Shuttle-breeding: An effective tool for rice varietal improvement in rainfed lowland ecosystem in eastern India

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Rice varietal development programme for rainfed lowland, which occupies 17.2 m ha in India, has lately received attention, compared to irrigated ecosystem. Efforts were intensified only during early nineties through launching different projects, in addition to national and state programmes, to enhance the productivity of this ecosystem. Shuttle breeding programme, a collaborative project between the Indian Council of Agricultural Research and the International Rice Research Institute, Philippines provided an opportunity for flow of breeding materials of diverse origin among the eastern Indian states to strengthen the breeding programme. The materials developed through this project also served as input to the other breeding programmes for this ecosystem. Many promising selections are in advanced stage (F_6/F_7).

RAINFED lowland rice accounting for nearly 40% of the rice area in India[1], received delayed attention from the rice research community compared to irrigated ecosystem, which was given priority by the researchers since early sixties. The first coordinated trial for rainfed lowland was constituted in 1976 with some pure line selections from Uttar Pradesh (UP), Bihar and West Bengal (WB). However, in the annual rice workshop of All India Coordinated Rice Improvement Project (AICRIP), Hyderabad, renamed as Directorate of Rice Research (DRR) under the Indian Council of Agricultural Research (ICAR), in April 1979 it was conceived to undertake systematic, multilocational coordinated programme for lowland situations, after fourteen years of dominance on the semi-dwarf breeding programme for irrigated ecosystem. Initially, for the first seven years, Rice Research Station (RRS), Chinsurah was entrusted with the responsibilities of coordinating and monitoring the rainfed lowland rice trials. Subsequently, in 1986 DRR took over when the programme received a good momentum[2].

The DRR programme has aided actively in the development and release of 632 rice varieties in the country so far[3,4], among which 257 (40.7%) are for rainfed ecosystem and the remaining 375 (59.3%) for irrigated ecosystem (Table 1). The number of released varieties for rainfed lowland ecosystem is only 167 (26.4%) among which 123 (19.5%) are for shallow, 30 (5%) for semi-deep and only 14 (2.2%) for deep-water ecosystems. The shallow water represents a situation where standing water generally rises up to 40 cm; for semi-deep it rises up to 41–75 cm and for deep-water more than 75 cm (according to DRR classification).

The reasons for the slow progress in varietal development for rainfed lowland ecosystem are intrinsic and complicated as given below[5]:

- Harsh, heterogeneous and unpredictable environment.
- Wide variability in intra- and inter-location; large G/E interaction.
- Less number of researchers involved compared to irrigated ecosystem.
- Rainfed lowland programme receives low priority.

Table 1. Varieties released in India for different ecosystems up to 2000

Ecosystem	No. of varieties	Percentage	National checks
Rainfed			
Upland	84	13	Heera, Aditya, Annada
Shallow	123	19.5	Savithri, Pooja, Salivahana
Semi-deep	30	5	Sabita, Purnendu
Deep	14	2.2	Jalmagna, Dinesh
Hill	6	1	VLDhan221, CH988
Total	257	40.7	
Irrigated			
Early	123	19.5	Heera, Aditya, Annada
Medium-E	17	3	Sasyasree, IR64
Medium	173	27	Jaya, Narendra359, Triguna
Saline–alkaline	15	2.4	CST7-1, CSR13, CSR27
Scented	20	3.1	P. Basmati1, T. Basmati
Hill	27	4.3	K-39, VL81, RP2421
Total	375	59.3	
Grand total	632	100	

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- Lack of proper testing facility – both field and artificial in many of the research stations.
- Lack of proper testing methodologies.
- Inadequate donors for desirable traits, required for this ecosystem.
- Inadequate generation of new material with wide genetic base.
- Advancing the generations (F_2 onwards) did not follow *in situ* testing in many of the locations.
- Lack of proper supporting environmental data like water depth, duration and depth of submergence while presenting trial results by researchers–inadequate environmental characterization.
- Crop generally grown once a year, as most of them are long-duration/photoperiod sensitive.
- Less involvement of NGOs, specially in varietal improvement unlike hybrid rice development programme.

This article summarizes the efforts of varietal improvement programme for the ecosystem and the contribution of shuttle breeding programme, especially at RRS, Chinsurah to this endeavour.

Programmes for enhancing the productivity of rainfed lowland rice in eastern India

Besides the state and national programmes, the following projects are in operation with different objectives for increasing the productivity of rainfed lowland rice.

Rainfed lowland consortium

This is a collaborative project between the International Rice Research Institute (IRRI) and National Agricultural Research Programme (ICAR) started in 1991. The objectives were to expand and strengthen the research base for rainfed rice ecosystems. The emphasis was on strategic and applied research to generate new technologies that will have both local and regional applications.

Initially, Masodha under NDUAT, Faizabad, and Polba-Chinsurah under the Department of Agriculture, Government of WB were the two key sites in India among eight locations in five countries[6]. Later on, Central Rice Research Institute (CRRI), Cuttack was also included as another site under the consortium. The main research focus for Masodha, Polba-Chinsurah and CRRI was flash flood, stagnant flooding and mechanization respectively. Information regarding characterization of the environment, mechanism of submergence tolerance and germplasm improvement have been generated for the ecosystem (below 50 cm water depth) through this project[7].

The other locations outside India are Rajshahi in Bangladesh, Jakenan in Indonesia, Batac and Tarlac in the Philippines and Ubon in Thailand. The main research focus varied widely depending on location-specific problems: Drought in transplanted rice and cold tolerance at reproductive stage for Rajshahi; soil problems, drought and K-deficiency in transplanted rice for Jakenan; weed problems and sustainability in direct seeded rice for Batac; drought at vegetative and reproductive stage and weeds in both direct seeded and transplanted rice for Tarlac, and drought at vegetative stage, blast and problems related to poor soil for Ubon.

AP Cess Fund Research Scheme

The ICAR has sanctioned a scheme entitled, 'Enhancement of genetic yield potential of rainfed lowland rice with emphasis on semi-deep water ecology' starting from 1997. CRRI is the coordinating centre with six others, one each in Assam (North Lakhimpur, AAU), Bihar (Pusa, RAU), Orissa (Bhubaneswar, OUAT), Eastern UP (Masodha, NDUAT), Chhattisgarh (Ambikapur) and WB (RRS, Chinsurah). The main objectives of the project are as follows[8]:

- Characterization of target environment.
- Collection and evaluation of germplasm for use in breeding programme.
- To study genetic, morphological and physiological basis of submergence tolerance and low light condition.
- Multilocational evaluation of promising lines in the respective location under the target environment.
- Reorientation of breeding objectives to develop plant type adapted to location-specific condition.

On-farm evaluation of deep-water (up to 100 cm water depth) rice varieties and production technologies in rainfed ecosystem of eastern India

Recently, starting in kharif 2001, under the National Agricultural Technology Project (NATP), ICAR has sanctioned the project with five centres in five eastern Indian states, viz. CRRI, Cuttack (Orissa); RRS, Chinsurah (WB); Titabar, AAU (Assam); Pusa, RAU (Bihar); and Ghagraghat, NDUAT (UP). The main objectives are as follows[9]:

- To test promising rice varieties under multilocation with farmers' participation.
- To analyse farmers' perception on adaptability and acceptability of rice varieties.
- To expedite inter-state flow of promising rice varieties.
- To verify and refine location-specific technology packages for improvement of rice yield.
- To exploit production potential employing improved technology for realizing maximum yield.

The efforts for increasing yield potential of rainfed lowland ecosystem were intensified during the nineties through the above projects.

Eastern India rainfed shuttle breeding programme at RRS, Chinsurah

A significant change in the breeding approach in the early nineties is the operation of the shuttle-breeding programme. For improving the genetic yield potential of the rainfed lowland rice varieties of eastern India, an ICAR–IRRI Collaborative Shuttle-Breeding Programme was initiated in 1992, mainly for the shallow water (up to 50 cm water depth) situation. Different cooperating centres are Titabar, North Lakhimpur and Gerua in Assam; Pusa and Patna in Bihar; Motto and Bhabanipatna in Orissa; Raipur in Chhattisgarh; Masodha in UP; Chinsurah in WB, with CRRI, Cuttack being the coordinating centre. The main objectives of the project are as follows[10]:

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

RRS, Chinsurah is one of the founder cooperators to this project. Initially, there were only five centres. The number of locations increased as the programme became more popular. Gerua in Assam has been included as one of the cooperating centres during kharif 2001. Figure 1 depicts the linkage between station and shuttle-breeding programme at RRS, Chinsurah.

The parents are selected either through artificial or field screening. Natural calamities like drought in 1979 and unprecedented floods in 1978 and 2000 in WB also helped to identify donors. The F_1s are grown in shallow water. RRS, Chinsurah shares its own F_1s with IRRI and other collaborators of the shuttle-breeding programme[11]. From F_2 onwards, the materials are grown in field condition. Dry seeds are sown in field during end April to early May prior to pre-monsoon rain. Drought is common for about a month or so as the monsoon generally sets in during mid-June. Water starts accumulating in the field from mid-July and increases gradually, depending upon rainfall and surface run-off from neighbouring fields and remains standing till harvest. As a result, the breeding materials during generation advancing have been exposed to several abiotic stresses such as drought at early vegetative stage, flooding of varying depth and duration at different growth stages, and biotic stresses like aquatic weeds, insects and diseases. Preliminary yield trials are conducted using F_6 under transplanted condition before the replicated yield trial in F_7.

The segregating population, mainly F_2s, received from IRRI is also assessed and advanced following the procedure mentioned above. RRS, Chinsurah shares its own F_1s and F_2s with IRRI and other collaborators to facilitate exchange of breeding materials. It is important to mention that locally adapted, traditional and long-duration cultivars were used in the IRRI breeding programme. For example, Sabita, a predominant variety for rainfed lowland ecosystem in WB has been used in more than fifty crosses by IRRI[12]. Exchange of breeding materials (F_3/F_4) among breeders also takes place in breeders' workshop at different sites, which facilitates breeders to select breeding materials that are suited to their condition (Figure 2).

The promising advanced breeding lines, identified after replicated yield trials are nominated to national trial (DRR), AP Cess Fund Scheme trial and shuttle-breeding trial, considering the suitability and merit of the material.

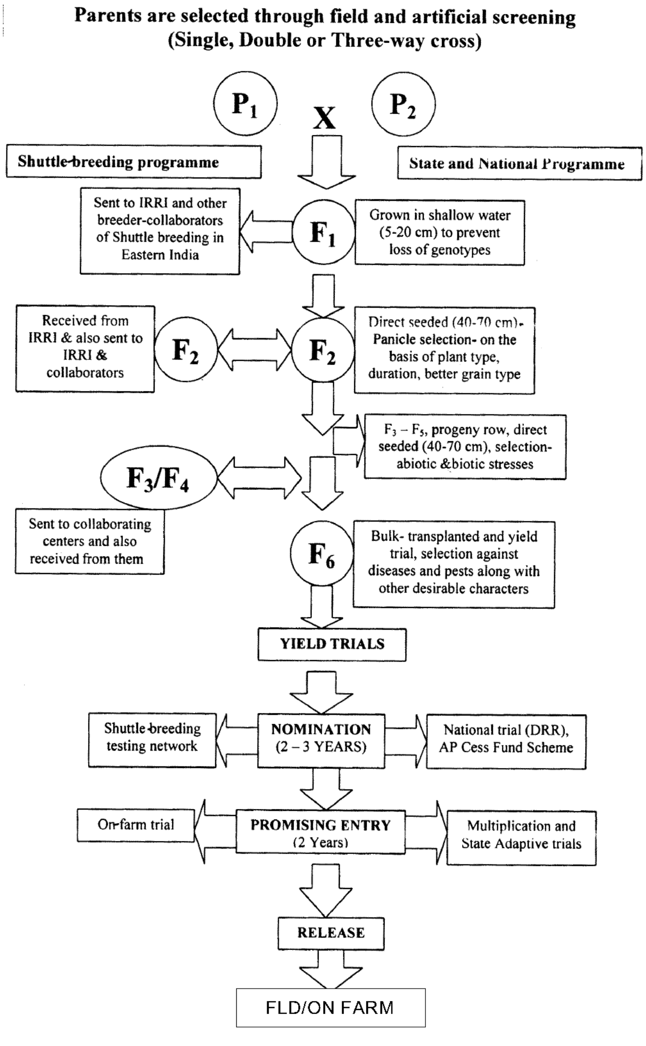

Figure 1. Linkage between station and shuttle-breeding programme at Rice Research Station, Chinsurah.

From RRS, Chinsurah thirty-five materials, developed through shuttle breeding programme have been nominated to the national programme during 1995 to 2001. They were received as F_2 from IRRI and selections were made at Chinsurah. In most of the crosses, one of the parents is a variety/line developed from RRS, Chinsurah.

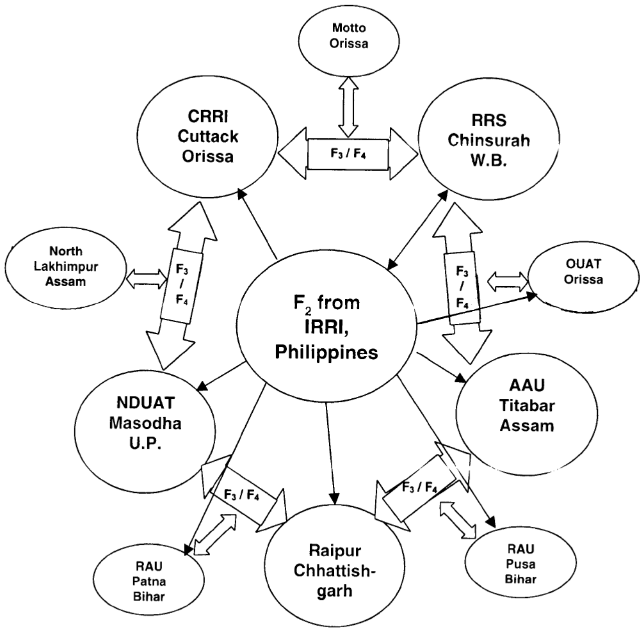

Figure 2. Flow of breeding materials to different sites of eastern India through shuttle-breeding programme.

CN 1035-61, a selection from IR 57540 has been recommended by the All India Rice Workshop, DRR in 1999 for large-scale testing and release in WB considering its performance in the national programme. The performance of CN 1035-61 during 1995–2000 in the national trial, shuttle-breeding trial and state multilocational, adaptive trial is presented in Tables 2–5 (refs 13–15). Pankaj, a well-adapted variety in rainfed shallow lowland, is one of the parents of CN 1035-61. In national trial under semi-deep water condition, the average yield of CN 1035-61 was more than 3 t ha^{1} (Table 2), while in shallow-water situation the average yield was 4.4 t ha^{1} (Table 3). The cultivar yielded 3.5 t ha^{1} in normal planting (within July), but the yield declined by more than a tonne when planted late (after mid-August) under shuttle-breeding programme (Table 4). In state multilocational adaptive trial, CN 1035-61 was tested along with six recently released varieties during kharif 2000. It ranked first, with 3.2 t ha^{1} yield (Table 5).

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 the farmers as to the performance and acceptance. Front Line Demonstration (FLD) in 20 acres compact block in farmers' field, a DRR/ICAR programme, is a useful tool for this purpose. Seeds and some of the essential inputs like fertilizers and pesticides are supplied to the farmers through this programme. It serves as a venue for visual assessment by the farmers to select location-specific varieties as well as a

Table 2. Performance of CN 1035-61 in national trial (semi-deep water) during 1995–98

	Trial/location	Yield (t ha^{1})				
Year	IVT–SDW	CN1035-61	Check 1 (U. Prabha)	Check 2 (Sabita)	CD (0.05)	Water depth (cm)
1995	Ghagraghat, UP	1.03	0.23	0.17	0.22	45
	Chinsurah, WB	2.08	0.67	2.50	0.29	77
	Ranital, Orissa	2.72	2.08	2.88	0.74	NA
	Faizabad, UP	1.60	1.41	1.08	0.36	40
1996	Bhubaneswar, Orissa	3.75(3)	1.67	1.81	0.63	40
	Pusa, Bihar	4.54(1)	3.00	2.09	1.22	40
	Canning, WB	2.60	Nil	Nil	0.92	NA
	Chinsurah, WB	1.85(4)	0.79	2.08	0.47	45
	Cuttack, Orissa	5.90	6.38	6.38	1.55	NA
	Mean (IVT)	2.90	1.80	2.11		
1997	AVT–SDW		Local	Sabita		
	Sabour, Bihar	5.92(1)	Nil	Nil	0.82	NA
	Masodha, UP	4.59(2)	1.41	3.04	0.43	40
	Karimganj, Assam	3.89(4)	3.46	2.99	0.34	21
	Gosaba, WB	2.67	2.55	2.50	NS	48
	Chinsurah, WB	2.67(2)	2.31	2.85	0.35	68
1998			U. Prabha	Sabita		
	Chinsurah, WB	3.02(2)	2.05	2.89	0.46	59
	Canning, WB	2.89(4)	2.02	2.08	0.52	NA
	Gosaba, WB	1.79(5)	1.30	1.40	1.09	75
	Mean (AVT)	3.43	1.79	2.22		
	Grand mean	3.16	1.80	2.16		

IVT–SDW, Initial variety trial–semi-deep water; AVT–SDW, Advanced variety trial–semi-deep water; NA, Not available. Figures in the parentheses indicate ranking in respective location.

source of lateral dissemination of seeds. CN 1035-61 has been included in the FLD programme during kharif 2001 in WB and has yielded 3.6 t/ha. CN1035-61 (Bhudeb) is now in pre-release stage.

Similarly, through shuttle-breeding programme several rice varieties have either been released or are in pre-release stage in different states. Kishori and Satyam have recently been released in Bihar. OR 1206-25-1 in OUAT, Orissa; NDR 96005 (IR 66363-10-NDR-1-1-1-1), NDR 8002 (IR 67493-M-2) and NDR 96006 (IR 67440-15-NDR-1-1-1-1) in UP; Prafulla (TTB 238-3-38-3) in Assam; R 650-1817 and IR 42342 in Chhattisgarh, and IR 54112-B-1-1-6-2-2-CR-1and IR 49745-CPA-42-B-1-5-1, developed at CRRI in Orissa are in pre-release stage.

Complementary effect of shuttle-breeding

One hundred and fifty three breeding lines of different generations (F_3 to F_9) were evaluated in six locations in five states, viz. Bhubaneswar, OUAT and CRRI, Cuttack in Orissa; Pusa in Bihar, North Lakhimpur in Assam, Masodha in UP and Chinsurah in WB, through AP Cess Fund Scheme and 2995 materials were selected during the wet season (kharif) 2000. Out of one hundred and fifty three breeding materials, 142 nominations were from RRS, Chinsurah[16]. The number of selections made by the individual location was 1180 at OUAT, 273 at CRRI, 452 at Pusa, 692 at North Lakhimpur, 268 at Masodha and 130 at Chinsurah. The maximum water depth was 160 cm at Chinsurah, 85 cm at North Lakhimpur, and for rest of the locations it was below 50 cm. Mention may be made of IR 67431-CN 7-1 (Biraj/IR 53479-B-45-3-2-3) and IR 72646-CN 6-1-16 (Banla Phdao/CN 846-6-6//IR 40931-33-2-3-2) from which 45 selections were made from both the crosses and they were in F_7 and F_5 stages respectively, during kharif 2000. Biraj and CN 846-6-6, developed from RRS, Chinsurah were one of the parents in the two breeding lines.

Table 3. Performance CN 1035-61 in advanced variety trial 1 – late (shallow) during kharif 2000

	Yield (t ha^{-1})			
Location	CN 1035-61	Savithri	R. check*	CD (0.05)
Jeypore, Orissa	5.20	6.04	4.69	0.56
Patna, Bihar	5.00	4.06	5.37	NS
Hazaribagh, Bihar	4.38 (2)	–	2.58	0.91
Faizabad, UP	1.54	0.61	0.84	0.18
Varanasi, UP	5.60	5.23	5.52	NS
Jagadalpur, MP	3.02	2.20	3.84	0.90
Karimganj, Assam	2.83 (4)	2.78	2.91	0.18
Maruteru, AP	5.77	4.93	5.98	NS
Coimbatore, TN	6.30	6.48	6.31	0.06
Raipur, Chattisgarh	4.47 (3)	2.01	4.33	0.89
Mean	4.41	3.81	4.24	

*Pooja and Salivahan are the regional check for eastern and other parts of India respectively. Figures in the parentheses indicate ranking in respective location.

Ten recently released rice varieties for rainfed lowland ecosystem, two from each of the five states, viz. Sarala and Durga (Orissa), Baraborodhi and Jallahari (UP), Rajshree and Sudha (Bihar), Ranjit and Bahadur (Assam) and Bhudeb and Mahananda (WB) are being tested in farmers' field in a large scale through NATP starting from kharif 2001. Five hundred farmers in each state (100 in one district) have been provided with five kg of seeds of new varieties to expedite inter-state flow of promising rice varieties. From WB, CN 1035-61(Bhudeb) is one of the nominations, which has been evaluated under the shuttle-breeding programme.

The initial effort for varietal improvement for the rainfed lowland ecosystem was mainly confined to the purification of landraces through pure line selection. Most of the varieties developed up to mid-eighties were pure line selections. Due emphasis on the breeding programme for this ecosystem was given by the breeders during mid-eighties. The operation of the shuttle-breeding programme in early nineties was a significant change in the breeding approach. Materials with broad genetic base of diverse origin were available. Exchange of breeding materials among the breeders in eastern India provided better opportunity for selection of ideal genotype suited to local condition. Normally, 10–15 years are needed to

Table 4. Performance of CN1035-61 in shuttle-breeding programme during 1998–99

		Yield (t ha^{-1})			
Year	Location	CN1035-61	Sabita	Mashuri	CD (0.05)
1998 (N)	CRRI, Orissa	4.03	4.80	1.98	1.24
	Ranital, Orissa	3.42	–	–	0.50
	Mahsodha, UP	3.78	1.58	1.42	1.40
	Chinsurah, WB	2.83	2.50	1.92	0.38
	Patna, Bihar	4.09	3.23	3.79	0.78
	Titabar, Assam	3.35	2.71	2.74	0.79
1999	Chinsurah, WB	3.70	2.45	2.45	0.42
	CRRI, Orissa	2.54	1.50	1.67	0.44
	Mahsodha, UP	3.32	3.05	3.62	0.52
	Raipur, Chhattisgarh	3.61	4.14	3.11	0.89
	Titabar, Assam	3.04	3.07	2.37	0.47
	N. Lakhimpur, Assam	3.97	3.78	2.48	0.80
	Mean	3.47	2.98	2.50	
1998 (D)	CRRI, Orissa	2.32	Nil	Nil	0.91
	Ranital, Orissa	2.92	–	–	0.44
	Mahsodha, UP	1.79	0.78	0.90	0.17
	Chinsurah, WB	3.20	3.50	1.80	0.38
	Patna, Bihar	2.88	2.53	2.78	0.84
	Titabar, Assam	1.47	1.31	1.70	0.46
1999	Chinsurah, WB	2.05	2.05	1.90	0.18
	CRRI, Orissa	0.53	0.37	0.29	0.14
	Masodha, UP	2.49	2.12	2.30	0.55
	N. Lakhimpur, Assam	2.80	2.93	1.68	0.30
	Titabar, Assam	2.25	1.75	1.79	0.25
	Mean	2.25	1.73	1.51	

N, Normal planting (within July); D, Delayed planting (within 1st week of September).

Table 5. Performance of CN1035-61 in multilocational state adaptive trial, semi-deep water (41–75 cm water) during kharif 2000

	Yield (t ha^{-1})						
Variety	Kakgachia	Pingla SARF	Chanchal SARF	Dhupguri SARF	Karandighi	Diamond Harbour	Mean
CN1035-61	3.85	2.80	5.25	3.10	2.4	2.12	3.25
Hanseshwari	4.02	1.40	2.00	2.36	1.20	2.45	2.24
Mahananda	3.73	2.20	2.25	2.59	0.60	2.31	2.28
Ambika	4.04	1.00	1.25	2.12	1.30	2.60	2.05
Golak	3.78	1.40	2.00	2.37	3.20	2.40	2.52
Sudhir	3.82	1.36	1.25	1.84	1.80	1.64	1.95
Sunil	3.92	2.00	2.00	2.65	3.80	2.21	2.76
Check	3.84	2.6	1.75	3.14	1.40	2.52	
Name of check	CR1009	Sabita	Sabita	Sabita	Sabita	Sabita	
Water depth (cm)	110	< 50	75	30	< 50	< 50	
Date of sowing	20.6.2000	NA	27.5.2000	16.6.2000	NA	3.8.2000	
Date of planting	17.7.2000	NA	12.7.2000	27.7.2000	NA	18.7.2000	

Kakgachia and Pingla in Midnapur District; Chanchal in Malda; Dhupguri in Jalpaiguri; Karandighi in Uttar Dinajpur and Diamond Harbour in South 24 Pgs. SARF, Sub-Divisional Agricultural Research Farm; NA, Not available.

release a variety for this ecosystem, starting from the year of crossing. The shuttle-breeding programme helps to cut down the time for varietal development by 3–4 years, as the breeders receive F_2 or even F_3/F_4 (Figure 2). It is expected that more productive varieties will be released for this harsh and unpredictable ecosystem within the next five years, which are now in advanced stage (F_7 to F_9) at different centres of eastern India.

Advanced research for developing superior genotype for rainfed lowland ecosystem through biotechnology is in progress at different institutions. Selection efficiency in breeding population could be enhanced by use of molecular markers. Identification of the RFLP/AFLP markers flanking Sub (1) t locus is an important step in this direction. A group at Kasetsant University, Bangkok has made polymorphism survey of parents. DNA markers for submergence tolerance have been identified and are being used in selection of breeding materials. Another group at CSIRO, Australia is working on genetically altering levels of pdc (pyruvate decarboxylase) and adh (alcohol dehydrogenase) in rice[11]. Three different rice *pdc* genes (*pdc1*, *pdc2* and *pdc3*) have been cloned and sequenced; pdc1 cDNA has been subcloned at the 3′ end of three different promoters (CaMV 35S, action 1 and anoxia-induced 6x ARE promoter, which is a synthetic promoter) in both sense and antisense orientations, and these plasmid constructions have been introduced into rice to yield a large number of transgenic lines. The recently initiated 'Rice Genome Project' aims to provide nucleotide sequence of the complete rice genome. The information from this project would hopefully provide function and location of additional genes important for flooding tolerance, needed for rainfed lowland rice varieties.

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