-1	CN566 (HTA-108/Patnai 23)	Resistant to bacterial blight, panicle blast, rice tungro disease, and sheath rot
		CN566-915-63-4		Resistant to bacterial blight, panicle blast, and sheath rot
		CN721-5-2-28	CN496/CNM 539	Follow-up trial in Cambodia and India
	IDRON	CN982		Used as parents in Vietnam and India
		CN1116		Follow-up yield trial in Myanmar and India

[a] IDRON = International Deepwater Rice Observational Nursery; IRLRON = International Rainfed Lowland Rice Observational Nursery. [b] Numbers in parentheses indicate overall ranking in the nursery. CN = Chinsurah. [c] Entries marked with asterisks have been released as a variety. [d] CNM = Chinsurah mutant.

Source: Final reports of different INGER nurseries, IRRI.

Table 4. Promising elite breeding lines identified from DRR trials from 1998 to 2004.[a]

Entry no.	IET No.	Parentage	Trial
CN1234-7-34	17683	CN1035-60/Abhaya//CR 753-29-9	AVT (DW) (1st)
CN1230-12-2	17684[b]	Banla Phdao/Sabita//Mahsuri	AVT (DW) (2nd)
CN1165-6-3	17674	IR67631-18-2/CN1015	AVT (DW) (3rd)
IR72035-CN32-8	17686[b]	Neang Sar/IR58910-202-1-3-2-2//Sabita	AVT (DW) (4th)
CN1231-11-7	17792	IR57519-PMI-4-1-1-3-1/IR58910-202-1-3-2-2//CN846-6-6	IVT SDW (1st)
CN1233-33-9	17714	IR58895-PMI-5-1-3-3/Rajshree//Sabita	NSDWSN (1st)
IR74355-CN3	17716	CN1013-21/Salivahan//CN846-6-6	NSDWSN (3rd)
IR72035-CN244-1-15-8	17731	Neang Sar/IR58910-202-1-3-2-2//Sabita	NSDWSN (4th)
IR72035-CN32-8	17732	Neang Sar/IR58910-202-1-3-2-2//Sabita	NSDWSN (7th)
CN1163-14-7	17720	IR67631-18-2/IET 8543	NSDWSN (9th)

[a]IET = initial evaluation trial, AVT (DW) = advanced variety trial (deep water), VT-SDW = initial variety trial (semi-deepwater), NSDWSN = national deepwater screening nursery, CN = Chinsurah. [b]During the Annual Workshop of the Directorate of Rice Research during 2004, IET17686 and IET17684 were recommended for release. These entries have long slender grain type and ranked first and second, respectively, in the AVT 1-DW trial of DRR during 2003.

2011, it was released as Kanak by the state variety release committee (SVRC). Some specific entries became very popular with farmers in shallow lowland areas (Table 5). Various baby trials are being conducted with these entries. CN1039-9 (yield of 4.8 t/ha) has been cultivated in Odisha and Assam for the past five or six years. Its grain quality (long slender) and taste are preferred. CN1231-11-7 may be an alternative to Sabita (Mallik et al 2006). Over the years in PVS trials, it has been observed that farmers consistently prefer this variety as evident from annual reports.

Sabita (NC 492, a pure-line selection from Boyen), Purnendu (CN573-221-7-1, Patnai 23/Jaladhi 2), and Dinesh (CN570-652-39-2, Jaladhi 2/Pankaj) released from RRS-Chinsurah, are national checks. Sabita, a national check since 1987, is a dominating variety in rainfed lowland ecosystems in West Bengal. Sabita is also popular in Odisha and Assam. Sudhir (IET 10543) is another variety that has been developed from an FR13A/Biraj cross. This variety was released by the Central Variety Release Committee, Indian Council of Agricultural Research, government of India, in 1999.

Amulya (NC493, a pure-line selection from Najani) and Jitendra (a selection from a landrace) are performing well in Bihar. Bhudeb's performance is outstanding in Assam. Hanseshwari and Ambika survived an unprecedented flood in Odisha in 2001. Many of these varieties/advanced breeding lines have been used as donors by

Table 5. Popular varieties for shallow areas developed by RRC-Chinsurah during 2004-09.

Designation	IET No.	Parentage
CN1039-9	IET 17713	Sabita/IR57540-8
CN1230-20-16		Banla Phdao/Sabita//Massuri
CN1231-11-7	IET 17792	IR57519-PMI-4-1-1-3-1/IR58910-202-1-3-2-2//CN846-6-6
CN1233-33-9	IET 17714	IR58895-PMI-5-1-3-3/Rajshree//Sabita
CN1265-7-16	–	Swarna/IR36
CN1232-12-1	–	IR58895-PMI-5-1-3-3/CR753-29-9//Sabita
CN1499-8-1-1	–	CN1233-14-27/IR55144-4R-81-3
CN1506-3-2	–	IR74335-CN-3/Swarna
CN1919	IET 20212	IR64588-2-3 (IR11141-6-1-4/*O. rufipogon*)
CN1920	IET 20213	IR64588-2-1(IR11141-6-1-4/*O. rufipogon*)
CN1592-5-1	IET 20086	CN1503/CN1366-7-2

breeders in India and abroad (IRRI-Philippines, Myanmar, Cambodia, Vietnam, and Thailand). Variety Sabita alone has been used in more than 50 crosses by IRRI and other states in India (Mallik et al 2002).

After the introduction of Swarna-Sub1 in areas that are prone to flash flooding, Chinsurah assisted in the popularization of this new variety through seed production and distribution to farmers in various districts of West Bengal. In the kharif season of 2007, 1,891 kg of seeds were produced in Hooghly, Nadia, Malda, Murshidabad, 24-Parganas (South and North), Midnapur (East), and Uttar Diajpur under the supervision of RRS-Chinsurah. Seeds were being distributed to farmers through baby trials. In 2009, 4,973 kg of Swarna-Sub1, 150 kg of IR64-Sub1, and 97 kg of Samba Mahsuri-Sub1 seeds were produced and distributed to farmers. To enhance the awareness and help in disseminating the best varieties identified through baby trials, 8,960 kg of Swarna-Sub1 and 1,591 kg of CN1039-9 seeds were distributed within and outside West Bengal during 2010.

Future needs and directions

It is of the utmost importance that submergence-tolerant rice varieties be made available for regions in which flash-flooding occurs. Early breeding work in India led to the release of highly tolerant varieties, including FR13A and FR43B. Submergence- and stagnant-flooding-tolerant varieties will help to minimize the annual fluctuation in rice yield in lowland areas. About one-third of India's total rice area of about 42 million ha is exposed to hazards of monsoon floods. Most varieties are susceptible to different types of floods, and the impact on yield loss may vary depending upon growth stage, depth of floodwater, flood turbulence, and water turbidity.

There are different physiological mechanisms of adaptation for different flood-prone conditions. Elongation ability is needed for deepwater situations of more than

100 cm, which is actually an avoidance mechanism. Submergence tolerance is required for flash-flood situations when the crop is submerged for 1 week to 2 weeks.

Future breeding objectives should be directed toward developing varieties suitable to different land situations considering the following characteristics: (1) seedling vigor, (2) drought tolerance at the early stage, (3) semitall plant type, (4) stiff culms, (5) photoperiod sensitivity, (6) seed dormancy, and (7) submergence tolerance.

Future breeding programs should involve collaborative efforts toward the exchange of parental and early-generation breeding materials. Rapid generation advancement through embryo culture or single seed descent would also be useful. Finally, marker-assisted selection for desirable characters can be done through the use of different kinds of molecular markers. Molecular markers have several advantages over traditional phenotypic markers: these markers are not regulated by environment and are detectable in all stages of plant growth.

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Twenty years of achievements of the EIRLSBN: accomplishments of the Regional Agricultural Research Station, Titabar, Assam

T. Ahmed

Rainfed lowland rice occupies 37 million ha worldwide, which is about one-quarter of the global rice area. The productivity of rainfed lowland rice is very low, ranging from 0.5 to 1.5 t/ha compared with that of irrigated rice (4.0–5.0 t/ha) because of the prevalence of biotic and abiotic stresses. In eastern India, rainfed lowland areas occupy 13.9 million hectares, which is little more than 50% of the total rice area of 26.4 million hectares in the region, and >75% of the total rainfed lowland areas of the whole country. However, production and productivity throughout the region are very poor. The role of eastern India (comprising the states of Assam, West Bengal, Odisha, Bihar, eastern Uttar Pradesh, and eastern Madhya Pradesh) in increasing the production and productivity of rainfed lowland rice is very important but challenging.

The rice-growing ecosystems of Assam: different constraints and varieties

Rice is the single most dominant crop of Assam and is grown in diverse ecosystems. Wide variation in physiographic features and climatic characteristics has resulted in three distinct growing seasons: ahu (February/March-June/July), sali (June/July-November/December), and boro (November/December-May/June). In Assam, out of 2.53 million hectares of total rice area, winter rice covers 1.8 million hectares and is basically a rainfed crop (Table 1). Winter rice (sali) is grown under diverse environments, including shallow lowland (0–30 cm), lowland (0–50 cm), and semideep (50–100 cm) to deepwater (>100 cm) conditions. However, the predominant situation is shallow lowland (1.0 million ha), in which high-yielding varieties such as Ranjit and Bahadur have been grown and the productivity of the ecosystem has been increasing recently (Table 2). However, lowland and semideep to deepwater ecosystems occupy 0.4 million ha each, and these ecosystems are unfavorable for rice cultivation and need special attention to increase their current productivity.

The climate of Assam is subtropical, with a warm humid summer and cool dry winter. On average, the state receives 2,252 mm of rainfall per annum. Although the total precipitation is very high, its distribution over places and seasons is very erratic, causing either flood or drought or sometimes both within the same season. Table 3 describes the general pattern of seasonal rainfall. The average maximum temperature ranges from 23.6 to 31.7 °C, and the minimum temperature is 10 to 24 °C. The average minimum temperature is about 10 °C in December/January while the maximum

Table 1. Rice ecosystems of Assam.

Class	Ecosystem	Area (000 ha)
Autumn rice (ahu)	Upland (unbunded)	128
	Transplanted	218
Summer rice (boro)	Marshy low-lying areas	146
	Nontraditional areas	248
Winter rice (sali)	Rainfed shallow lowland (0–30 cm)	1,000
	Rainfed lowland (0–50 cm)	368
	Hill rice	21
	Deepwater (50–100 cm)	300
	Very deep (>100 cm)	100
	Total	2,529

Table 2. Area, production, and productivity of rice in Assam.

	Years					
Rice	2005-06	2006-07	2007-08	2008-09	2009-10	2010-11
Area (million ha)	2.420	2.190	2.324	2.484	2.530	2.616
Production (million tons)	3.552	2.916	3.319	4.070	4.408	5.086
Yield (quintals/ha)	14.87	13.49	14.28	16.38	17.65	19.69

Table 3. Climate of Assam.

Season	Months	Rainfall (mm)	Characteristics
Premonsoon	March-May	549.5 (25%)	Low and erratic rainfall with dry spells
Monsoon	June-September	1,430.0 (65%)	Heavy rainfall with flood
Postmonsoon	October-November	152.3 (7%)	Low and erratic rainfall
Winter	December-February	65.9 (3%)	Cool and dry
Total		2,197.9 (100%)	

temperature of 32 °C is reached in July/August. However, the minimum temperature drops to as low as 6 °C and the maximum temperature can reach 37 °C. On average, relative humidity exceeds 80% in almost all locations of Assam throughout the year. The state receives 4 hours of sunshine per day during the kharif season and 6 hours in the rabi season. This indicates that radiation interception is only 36–38% of sunshine hours during June to August due to overcast sky, whereas, during November to February, it is 70–74% due to the foggy weather.

Agro-climatic zones

Based on rainfall pattern, terrain, and soil characteristics, Assam has been delineated into six agro-climatic zones:

1. The North Bank Plain Zone (NBPZ) occupies 18.4% of the state's total area, with 75% of this area monocropped. Deepwater rice is widely grown.
2. The Upper Brahmaputra Valley Zone (UBVZ) has 20.4% of the state's area. It features monocropping with rainfed rice.
3. The Central Brahmaputra Valley Zone (CBVZ) occupies 7.1% of the state's area, in which 71% is grown to rice. Double cropping of jute-rice and rice-rabi crops is also popular.
4. The Lower Brahmaputra Valley Zone (LBVZ) has 25.8% of the state's area. Rice, jute, wheat, pulses, potato, and oilseeds are the principal crops.
5. The Barak Valley Zone (BVZ) occupies 8.9% of the state's total area where rice, sugarcane, pulses, toria, and potato are major crops.
6. The Hill Zone (HZ) contains 19.4% of the state's area. Jhum rice is the predominant feature, with some wet-season rice grown in terraced fields and valleys. Jhum rice is a special class of ahu rice grown on hilly slopes following slash and burn. Efforts are being made to educate farmers to avoid this practice so as to minimize soil erosion and other adverse effects arising from this practice.

Agriculture is the major occupation of the people of Assam. This sector continues to support more than 75% of the population of the state directly or indirectly, providing employment to more than 53% of the work force. About 99% of the total area of the state is rural and almost 50% of the total land area is used for cultivation. The net cultivated rice area of the state is 2.753 million hectares, of which 23% is either flood or drought prone and the per capita availability of the net sown area is around 0.1 hectare. The average operational holding is 1.15 hectare only and more than 83% of the farm land belongs to small and marginal farmers.

Farming systems

More than 40 combinations of crops and various other enterprises have been identified, with four or five of these being noted as major ones. The important difference in the farming systems lies in the inclusion of one or more animal activities. Different systems have variation in crop area and types, but this variation is not that substantial. Rice is the main crop in these systems. Of total farm income, rice alone contributes about 60% and livestock rearing is of secondary importance. Of the three major components of a whole farm business, the homestead component is important after field crops and contributes substantially toward farm income and employment generation. The following sequences are the major farming systems adopted in the state:

- Crops + dairy cows + goats + pigeons + ducks (LBVZ, CBVZ, NBPZ)
- Crops + dairy cows + poultry (CBV, LBV, NBPZ, and *chaur* areas)
- Crops + dairy cows + poultry + pigs (hill zones)
- Crops + dairy cows + pigeons + fish + pigs (UBVZ)
- Crops + dairy cows + poultry + fish (NBVZ, BVZ)
- Crops + dairy cows + fish (NBVZ, BVZ)
- Crops + dairy cows + goats + poultry + ducks (UBVZ)
- Crops + dairy cows + goats + ducks (LBVZ)
- Crops + dairy cows + goats + sheep + poultry (*chaur* areas)
- Crops + dairy cows + poultry + ducks + fish + pigeons (BVZ)

Almost invariably, rice is one of the crops grown, and thus the rice-based farming system is the most dominant among the systems adopted in the state.

Major stresses facing crop production in Assam

Abiotic stresses

In Assam, rice is grown in a variety of seasons, soil types, and water regimes. Therefore, the crop encounters different stresses.

1. Floods. Flooding is the major problem of the state, which affects all the classes of rice. Sali rice is damaged during its vegetative stage while ahu and boro are affected during their reproductive and maturity stages due to inundation in low-lying areas. Nearly 0.50 million ha of rice area are chronically flood-prone and, in some years, flood-affected areas reach 1.1 million ha.

2. Drought. Although Assam receives very high rainfall, the distribution and timing of the onset is erratic over seasons and years. Rainfed ahu rice suffers from prolonged drought due to the late arrival of the monsoon in some years, while transplanted sali is affected by intermittent drought due to rainless periods during different growth stages of the crop. Drought causes substantial yield losses in rice when it occurs at the panicle initiation stage.

3. Stagnant flooding (waterlogging). A large area under sali rice is low lying and ill drained. Such areas get inundated by floodwater or rainwater at the beginning of the season, and remain submerged with more than 30 cm of water throughout the growing period. Continuous waterlogging causes problems for farmers in preparing the land, transplanting, applying fertilizer, and sometimes during harvesting. Because of continuous submergence, the soil remains under reduced conditions and many toxic chemicals and gases are produced, which affect plant growth. Constant submergence reduces tillering, causes iron toxicity symptoms to appear on the leaves, causes sheath blight to be more common, and causes plants to lodge during the reproductive stage. All these factors are responsible for low yields in these areas.

4. Low temperature. The boro season is the most productive season for growing rice in Assam as the sky remains clear during the crop growing period and the risk of flooding is extremely low. Farmers are encouraged to begin cultivation in this season when irrigation facilities are available. However, the main environmental factor limiting boro rice cultivation is cold stress. Cool water and air temperatures affect seedling growth, tillering ability, plant height, and crop duration, and cause yellowing of leaves and high sterility. Minimum temperatures reach as low as 10 °C in the vegetative stage and 15 °C during panicle initiation and this is detrimental to grain formation and yield. Cold also affects the late sali rice during the reproductive stage. Late sali rice flowers in late October or November when the air temperature is around 15 °C, which is detrimental at this sensitive reproductive stage.

5. Low light. It is a well-established fact that temperature and solar radiation influence rice yield directly by affecting the physiological processes involved in grain production (Yoshida 1981). The solar radiation requirement for the rice plant differs from one growth stage to another. In Assam, average bright sunshine hours are fewer than in other states of the country because of the overcast sky during the summer and the foggy forenoon in the winter. The average bright sunshine hours in the sali season (June-November) are 5.1 per day and in ahu (March/July) and boro (November/May) are 4.7 and 6 per day, respectively. Insufficient solar radiation is the most important factor responsible for the low productivity of rice in the state.

6. Iron toxicity. The soil in Asam is mostly acidic, and rice is grown under submerged soil conditions after puddling. The reduced condition of the soil and low pH favor reduction of Fe^{+3} to Fe^{+2}, resulting in higher uptake of the reduced ferrous iron, which can readily be absorbed by plants, causing iron toxicity. This is depicted as bronzing of leaves, low tillering, and lower yield. The problem is usually seen in rice fields with prolonged waterlogging in the sali season. Continuous pumping of iron-rich underground water through shallow tube wells for growing boro rice might aggravate iron toxicity problems in new areas traditionally not affected by this problem.

Biotic stresses

1. Insect pests. More than 20 species of insects attack rice plants in Assam. Among them, stem borers can attack in all the seasons. This pest has three peaks of appearance; the March-April peak is the major one, followed by that of September and then June-July. The first peak damages the ahu and boro crop, causing deadhearts and whiteheads, respectively, in the field. The June-July peak affects sali rice at the seedling and early vegetative stages, causing deadhearts, and ahu in its reproductive stage. During September-October, the pest infests sali rice at the reproductive stage, resulting in whiteheads. Rice hispa is endemic to some pockets, particularly in the low-lying areas in the sali season. Gall midge is known to attack late-planted sali crops in particular, whereas rice bug attacks are very high during the ahu and boro seasons, and rice bug also affects early-maturing sali varieties.

2. Diseases. The hot and humid climate of Assam favors a number of insect pests and diseases of rice. Intensive cultivation of susceptible modern HYVs, overlapping growing seasons, the use of high doses of chemical fertilizers, and injudicious use of plant protection chemicals have changed the pest and disease scenarios in the state. Many diseases of rice, which are now of concern, had little importance a few years back. Blast, sheath blight, and bacterial leaf blight (BLB) are a few important diseases of rice in Assam. Sheath blight, BLB, sheath rot, leaf scald, and rice tungro virus have gained importance in recent years.

Rice breeding

The Regional Agricultural Research Station is the premier rice research station of the whole northeast region. Varietal improvement, especially rice breeding to cater to the needs of farmers, occupies the major part of the research targets of this station. Based on location specificity and need, breeding programs are tailored to suit the objectives. However, varietal improvement for the lowland ecosystem is the major thrust area for which scientists such as physiologists, plant pathologists, entomologists, and agronomists are working together with breeders.

The pedigree method of breeding is the major breeding approach, although backcross breeding is also used. Recently, a biotechnology laboratory was established at the station to assist in breeding for tolerance of biotic and abiotic stresses. A large number of crosses are made every year, from which selected promising lines are being evaluated and nominated in different trials (the All India Coordinated Rice Improvement Program/Shuttle Breeding Program). The number of entries developed and evaluated in different trials are presented in Tables 4, 5, 6, 7, and 8.

Systematic research on rice in Assam started with the establishment of Rice Research Stations at Karimganj in 1913, at Titabar in 1923, and at Habiganj (now in Bangladesh) in 1934. In the early era of rice research, emphasis was placed on improving indigenous rice varieties through breeding (Table 9). Germplasm collection, evaluation, cataloguing, and conservation began with the inception of these research stations (Ahmed et al. 2010). Pure-line selection followed by yield evaluation resulted in the development of a number of varieties that were recommended for growing in different situations. The recommendation of Indrasali (1918), Georgesali (1918), and Latisali (1920) varieties was noteworthy. Altogether, 49 pure-line selections (16 ahu, 16 sali, 12 asra and bao, and 5 boro) were developed and recommended for cultivation in the preindependence era (Choudhury and Ganguli 1948, Barua and Ujir 1962). Asra and bao are generally sown at the same time as normal ahu crops but harvested with sali crops, and are suitable in waterlogged and flood-prone areas.

Hybridization programs started during the early years of rice research in 1921 in the state, with the dual objective of studying the inheritance pattern of different characters as well as developing varieties by combining desirable traits from different parents. Through this program, 11 varieties (2 ahu, 7 sali, and 2 asra) were developed and recommended for farmers before independence. However, up to 1970, such hybrid-

Table 4. Rice varieties developed and released by Regional Agricultural Research Station, Titabar (Assam Agricultural University).

Season/ situation	Variety	Cross	Duration (days)	Year of release	Remarks
Sali (normal winter rice)	Ranjit	Pankaj/Mahsuri	150–155	1992	Suited to shallow lowland, good-quality grain type
	Bahadur	Pankaj/Mahsuri	150–155	1992	Suited to shallow lowland, resistant to blast
	Moniram	Pankaj/Mahsuri	150–155	1992	Suited to shallow lowland, resistant to blast
	Kushal	Pankaj/Mahsuri	150–155	1992	Suited to shallow submerged conditions, resistant to blast
	Piyolee	Pankaj/Mahsuri	150–155	1992	Suited to shallow lowland, resistant to blast, with good grain quality
	Satyaranjan	IET9711/ IET11162	130–135	1996	Suitable in double-cropped areas and tolerant of gall midge, BPH, and WBPH
	Basundhara	IET9711/ IET11161	130–135	1996	Suitable in double-cropped areas and tolerant of gall midge, BPH, and BLB
Sali (delayed-planting conditions)	Prafulla	Kushal/Aki sali	150–155	2009	Suitable for staggered planting with aged seedlings (up to 80 days old)
	Gitash	Kushal/Aki sali	150–155	2009	Suitable for staggered planting with aged seedlings (up to 60 days old)
Sali (submergence tolerance)	Jalashree	Pankaj/FR13A	150	2000	Suitable in flash-flood-affected areas, tolerant of submergence for up to 13 days
	Jalkunwari	Pankaj/FR13A	150	2000	Suitable for flash-flood-affected areas, tolerant of submergence for up to 13 days
Sali (short-duration cultivars for late planting/sowing	Luit	Heera/Annada	90	1993	Suitable for sowing/planting after recession of flood
	Kapilee	Heera/Annada	90	1993	Suitable for sowing/planting after recession of flood
	Disang	Lachit/Kalinga-3	90	2005	Suitable for sowing/planting after recession of flood

Cont.

Table 4. continued

Season/ situation	Variety	Cross	Duration (days)	Year of release	Remarks
Glutinous rice (special class of rice)	Aghoni bora	Kmj 1-52-2/Gandhi bora	155–160	1992	Substantially higher yield than traditional bora cultivars
	Bhogali bora	Kmj 1-52-2/ Ghew bora	155–160	1992	Substantially higher yield than traditional bora cultivars
	Rongilee	Kmj 1-52-2/ Ghew bora	155–160	1992	Substantially higher yield than traditional bora cultivars
Scented rice	Keteki joha	Savitri/ Badsha bhog	160	1995	Substantially higher yield than traditional joha cultivars
Ahu (transplanted)	Lachit	CMR 13-3241/ Kalinga II	120	1987	Suitable for flood-free medium land situation under irrigated conditions in ahu season
	Chilarai	IR24/CR44-118-1	125–130	1987	Suitable for flood-free medium land under irrigated conditions
	Gopinath	Pusa 2-21/IR36	110–115	1997	Suitable for flood-free medium land under irrigated conditions
	Mulagabhoru	Jaya/Mahsuri	125–130	2011	Suitable for flood-free medium land under irrigated conditions
Ahu (transplanted)	Disang	Lachit/Kalinga-3	100–105	2005	Suitable for flood-free medium land under irrigated conditions
	Kolong	Chilarai/Kalinga-3	100–105	-	Suitable for flood-free medium land under irrigated conditions
Boro (summer rice)	Bisnuprasad	K343-29-1/Suweon 334	160–170	1997	Recommended as boro rice under irrigated situations
	Jyotiprosad	K343-29-1/ Suweon 334	160–170	1997	Recommended as boro rice under irrigated situations
	Jaymoti	Jaya/Mahsuri	165–175	1997	Recommended as boro rice under irrigated situations
	Kanaklata	Jaya/Mahsuri	165–175	2011	Recommended as boro rice under irrigated situations

Table 5. Varieties recently released (2011) in the state of Assam. All the varieties have medium slender grain.

Season/ situation	Variety	Cross	Duration (days)	Plant height (cm)	Ave. yield (t/ha)	Remarks
Sali (waterlogging situation)	TTB 303-18-3	Kmj 1-17-2/ Aki sali	150–155	137	5.0	The varieties with taller seedlings are suitable for growing in waterlogged/ stagnant-flood areas.
	TTB 303-1-42	Kmj 1-17-2/ Aki sali	150–155	135	5.0	
	TTB 303-1-26	Kmj 1-17-2/ Aki sali	150–155	138	5.0	
	TTB 303-2-23	Kmj 1-17-2/ Aki sali	150–155	145	5.0	

ization programs were made using tall × tall indica varieties. Therefore, the program failed to bring about a significant yield improvement over the pure lines, mainly due to the use of a narrow genetic base involving closely related tall indica parents and failure to select plants with desirable architecture (Pathak 2001).

In 1965, TN-1 was introduced into India, followed by IR8 in 1966. Immediately, rice workers in Assam (as in other parts of India) started working on the semidwarf plant type concept as a means of achieving a breakthrough in rice yields. However, since rice-growing situations in Assam are highly diverse, semidwarf varieties alone could not meet the needs of all situations.

A new era of rice research began in the 1980s with the systematic approach of research based on needs, location specificity, and problems, involving both traditional and modern semidwarfs, but giving emphasis to farmers' needs. As a result of the breeding program launched with the new concept, 42 rice varieties have been developed over the last 3 decades (Tables 4 and 5). The rainfed lowland ecosystem is very diverse and complex due to fluctuations in climate, hydrology, and soil heterogeneity, and variation within lowland areas from year to year with regard to time, depth, and duration of stagnant flooding and submergence, in addition to unpredictable and erratic drought. Farmers are often compelled to transplant twice or more or to delay transplanting because of erratic monsoon and floods. Tall traditional cultivars provide more stable but low yields in these vulnerable situations. Most of the improved high-yielding varieties (HYVs) are not popular in these ecosystems because of their instability of yield. These HYVs produce high yield under favorable conditions but fail miserably in unfavorable situations. Resource-poor farmers need assured yield and are not willing to take risks in highly unpredictable environments. Therefore, efforts are needed to develop high-yielding varieties having a stable performance in these harsh and fragile environments. There is an abundance of rice germplasm (especially traditional varieties) that could be exploited to develop new rice varieties with specific adaptation to this region (Ahmed et al 2010). This should be a high priority for rice breeding activities in the future.

RARS has developed a few varieties for such adverse situations, such as Prafulla and Gitesh for staggered planting; TTB 303-2-23, TTB 303-18-3, and TTB 303-1-42 for stagnant flood-prone areas; Jalashree and Jalkuwari with submergence tolerance; and Luit and Disang, two very short duration varieties, to escape floods. However, there are some areas, particularly in unfavorable ecosystems (flood- and drought-prone areas), where production and productivity are still very low and need special attention to breed varieties for such situations. A description of the varietal needs for different rainfed ecosystems follows:

For shallow lowland (<30 cm water depth)

- Semidwarf plant type
- Nonlodging
- Duration of 140–150 days
- Submergence tolerance for brief periods of inundation
- Long and heavy panicles
- Medium slender grain type
- Resistance to major pests (stem borer, gall midge, leaffolder) and diseases (blast, BLB, sheath blight)
- Yield of more than 6 t/ha

For lowland (30–50 cm water depth)

- Semitall plant type (125–135 cm)
- Nonlodging
- Early seedling vigor to avoid inundation immediately after transplanting
- High tillering habit and long panicles
- Suitable for staggered planting
- Submergence tolerance
- Cold tolerance at the reproductive stage
- Medium slender grain type and resistance to caseworm, leaffolder, and stem borer

For flood-prone areas

a. Flood-escaping varieties

- Very early maturity (90–100 days)
- Photoperiod insensitive
- Uniform tillering habit
- Semidwarf plant type
- Resistance to gall midge and stem borer
- Intermediate to high yield (3–4 t/ha)
- Cold tolerance at the reproductive stage

b. Varieties for delayed planting

- Photoperiod sensitive and long duration
- High tillering ability
- Semitall stature with nonlodging habit
- Suitable for staggered planting

Table 6. Generation advancement of breeding lines under the shuttle breeding program since 1995.

Year	Generation	No. of crosses	Name of crosses	Lines evaluated (no.)	Lines selected (no.)
1995	F_3	22	IR70148, IR70149, IR70153, IR70182, IR70231, IR70235, IR70237, IR70236, IR70238, IR70239, IR70242, IR70243, IR70246, IR70251, IR70254, IR70257, IR70266, IR70270, IR70198, IR70197, IR69974, IR69959	404	284
1995	F_6	13		26	19
	F_7	2		26	23
1996	F_5	19	IR69543, IR69544, IR69545, IR69561, IR69563, IR70161, IR71517, IR70317, IR69485, IR69526, IR69527, IR69528, IR69529, IR70220, IR70227, IR70228, IR70231, IR70233, IR71517	193	35
1997	F_3	5	IR72035, IR72002, IR72015, IR72715, IR72723	242	193
1998	F_3	12	IR73220, IR73228, IR73230, IR73237, IR73238, IR73257, IR73721, IR73727, IR73729, IR73740, IR73747, IR73748	520	130
1999	F_3	9	CN1203, CN1204, CN1205, CN1206, CN1207, CN1208, CN1211, CN1212, CN1216, CN1217	294	196
	F_3	3	IRRI lines involving parents BKP246 and Mahsuri	144	60
2000	F_3	14	IR77199, IR77791, IR77792, IR77794, IR76217, IR76218, IR76219, IR76272, IR76273, IR76234, IR76302, IR76304, IR76511, IR76519	190	115

Cont.

Table 6. continued

Year	Generation	No. of crosses	Name of crosses	Lines evaluated (no.)	Lines selected (no.)
2001	F_3	8	CN1334, CN1337, CN1341, CN1335, CN1343, CN1347, CN1336, CN1348	290	110
2002	F_1	7	CN1506, CN1341, CN1589, CN1493, CN1491, CN1495, CN1500	–	215
2003	F_1	22	CN1554, CN1556, CN1558, CN1559, CN1560, CN1561, CN1563, CN1569, CN1570, CN1572, CN1574, CN1575, CN1576, CN1577, CN1584, CN1585, CN1587, CN1588, CN1590, CN1593, CN1597, CN1598	–	240
2004	F_1	12	CN1666, CN1667, CN1669, CN1672, CN1673, CN1674, CN1676, CN1677, CN1678, CN1679, CN1689, CN1690	–	143
2005	F_1	4	CN1873, CN1874, CN1875, CN1894	–	300

Table 7. Varieties developed through the Eastern India Rainfed Lowland Shuttle Breeding Network program and evaluated through the AICRIP network.

S. no.	Designation	IET no.	Trial[a]
1	TTB 522-SB-IR70237-3-1	16679	IVT SHW Kh 1999
2	TTB 532-SB IR70197-23-2	16680	IVT SHW Kh 1999
3	TTB 528-SBIR70251-15-2	16681	IVT SHW Kh 1999
4	TTB 517-44-SBIR70149-33	16682	IVT SHW Kh 1999
5	TTB 517-SBIR70149-33	16683	IVT SHW Kh 1999
6	TTB 518-SB-IR70153-7	16684	IVT SHW Kh 1999
7	IR70182-146-1-TTB 4-3	17965	IVTL Kh 2004
8	IR70182-44-TTB 15	17966	IVTL Kh 2004
9	IR73227-32-TTB 3-2	18619	AVT 1-L
10	IR72723-TTB 8-2-1	20770	IVT-L Kh 2008
11	IR70153-TTB 15-3-2-1	21474	ITV-L Kh 2009
12	IR73727-20-TTB 1-2-321475	21475	ITV-L Kh 2009
13	IR73727-20-TTB 1-2-3	21475	AVT 1-L Kh 2010
14	IR69485-10-2-B-1-TTB 86-1-4	22002	IVT RSW Kh 2010
15	IR69545-33-1-B-3-TTB 14-3-1		NSDWS Kh,2011
16	IR70153-13-TTB 3-1-3-3		IVT-L Kh, 2011

[a] IET = initial evaluation trial; IVT SHW Kh = initial variety trial—shallow water, kharif; IV-L = initial variety trial, lowland; AVT 1-L: advanced variety trial 1—late; RSW = rainfed shallow lowland; NSDWS = national semideepwater screening.

- Long panicles
- Tolerant of intermittent drought
- Resistant to major pests and diseases
- Cold tolerant at the reproductive stage
- High and stable yield

c. Varieties for flash-flood-affected areas
  - Semitall and nonlodging
  - Long duration
  - Submergence tolerance for at least 15 days, with fast recovery
  - Long and heavy panicles
  - Resistance to pests and diseases
  - High yield

Cold-tolerant varieties for boro season
  - Semidwarf plant stature
  - Shorter duration (<170 days) to avoid early floods at maturity stage. Generally, duration of boro rice is prolonged up to 200 days due to low temperature early in the season, and the crop may be inundated by early floods at the ripening stage.

Table 8. Varieties developed for the lowland ecosystem and evaluated in All India Coordinated Rice Improvement Program trials.

S. no.	Designation	Parentage	IET no.	Trial[a]
1	TTB 283-1-26	Aki sali/Kushal	17963	IVT-L Kh 2004
2	TTB 283-1-32	Aki sali/Kushal	17964	IVT-L Kh 2004
3	TTB 283-1-26-1	Aki sali/Kushal	18616	IVT-L Kh 2004
4	TTB 292-4-2-6	Andrew Sali/IET 8002	18617	IVT-L Kh 2004
5	TTB 291-3-9-4-3	Andrew sali/IR64	18618	IVT-L Kh 2004
6	TTB 300-19-3	Kmj 1-17-2/Aki sali	19929	IVT-L Kh 2006
7	TTB 297-8-9	IET 6987/Aki sali	19930	IVT-L Kh 2006
8	TTB 302-1-2	Kmj 1-17-2/Herapoa sali	19931	AVT-1-L Kh 2007
9	TTB 297-18-9	IET 6987/Aki sali	20273	IVT-L Kh2007
10	TTB 298-1-9	IET 6987/Mugi sali	20274	IVT-L Kh 2007
11	TTB 303-18-3	Kmj 1-17-2/IET 10016	21121	NSDW Kh 2008
12	TTB 303-18-3	Kmj 1-17-2/IET 10016	21121	IVT 1-SDW -2009
13	TTB 303-1-42	Kmj 1-17-2/IET 10016	21336	NSDW-Kh 2009
14	TTB 283-3-38	Aki sali/Kushal	21472	IVT-L Kh 2009
15	TTB 303-2-23	Kmj 1-17-2/IET 10016	21473	IVT-L Kh 2009
16	TTB 303-1-26	Kmj 1-17-2/IET 10016	21895	NSDW Kh 2010
17	TTB 303-2-24	Kmj 1-17-2/IET 10016	21896	NSDW Kh 2010

[a] See note in Table 7.

Therefore, varieties that mature in less than or around 175 days are preferred to escape flooding before harvest.

- Cold tolerance at seedling stage, vegetative stage, and reproductive stage
- High tillering
- Good grain type
- High yield
- Resistant to blast and stem borer

Altogether, 13 categories of rice are traditionally grown in Assam. A brief description of the various rice varieties appears in Table 9 (Sharma and Ahmed 2004).

Initiation of the EIRLSBN

To improve the genetic yield potential of the rainfed lowland rice varieties of eastern India, an ICAR-IRRI Collaborative Shuttle Breeding Program began during 1992 with the following objectives:

1. To make available diversified donors/improved breeding lines suitable for rainfed lowlands in all cooperating centers.

Table 9. Classes of indigenous rice in Assam.

Seasonal class	Growing season	Duration (days)	Remarks
A. Ahu (autumn rice)	March/April to June/July	80–130	Photoperiod insensitive, early maturing, grown under variable water depth (0–25 cm). The early-maturing varieties are normally broadcast and relatively late-maturing ones are transplanted.
Dumai		80–90	Generally broadcast, red kernel
Murali		90–100	Generally broadcast, red kernel
Chengri		90–100	Generally broadcast, red kernel
Ahu		>100	Transplanted
B. Sali (winter sali)	June/July to Nov/Dec	150–180	Photoperiod sensitive, long duration, transplanted under variable water depths. There are subclasses such as sali, lahi, and joha based on grain characteristics.
Sali		150–180	Coarse grain
Lahi		150–180	Medium grain
Joha		150–180	Scented, fine grain
Bora		150–180	Glutinous or sticky rice
Chakua		150–180	Soft rice with low amylose content
Asra	April/May to Dec/Jan	240–270	Medium deepwater rice, broadcast or transplanted in low-lying areas, can endure water depth of up to 100 cm.
Bao	April/May to Dec/Jan	270–300	Deepwater or floating rice, normally broadcast, can endure water depth >100 cm. Sown at the time when ahu rice is sown and harvested at the time when sali rice is harvested.
C. Boro (summer rice)	Nov to May/June	180–200	Photoperiod insensitive, cold tolerant at the vegetative stage, transplanted traditionally in beel and marshy land situation with minimal or no tillage.
D. Jhum (hill rice)	March/April to Sept/Oct	210–250	Photoperiod insensitive, grown on hill slopes, direct seeded

2. To provide segregating populations with a broad genetic background to all centers for effective selection according to location-specific requirements.
3. To evaluate elite breeding lines developed by the cooperating centers and IRRI, especially for submergence tolerance, photoperiod sensitivity, genetic plasticity of planting time, yield potential, and adaptability in eastern India.
4. To organize a breeders' workshop for eastern India to evaluate and select breeding materials at key sites.
5. To conduct on-farm evaluation of promising lines to judge their adaptability and acceptability by farmers.

The program began to develop and evaluate genetically diverse lowland genotypes throughout eastern India, with partner centers located in Titabar, North Lakhimpur in Assam, Pusa and Patna in Bihar, Motto and Bhabanipatna in Odisha, Raipur in Chattisgarh, Masodha in Uttar Pradesh, Chinsurah in West Bengal, and the Central Rice Rresearch Institute in Cuttack (Mallik et al 2002). Promising breeding lines were further evaluated in farmers' fields through participatory varietal selection (PVS) trials (i.e., mother and baby trials).

Based on the objectives, the first activities of the EIRLSBN were the following:

- Using Mahsuri to develop improved breeding lines
- Screening of submergence-tolerant varieties for better adaptability
- Genetic studies of submergence tolerance
- Evaluation of photoperiod-sensitive varieties for delayed planting
- Genetic studies of photoperiod sensitivity
- Improvement of direct seeding under rainfed lowland ecosystems
- A strategy for the development of breeding lines and co-evaluation in participating centers

Activities of the EIRLSBN

One of the mandates of the EIRLSBN is to facilitate developing a large number of diverse breeding lines suitable for rainfed lowland ecosystems throughout eastern India. Through this program, segregating populations, mainly F_2s from IRRI and other cooperating centers, were accessed and advanced in the participating centers (Table 6). It is important to emphasize that locally adapted traditional and long-duration cultivars were used in the breeding program of IRRI as well as in network centers' projects. Effective selections were made in all participating centers following a standard methodology and under specific environments. Exchange of breeding materials among breeders also took place in breeders' workshops at different sites, which helped breeders to select breeding materials suitable for their own regions. A brief summary of the key activities performed at Titabar follows:

- During 1995, 404 F_2s from 22 crosses were received from IRRI and were evaluated in RARS. Out of these, 284 selections were made. In 1996, 190 F_4 lines were selected for further advancement. In the same year, during breeders' workshops in Masodha, Chinsurah, and Raipur, 52 F_6 and F_7 lines from 15 crosses were selected and evaluated. Out of 52 lines, 42 families were selected for further advancement.

- One hundred ninety-three F_5 families from 19 crosses received from IRRI were grown in 1996. Altogether, 35 F_6 families were advanced in 1997 for further selection and advancement.
- During 1997, 242 F_2 seeds from 5 crosses received from IRRI were evaluated for further selection. Out of 242 lines, 193 lines were selected for further advancement.
- Five hundred and twenty F_2 seeds were received in 1998 from 12 crosses and were grown on-station. Out of 520 lines, 130 F_3 families were selected for further advancement.
- During 1999, 144 F_3 lines from 3 crosses received from IRRI were evaluated, out of which 60 families were selected for advancement of F_4 families in 2000.
- Another set of F_2 lines from 14 crosses received from Chinsurah was evaluated in 1999. Out of 294 F_3 lines, 196 families were selected for further advancement.
- One hundred and ninety F_2 seeds received from 14 crosses were grown in 2000 and 115 lines were selected for advancement to the F_4 generation in 2001.
- During 2001, 250 F_2 seeds from 8 crosses were received and grown at the station. Out of 250 lines grown, 110 lines were selected for advancement to the F_4 generation.
- During 2002, 215 F_2 lines were selected from F_1 seeds of 18 crosses received, and were advanced at the station for further selection.
- During 2003, F_1 seeds from 22 crosses were received and were evaluated. Altogether, 240 F_2 lines were selected for further generation advancement.
- F_1 seeds from 12 crosses were received in 2004 and were grown at the station. Altogether, 143 F_2 lines were selected for further advancement.
- F_1 seeds from four crosses received were grown in the field in 2005. About 300 F_2 lines were selected for generation advancement.

Further, breeding lines of the F_3 and F_4 generation were selected at the participating centers during a breeders' monitoring tour. Those selected breeding lines are being grown on-station for further evaluation and selection.

During the course of advancement and selection, a large number of shuttle breeding materials were developed and underwent further evaluation in eastern India through various trials. Altogether, 142 cultivars developed from the shuttle breeding program at RARS, Titabar, were nominated to evaluate their adaptability throughout the region in observational yield trials (OYT) within the EIRLSBN from 1998 to 2011 (Table 10). In the EIRLSBN, promising breeding lines are first evaluated under an OYT and the best-performing lines are promoted to an advanced yield trial (AYT)/replicated yield trial (RYT) (Table 11). From the nominated breeding lines from OYT, 19 breeding lines were promoted to an AYT and were evaluated by different centers of eastern India. Another 13 elite lines were also evaluated in normal and delayed planting trials from 2000 to 2005 (Table 12). Promising breeding lines were further nominated for evaluation in national trials. Altogether, 50 lines were evaluated in AICRIP trials (i.e., IVT L, AVT L, and NSDWS) (Tables 7 and 8).

Table 10. Number of varieties developed at RARS, Titabar, and evaluated in an observational yield trial (OYT).

Year	No. of lines evaluated[a]
1998	10 (TTB 517-42-SBIR70149-29-1, TTB517-44-SBIR70149-33, TTB517-50-SBIR70149-39-1, TTB517-57-SBIR70153-28-5, TTB518-92-SBIR70153-11-2, TTB524-238-SBIR70239-23-4, TTB524-240-SBIR70239-13-2, TTB-518-105-SBIR70153-1-5-2, TTB521-197-SBIR70253-46, TTB507-20-SBIR67664-3-3-2)
1999	11 (TTB517-44-SBIR70149-33, TTB528-SBIR70251-15-2, TTB532SBIR70197-23-2, TTB518-SBIR70153-7, TTB522-SBIR70237-3-1, TTB518-SBIR70149-33, TTB518-SBIR67401-17, TTB526-SBIR70243-1-21, TTB514-SBIR60844-40, TTB517-SBIR70149-35, TTB517-SBIR70149-39-1)
2000	13 (TTB283-1-26, TTB283-132, TTB292-426, TTB285-714, TTB291-943-1,TTB286-731, TTB SB528-169, TTB SB518-54, TTB SB519-146, TTB SB518-31, TTB SB522-127, TTB SB518-27, TTB SB517-246)
2001	7 (TTB283-3-38-3, IR70153-TTB 1-2-7, IR674601-TTB17-1, IR70153-TTB54-7, IR70237-TTB127-3-1, IR70153-TTB13-1-2, IR70182-TTB102)
2002	8 (IR70182-44-TTB 15, TTB283-38-3, IR70153-76-TTB11-2, IR70153-94-TTB2-1, IR70251-169-TTB15-2, IR70197-193-TTB1-2, TTB283-1-26-3, TTB286-2)
2003	10 (IR73237-1-TTB1-1, IR73747-44-TTB1-3, IR73748-72-TTB2-2, IR70237-3-TTB2-2, IR73228-45-TTB1-1, IR67461-17-TTB225-2, IR73228-9-TTB1-2, IR73748-75-TTB5-2, IR73747-63-TTB1-2, IR73237-32-TTB3-3)
2004	13 (IR78162-TTB44-1, IR67461-TTB1-7-1, IR67461-TTB1-7-2, IR68844-TTB40-2, IR67637-TTB2-1-12, TTB281-22, TTB281-9-2TTB286-2-2, TTB287-1-3, TTB283-5-2, TTB281-1-2, TTB286-1-5-1, TTB286-1-2)
2005	10 (TTB297-18-2, TTB297-8-12, TTB297-18-9, TTB297-8-9, TTB298-1-9, TTB298-1-2, TTB300-14-5, TTB300-19-3, TTB302-1-2, TTB303-1-2)
2006	10 (TTB303-1-13, TTB303-2-23, TTB303-4-12, TTB303-4-20, TTB303-6-3, IR72715-92-TTB2-1. IR72715-92-TTB2-4, IR72723-103-TTB3-2-1, IR70242-24-TTB1-3, IR70243-21-TTB 2)
2007	10 (IR72723-105-TTB3-2-1, IR73727-20-TTB1-2-1, IR72715-92-TTB2-1, IR67461-17-TTB225-2, IR69543-33-1-3-3-TTB41-2-1, TTB297-18-2, IR70153-19-TTB2-2-1, TTB298-1-2, IR73727-20-TTB1-2-2, IR73727-4-TTB1-1)
2008	10 (IR73727-TTB20-1-2-1, IR73727-TTB4-2-1, IR73747-TTB63-1-1, IR73748-TTB51-3-2, IR73747-TTB60-1-1, IR69545-33-1-B-3-TTB41-3-1, IR70153-TTB9-3-3-1-2, IR70153-TTB9-3-3-1-3, IR70153-TTB15-3-1-2, IR70153-TTB11-1-3)
2009	10 (IR73228-20-TTB 3-1, IR73747-60-TTB1-2, IR69485-10-2-B-TTB86-1-3, IR69485-10-2-B-1-TTB86-1-4, IR69485-10-2-B-TTB86-23, IR70153-9-TTB2-1 IR70153-9-TTB3-3-1-1, IR70153-11-TTB1-3, IR70153-13-TTB3-1-2-3, IR70153-21-TTB1-2-2)
2010	10 (TTB303-18-3, TTB303-2-23, TTB303-2-24, TTB303-1-42, IR70153-11-TTB1-8, IR70153-11-TTB1-10, IR73747-63-TTB1-3, IR73747-51-TTB3-2, IR73727-4-TTB1-2, IR69545-33-1-B-TTB41-3-2)
2011	9 (IR73727-4-TTB 1-2, IR72015-77-TTB 1-4, IR69545-33-1-B-3-TTB 41-3-1, IR70153-11-TTB 1-5, IR70153-11-TTB 1-6, IR70153-11-TTB 1-8, IR73727-20-TTB 1-2-2, TTB281-3-1, TTB281-3-2)

[a] Designation of lines is indicated in parentheses.

Table 11. Number of varieties developed through the shuttle breeding program and evaluated in a replicated yield trial (RYT).

Year	No. of lines evaluated[a]
2006	7 (TTB297-8-9, TTB302-1-2, TTB303-1-2, TTB297-18-2, TTB297-18-9, TTB297-8-12, TTB298-1-9)
2007	2 (TTB303-1-13, IR70242-24-TTB1-3)
2008	3 (IR72715-92-TTB 2-1, IR72715-92-TTB 2-2, IR73727-20-TTB 1-2-3)
2009	1 (IR73727-92-TTB 4-1-2)
2010	4 (IR69485-10-2-86-1-4, IR70153-9-TTB 3-3-1-1, IR70153-11-TTB 1-3, IR70153-21-TTB 1-2-2)
2011	2 (TTB303-1-42, IR73727-4-TTB 2)

[a]Designation of lines is indicated in parentheses.

Table 12. Number of varieties developed through the shuttle breeding program and evaluated under normal (control) and delayed planting trials.

Year	No. of lines evaluated[a]
2000	3 (TTB517-16-SBIR70149-33, TTB518-225-SBIR67401-17-2, TTB517-17-SBIR70149-35)
2001	3 (TTB SB 518-31, TTB SB 519-146, TTB292-426)
2002	1 (TTB292-426)
2003	1 (IR97197-193-TTB 1-2)
2004	2 (IR74501-17-TTB 225-2-138, IR73228-9-TTB 1-2-139)
2005	3 (TTB281-1-2, TTB281-9-2, TTB286-2-2)

[a]Within parentheses are the designations of the lines.

The Bill & Melinda Gates Foundation project “Stress-Tolerant Rice for Africa and South Asia” (STRASA) facilitated the evaluation of promising breeding lines in diverse ecosystems, as farmer-managed “baby trials” and researcher-managed “mother trials.” Through this program, several varieties were popularized among the farmers and are now being released for growing in the rainfed lowland ecosystem of Assam. TTB 303-18-3, TTB 303-1-42, TTB 303-1-26, and TTB 303-2-23 were the varieties released for growing in stagnant-flood areas of the state during 2011.

Two varieties, Gitesh (TTB 283-1-26) and Prafulla (TTB 283-3-38), evaluated through PVS trials were released in the state during 2009 for their wide adaptability. Prafulla, a high-yielding photoperiod-sensitive variety, can even be transplanted when seedlings are 80 days old. However, up to 60-day-old seedlings can be used for Gitesh.

Up to now, about 505 lines have been generated at RARS, along with 43 bulk seed populations selected and evaluated through the shuttle breeding program (Table 13). The selections were made from very early generations (F_1s and F_2s) received from IRRI. Those selected advanced lines were evaluated in different trials and promising lines were also recommended for the state. Therefore, seed production and multipli-

Table 13. IRRI advanced lines used for seed production and evaluation.

S. no.	Designation	S. no.	Designation	S. no.	Designation
1	IR70153-11-TTB 1-3	16	IR73727-20-TTB 1-2-3	31	TTB 283-3-38
2	IR69485-10-2-B-1-TTB 86-1-4	17	IR73747-60-TTB 1-2	32	TTB 303-14-9
3	IR70153-9-TTB 3-3-1-1	18	IR69485-10-2-B-1-TTB 86-2-3	32	TTB 303-5-1
4	IR70153-13-TTB 3-1-3-3	19	IR69485-10-2-B-1-TTB 86-1-4	34	TTB 298-1-9
5	IR70153-21-TTB 1-2-2	20	IR70153-9-TTB 2-1	35	TTB 297-18-2
6	IR73728-20-TTB 3-1	21	IR70153-TTB 9-3-3-1-2	36	TTB 303-1-13
7	IR70153-11-TTB 1-8	22	IR70153-TTB 9-3-3-1-3	37	IR72015-77-TTB 1-4
8	IR70153-11-TTB 1-10	23	IR70153-TTB 15-3-2-1	38	IR69545-33-1-B-3-TTB 41-3-1
9	IR73747-63-TTB 1-3	24	TTB 303-1-26	39	IR70153-11-TTB 1-5
10	IR73727-4-TTB 1-2	25	TTB 303-2-24	40	IR70153-11-TTB 1-6
11	IR73747-51-TTB 3-2	26	TTB 303-1-14	41	IR73727-20-TTB 1-2-2
12	IR69545-33-1-B-TTB 14-3-2	27	TTB 303-18-3	42	IR69545-33-1-B-3-TTB 14-3-1
13	IR72723-1-B-TTB 8-2-1	28	TTB 303-2-23	43	IR70153-13-TTB 3-1-2-3
14	IR72727-TTB 4-1-2	29	TTB 303-2-24		
15	IR69545-33-1-B-TTB 4-3-2-1	30	TTB 303-1-42		

cation are essential for evaluating lines in large-scale demonstrations. Furthermore, some of the lines with desired attributes are used in the hybridization program.

Achievements of the RARS program

- The program provides diverse genotypes/segregating populations for use in the breeding program as well as for the evaluation of a large number of diverse genotypes in target environments throughout eastern India.
- Two varieties, PSR 119-13-1 and BR 4974-3-6-3-2, were recommended for the lowland ecosystem as Namdang and Godapani.
- Two varieties, Prafulla (TTB 283-3-38) and Gitesh (TTB-238-1-26), were released for the state during 2009. Seedlings of Prafulla of up to 80 days of age can be used for transplanting; for Gitesh, seedlings that are up to 60 days of age can be used.
- TTB 303-18-3, TTB 303-1-42, TTB 303-1-26, and TTB 303-2-23 developed and evaluated through PVS trials were found to be promising for stagnant flood-prone areas in different districts of Assam.
- Through breeder workshops since 1995, scientists from participating centers selected segregating lines, which were subsequently evaluated in all centers based on their own adaptability.
- The promising lines were evaluated in national trials and then in target environments in farmers' fields before recommendation for release.

Future directions and IRRI's role

IRRI plays a pivotal role in improving the economic status of poor farmers, especially in stress-prone areas, by introducing suitable technologies. As rainfed ecosystems usually encounter manifold constraints, this requires specific technologies to overcome such problems. IRRI has helped to train a number of scientists for capacity building of research teams over the past few decades. However, lots of support is required from IRRI to tackle some specific needs of the region, especially for

- Enhancing yield and stability in rainfed ecosystems.
- Introgressing disease resistance, especially to blast and bacterial leaf blight, and genes for insect resistance, including stem borer and hispa, into popular varieties.
- Introgressing drought tolerance for autumn (ahu) rice and intermittent drought tolerance in winter (sali) rice.
- Introgressing cold tolerance in both the vegetative and reproductive stages.
- High-yielding varieties having high zinc and iron concentrations.

Collaboration with IRRI, using either conventional or molecular breeding methods, may help to solve those complex problems. The generation of new breeding lines should be boosted, so that a large number of breeding lines of diverse origin can be evaluated in specific locations. Further, mega-/adapted varieties of different regions should be used in hybridization programs to ensure the possibility of selecting materials adapted to the target environments.

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Notes

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Rice for stress environments in Lakhimpur District of Assam

K.K. Sharma

The state of Assam is situated in the northeastern region of India between 24°8′ to 28°9′ N and 89°42′ to 95°16′ E. The state has an area of 7.85 million ha comprising 2.4% of the total geographic area of the country. Two main rivers, the Brahmaputra and Barak, flow through the state with their 40 and 7 tributaries, respectively. The total population of the state is 31.2 million (Census 2011). Assam is predominantly rural and the economy is agrarian in nature, and nearly 70% of the population directly depends on agriculture as a source of livelihood.

In Assam, the soil, topography, rainfall, and climate in general are congenial for rice cultivation and the crop is grown in a wide range of agroecological conditions, with the net cropped area comprising 65.9% of the gross cropped area (Anonymous 2011). The total rice area in 2009-10 was 2.53 million ha. Rice is grown in three seasons in the state: sali or winter rice (June/July-November/December), ahu or autumn rice (February/March-June/July), and boro or summer rice (November/December to May/June). The area, production, and productivity of the three seasons are presented in Table 1 (Statistical Handbook of Assam 2011). Bao or deepwater rice is invariably grown under rainfed conditions, while boro is cultivated under irrigated conditions. Direct-seeded ahu is rainfed while transplanted rice is grown under irrigated conditions.

Based on rainfall pattern, terrain, and soil characteristics, Assam has been delineated into six agro-climatic zones: North Bank Plain Zone, Upper Brahmaputra Valley Zone, Central Brahmaputra Valley Zone, Lower Brahmaputra Valley Zone, Hill Zone, and Barak Valley Zone. Lakhimpur is located in the North Bank Plain Zone in the northeastern part of the state, between 26°45′ N to 27°35′ N latitude and 93°45′ to 94°55′ E longitude, with an average altitude of 102 m above mean sea level (Fig. 1). A number of major tributaries, including Subansiri, Dikrong, and Gainadi, originat-

Table 1. Area, production, and yield of different seasons of rice in Assam.

Season	Area (million ha of high-yielding varieties)	Production (million tons)	Yield (kg/ha) of HYVs
Sali (winter rice)	1.79	3.26	1,824
Ahu (autumn rice)	0.35	0.34	982
Boro (summer rice)	0.39	0.85	2,180
Total	2.53	4.45	1,584

Source: Directorate of Economics and Statistics, Assam.

Fig. 1. Map of Assam.

ing from the nearby hills of Arunachal Pradesh pass through Lakhimpur District. The total net area sown in the district is 100,169 ha vis-à-vis the gross area of 176,113 ha of cultivated land. The total population of the district is 1.04 million (Census 2011), which is 3.3% of the total population of the state.

Lakhimpur receives about 2,850 mm of annual rainfall, which often causes severe flooding of the tributaries arising from Arunachal Pradesh, frequently damaging sali rice due to submergence. Agriculture in Lakhimpur and nearby districts is characterized by monocropping, subsistence farming, and a low input–low output system.

Rice is the most important staple crop of Lakhimpur. Other crops of importance are rape and mustard, black gram, pea, potato, and vegetables. Rice is grown in a wide range of environments. It is chiefly grown in ahu, sali, and boro seasons. Sali is the predominant season of rice, followed by direct-seeded ahu rice, which is grown under rainfed conditions. Area, production, and productivity of the three classes of rice in 2009-10 are presented in Table 2 (Statistical Handbook of Assam 2011).

The district has around 10,000 ha of deepwater rice, which has been declining in recent years. Flood is the major constraint of rice production in the district. In 2009-10, Lakhimpur alone recorded crop damage of 21,241 ha due to flood, affecting 68,901 farm families. Recurring floods followed by sand and silt deposition in some areas have caused distress to the tribal communities residing by riversides.

In 2009-10, 3,846 ha of crop land were reported to be damaged by silt deposition in Lakhimpur (DAO 2010). Silt deposition in river water has converted substantial

Table 2. Area, production, and productivity of the three seasons of rice in Lakhimpur District of Assam.

Season	Area (ha)	Production (tons)	Yield (kg/ha)
Ahu (autumn rice)	15,800	12,263	789
Sali (winter rice)	106,249	153,688	1,469
Boro (summer rice)	15,572	11,320	727

Source: Directorate of Economics and Statistics, Assam.

deepwater areas into shallow areas. Sand casting proved to be one of the worst hazards because it results in degradation of farmland and wetlands due to deposition of debris, mainly coarse particles carried by floodwater. In recent years, extreme weather events such as unexpected flash floods, submergence, and drought, and incidences of pests and diseases increased in rice cultivation areas.

Farming systems

More than 20 crops and numerous enterprises have been identified and 4 or 5 of these are found in major areas. Rice is the main crop in farming systems, contributing about 60% of total farm income. Livestock rearing constitutes the second most important component of farming systems, followed by farming in the "homestead" (i.e., farming connected to a household). The following are a few of the major farming systems adopted in Lakhimpur District:

- Crops + dairy cows + goats + pigeons + ducks
- Crops + dairy cows + poultry
- Crops + dairy cows + pigs + poultry
- Crops + dairy cows + fish
- Crops + goats + fish + ducks

Almost invariably, rice is one of the crops grown in all farming systems, and rice-based farming systems are the most common. About 68% of the farmers in Lakhimpur are marginal and small, and the remaining 32% are medium and large. The average size of the landholding is 1.5 ha. Rice is the chief source of income, followed by other nonrice crops such as toria (mustard), black gram, pea, potato, and vegetables.

Because of very poor road conditions and connections and remoteness, agricultural inputs are not readily accessible to poor farmers. Seed, fertilizer, and farm machinery are not available in time. Although the use of HYVs is about 43% in the district, the seed replacement ratio is very low due to nonaccessibility to poor farmers.

Breeding objectives

Constraints to rice production

The hot and humid climate of Lakhimpur District favors a number of insect pests and diseases of rice. The major biotic stresses are listed in Table 3 (Sharma and Ahmed 2004).

Table 3. Major biotic stresses affecting rice in Assam.

Causal agent	Species	Ecosystems
Insects		
1. Rice stem borer	*Scirpophaga incertulus*, *S. innotata*	All
2. Rice hispa	*Dicladispa armigera*	Lowland
3. Caseworm	*Nymphula depunctalis*	Lowland
4. Whorl maggot	*Hydrellia philippina*	Upland
5. Gall midge	*Orseolia oryzae*	Lowland
6. Rice bug	*Leptocorisa oratorius*	All (early)
7. Thrips	*Stenchaetothrips liformis*	Nursery
Diseases		
1. Blast	*Pyricularia oryzae*	Upland and lowland
2. Brown spot	*Helminthosporium oryzae*	Upland and lowland
3. Bakanae	*Fusarium moniliforme*	Lowland
4. Sheath blight	*Rhizoctonia solani*	Lowland
5. Sheath rot	*Sarocladium oryzae*	Lowland
6. False smut	*Claviceps oryzae sativa*	Lowland
7. Bacterial leaf blight	*Xanthomonas oryzae* pv. *oryzae*	Lowland
8. Bacterial leaf streak	*X. oryzae* pv. *oryzicola*	Lowland
Nematodes		
1. Ufra	*Ditylenchus angustus*	Deep water
2. Root-knot disease	*Meloidogyne graminicola*	Upland

Abiotic stresses: Rice is grown over a wide range of ecosystems and hence the crop encounters different stresses in different growing environments:

- Flood: very common, often destroys rice during the vegetative stage.
- Drought: delay in monsoon affects the nursery and vegetative stage while early cessation of rain causes moisture stress during the reproductive stage.
- Stagnant flooding (waterlogging) in low-lying areas.
- Low temperature: affects the boro crop.
- Low light intensity: The average bright sunshine hours are about 5.1 hours/day in the sali season and 4.7 and 6.0 hours/day, respectively, in the ahu and boro seasons.

Weeds: Luxuriant weed growth is observed in the rice fields of Lakhimpur (Roy 1995). The most important weeds of rice fields are

- *Ageratum conyzoides*
- *Borerera hispida*
- *Cynodon dactylens*
- *Cyperus rotundus*
- *Cyperus iria*
- *Echinochloa crus-galli*

- *Imperata cylindrica*
- *Monochoria vaginalis*
- *Oryza rufipogon*

Socioeconomic constraints. For relevant breeding methods and objectives to be established, it is necessary to know the situations of typical farmers in the region. Most farmers practice subsistence farming on small and fragmented landholdings. The majority of farmers are small and marginal. Illiteracy is high and the incidence of poverty is prominent in the flood-prone areas of the district. Calorie intake of the population is low.

Other important factors are

- Weak draft power.
- The problem of stray cattle.
- Migration of the rural population in search of alternate sources of income. This causes a scarcity of labor during the peak periods of rice operations.
- Absentee farmers. This occurs when some farmers leave farming for another profession but employ other workers to farm their fields.

Infrastructure and institutional constraints. Generally, the economic capacity of the farmers to buy inputs is low. In conjunction with this, many limitations are caused by poor infrastructure within the state that directly or indirectly affects farmers' ability to acquire resources or access markets. This includes

- Poor road conditions and connections due to floods
- Market accessibility is poor, limiting sales of farm produce
- Nonavailability of inputs in time
- Credit accessibility is cumbersome
- Poor infrastructure for seed, irrigation, drying, and storage
- Lack of facilities for training of farmers to manage risks
- Lack of confidence of farmers in new technologies

Old and current varieties

Assam is known for the wide diversity of its rice germplasm. Farmers prefer different varieties in different seasons, ecosystems, and soil conditions. A brief list of common old varieties for different seasons in North Lakhimpur District appears in Table 4. All the traditional cultivars are tall and of long duration. The sali and deepwater cultivars are photoperiod sensitive and many of them are tolerant of biotic and abiotic stresses (Baruah and Das 1995).

In contrast to favorable environments, the adoption of modern varieties and improved cultivation practices is very low. In the deepwater ecosystem, the adoption of modern varieties is negligible. Similarly, no adoption of modern cultivars occurs in the upland ecosystem. There has been some impact of modern varieties in the lowland ecosystem for sali and boro seasons. Ranjit represents more than 50% of the HYVs being grown in the district. Table 5 depicts some of the modern varieties found in Lakhimpur and adjoining districts.

Table 4. List of indigenous rice varieties for different seasons and ecosystems.

Ecosystem	Variety name	Ecosystem	Variety name
Upland direct-seeded ahu	Ikhojoy		Ahomsali
	Garem		Kolasali
	Fapori		Biriabhanga
	Mesaki		Bokulbora
	Phul pakhori		Malbhog
	Dubaichenga		Chakuwa
	Bengenaguti		Saru chaokuwa
	Betguti		Kolajoha
	Rongadoria		Prasadbhog
	Begonbisi		Govindbhog
Lowland transplanted sali	Solpona	Deepwater (direct seeded + transplanted)	Adolia bao
	Gomiri		Amona bao
	Borjahinga		Jul bao
	Sorainakhi		Maguri bao
	Konjoha		Herepi bao
	Tejsali		Dhepa bao
	Katineuli		Negheri bao
	Ampakhi		Rongabao
	Khorikajai		Kekoabao
	Biroi		Ahiniabao

Table 5. List of modern rice varieties being grown in Lakhimpur District.

Variety	Season	Preferred characteristics
Ranjit	Sali	High yield
Bahadur	Sali	High yield
Basanti	Sali	High yield
Mahua	Sali	Earliness
Jaya	Sali and transplanted ahu	Grain quality, high yield, earliness
Manohar Sali	Sali	Stable yield under delayed conditions
Luit	Ahu	Very early maturity
Lachit	Ahu	Early in transplanted conditions
No. 9 Dhan	Boro	High yield
Jaymoti	Boro	High yield and good grain
Kanaklata	Boro	High yield and good grain
Biplab	Boro	High yield
Arize 6444	Boro	Hybrid with high yield

Quality preferences

Farmers are concerned about grain size and color rather than nutritional value. However, there is variation in the traits of preference among consumers. Some key quality attributes follow:

- Medium slender grains and white kernel: for selling in local markets.
- Bold and white kernel: preferred by hard-working people.
- Grains with red kernel: preferred by people for their good taste.

For general purposes, nonaromatic waxy grains are preferred, whereas, for special occasions, waxy and aromatic varieties are preferred. Farmers invariably grow waxy and aromatic varieties for home consumption (Sharma and Ahmed 2004).

Rice is consumed with all meals in the district and even snacks and special dishes are prepared only from rice. In Lakhimpur District, the tribal communities prepare rice beer for home consumption. Hence, different classes of rice such as waxy, aromatic, and semiwaxy varieties are required in the household. There is also an urgent need to evaluate the indigenous varieties for iron, zinc, and vitamin A so that undernourished people could be provided with food rich in those minerals and vitamins.

A brief description of the breeding program in Lakhimpur

The Regional Agricultural Research Station located in North Lakhimpur is a zonal station of the North Bank Plain Zone of Assam Agricultural University, and was established in 1981, with research activities starting in 1984. However, due to a lack of human resources, the station carried out only a few activities regarding the varietal improvement program. The station was given the mandate of improving deepwater rice (DWR), as the area in which the station was established was known for deepwater rice in Assam. In later years, more emphasis was given to breeding varieties for other classes of rice.

Methods used

Pure-line selection: In the early years, elite germplasm was collected from deepwater rice-growing areas and several varieties were recommended for cultivation, such as

1. Amana bao
2. Negheri bao
3. Maguri bao
4. Herepi bao
5. Padmapani
6. Kekua bao
7. Sailbadal
8. Panikekuwa (ADW 1)
9. Ahinia bao

Padmapani, a pure-line selection form Ahinia bao, is an early-maturing deepwater variety, which escapes ufra caused by nematodes (*Ditylenchus angustus*). Hence, the variety is recommended for cultivation in ufra-endemic areas. Amana bao, Kekua bao, Negheri bao, and Maguri bao are the most popular varieties in deepwater areas of the district. They have elongation and kneeing ability, and are suitable for areas where floodwater surpasses 1 meter. Three cultivars were developed through pure-line selection for cultivation in areas with stagnant flooding (up to 50-cm water depth):

- LPR 245 (selection from Borjahinga)
- LPR 345 (selection from Rangoonsali)
- LPR 85 (selection from Maguri)

Hybridization. Hybridization work started in 1984-85 in RARS, North Lakhimpur. A few crosses were made in collaboration with CRRI, Cuttack, in the late 1980s. Table 6 indicates the important varieties/lines developed at RARS, North Lakhimpur, through hybridization. Currently, 10–15 crosses are made per year.

Current program. Pedigree and bulk population breeding methods are used. In general, F_2 populations consist of 200–250 plants. Selection is based on visual appearance (leaf color—dark green color is preferred), plant height, panicle compactness, panicle exsertion, grain size and shape, and yield and yield component traits (effective bearing tillers, panicle length, and grains per panicle). Breeding material is also selected based on resistance to blast, brown spot, and bacterial blight and insect resistance (stem borer, caseworm, and ufra) under natural field conditions. Ufra is a nematode disease caused by *Ditylenchus angustus*, and infestation causes the panicles to dry up and spikelets to become sterile. It is a notorious problem of direct-seeded

Table 6. Varieties and elite lines developed through hybridization for Lakhimpur District of Assam.

Variety/line	Designation	Cross combination	Breeding objectives
Padmanath	LPR96-10 and PJNB 96-1	Pankaj/Jaganath and Pankaj/Jaganath//Negheribao followed by bulk pedigree method	Variety with elongation ability. Tolerates flood up to 1 m. Recommended in 1988.
Panindra	LPR 56-49 and PN 56	Pankaj/Negheribao followed by bulk pedigree method	Variety with elongation ability. Tolerates flood up to 1 m. Recommended in 1989.
Panchanan	LPR106	Rangabbao/*Oryza rufipogon*	Submergence and drought tolerant. Tolerates submergence up to 100 cm.
Boginodi	JM50	Jajati/Mahsuri	Flood-prone lowland situations up to 50-cm water depth
Dhal	LPR95	ARC5560/Jaya//Sundara Samba	Flood-prone lowland situations up to 50-cm water depth
–	LPR 256	Mahsuri/Padmapani	Flood-prone semideep areas

deepwater rice in Assam. Important abiotic stress tolerances include flood tolerance, intermittent drought tolerance, and cold tolerance at the reproductive stage for winter rice. For grain quality, 100-grain weight, grain size and shape, and endosperm color (opaqueness) are attributes used for selection.

Observational yield trials consist of 20–25 entries using an augmented (unreplicated) design. The best 10–12 entries are promoted to advanced yield trials using a randomized complete block design with three replications. Both trials are performed at the research station.

Participatory varietal selection

The concept of PVS is new for the breeders of the state. However, two submergence-tolerant rice varieties, Jalashree and Jalkuwari, were bred and evaluated through participation of the farmers in flood-affected villages of upper Assam. Most of the deepwater rice varieties adopted by the farmers of the state have been recommended for cultivation. In North Lakhimpur, there has been an attempt to identify stress-tolerant rice varieties under the STRASA (Stress-Tolerant Rice for Africa and South Asia) program of IRRI, funded by the Bill & Melinda Gates Foundation. Under this project, a few varieties preferred by farmers were identified in Lakhimpur District (Fig. 2).

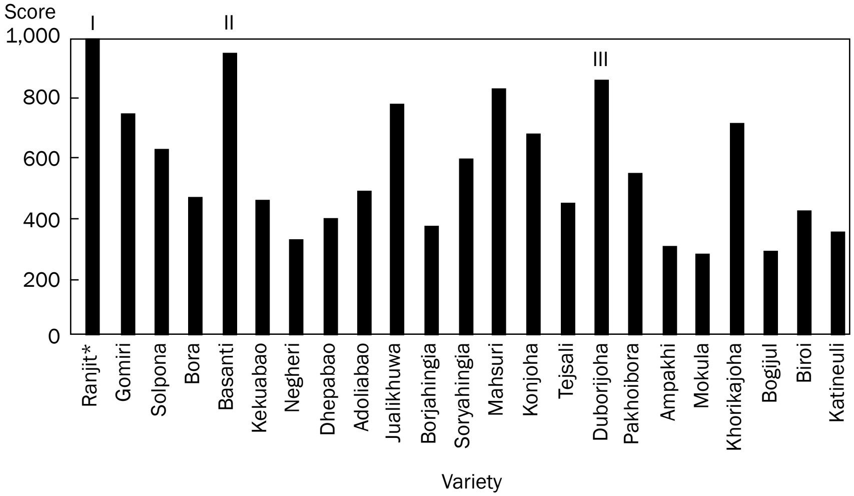

Fig. 2. Participatory varietal selection of farmers' existing varieties.

The role of IRRI

IRRI has played a major role in strengthening rice research and extension in Assam. A number of scientists were trained to ensure capacity building in the frontier areas of rice research over the last three decades. Several rice varieties developed at IRRI such as IR8, IR36, IR64, Pankaj (IR5), and Swarna-Sub1 have contributed to increased rice production in Assam. Many elite germplasm accessions and breeding lines were evaluated through various nurseries and collaborative projects such as the EIRLSBN, STRASA, etc. Farmers of the state are exposed to elite varieties through various on-farm trials, and breeders are gaining access to various lines to be used as parental materials in local breeding programs.

In the future, IRRI will play a pivotal role in providing food security to millions of poverty-stricken people, particularly for South and Southeast Asia. The impact of global climate change is influencing rice production and productivity, and it may become more severe in the years to come. IRRI should tackle these challenges through collaborative projects with the rice-growing countries in Asia and elsewhere. Human resource development should continue in frontier areas such as molecular breeding, allele mining, and bioinformatics to implement these new technologies for germplasm improvement and to enhance and stabilize production. IRRI is also expected to develop rice varieties with high nutritional quality to combat malnutrition in rice-growing countries. Furthermore, varieties tolerant of biotic and abiotic stresses should be developed and evaluated in hot spots through the EIRLSBN and other networks' activities.

Requirements for continuation and improvement of the network

It is important that the activities of the EIRLSBN continue as a joint venture between IRRI and ICAR. Specific research activities should include the following:

- The generation of more breeding materials with a broader genetic base.
- Establishment of efficient testing and molecular breeding facilities in centers.
- Monitoring of trials at least once a year by breeders from participating institutions.
- Delineation of problem areas and the generation of site-specific technologies.
- Enhanced access to funds to provide sufficient funds for research and evaluation.
- Capacity building of staff and training of farmers in new rice technologies.

Strategies and modern techniques to enhance rice production

Rice production in Assam in general and in Lakhimpur District in particular is predominantly rainfed and more than 0.5 million ha of rice area are chronically flood-prone. The rainfed ecosystem of Assam is characterized by diverse environmental conditions such as variation in rainfall, depth and frequency of flooding, time of flooding, occurrence of drought, soil type, and topography. Rainfed ecosystems need to be rigorously characterized for the targeted development and distribution of useful technologies for enhancing rice productivity. Modern tools such as geographic information systems (GIS), remote sensing, and global positioning systems (GPS) can be used for understanding the heterogeneity of the rainfed and flood-prone environment of the state. This will help in prioritizing research in such areas and for interpreting multilocation data and planning future research. No single technology can consistently enhance rice production in these unpredictably harsh rainfed ecosystems. Farmers' PVS trials combined with biotechnological tools for modern breeding can be employed to fast-track germplasm development and testing, to ultimately improve yield and tolerance of flood and drought in specific locations, and to ensure fast dissemination of suitable varieties. Research on crop establishment techniques, fertility management, and pest management practices should be emphasized.

The majority of the rice fields in Assam remain vacant after growing rice in the sali season. However, another crop would enhance the income of farmers and food security in the region. In light-textured soils, the possibility of diversification with pulses or oilseed crops should be explored. In heavy soils, however, no other crop except rice can be grown. Such rice should be of short duration with cold and drought tolerance.

Market preferences, cooking characteristics, and value addition for rice and its products need more attention of rice scientists, to generate demand for specialty varieties that have good potential in rainfed ecosystems. Emphasis should be given to improving the nutritional quality of the varieties to eradicate malnutrition problems of the state's rice consumers.

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Achievements and role of the EIRLSBN in rice research of Bihar

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Bihar has diverse agroecological zones extending between 21°58′10″ to 27°31′15″ N latitude and 83°19′50″ to 88°17′40″ E longitude. Its average elevation above sea level is 53 m. Its temperature is subtropical in general, with hot summers and cool winters. Bihar occupies a vast stretch of fertile plains. It is drained by the sacred Ganges River, including its northern tributaries Gandak and Koshi, originating in the Nepal Himalayas, and the Bagmati originating in the Kathmandu valley that regularly floods parts of the Bihar plains. The total area covered by the state of Bihar is 94,163 km^2.

Bihar is mildly cold in winter, with the lowest temperatures being 2–10 °C. Winter months are December and January. It is hot in the summer, with average highs of 35–40 °C. April to mid-June are the hottest months. High rainfall occurs during the monsoon months of June, July, August, and September. Mid-September, October, November, February, and March have a pleasant climate.

Physiographic divisions of the state

Bihar is endowed with fertile Gangetic alluvial soil with abundant water resources, particularly groundwater resources. The state also has three or four different agro-climatic zones with rich biodiversity (Table 1, Fig. 1). The North Bihar alluvial plain has two broad climatic zones: (1) northwest plains (13 districts) and (2) northeast plains (8 districts). The South Bihar alluvial plain has also been subdivided into two zones: (1) Zone III A (6 districts) and Zone III B (11 districts). Thus, a variety of crops (cereals, pulses, oilseeds, fibers, fruits, and vegetables) are produced in the state.

The soil of the northwest plains (Zone I) is sandy loam to loam type and slopes toward the southwest with a very low gradient. The major rivers, the Gandak, Burhi Gandak, and Ghaghra, flow through this region. Approximately 60% of the rice lands of this zone experience flooding during the rainy season. The period of inundation varies from as short as 1 week to prolonged periods of up to 3–4 months. More than 1.35 million hectares of area are covered by rice.

The northeast alluvial plain (Zone II) of the Koshi and Mahananda rivers and their tributaries, and the Ganga, has slightly undulating to rolling landscape with loam to clay loam soil. The area is full of streams and abandoned or deep channels of the Koshi, small lakes, and shallow marshes. Stagnant flooding is common in the vast area of this zone during the rainy season. In this zone, deepwater *chaurs* are common (areas inundated by overflow from rivers and monsoon runoff). These areas are usu-

Table 1. Agro-climatic zones of Bihar.

Agroecological zone	Area (million ha)	Production (million t)	Average yield (t/ha)	Districts	Rainfall (mm)
Northwest plain (Zone I)	1.35	2.70	2.0	West Champaran, East Champaran, Saran, Siwan, Gopalganj, Muzaffarpur, Sitamarhi, Sheohar, Vaishali, Darbhanga, Samastipur, Madhubani, and Begusarai	1,040–1,450
Northeast plain (Zone II)	0.68	1.56	2.2	Supaul, Saharsa, Madhepura, Purnia, Katihar, Kishanganj, Araria, and Khagaria	1,200–1,700
Southeast plain (Zone IIIA)	0.27	0.67	2.5	Sheikhpura, Lakhisarai, Jamui, Munger, Bhagalpur, and Banka	990–1,300
Southwest plain (Zone IIIB)	1.17	3.67	3.1	Patna, Nalanda, Gaya, Jehanabad, Nawada, Aurangabad, Bhojpur, Rohtas, Kaimur, Arwal, and Buxar	990–1,300

Fig. 1. Agro-climatic zones of Bihar.

ally submerged for 3 to 9 months or more in a year. Typically, they have a maximum depth of 1.5 m of water during the monsoon, and dry out completely during the summer (March-June). Rice is grown on 681,000 hectares.

The South Bihar plain located just south of the Ganga River has two subdivisions having sandy loam, clay loam, loam, and clay soils. There are no marshy lands or *chaurs* and more than 60% of the cultivable area is under command irrigation. These divisions have comparatively high yield potential. About 1.5 million ha are covered by rice in this zone.

Rice seasons

In the state of Bihar, rice is grown mainly in three seasons: summer, kharif, and spring (boro).

Summer rice is now mainly confined to the Triveni canal system of Zone I and around the mini-command areas of tube wells scattered around various places in Bihar. In this season, sowing takes place in February-March and transplanting in March-April, with harvesting in July-August. During the 1970s, summer rice became popular when short-duration high-yielding varieties were introduced and the area was estimated to be up to 0.5 million ha. But, because of high irrigation costs and problems in harvesting/threshing coinciding with the onset of the monsoon, the area decreased. However, there is potential for this season to become more productive taking advantage of increased solar radiation, efficient water and fertilizer management, and comparatively fewer pests and diseases in this season. Also, the average yield surpasses 3 t/ha**.**

The kharif season is the main season of rice all over Bihar. The southwest monsoon with well-marked seasonal rhythm involving warm humid weather and high precipitation during June to September coincides with the rice-growing season and with harvesting after rainfall ceases. Early- to late-maturing varieties are cultivated during this season. Average yield normally depends on the amount of rainfall during the season. Cessation of monsoon in Hathia Nakshatra (this generally occurs from late September to the first fortnight of October) is very important for early and late aman photosensitive varieties grown in low-lying areas. Failure of Hathia rain not only adversely affects aman rice but also delays the sowing of rabi crops.

Rabi rice, grown in the boro (spring) season, now popular in tropical regions of the country, is not possible in Bihar due to severe cold during the winter season. However, since time immemorial, tall traditional rice, known as boro, is grown on the banks of the Ganga, Gandak, and Ghaghra rivers. The area on these banks decreased for several reasons, including growing of alternative rabi crops (e.g., maize). But, when boro cultivation became popular in West Bengal, the same technology spread in adjoining districts of the Kosi River area of Zone II in Bihar. The entire boro crop is now covered by high-yielding varieties (HYVs). Traditional boro varieties are cultivated on the banks of rivers in patches only. In damp areas, seedlings are raised in October-November and transplanted from January onward when the temperature starts rising. During the seedling period, severe cold affects plant growth, and plants usually remain dormant and become stunted. The total growth period is prolonged due to cold weather, but the climate is very favorable after transplanting. The crop is harvested in April-May. The average yield is relatively high, about 4 t/ha.

The land situation for rice cultivation in Bihar

The land situation under which rice is cultivated is highly variable and causes many problems. Broadly, the land hydrological situation, which determines the type of rice varieties, can be divided into four categories: upland, medium land, lowland, and deep water.

1. *Upland.* This area constitutes roughly 10% of the total rice area in Bihar. The cultivation of rice is either totally dependent on the monsoon or on irrigation facilities. The topography of upland areas is such that the water-holding capacity of land is low and the crop faces moisture deficit stress when rainfall is not uniform and/or adequate. Usually, water does not stagnate in the field even after rain.
2. *Medium land.* This constitutes roughly 40% of the area, where irrigation facilities exist and drainage is possible if required. This is high-potential area where optimum yield could be secured and the crop normally gives higher yields. In these areas, water stagnates for up to 25 cm for some period and drainage facilities usually exist.
3. *Lowland.* This area includes those lands where the depth of water reaches 50 cm (i.e., stagnant flooding) and drainage is not feasible, and the crop is mostly harvested after the monsoon season. Because of low-lying situations, water accumulates easily in the lowland after rain and, as a result, water stagnates in the field for most of the season. Lowland covers about 40% of the total area grown to rice.

4. *Deep water*: This constitutes roughly 10% of the rice area, mostly spread all over North Bihar. The cultivation practice depends upon the type of deepwater area. Deep water is defined as the condition where the depth of water varies from more than 50 cm to 4 m. Rice is mostly broadcast in March-April along with other crops such as maize, *jowar* (sorghum), mung bean, etc. Transplanting is also practiced in some areas. Yield is poor due to the use of low-yielding varieties and management practices are almost negligible in this ecosystem. Crop yield depends on the depth and duration of water. Depending upon the depth of water, this ecosystem is subcategorized as
    (i) Shallow deep water—50 cm to 1.0 m water depth
    (ii) Medium deep water—1.0 m to 2.0 m depth
    (iii) Typical deep water—more than 2.0 m water depth and often reaching 4.0 m

The water usually dries up in November in shallow deepwater areas and the land becomes cultivable by December, whereas the medium deepwater areas dry up by February and March. On the other hand, the typical deepwater areas dry up by the middle of March to April.

Trends of area, production, and productivity of rice in Bihar

Rice cultivation has many limitations in Bihar. Except for 25% to 30% of the rice area, the rest is rainfed. This implies that, in the vast majority of rice land area, proper management and sufficient inputs could not be provided for high yield as the crop is grown under risky situations, which are the main reasons for the lower yields in the state. For these problematic areas, appropriate strategies and technologies need to be devised and used to suit the varying conditions of land where rice is cultivated. Because of the unique topography of the state, there was no impact on average yield even after the introduction of high-yielding varieties, whereas, in other states such as Punjab, Haryana, and Tamil Nadu, average yield increased considerably in recent years. However, the period 2011-12 witnessed a tremendous increase in the productivity of rice (2.5 t/ha) in comparison with the highest productive period, 2008-09 (1.7 t/ha), over the past seven years. This may be due to normal rainfall, mechanized farming, and the comprehensive efforts made by the state government for a timely supply of seeds of HYVs and other inputs. Generally, high-yielding varieties developed for irrigated ecosystems, which require high inputs, did not significantly increase rice production except in favorable pockets, as these varieties were not adapted to rainfed conditions.

Production factors

Rainfall

Rainfall in Bihar is largely dependent on the southwest monsoon, which accounts for around 85% of the total rainfall in the state. The average rainfall in Bihar is 1,091 mm. Other sources, such as the northwest monsoon, winter rain, and hot-weather rain, account for the remaining 15% of the rainfall. The average rainfall could be considered adequate, yet the year-to-year variation causing both drought and floods in the state is responsible for variations in agricultural production and farmers' income. This is because around 50% of the cultivated area is still dependent on rains or some traditional modes of irrigation, which fail during low-rainfall years. During 2000 to 2009, annual rainfall varied between 897 mm in 2005 (82.2% of the average annual rainfall) and 1,506 mm in 2007 (138.0% of the average annual rainfall). In 2005, the rainfall from the southwest monsoon, the major contributor, was 16.5% less than the average annual rainfall. Similarly, in 2007, the rainfall from the southwest monsoon was 45.9% more than the average. In 2010, the rainfall from the southwest monsoon was much less than normal, which caused drought-like situations in certain parts of the state. Delays in the monsoon usually cause delays in sowing and transplanting for farmers, causing reduced production.

Seed production

One of the major requirements for successful agricultural operations is good-quality seed. Seeds of high quality can go a long way toward improving rice productivity. The use of seeds of high-yielding varieties and their replacement rate are important determinants of productivity in agriculture. Because of the dearth of seed companies in Bihar supplying certified seeds, low seed replacement rates (SRR) are often cited among the reasons for the low productivity of agriculture in Bihar. The SRR for major crops such as rice, wheat, and maize has increased significantly in the state since 2007. Importantly for rice, the SRR increased from >10% in 2007-08 to >15% in 2008-09, to 25% in 2009-10, and it reached 31% in 2010-11, which is about the recommended 33% for self-pollinated crops.

Fertilizer

With the use of improved seeds and high-yielding varieties, fertilizer—in an appropriate quantity and at the appropriate time—becomes much more important for enhancing agricultural productivity. Fertilizer consumption in the state has been rising constantly since 2007. In recent years, the growth has been even faster. The rising trend indicates the awareness and willingness of farmers to adopt new technologies, such as the increased use of fertilizer, to enhance agricultural productivity even with a severe shortage of irrigation and other facilities. The per hectare application of fertilizer increased to 181.1 kg in 2009-10 from 141.7 kg in 2006-07.

Cropping pattern

In Bihar, cereals dominate the cropping systems. The rice-wheat cropping system occupies more than 70% of the total cropped area. Rice is mainly transplanted, although direct-seeding and aerobic approaches are also being followed in some regions. Recently, several stakeholders in Bihar have been advocating zero-tillage sowing of rice and winter crops, especially wheat and lentil, in order to facilitate sowing at the right time. Table 2 reports the important cropping sequences adopted normally in different zones.

In the case of the predominant rice-wheat cropping system, sowing of rice is during late May to July, whereas wheat is sown from 15 November to the end of December. The average grain yield of rice under this system is 4.0–4.5 t/ha and wheat yields 3.5–4.0 t/ha when timely sown, and 2.0–2.5 t/ha with late sowing. The major constraints to higher yields for rice and wheat crops under this cropping system are as follows:

For rice:

1. It covers more area under the lowland ecosystem, where accumulated rainwater stands (i.e., stagnant flooding) until at least mid-November, which makes agricultural management difficult.
2. Use of seedlings that are too old due to erratic rains.
3. Zinc and sulfur deficiency in most soils.
4. No adoption of biofertilizer and proper plant protection measures.

For wheat:

1. Delayed sowing of wheat due to wet soils after rice and nonadoption of zero-tillage machines.
2. Lack of line sowing, faulty methods of fertilizer application, and unbalanced use of fertilizer.
3. Inadequate supply of proper varieties for specific conditions.

Production constraints

India has one of the largest rainfed lowland areas (17.2 million hectares) in Asia (Khush and Baenziger 1998). Eastern India, comprising the states of Odisha, West Bengal, Bihar, Assam, Chhattisgarh, and eastern Uttar Pradesh, with a total rice area of 26.4 million ha, has nearly 14.6 million ha under rainfed lowlands. These lands are highly diverse, heterogeneous, and prone to flooding, have poor drainage, and are prone to waterlogging. In a typical drought-affected year, productivity is about 1.0 t/ha. In Bihar, about 2.2 million ha often encounter drought, submergence, or both stresses in the same season. Out of 42 biotic and abiotic stresses that prevail in rainfed lowland rice areas of eastern India, submergence stress is the third most important limitation to rice production (after drought and weeds) (Widawsky and O'Toole 1995). In general, two types of flooding cause damage to rice: flash flooding that results in complete inundation for short periods, and stagnant flooding, where water stagnates for up to a few months (especially in deepwater and tidal flood areas). Submergence stress can also damage crops in irrigated areas due to high rainfall and impeded drainage, particularly early in the season as most (if not all) varieties are sensitive to submergence

Table 2. Zone-wise major cropping pattern in Bihar.

Zone	Cropping pattern
Zone I	Rice-wheat, maize-sugarcane (autumn), maize-wheat-mung bean
Zone II	Rice-wheat, jute-rice-wheat, jute-wheat, jute-potato, jute-mustard, rice-wheat-mung bean, rice-toria
Zone III (A & B)	Rice-wheat, rice-gram/lentil, maize-potato-onion

(Lafitte et al 2004). The annual average yield loss from submergence is estimated at about 80 kg/ha (Dey and Upadhaya 1996).

These factors often lead to the cultivation of tall traditional photoperiod-sensitive cultivars that are prone to lodging; poor plant establishment, poor tillering, and poor panicle production; and increased disease incidence. With poor crops, farmers often neglect proper crop management and are less likely to apply fertilizer.

Rice breeding in Bihar: historical and current perspective

With the separation of Bihar from Bengal in 1911 and the establishment of the Department of Agriculture in Bihar in 1914, research on rice improvement of this state was undertaken by the deputy directors of agriculture in different areas: (1) South Bihar, with headquarters in Patna; (2) Southeast Bihar, with headquarters in Sabour; (3) Chhotanagpur at Kanke (Ranchi); and (4) Cuttack, with headquarters at Cuttack, which is now the Central Rice Research Institute. Some improved varieties selected from local varieties by the then deputy director Mr. D.R. Sethi resulted in the development of Dahia and an early Katika type, and Latisal, a late Aghani type. Mr. C.B. Machean developed Kanke-I and Kanke-II from Kanke. These were some of the varieties released and distributed to the farmers of Bihar through 1932.

More systematic research activities on rice began in 1932. The late Mr. Madam, an economic botanist working on improvement of all cultivated crops, was appointed as the rice specialist in Bihar, with headquarters at Sabour, supported by two assistant botanists (rice) and a contingent of senior and junior research assistants, field workers, and plant collectors.

The main focus of the rice improvement program was in the following areas: (1) botanical and agricultural surveys of the paddy varieties of the province; (2) isolation of pure lines and their classification and maintenance, in addition to the selection of improved strains; (3) conduct of management research and use of organic fertilizers; and (4) genetic studies.

As a result of the research work from 1932 to 1938, a few improved varieties were recommended after their testing with local varieties on different departmental farms. They were (1) early aman (Katika) 115 BK and 141 BK, (2) medium aman 88 BK and 16 BK, and (3) late Aghani 36 BK 498-2A. These new varieties rapidly replaced earlier released varieties and became very popular among farmers all over the state. Two more fine-grain varieties, Tulsi-Manjari and Badshabhog, were also released.

Along with varietal improvement, suitable manure application and other cultural recommendations were also established for higher rice production in different rice areas. Apart from the research work on rice at the main station at Sabour, a few substations also started to test the results from Sabour, including (1) Patna (South Bihar), (2) Kanke (Chhotanagpur), (3) Purnia (Southeast Bihar), (4) Sipaya (North Bihar), and (5) Dumka (Santhal Parganas). The substations at Cuttack, Kanke, and Dumka were discontinued after the separation of Orissa in 1938 and Jharkhand in 2000 from Bihar.

The entire rice research work at Sabour declined drastically in 1941 when ICAR greatly reduced funding, and the work was somehow maintained at Sabour with one assistant botanist, one junior research assistant, and a few field supervisors. They could only maintain the pure lines selected before, but the research work came to a near standstill in 1944 when ICAR ceased its funding.

In 1951-52, the agricultural development and research work got another big boost with the launching of the first five-year plan. The post of rice specialist was again revived with headquarters at Sabour, with a contingent of an assistant botanist, senior research assistant, junior research assistants, and field workers. Rice substations were also sanctioned at Patna, Sipaya, Purnia, Kanke, and Dumka, with one assistant botanist, one senior research assistant, and two field overseers for each substation.

Between 1942 and 1951, when the rice work was supervised by the economic botanist, at the headquarters in Sabour, some exotic varieties were released for farmers such as CH10 (BR24) and CH1039. These were very early maturing aus varieties and they replaced mostly some of the low-yielding Gora varieties of Chhotanagpur uplands. These became very popular with early aus-growing farmers of Bihar. Other early aus varieties released were Sona and Sathika (Big 19 and BR20, respectively) but they did not become very popular.

With the establishment of rice research work at Sabour under the rice specialist and his associates, one variety, 2206 B, was released in 1953-54, which was later named BR34. This was a selection from a local variety of Munger District. BR34 became very popular as an early Katika type replacing 115-BK and 141-BK, which were later named BR-4 and BR-5, respectively.

During 1952-70, pure-line selections continued to occupy an important place in the breeding program. The number of exotic accessions increased the genetic stock, in addition to the introduction of germplasm from a number of rice-growing countries. A large number of japonica × indica-derived materials received from CRRI were evaluated and compared with the local standard varieties. Most of the earlier selections were important for the development of new rice varieties of Bihar. No success, however, was directly obtained from the japonica × indicia crosses.

In 1964, two indicas, namely, Taichung Native 1 (TN1) and Deo-geo-woo-gen from Taiwan, were introduced. These had very short duration, were very high yielding, and had coarse grain. During the summer, yields as high as 8 t/ha were obtained from TN1. However, this variety was very susceptible to bacterial leaf blight, particularly when grown in the kharif season. But, later on, it was used as one of the parents to provide specific traits. The evolution of IR8 and later Jaya completely replaced TN1. IR8 and Jaya were equally high yielding with better grain quality, were fertilizer responsive, and were not as susceptible to bacterial leaf blight as TN1. At the time, these two varieties occupied a very large rice area in almost all of the rice-growing states of India.

During 1963-64, summer paddy (sown in February-March and harvested in June-July) in Bihar was introduced in the irrigated areas. Summer paddy in those years occupied 0.1–0.2 million ha, yielding 2–3 t/ha, thereby adding 0.6–1.0 million tons of rice to the state’s food grain production. Previously, the variety of rice used in the three-crop sequence (paddy-paddy-wheat) was N-136, but it was soon replaced by TN1. Rice improvement work was given greater emphasis after the initiation of the All India Coordinated Rice Improvement Project at Hyderabad under the joint auspices of ICAR, the government of India, USAID, the Rockefeller Foundation, and the Ford Foundation of the U.S.

Early breeding approaches of rice improvement (1970s to 1980s)

Variety introduction and testing for suitability and direct release as varieties were a common practice in the 20th century. Mahsuri is one such example; it was introduced to India and other countries from Malaysia and became popular with farmers in eastern India because of its moderate resistance to lodging and good grain quality (Rao Balakrishna and Biswas 1979). The varietal development program for rainfed lowland rice has only recently received attention, compared with irrigated rice. The initial effort for varietal improvement for the rainfed lowland ecosystem was mainly confined to the purification of landraces through pure-line selection (Mallik et al 2002). Such breeding activities began with the selection of superior lines within local landraces. Panicles from the best plants were harvested and bulked, which improved the uniformity and increased yield in some cases. In Bihar, BR8, BR9, BR34, Sugandha, Rajshree, and Tl41 were released through this process. These cultivars are tall and photoperiod sensitive, and have varying degrees of submergence tolerance (Malik et al 1995).

Pedigree, bulk, and modified bulk pedigree are the most common breeding methods used for rainfed lowland conditions (Maurya and Mall 1986, Mackill et al 1996). Although a large number of varieties developed using these methods were released in India, only a few were adopted by farmers in rainfed areas. In Bihar, Rajendra dhan, Panidhan 2, Radha, Shakuntala, and Mahsuri have been released, of which Mahsuri is popular among the farmers. The poor performance is believed to be because segregating breeding material was grown and tested at the research station instead of on-farm, where many environmental stresses are present (Maurya et al 1988, Goet 1989, Thakur 1995). In view of the poor adaptability of the on-station selected genotypes in the heterogeneous and uncertain on-farm conditions, the breeders at Rajendra Agricultural University (RAU), Pusa (Bihar), developed a strategy that includes early-generation testing of segregating materials under on-farm situations, followed by on-station evaluation and release (Thakur 1995). Thus, the modified bulk method at RAU handles bulk populations up to the F_4 generation in farmers' fields, under direct-seeded conditions, followed by single-panicle selection in the F_4 and F_5 generations and testing at the research station. The main drawback of this method appears to be increased plant competition in the direct-seeded early generations. Thus, there is a risk of losing otherwise genetically superior but competitively poor genotypes. Vaidehi was released after testing its performance under on-farm conditions (Thakur 1994). The modified pedigree method (single-panicle selection) was adopted by breeders at Narendra Deva University of Agriculture and Technology (NDUAT), Faizabad, Uttar Pradesh. This method was used to handle larger population sizes in the F_2 and subsequent generations up to F_4 (Mishra et al 1996). Using mutation breeding, two widely accepted rainfed lowland cuitivars, Biraj and Jagannath, were developed from OC 1393 and T141, respectively. They are suitable for use in 5–30 cm of standing water (Rao Balakrishna and Biswas 1979).

Brief description of the breeding program under the EIRLSBN at ARI, Patna (BAU, Sabour), and RAU, Pusa

Most of the rice varieties developed for the rainfed lowland ecosystem up to the mid-1980s were pure-line selections. From the mid-'80s, the focus shifted to rainfed rice breeding and research. The inception of the EIRLSBN in 1992 in collaboration with the Rainfed Lowland Rice Research Consortium coordinated by IRRI (Sarkarung 1995) was a milestone in rice breeding for the rainfed lowland conditions of eastern India. Different cooperating centers of this program are Titabar, North Lakhimpur, and Gerua in Assam; Pusa and Patna in Bihar; Motto and Bhabanipatna in Odisha; Raipur in Chhattisgarh; Masodha in Uttar Pradesh; and Chinsurah in West Bengal, with CRRI, Cuttack, being the coordinating center. The main objectives of the project were as follows:

- To make diversified donors/improved breeding lines, suitable for rainfed lowlands, available for all cooperating centers.
- To provide segregating populations with broad genetic backgrounds to all the centers for effective selection in location-specific areas.
- To evaluate elite breeding lines developed by the cooperating centers and IRRI, especially for submergence tolerance, photoperiod sensitivity, yield potential, and adaptation to eastern India.
- To organize a breeders' workshop for eastern India to evaluate and select breeding materials at key sites.
- To conduct on-farm evaluation of new promising breeding lines to study their adaptation and acceptability to farmers.

The exchange of breeding materials with a broad genetic base among the breeders in eastern India provided a better opportunity for selection of ideal genotypes suited to local conditions. Normally, 10–15 years are needed to release a variety for this ecosystem, starting from the year of crossing. The shuttle breeding program helps to cut down the time for varietal development by 3–4 years, as breeders receive F_2 or even F_3 or F_4 materials (Mallik et al 2002).

RAU (Pusa) and ARI (Patna center) of Bihar also benefited from this program in several ways such as evaluation and selection of hundreds of advanced breeding lines for use in their breeding program. One hundred and fifty-three breeding lines of different generations (F_3 to F_9) were evaluated in six locations in five states: Bhubaneswar, OUAT, and CRRI, Cuttack, in Odisha; Pusa in Bihar; North Lakhimpur in Assam; Masodha in Uttar Pradesh; and Chinsurah in West Bengal, through the AP Cess Fund Scheme, and 2,995 materials were selected during the wet season (kharif) of 2000. The Pusa center made 452 selections in that year. Ten released rice varieties for the rainfed lowland ecosystem, two from each of the five states—Sarala and Durga (Orissa), Baraborodhi and Jallahari (UP), Rajshree and Sudha (Bihar), Ranjit and Bahadur (Assam), and Bhudeb and Mahananda (WB)—were tested in farmers' fields on a large scale starting in kharif 2001. Five hundred farmers in each state (100 in one district) had been provided with 5 kg of seeds of new varieties to expedite the interstate flow of promising rice varieties (Mallik et al 2002).

Rajendra Mahsuri-1 (designated RAU83-500) developed from the cross BR51-46/Mahsuri was also tested in shuttle breeding trials at 10 sites of eastern India: under normal planting with 30-d-old seedlings and delayed planting with 60-d-old seedlings under rainfed lowland conditions. Rajendra Mahsuri-1 ranked second under normal planting and fourth under delayed planting. This variety was released by RAU for commercial cultivation in 2003 (Sahay et al 2004). Altogether, 55 breeding lines were nominated to shuttle breeding trials from 2007 to 2012 (Table 4). Additional promising entries in the pipeline are reported in Table 5.

Current work is being pursued with the main objective of developing suitable varieties for different agro-climatic regions of Bihar by combining the high yield potential of dwarf indicas with other traits, including tolerance of diseases and pests and the superior grain quality of traditional local varieties.

In general, early to medium-early groups of varieties such as Turanta, Prabhat, and R. Bhagwati are being grown in upland areas, whereas medium-maturing varieties (120–135 days) such as MTU1010 and Sita, Rajendra Sweta (nonscented), Rajendra Bhagwati, Rajendra Suwasini, Rajendra Kasturi, and Sabour Surbhit (scented) are grown in medium lowland irrigated areas. In irrigated and rainfed medium lowland areas, late-maturing (more than 135 days to maturity) varieties such as Swarna (MTU7029), Rajendra Mahasuri, MTU1001, Rajshree, Kanak, and Swarna-Sub1 and traditional aromatic varieties are being grown. Several scented rice varieties such as Tulsi-Manjari (BR-9), Katarni, Kamod, Khirsapati, Badshahbhog (BR-10), and Cuttack Basmati have been grown by farmers; however, these varieties do not satisfy export quality requirements. With concerted efforts, several varieties (nonscented and scented) for different rice ecosystems have been identified for commercial cultivation to enhance the production and productivity of rice in the state (Table 3).

Current rice research and improvement work at Rajendra Agricultural University (RAU) and Bihar Agricultural University (BAU) defined the following breeding objectives:

1. Breeding for high yield and superior grain quality in the different maturity groups/ecosystems.
2. Breeding for resistance to major diseases, especially bacterial leaf blight, blast, rice tungro virus, and sheath blight.
3. Breeding for resistance to major pests, especially stem borer and gall midge.
4. Breeding for suitability to adverse conditions such as submergence, deep water, stagnant flood, and drought.
5. Breeding high-yielding aromatic rice varieties suitable for different maturity groups.

Pedigree and bulk population methods are most frequently used for the development of varieties. The most commonly used method is the randomized complete block design followed by an augmented design. For the conduct of field trials, screening

Table 3. List of varieties released/recommended for cultivation in Bihar for different eco-systems.

S. no.	Name of variety	Days to maturity	Grain type	Yield (q/ha)
For upland				
1.	Turanta	75–80	Long bold	25–30
2.	Prabhat	90–95	Long slender	35–40
3.	Richharia	90–95	Long slender	30–35
4.	Dhan Lakshmi	95–100	Long slender	30–35
5.	Saroj	115–120	Long slender	45–50
6.	Pusa 834	100–110	Long slender	35–40
7.	Rajendra Bhagwati	115–120	Long slender (scented)	40–45
For medium land				
8.	Sita	130–135	Long slender	45–50
9.	Santosh	130–135	Long slender	45–50
10.	Rajendra Suwasini	120–125	Long slender (scented)	40–45
11.	Rajendra Kasturi	125–130	Medium slender (scented)	35–40
12.	Rajendra Sweta	130–135	Medium slender	40–45
13.	MTU1001	130–135	Long slender	40–45
For lowland				
14.	Rajshree	140–145	Medium slender	40–45
15.	Rajendra Mahsuri	150–155	Medium slender	55–60
16.	Satyam	140–145	Long bold	40–45
17.	Swarna (MTU7029)	145–150	Medium slender	55–60
18.	BPT 5204	140–145	Medium slender	50–55
19.	Shakuntala	140–145	Long slender	40–45
20.	Swarna-Sub1	145–150	Medium slender	40–45
For deep and chaur land				
21.	Sudha	155–160	Long bold	30–35
22.	Vaidehi	155–160	Long bold	30–35
23.	TCA 177	155–160	Long bold	25–30
24.	Janaki	December	Long bold	20–25

facilities for different traits for specific ecosystems are available; however, the lack of field staff as well as technical personnel is a major bottleneck in the development of breeding materials. Field trials for fixed breeding lines typically consist of observational yield trials (OYT) and advanced yield trials (AYT), which are conducted during kharif. Both trials are usually sown in early to mid-June and transplanting is normally completed by the third week of July. For example, at RAU, Pusa, OYTs consist of 80 test entries with five checks using an augmented design. The plot size is 0.8 m^2. The AYTs usually consist of 24 or 25 entries, including 5 checks (Rajshree is the local check used), with plot size of 8 m^2. Apart from yield, days to flowering, and plant height measurements, data on panicle length and panicles/m^2 are also recorded.

The following notable varieties have been released:

- Shankutla (Pankaj/BR8): days to maturity—140–145, tall, medium slender kernel, grain yield 4.0–4.5 t/ha, suitable for rainfed lowlands, released in 1994.
- Rajendra Mahsuri 1 (BR51-46/Mahsuri): days to maturity—140–145, semi-dwarf, medium slender kernel, grain yield 5.0–6.0 t/ha, suitable for rainfed lowlands, released in 2002.
- Kishori (IR8/Barogar; PSR 1119-13-3-1): suitable for rainfed areas, drought tolerant, long bold grain, released in 1998.
- Satyam ((RD19/Desaria 8; SBR 3025): suitable for rainfed areas, BPH resistant, medium-long grain, released in 1997.
- Santosh (Pankaj/BR34; RAU 1306): suitable for rainfed areas, multiple disease resistance, long slender grain, released in 2001.
- Swarna-Sub1 (Swarna*3/IR49830-7-1-2-3): days to maturity—145–150, semi-dwarf, medium slender kernel, grain yield 4.0–4.5 t/ha, suitable for lowlands.

It is noteworthy that Kishori and Satyam were evaluated in field trials within the EIRLSBN (Thakur et al 1998). Promising entries in the pipeline appear in Table 5.

Variety adoption and dissemination

The promotion of new varieties and adoption in the state have involved three groups: Krishi Vigyan Kendra, local NGOs, and progressive farmers. Recently, RAU released Rajendra Bhagwati, a short-duration, high-yielding, drought-tolerant variety with good eating quality. Its short duration is desirable for multiple cropping systems in the region, especially in upland and medium land areas where farmers also grow maize, potato, chilli, tomato, or tobacco.

Some local NGOs were involved in extension activities in the Jhanjharpur area of Madhubani District. Preliminary data and reports regarding the performance of Satyam and Rajshree have been positive, and it is hoped that these varieties will gain popularity. Front-line demonstrations in farmers' fields have also been conducted in different districts. These farmers have been involved in the promotion of new varieties and selling seeds.

Table 4. Elite breeding lines nominated to shuttle breeding trials.

Years	Breeding lines		
	OYT	RYT	Total
2007-08	16 entries	RAU 759-5-41, RAU 1338-33	18
2008-09	RAU 670-5-20, RAU 671-9, RAU 730-20-78, RAU 731-2-20, RAU 732-106-3, RAU 751-176-9, RAU 759-5-41	RAU 678-82-4	8
2009-10	RAU 716, RAU 631-9-10, RAU 718, RAU 720, RAU 640-204-15, RAU 649-108-5, RAU 729-12-44, RAU 735-17-2, RAU 417-79-60	RAU 731-2-20, RAU 106-3, RAU 671-9	12
2010-11	RAU 462-86-72, RAU 678-95-15, RAU 755-13-15, RAU 733-11-20, RAU 639-200-55, RAU 763-15-33	RAU 631-9-10, RAU 640-204-15, RAU 720	9
2011-12	RAU 635-8, RAU 760-16-30, RAU 718, RAU 678-82-4, RAU 640-204-15, RAU 732-106-3	RAU 639-200-55	8

Table 5. Promising elite breeding lines.

IET no.	Designation	Days to flowering	Grain type	Yield (q/ha)	Ecosystem
18620	RAU 678-82-4	118	Long slender	50–60	Medium to lowland
19924	RAU 637-99-52	107	Medium slender	45–55	Medium to lowland
18874	RAU 724-88-33	108	Medium slender	45–55	Medium to lowland
	RAU 759-5-41	112	Fine rice	50–55	Shallow lowland

Future directions

Many traits should be considered as high-priority traits in the future, especially for abiotic and biotic stress tolerance. New varieties with preferred maturity groups also need to be developed, and currently there is a lack of suitable varieties of aerobic rice or hybrid rice for rainfed ecosystems.

1. Abiotic stress tolerance
    a. Drought at early growth stage and at reproductive stage
    b. Submergence-tolerant varieties for flash-flood-prone areas
2. Biotic stress resistance
    a. Sheath rot, brown leaf spot, and false smut
    b. Brown planthopper and stem borer resistance
3. Maturity: long duration (140–145 days)

The following research areas have high priority for Bihar:

1. Development of long-duration (140–145 days) hybrid rice along with stress (biotic and abiotic) tolerance for use in rainfed lowland ecosystems in the background of locally adopted cultivars
2. Development of hybrids with fine grain and aroma to enhance the yield of aromatic fine rice
3. Identification of suitable varieties of aerobic rice
4. Development of clean field technology by incorporating herbicide tolerance, to reduce labor costs for weed management
5. Identification of new sources of a gene for abiotic and biotic stress tolerance to mitigate the effects of climate change
6. Biofortification of rice to improve nutritional content

The following research deliverables are important:

1. Hybrid rice varieties for rainfed lowlands
2. Varieties for aerobic rice cultivation
3. Hybrids for fine-grain aromatic rice
4. Targeted varieties for abiotic stress-prone areas
5. A "clean" (weed-free) crop cultivation system

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Notes

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Contribution of NDUAT in Uttar Pradesh to the EIRLSBN

V.N. Singh, A.K. Singh, A.H. Khan, S.K. Singh, O.N. Singh, S. Singh, and R.K. Singh

Uttar Pradesh (UP) is the fourth-largest state in India, with an area of 246,413 km^2, and it possesses varied topographic features ranging from plains to Vindhyan hills. The state is divided into two physiographic regions, the Gangetic plains and the southern plateau. Regarding cultivation, the Gangetic plains cover the major portion of the state. Uttar Pradesh is the most populous state in India, with a population density of 776 per km^2. The state has 16.5% of the country's population (199.5 million as of the 2011 census), with 22.5 million farm families. Agriculture is the most important industry in the state because about 80% of the population resides in rural areas, and 75% of the total workers are involved directly or indirectly in cultivation/farming, which accounts for 27% of the state's GDP. Agriculture is thus the main source of income. The state has nearly 19 million ha of cultivated area, constituting 70% of the total geographic area. The irrigated area covers 13.43 million hectares. The small and marginal farmers jointly make up 19.5% of the farming households in the eastern region, compared with 19.1% across Uttar Pradesh.

The important crops in UP are rice, wheat, maize, sugarcane, chickpea, pigeon pea, mustard, lentil, urd, and mung bean. The majority of the agricultural land is used to grow major cereal crops, including rice and wheat. Uttar Pradesh has favorable climates, vast areas of fertile soils, ample sunshine, and adequate water resources.

Rice production

Rice is grown in all 72 districts of Uttar Pradesh with low to high area. The state ranks third in India and its annual rice production is around 12 million tons. Rice is cultivated mainly in the kharif season (wet season) on about 5.9 million hectares, followed by *zaid* (summer season) on 35,000–40,000 hectares only. Boro rice is grown on 3,000 ha only in deep flooded areas, mainly in the eastern districts of UP. The average productivity of the state is around 2 t/ha. The overall production and productivity of the state are highly influenced by rainfall and its distribution during the crop growth period. Drought affects production and productivity by reducing the area as well as yield. It is observed that high production was achieved in the years when adequate rainfall was received. During 2003-04 and 2008-09, high rice production was achieved due to normal rainfall and its proper distribution. During the drought years in 2002-03 and 2009-10, there was a drastic reduction in yield and area. In 2009-10 alone, area declined to the tune of about 1 million ha and production declined by 1.07 million metric tons.

Uttar Pradesh has a major share in rice area that constitutes about 13.5% of the total rice grown in the country. It contributes 18–20% of national production and about 29.1% of the state gross domestic product. Details on area, production, and productivity in the last 30 years (i.e., 1980-81 to 2010-11) are presented in Table 1. The average productivity of favorable irrigated areas is more than 3.0 t/ha, whereas the average productivity in rainfed lowland and upland areas is 1.5 t/ha and 1.0 t/ha, respectively.

Table 1. Area and productivity from 1980 to 2011.

Years	Area (ha)	Productivity (t/ha)
1980-81	5,014,679	1.05
1981-82	5,120,175	1.07
1982-83	4,787,674	1.09
1983-84	5,082,167	1.27
1984-85	5,225,206	1.30
1985-86	5,319,654	1.13
1986-87	5,261,487	1.36
1987-88	4,518,012	1.35
1988-89	5,112,221	1.75
1989-90	5,120,932	1.75
1990-91	5,327,047	1.83
1991-92	5,409,704	1.74
1992-93	5,193,060	1.76
1993-94	5,080,778	1.90
1994-95	5,280,502	1.85
1995-96	5,278,812	1.85
1996-97	5,276,843	2.12
1997-98	5,438,809	2.15
1998-99	5,573,067	1.94
1999-00	5,778,812	2.19
2000-01	5,904,128	1.98
2001-02	6,068,496	2.12
2002-03	5,209,137	1.84
2003-04	5,719,933	2.18
2004-05	5,934,405	1.81
2005-06	5,868,870	2.00
2006-07	5,820,022	1.87
2007-08	5,756,233	2.06
2008-09	6,011,761	2.17
2009-10	5,148,046	2.08
2010-11	5,631,949	2.12

Rice is cultivated on about 5.9 million ha covering five major ecosystems: favorable irrigated, unfavorable rainfed upland, rainfed lowland, deepwater and flood-prone, and inland salt-affected areas. Data on the exact extent and area distribution for each ecosystem are not available.

Rice production has been stagnating between 11 and 12 million metric tons since 1990, with slightly lower or higher production in unfavorable and normal years based on rainfall (Table 2). During these decades, the highest rice production was obtained in 2008-09 (13.05 million tons), which was considered the most productive year. The average productivity of the state is almost equal to the national average (≤ 2.0 t/ha). However, natural hazards, including submergence, drought, or both, adversely affect productivity.

Geographic and environmental factors

As the fourth-largest state of the country, Uttar Pradesh lies between 23°52′ and 30°16′ N latitude and 77°84′ and 84°38′ E longitude, bordered by Nepal in the north. The neighboring states are Bihar, Jharkhand, and Chhattisgarh in the east; Uttarakhand in the north; Madhya Pradesh in the south; and Rajasthan, Haryana, and Delhi in the west. The state covers an area of 24,613 km^2 and possesses varied topographical features spreading from plains to the Vindhyan hills; thus, it has been divided into Gangetic plains and the southern plateau. The state is considered the hub of the Indo-Gangetic Plains, one of the most fertile areas of the world.

Climate

The state's climate is subtropical and congenial for agriculture. In winter, the average minimum temperature ranges from 25° C in the northern part of the plains to 15° C in the eastern part of the state. The maximum temperature during the hot season varies from 32 °C in the northern parts to 46 °C in the southwestern part of the state. The annual relative humidity ranges from 60–70% in the northeastern Terai region to 30–40% in the southwestern areas.

Rainfall

The average annual rainfall of the state is 947.4 mm and it has ranged from 710 mm to 1,750 mm during the past 40 years. The Terai foothills receive heavy rainfall, whereas rainfall decreases in the southern part. The highest amount of rainfall in the state is received during June to September. Regarding the precipitation trend in the southwest and southeastern parts of the state, it ranges from 672 to 1,381 mm. Four decades of data (Table 2) on rainfall show that there was a gradual decrease in rainfall distribution between 1971 and 2011. During 1971-81, the average rainfall of the decade was 1280.1 mm, whereas, in the last two decades, average precipitation was 859.0 mm. The lowest average rainfall, from 2001 to 2011, was only 737.4 mm.

Table 2. Rainfall distribution during the last 40 years (in mm).

Years	June	July	Aug	Sept	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Total
1971-80	144.6	403.6	345.2	246.7	41.6	5.5	5.6	17.3	20.9	10.9	8.5	29.8	1,280.1
1981-90	92.1	289.2	237.1	185.5	35.8	3.9	11.0	13.6	15.6	9.9	9.8	20.4	923.8
1991-2000	94.6	226.3	287.9	169.9	30.7	5.3	8.5	12.6	12.3	4.9	5.5	14.6	872.9
2001-10	90.7	225.8	194.6	148.6	22.7	2.3	2.5	7.3	14.7	6.4	4.1	17.7	737.4
Average	106.0	286.0	266.0	188.0	33.0	4.0	7.0	13.0	16.0	8.0	7.0	21.0	953.7

Soil types

Six well-defined and distinct soil groups differing from one another in their geological formation and pedogenic characters have been recognized: Bhabar soils, Terai soils, Vindhyan soils, Bundelkhand soils, Aravali soils, and alluvial soils. Each of these soil groups had developed under the combined influence of a wide range of soil-forming factors, including climate, vegetation, and plant material. The major coverage of alluvial soil is further grouped as saline-alkaline soils, Karail soils, and Bhatt soils. The saline-alkaline soils are divided into three groups: saline soils, saline-alkaline soils, and alkali soils. The major soil types, area, and their coverage are depicted in Table 3.

Agro-climatic zones

Based on rainfall, terrain, and soil characteristics, eight agro-climatic zones have been identified in the state of Uttar Pradesh: Terai Western Plains, Mid-Western Plains, Southwestern Semiarid Plains, Central Plains, Bundelkhand, Northeastern Plains, Eastern Plains, and Vindhyan hills zone (Fig. 1). Agro-climatically, the southern plateau is most erratic and diversified as it lies between the Bundelkhand and Vindhyan agro-climatic zones.

There is no recent information on rice ecosystems based on the districts of Uttar Pradesh. Huke and Huke (1997) estimates of the area under different ecosystems in the state are shown in Table 4. The major lowland flood-prone area is located in the eastern part of Uttar Pradesh, covering 15 districts, which constitute about 30% of the total rice cultivated area in the state. The favorable irrigated area is more than 50%, while upland and very deepwater and flood-prone areas are restricted to only 10% and 4%, respectively. About 2% of the rice-growing area is salt-affected. Inland saline areas are mainly concentrated in Raibarelly, Azamgarh, Sultanpur, Faizabad, Lucknow, Unnao, and Pratapgarh districts. In the western and central parts of the state, the majority of rice is grown under favorable irrigated conditions. The lowest rainfall coupled with low area of rice is reported in Jhansi and Chitrakoot divisions, where water scarcity enables the cultivation of only short- and medium-duration varieties.

Table 3. Soil types of Uttar Pradesh and their area.

Soil type	Area (million ha)	Districts covered
Bhabar	0.5	Saharanpur, Bijnour
Terai	1.7	Pilibit, Bareilly, Rampur, Bahraich, Sarawasti, Balrampur, Siddhartnagar, Kushinagar, Maharajganj, Deoria
Alluvial	18.2	Central, eastern, western, and southwestern part of the state
Vindhyan	1.5	Mirzapur, Varanasi, Allahabad, Sonbhadra
Bundelkhand	3.2	Jhansi, Jalaun, Hamirpur, Banda, Lalitpur, Mahoba, Chitrakoot

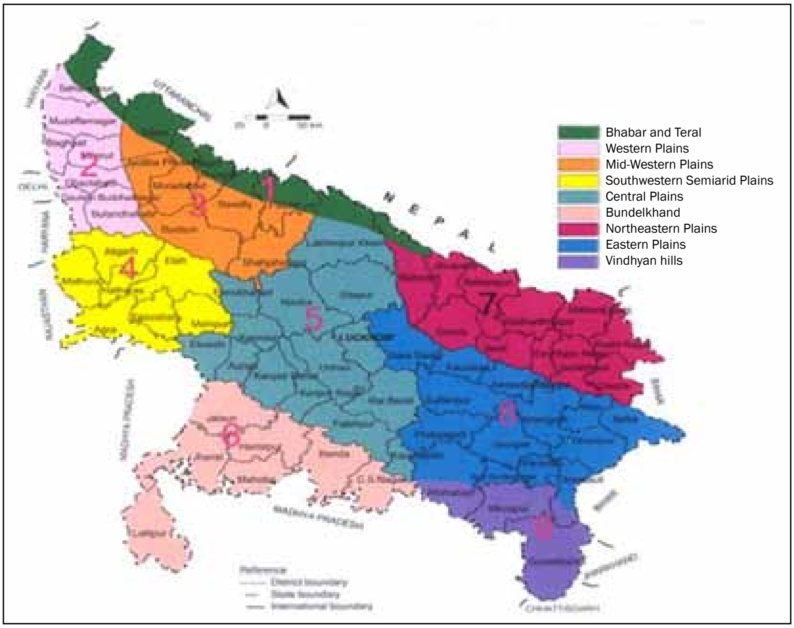


Fig. 1. The nine agro-climatic zones of Uttar Pradesh.

Table 4. Rice ecosystems in Uttar Pradesh.

Ecosystem	Area (million ha)
Upland	0.55
Irrigated	2.575
Deep water (>100 cm)	0.22
Rainfed shallow lowland	1.35
Intermediate	1.07
Total	5.76

Farming systems

Cropping systems have many dimensions and are determined by factors such as the physical environment, production technology, resource constraints, and socioeconomic conditions. Wheat and rice are the major cereal crops grown in Uttar Pradesh. The majority of the area is covered with the rice-wheat cropping system. Kharif pulses, rabi pulses, and oilseed crops are also important. However, their area is relatively small. The other major crops are sugarcane, maize, chickpea, and pigeon pea in the kharif and rabi seasons. Groundnut, smaller millets, sorghum, potato, and mustard are also cultivated in different districts of the state. The major cropping systems followed in different zones are presented in Table 5.

The state has three rice-growing seasons: the wet season (kharif), winter season (boro), and summer season (zaid). The growing period of rice in the different seasons is kharif—June-July to October-November; boro—October-November to April-May; and zaid—February to May-June. Kharif is the main rice-growing season in the state and more than 98% of the rice (around 5.9 million ha) is cultivated during this season, covering early, medium, and long-duration varieties. A limited rice area is grown in zaid (35,000–40,000 ha) and only 3,000–3,500 ha are cultivated in the boro season. During the kharif season, rice is cultivated in all the regions of the state, whereas boro rice is restricted to the eastern areas of the state, covering different districts (Gorakhpur, Basti, Deoria, Ballia, Ghazipur, Mirzapur, and Varanasi). Regarding the cultivation of zaid rice in the state, it is grown only in the Terai region covering Pilibhit, Bareilly, Rampur, Bahraich, Sarawasti, Balrampur, Siddharthnagar, Kushinagar, Maharajganj, and Deoria districts.

Relevant information about farmers

Uttar Pradesh is a land of small farmers, with marginal farmers accounting for around 80% of the operational holdings in 2002-03. About 80% of the area has irrigation facilities. Most irrigation comes from diesel-powered tube-well pumps and shallow bores using mobile pump sets. Canal irrigation and public and private electric tube wells are also available. Electric tube wells are preferred because of the lower cost of water, but the electricity supply is unreliable, which restricts their use. Diesel is expensive, and fertilizer use is associated with water availability: farmers having assured irrigation use higher rates than those with water constraints.

Table 5. Cropping systems by zones in Uttar Pradesh.

Zone	First year	Second year
Terai	Rice-wheat	Rice-sugarcane
Western plains	Rice-wheat/oilseed/pulse	Rice-sugarcane
Mid-western plains	Rice-wheat/oilseed/pulse	Rice-sugarcane
Southwestern plains	Rice-wheat/oilseed/pulse	Rice-sugarcane-pulse
Central plains	Rice-wheat/oilseed/pulse	
Bundelkhand	Rice-oilseed/pulse	
Northeastern plains	Rice-wheat/oilseed/pulse	Rice-sugarcane-pulse
Eastern plains	Rice-wheat/oilseed/pulse	
Vindhyan hiills	Rice-wheat/oilseed/pulse	

Important biotic and abiotic stresses

Diseases, insect pests, and weeds are the most common biotic stresses. The major diseases of rice in this region are sheath blight, sheath rot, rice tungro virus, bacterial leaf blight, leaf blast, neck blast, and brown spot. All of these diseases cause significant yield losses. The common insect pests of this region are brown planthoppers, stem borer, rice hispa, Gundhi bug, and armyworms. Weeds are a major and severe problem in rice production. The most important weed flora of the rice fields are grasses (*Echinochloa colona and E. crus-galli*) and sedges (*Cyperus* spp. and *Fimbristylis* spp.). Other weeds are also present but their frequency is relatively low. The major abiotic stresses are submergence, salinity, and drought. In the eastern part of Uttar Pradesh, these stresses are responsible for the low productivity of rice.

Farmers prefer to grow high-yielding, early-maturing varieties with good taste and ones that suit the timely sowing of wheat, as the rice-wheat cropping system is the most common in this region. In recent years, farmers have become more quality conscious and their preferences for fine grains and good eating quality have become more predominant than for the bold grain types with poor cooking quality.

The EIRLSBN and breeding activities at NDUAT

The challenges of increasing and sustaining productivity in the different rainfed rice environments required a new approach. First, strategic research is needed to overcome the severe biotic and abiotic constraints. Second, improvement in the conduct of research is needed to make it more relevant to the variable and heterogeneous rainfed environments. In the early 1990s, the International Rice Research Institute (IRRI) proposed the formation of a decentralized, multidisciplinary, and multi-institutional system-oriented research consortium, as a means to address the research needs of rainfed rice-based systems (Ingram 1995). Two consortia consisting of partnerships between IRRI and selected strong national agricultural research and extension systems (NARES) in Asia were founded: the Rainfed Lowland Rice Research Consortium (RLRRC) and the Upland Rice Research Consortium (URRC). Sharing of responsibilities and resources was the basic strength of these consortia. Among different centers, the Central Rice Research Institute (CRRI) and Narendra Deva University of Agriculture and Technology (NDUAT) were the two key sites of the RLRRC in India, each site having a different mandate but a common goal. A lot of useful information was generated, thus providing a better understanding of the mechanisms of tolerance of submergence and drought. In addition, a number of morpho-physiological indices were identified to be used for selection in breeding programs. By characterizing rainfed environments, submergence-prone, drought-prone, and drought- and submergence-prone areas were mapped and, accordingly, research and development strategies were planned.

Germplasm improvement was one of the important components of the RLRRC. The shuttle breeding approach was introduced in 1992, in which different phases of the program were carried out for different institutions. In this particular case, IRRI performed the prebreeding work and helped in generation advancement, while the collaborating centers did the selection and evaluation work. The shuttle breeding program was linked to the RLRRC as a vehicle for the decentralization of rainfed lowland rice breeding, in which *in situ* evaluation and selection of breeding materials (F_2 onward) are done at the designated key sites in submergence-prone and drought-prone areas. The scheme of the flow of the materials for eastern India is shown in Figure 2. As indicated, CRRI, Cuttack, and IRRI were responsible for parental characterization and for generating breeding material with diverse genetic backgrounds. The other centers in eastern India, including Assam Agricultural University (AAU), Assam; Rajendra Agricultural University (RAU), Bihar; Rice Research Station (Chinsurah), West Bengal; Indira Gandhi Agricultural University (IGAU), Madhya Pradesh; and NDUAT, Faizabad, participated in the selection and evaluation of breeding populations in the specific growing conditions. The main objectives of the program were to

- Make available a diversified set of donors/improved breeding lines, suitable for rainfed lowlands, to the cooperating centers.
- Provide segregating populations with a broad genetic background to all centers for effective selection under location-specific environments.
- Evaluate elite breeding lines, developed by the cooperating centers and IRRI, especially for submergence tolerance, photoperiod sensitivity, thermo-insensitivity, yield potential, and adaptability in eastern India.
- Carry out on-farm trials of promising cultures to study their adaptability and acceptability.

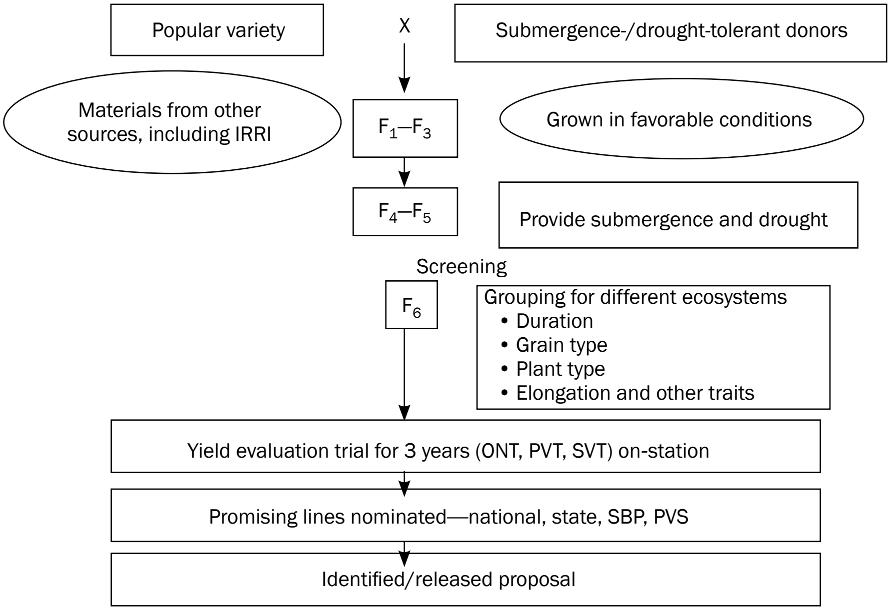


Fig. 2. Overview of the breeding methodology at NDUAT.

Keeping in view these objectives, the activities and the type of materials to be tested at any location were decided jointly by the collaborating centers in annual meetings. Although the same basic principle of genetic flow of materials, as shown in Figure 3, is followed by each center, some changes were made to suit local conditions. NDUAT followed a modified-pedigree method (single-plant selection) with farmers' participatory testing of advanced materials.

Overview of the breeding program at NDUAT

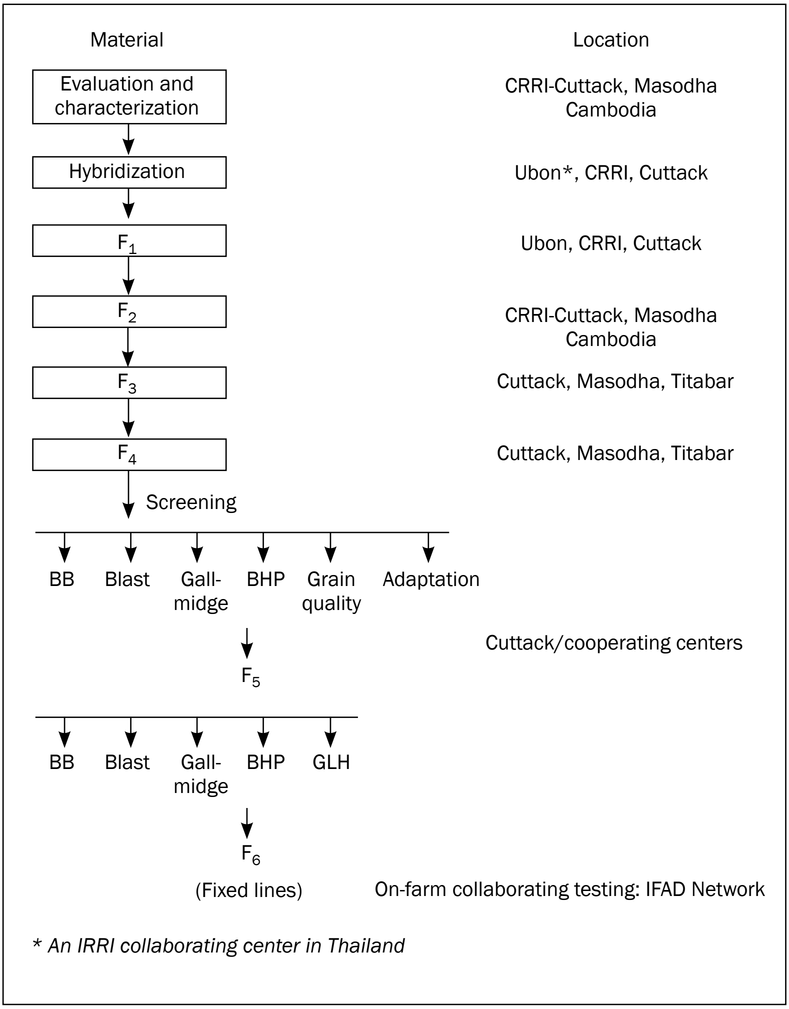
The pedigree and bulk-population breeding methods were used at NDUAT to produce new breeding lines. Generally, 8 to 10 crosses were made each year. Typical F_2 population sizes used consisted of 500 to 1,000 individual plants. Segregating populations were evaluated for plant height, effective bearing tillers, test weight, and yield. Visual selection was used to select for plant type and grain type. Cooking and eating quality were also considered for selection. Because of limited screening facilities, breeding material was screened for diseases and abiotic stresses under natural field conditions.

Once breeding lines were genetically fixed, they were given to different collaborating centers for evaluation and, simultaneously, on-farm testing was also accomplished. Screening for submergence and photoperiod sensitivity was done in the F_3 and F_5 generations, respectively. In contrast, CRRI-Cuttack used the pedigree breeding method for developing breeding material for direct seeding and transplanting in alternate generations. The idea here was to select materials suited for both direct seeding and transplanting.

Over time, the breeding method changed to become compatible with the All India Coordinated Rice Improvement Program testing (Fig. 3). The flow of breeding material originating from IRRI was important for the breeding scheme. NDUAT, Kumarganj, Faizabad, in collaboration with IRRI, became involved in the shuttle breeding network program in 1993, and subsequently in a farmer participatory breeding program in 1997, keeping in view the needs and priorities of farmers. A total of 9,757 entries have been tested across centers. The details of the different trials, number of entries, and designs are given in Table 6.

In contrast to the International Network for the Genetic Evaluation of Rice (INGER), which supplies mostly improved germplasm and advanced breeding lines for testing by NARES, in the shuttle breeding program, the genetic material is developed in the specific environments in which the varieties will be grown. The material includes donors, improved breeding lines, broad-based early generations (F_2, F_3, F_4), and anther culture–derived lines. Breeders and scientists from throughout the region were invited to participate in evaluating and selecting materials. Thus, this was an excellent opportunity to select materials suited to targeted environments.

The EIRLSBN is closely linked to the molecular genetics research at IRRI headquarters. The donors for photoperiod sensitivity, submergence tolerance, and blast resistance identified in this program were used for mapping and tagging useful genes using DNA markers, and to permit the use of marker-assisted selection (MAS) in breeding.



** An IRRI collaborating center in Thailand*

Fig. 3. Flow of genetic material in the shuttle breeding program. Adapted from Sarkarung (1995).

Table 6. Composition of breeding trials, with total number of entries included since the beginning of the shuttle breeding program.

Type of trial	Number of entries	Design used[a]	Number of replications
A. Multilocation trial[b]			
A-1. Observational yield trial	1,440	Augmented	Single
A-2. Advanced yield trial	270	RCBD	Three
B. Screening trial[c]			
B-1. Standard varietal trial	1,530	RCBD	Three
B-2. Preliminary varietal trial	3,025	RCBD	Two
B-3. Observational nursery trial	5,022	RCBD	Single

[a]RCBD = randomized complete block design. [b]Entries included from all coordinating centers. [c]NDUAT entries.

On-farm testing and farmers' participation

On-station conditions often do not match those in farmers' fields in rainfed lowland areas. Testing of breeding lines in farmers' fields was therefore necessary. In view of this, a close linkage was established with a project funded by the International Fund for Agricultural Development (IFAD), which had developed a network of technology testing (including varieties) in eastern India. Promising selections were tested in farmers' fields in this project. Later, a new program—farmers' participatory plant breeding (PPB)—was launched to test the efficacy of decentralization and farmers' participation in a formal breeding program. Four centers from eastern India (CRRI, NDUAT, IGAU, and CRURRS; also the RLRRC centers) were involved as collaborators. The EIRLSBN was also directly linked to the PPB program.

Varieties released and other outputs of these collaborative activities

The program has led to the development and release of a large number of materials suited for rainfed lowland conditions. The major varieties cultivated during kharif season are NDR-359, Narendra 97, Sarjoo-52, Kalanamak, Pusa basmati-1, BPT-5204, Swarna, and Narendra-118. Details on the varieties grown in different ecosystems are indicated in Table 7.

Table 8 summarizes the performance of the material selected for normal and late planting conditions. Importantly, these selections have a high degree of submergence tolerance (>80%) and yield advantage of more than 40% compared with the local checks. Varieties released during the past few years are presented in Table 9. These varieties are submergence tolerant and high yielding, but also have long and fine grains. Some of them have already covered large areas in eastern U.P.

Table 7. Popular varieties being grown in different rice ecosystems in Uttar Pradesh.

Rice ecosystem	Varieties
Upland	Baranideep, Jawahar Dhan 75, Nagina 22, Narendra Dhan 118, Narendra Dhan 80, Narendra Dhan 1, Renu, Sudha, Shushk Samrat, Narendra Lalmati, Narendra-97
Lowland and flood-prone	Swarna (MTU 7029), Sambha Mahsuri (BPT 5204), Jalpriya, Jalnidhi, Jal Lahri, Swarna Sub-1, Barh Avrodhi (intermittent flooding), NDR8002, Narendra Mayank, Narendra Jalpusp, and Naredra Narayani
Irrigated	Malviya Dhan 2, Narendra Dhan 2026, Saket 4, Ashwani, NDR 2064 , Malviya Dhan 36, Narendra Sankar Dhan 2, Narendra 3112-1, Sarjoo 52, NDR 359, Type-21 Hybrids: Narendra Sankar Dhan 2, PHB -71, KRH-2, Arize 6444, Arize 6201, PRH-10

Future needs and directions

It is essential to harness the available rice knowledge to enhance rice productivity, tolerance of the crop of abiotic and biotic stresses, and grain and nutritional quality to meet the future demand of rice domestic and international markets. Issues related to input-use efficiency, sustainable management of rice-based production systems, postharvest losses, and value addition will continue to be examined with the availability of newer research techniques, tools, and technologies. The growing human population requires reorientation of research efforts in rice-based agricultural production systems to ensure higher productivity with less land, less water, and less labor. These technologies need to be environment-friendly and more resilient to climate change, with objectives set to minimize the environmental footprint. Harnessing genetic diversity to widen the horizons of productivity and quality using multiple means for exploiting rice genetic diversity is essential for effective conservation and use to meet both present and future needs.

The increase in rice productivity during the last few decades has been possible mainly because of the emphasis on collection, characterization, and use of rice germplasm from various ecosystems and its use in breeding programs. However, thousands of yet undiscovered genes can potentially benefit rice productivity and quality, and help in coping with the increased demand for food in the face of deteriorating resources.

Table 8. Performance of the material selected for normal and late-planted conditions.

Promising selections	Pedigree	Weighted mean (t/ha)		Superiority over best check (%)		Submergence tolerance (%)[a]	Remarks[b]
		Normal	Late	Normal	Late		
IR67471-M-1-1-1-1	IR54977-UBN-6-1-3-3-3/IR41431-68-1-23	4.5	3.2	46.4	44.3	80.6	LS; nonlodging
IR6701-M-15-1-1-1-1	IR50499-17-2-2-1-1/IR43342-10-1-1-3-3/IR52533-52-2-1-2-1-B-2-3	4.4	3.1	44.7	39.3	83.8	LS; nonlodging
IR66363-M-10-1-1-1-1	KDML-105/IR 48083-SRN-37-1-1-1-3	4.2	3.0	36.5	42.1	89.6	LS; nonlodging
IR66876-13-M-10-2-1-1	IR40931-33-1-3-2/IR53519-26-4-2-1-3	4.1	3.2	35.5	45.5	87.2	LS; nonlodging
BR 9051-M-1-1-1-1		4.1	3.2	34.6	46.6	90.8	LS; nonlodging
Local checks							
Sabita	Selection from landrace	2.8	2.7			74.0	SB; lodging
Rajshree	Selection from landrace	2.8	2.2			56.0	MB; lodging
Jal-lahari	Pankaj/Mahsuri//TKM6	3.1	2.2			55.0	MB; lodging
Madhukar	Selection	1.8	1.8			78.0	SB; lodging

[a] Survival percentage of 21-day-old seedlings under 15 days of submergence. [b] LS = long slender grains; SB = small bold grains; MB = medium bold grains.

Table 9. Rice varieties released during recent years in Uttar Pradesh.

Variety	Pedigree/designation	Year of release	Duration (days)	Yield (t/ha)	Remarks
NDR-8002	IR67794-M-2	2005	145–150	5.5–6.0	Long fine, moderately submergence tolerant
Narendra Mayank (NDR9830144)	IR68828-24-NDR-1-1-1-1	2008	140–145	5.0–5.5	Long fine, submergence tolerant
Narendra Jal Pushp (NDR 9830135)	IR68850-71-NDR-1-1-1-1	2008	140–145	5.5–6.0	Long bold, good submergence tolerance
Narendra Narayani (NDR9830132)	IR68815-1-NDR-1-1-1-1	2008	140–145	5.0–5.5	Medium fine, moderate submergence tolerance
Improved Swarna (Swarna Sub1)	Swarna*3/IR49830-7-1-2-3	2009	150–155	5.5–6.0	Medium fine, small, highly submergence tolerant

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Defining IRRI's role in the EIRLSBN: current status and future directions

B.C.Y. Collard, Y. Kato, E.M. Septiningsih, A.M. Ismail, and D.J. Mackill

IRRI's effort to develop submergence-tolerant rice dates back to the 1970s, when breeders began making crosses between modern semidwarfs and traditional donors of tolerance such as FR13A (Mackill et al 1993, Ismail and Mackill 2013). In 2006, IRRI established a breeding program to specifically develop new breeding lines/varieties with submergence tolerance that would be suitable for flood-prone areas. This breeding program was one of three trait-based, abiotic stress tolerance breeding programs forming the core of the realigned program on rainfed environments at IRRI; the other two were for drought and salinity/other soil problems. At the time, only a small number of varieties with tolerance of these particular stresses were available, and relatively little was known about the genetic control and physiological basis of these complex traits.

The main efforts for submergence tolerance breeding involved introgressing the submergence tolerance gene *SUB1* into popular mega-varieties using marker-assisted backcrossing (MABC). A large-scale MABC program began in 2003 and, to date, eight varieties have been "upgraded" with *SUB1* (Neeraja et al 2007, Iftekharuddaula et al 2011, Septiningsih et al 2009, 2013). These new Sub1 varieties retained the essential features of the original varieties (i.e., yield, quality, and agronomic characters) and are being rapidly adopted (Mackill et al 2012, Ismail et al 2013). These varieties included Swarna-Sub1, Savitri-Sub1 (CR1009-Sub1), and Samba Mahsuri-Sub1, which are the most popular varieties in India; and BR11-Sub1 and Ciherang-Sub1, the most popular in Bangladesh and Indonesia, respectively. In 2012, some of these varieties replaced the original varieties as checks in observational yield trials (OYTs) of the EIRLSBN.

Another main objective was to develop new breeding lines with *SUB1* and tolerance of stagnant flooding using forward breeding approaches (Collard et al 2013). Breeding material was also screened for disease and insect resistances, yield, and quality. Target areas for the breeding program included South Asia (eastern India, Bangladesh, Nepal) and Southeast Asia (Indonesia, the Philippines, Laos).

The current breeding pipeline

Over the years, a modified bulk-pedigree breeding method was established to develop new breeding material (Collard et al 2013; Fig. 1). About 50 new crosses are generated each season. Submergence screening is routinely done in field ponds in the F_2 and F_3 generations using a selected bulk method; in both generations, only survivors are transplanted to normal field conditions. Repeated submergence screening in the F_3 generation ensures that plants are tested for submergence tolerance during both

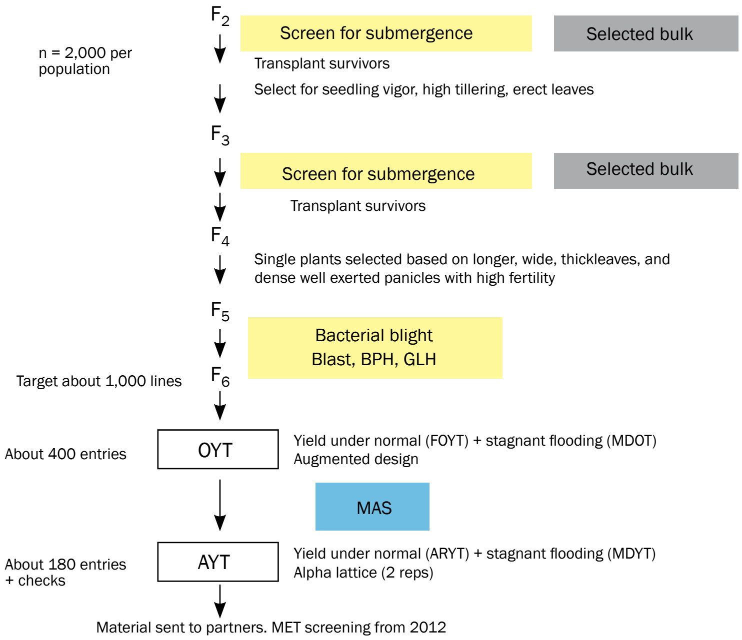

Fig. 1. The IRRI submergence breeding scheme. Advanced breeding lines are tested in IRRI multienvironment trials (MET) and by NARES partners, including the EIRLSBN.

the wet and dry seasons and that there are few escapes, and the frequency of *SUB1* is increased. Visual selection is casually performed at the F_2 and F_3 stages for plant type and yield components. Careful single-plant selection based on plant type is performed during the F_4 and F_5 stages, combined with line selection for specific traits (i.e., pedigree selection steps). Disease and insect resistances are evaluated at the F_5 and F_6 stages, including bacterial blight, blast, brown planthopper (BPH), and green leafhopper (GLH). Preliminary selection for yield is also performed in the F_6 generation. At the F_7 stage, approximately 400 lines are tested under normal and stagnant flooding conditions, in an unreplicated (augmented) design with at least four checks, called the observational yield trial (OYT). At the next stage, material is tested in an advanced yield trial (AYT) with approximately 80 entries (including checks) using an alpha lattice design with two replications. Like the OYT, AYT field trials are conducted in normal and stagnant flooding conditions in order to develop lines that perform well under both conditions (Fig. 2). Generally, OYT and AYT breeding lines are screened again to confirm submergence tolerance (Fig. 3). A late-generation marker-assisted selection (MAS) step is performed at the OYT and AYT stages so that the *SUB1* genotypes of the advanced breeding lines are known (Collard et al 2013). This scheme has been designed to suit the available land area, budget, and personnel within the program. A major constraint is the limited field area available for submergence and

Fig. 2. Photo of part of an observational yield trial in stagnant flooding conditions. Water depth is 50 cm (field pond G16, IRRI, 2012 wet season). Yield under stagnant flooding stress is the main selection criterion. Other field ponds are seen in the background.

Fig. 3. Routine screening of OYT and AYT fixed lines from the submergence program, and other IRRI breeding material from other breeding programs (Field pond G20, 2012 dry season). Approximately 7 g of seed is sown in wet beds (using 2 × 30-cm short rows). Lines are completely submerged for 16 to 18 days based on checks. Note the clear discrimination of tolerant and susceptible lines.

stagnant flooding screening, and some fields are irregularly shaped. Because of field screening limitations (i.e., only a small field pond area is available) for evaluating tolerance of stagnant flooding, this trait is not screened for earlier.

The most promising entries from the AYT are sent to the EIRLSBN and other collaborators or NARES partners in several different countries. Usually, 10 entries from the AYT are sent to CRRI for seed multiplication and inclusion in the EIRLSBN OYT in the subsequent year. These entries have tolerance of submergence and stagnant flooding, and high yield potential. A slightly larger set of entries (total of 20–30, including the set of 10 entries sent to CRRI) is sent to Bangladesh and Nepal. The overall scheme is shown in Figure 4. Efforts are made to ensure that the selected elite breeding lines have suitable growth duration, agronomic characteristics, and quality attributes for the target region. Hence, the IRRI submergence program consists of breeding material suitable for different regions.

In the early years of the EIRLSBN, IRRI provided early-generation, segregating breeding populations. This exploited the high "crossing power" at IRRI, which has a favorable environment for successful hybridization, technical expertise, and adequate facilities. More recently, IRRI has provided fixed lines rather than segregating material so that germplasm exchange is not restricted, and fixed lines can be sent to other countries. Because of government policy, even breeding lines arising from IRRI populations that are fixed in India are not allowed to be exchanged. IRRI-developed fixed lines are then exchanged with national agricultural research and extension system partners primarily in Asia but also in Africa.

During the STRASA (Stress-Tolerant Rice for Africa and South Asia) project, the focus has been on developing varieties and elite breeding lines for South Asia, so there has been a concerted effort to develop lines with suitable growth duration (i.e., late maturity, 140–150 days, like Swarna) and quality characteristics (e.g., intermedi-

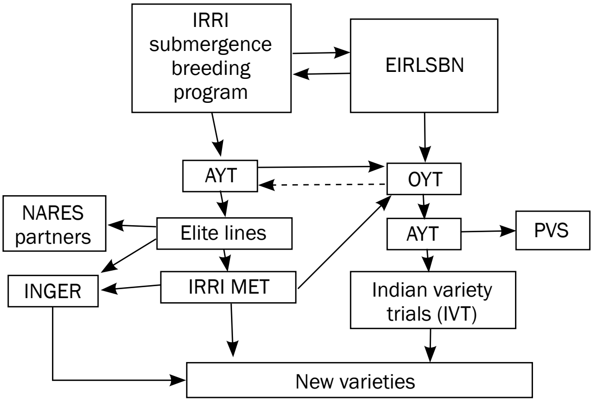

Fig. 4. Flow of breeding material from IRRI and EIRLSBN.

ate/high amylose). This presented many challenges, especially selecting material with long growth duration because this is too long for conditions in the Philippines (i.e., varieties typically have growth durations of 110–120 days), and, due to management practices implemented at IRRI, there is a closed-season period after each season as a disease break measure. Photoperiod-sensitive varieties are often preferred in South Asia for the kharif season but breeding for this trait has been extremely difficult at IRRI. Furthermore, Los Baños is an atypical location for rainfed lowland breeding (e.g., soil type, thermal period, and photoperiod) and there are region-specific constraints such as the prevalence of tungro virus and unique soil structure and radiation patterns in Los Baños that are not representative of the target environments.

Despite these challenges, many IRRI varieties or breeding lines have been very useful as donor parents in South Asia (Reddy et al 2013). Many NARES partners lacked or had a limited capacity to screen for flood tolerance (submergence or stagnant flooding) or for screening for tolerance of other abiotic stresses, so the exchange of germplasm that was prescreened for target traits (i.e., as donor parents) has been an important contribution by IRRI.

Defining IRRI's role in the EIRLSBN

First and foremost, IRRI provides important germplasm. IRRI breeding material represents a genetically distinct gene pool for eastern India that has been prescreened for specific target traits such as tolerance of submergence and stagnant flooding, and resistance to bacterial blight and blast. Therefore, this material should be useful for improving key traits and for obtaining transgressive segregation for yield. Breeding material in the current submergence program exploits elite lines from irrigated and other rainfed breeding programs (drought and salinity) for developing new populations, in addition to selected accessions from the broad range of genetic diversity available at IRRI, including INGER nurseries and the International Rice Germplasm Collection. Moreover, elite IRRI material has been fixed for key loci such as *SUB1* and enriched for major genes. It is critical that IRRI continue to provide germplasm to eastern India since, at present, resources for breeding programs to screen for critical traits are limited.

A second role IRRI should play is in the optimization and standardization of phenotyping protocols, and evaluation and dissemination of new methods and technologies for possible adoption by partners within the EIRLSBN. New methods include improved phenotyping for target traits and "breeding informatics" involving experimental design (such as partially replicated trials) and data analysis, such as spatial analysis (Ye et al 2013). Partial replication and spatial analysis are routinely used in many cereal breeding programs in other countries. IRRI is currently implementing and evaluating new technologies for improving efficiency in field-note taking (i.e., electronic field books), data collection (e.g., bar-coding), and data management. Once these are fully established, there could be many "trickle-down" advantages for the network by information sharing and training in adopting these technologies. Effective database management systems are critical for every breeding program, and the adoption of an open-source system would be extremely useful for the network. Since most centers in the network have limited funds, software tool options for data analysis are often limited and restricted to open-source programs (e.g., CropStat). Therefore, new open-source "breeder-friendly" tools for data analysis would also be very useful.

Finally, IRRI plays an important role in coordinating and generating funding support for the network. In the current system, the STRASA reporting for the project is jointly completed by IRRI and the Central Rice Research Institute (CRRI). The main breeding research activities are led by CRRI. IRRI plays a key role as an independent and objective collaborator for discussion of breeding methodologies, capacity building (especially through training), and sharing of information.

Like all good and effective networks, benefits are mutual. The benefits for IRRI are the inclusion and evaluation of elite lines developed at IRRI in the OYT of the EIRLSBN, and the vibrant discussions, feedback, and information sharing that take place at the annual selection, and planning and review meetings. Furthermore, IRRI's knowledge of eastern India and breeding and research networks in South Asia is enhanced.

Future directions

In the future, it is important that the current activities continue and be enhanced or strengthened. In particular, germplasm development should be more customized based on traits and agronomic requirements (especially growth duration or photoperiod sensitivity). Stagnant flooding tolerance and anaerobic germination ability will be high priorities for new breeding efforts. Because eastern India is such an environmentally diverse region, there is also a need to focus on combining multiple stress tolerances (i.e., abiotic and biotic) into new varieties (Reddy et al 2013). Further streamlining of IRRI and EIRLSBN breeding programs should be considered for improving efficiency.

IRRI should also continue to be a leader for basic and applied research, and progressively involve institutions within the network with the capacity to undertake some of these basic research activities; which could further strengthen their capacity and help generate more funds. Trait phenotyping is always an important area of research for breeders, and needs to be continuously improved for routine and new traits. Enhancing submergence tolerance beyond 14 days (conferred by *SUB1*) is important in specific flood-prone areas where submergence extends beyond 2 weeks or occurs more than once during the season. Characterizing new donors and identifying new genes or QTLs would be important for this objective and such efforts have begun recently (Septiningsih et al 2013). Much progress has been made to combine tolerances of submergence and stagnant flooding together using conventional methods as, in most flood-prone areas, water stagnates in the field for longer duration following complete submergence (Singh et al 2011). Currently, information is limited on the physiology and molecular genetics of many traits such as stagnant flooding tolerance (Collard et al 2013). Since this stress is widespread in the region and may further intensify due to climate change, it is important that this trait receive adequate attention.

For the EIRLSBN, two research areas need urgent attention: greater environmental characterization of rice production areas and an understanding of the correlation between sites within different states of eastern India. Environmental characterization would permit a more accurate analysis of trial data and the development of more precise breeding objectives and strategies (Tuong et al 2000). Ideally, data on climate, incidence of flooding, depth of floodwater, and disease notes should be routinely recorded and stored in a database. The importance of recording disease notes and observations on the reactions of test entries is very high for rice varietal development in the region, and ideally should be closely linked to state-wise, national, and IRRI research on plant health. More information regarding floodwater characteristics could be collected by using simple equipment, and water depth during the crop season could be monitored by the installation of rulers in field trials. This environmental information could be useful for fine-tuning of the breeding program and variety deployment.

Since a common set of germplasm is typically exchanged and tested, a genotype × environment (G × E) analysis would provide important information about the correlation between trial locations. This information could be exploited by breeders to judiciously select and justify trial locations and use specific parental donors for making new breeding populations. It is conceivable that IRRI could facilitate a more sophisticated G × E analysis by expanding data analysis to include extra regions (i.e., northeast India) and neighboring countries such as Bangladesh and Nepal, by performing data analysis for the entire region. At the time of writing, the inclusion of Meghalaya State in the EIRLSBN is being planned so that northeast India will be well represented. It is anticipated that mutual benefits for breeding in the region will be gained by the expansion of the network, especially regarding increased germplasm exchange and evaluation, and increasing the critical mass of rice breeders and scientists within the network.

The EIRLSBN also has great potential to be involved in current research activities in rice genomics and its application for germplasm improvement. The network could be used for phenotyping recombinant inbred populations for QTL mapping, association genetic studies, or the evaluation of specialized genetic stocks such as multiparent advanced generation intercross (MAGIC) populations (e.g., derived from 8-way crosses). MAGIC populations derived from indica, japonica, and intercrossed populations have been developed at IRRI and will be shared with partners throughout Asia and Africa. In the future, as the use of MAS becomes more routine, research regarding the characterization of which major genes and QTLs are present and have been selected in elite lines that are adapted to these environments would be extremely useful, and some of the network partners already developed the capacity to undertake these types of analyses. As their capacity develops further, the network partners could take the responsibility of introgressing agronomically important loci and genes that are becoming available at IRRI and elsewhere into their preferred varieties and elite lines and also take part in generating new genetic stocks and identifying new traits and genes.

Finally, capacity building and training of the next generation of plant breeders should not be overlooked. This has become evident by the recent retirement of several key breeders. Ideally, replacement breeders should be designated as "long-term" breeders and should not be shuffled to other roles as it takes several years to understand the requirements for developing rainfed lowland varieties. New breeders require sufficient time to become familiar with breeding objectives, germplasm, methods for trait selection, and the target environment. Fortunately the EIRLSBN has been defined by strong collaborative linkages since its formation, and this structure will undoubtedly provide a solid foundation for training new, younger breeders (Fig. 5). Given the enormous challenges ahead for breeding new varieties in the region, this network will be critical for sustaining increases in rice production in eastern India, with spillover benefits to other countries with similar ecosystems in other parts of Asia and Africa.

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Fig. 5. Master and apprentice rice breeders. (A) Retired Professor S.R. Das (Odisha University of Technology), a key member of the EIRLSBN, instructs Mr. Jerome Carandang (IRRI, Philippines) on the finer points of plant selection (annual meeting, November 2011, CRRI). (B) Dr. S.K. Chetia (right) from Assam Agricultural University provides a wealth of advice to Mr. Batseng Watre Momin, agricultural development officer, Meghalaya, during participation in his first annual shuttle breeding meeting (November 2012, CRRI).

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All in a day's work. The shuttle breeders happily wash their muddy feet at the end of a long day in the field making selections (CRRI, Cuttack, November 2011).