Rainfed Upland Rice:
Activities, Achievements and Aspirations

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SUMMARY

Central Rainfed Upland Rice Research Station (CRURRS) was established in 1980 as unit of ICAR-National Rice Research Institute to undertake field research for generating location specific technologies suited to diversified rainfed upland ecologies. The station undertook various research projects on varietal improvement, crop management, crop protection and transfer of technology. These efforts resulted in developing technologies to suit different types of rainfall patterns, land topography, hydrology, health status and socio-economic conditions of rainfed upland ecology. CRURRS has developed more than a dozen of suitable rice varieties and their package of practices in appropriate cropping systems mode, the most prominent among them are Vandana, Anjali, Sahbhagi Dhan and Abhishek. The technologies, after having validated through on-farm trials, are being disseminated to the target clients through participatory on-farm trials (OFT) and demonstrations (Front Line Demonstrations; FLD) in the region. The new varieties significantly out-yielded the farmers' variety in many of these demonstrations conducted in the state (FLD) and also at the national level (NFSM, BGREI etc.) making these varieties attractive to the farmers nationwide. It has been estimated that the area coverage by CRURRS bred varieties is about 323.35 thousand ha in Jharkhand alone. The most popular variety Sahbhagi Dhan is being cultivated in 12 states of the country and it is one of the top 5 varieties of the country for breeder seed production indent by the DAC&FW, establishing itself as the first mega variety for drought-prone areas of the country. The achievements of the research station, the aspirations that would help to raise the economic level of the rice farmers in rainfed drought-prone ecosystem, in particular, and to enhance rice production of the country, in general, have been discussed in this chapter.

1. INTRODUCTION

In India, rice is grown under upland rainfed ecologies in approximately 6 million hectare (Mha), which is about 13% of total rice growing area of India (Adhya et al. 2009). Rice is the major crop in rainfed ecology owing to its socio-economic needs despite marginal growing environment. The rainfed rice ecology is mostly (85%) distributed in Eastern India with its wide spread over the states of Jharkhand, Odisha, West Bengal, Bihar, Chhattisgarh, Madhya Pradesh, Uttar Pradesh and Assam. Resource poor farmers including several tribal communities in Eastern India constitute a sizable part of the demography of this region. During first Green Revolution full potential of irrigated ecology was captured. Hence, major focus was laid in recent years to realize untapped potential of rainfed ecology, predominantly distributed in eastern India, through the flagship project of "Bringing Green Revolution to Eastern India (BGREI). Although the potential yield of upland rice varieties can be up to 4.5-6.0 t ha^{-1}, the average yield of upland rice is usually <2.0 t ha^{-1} in farmers fields. Poor yield of upland rice is due to several environmental and socio-economic constraints.

Since inception, the Central Rainfed Upland Rice Research Station (CRURRS), Hazaribag is actively engaged in improving rural livelihood of rainfed rice farmers by developing suitable technologies for increasing productivity of rice and rice-based cropping systems through applied and strategic research and their dissemination. In this mission the research station has developed fifteen suitable high yielding rice varieties, their package of practices and appropriate cropping systems for increasing productivity of rainfed sub-systems prevalent in the target ecology. A basket of technology options offers the cliental group to choose according to their specific requirements and capability. Research efforts in the recent past has contributed to modest (15-20%) increase in rice yields in the upland ecosystem but the need remains for stronger research and development to further improve production and sustainability of rice-based cropping systems in uplands.

The objectives of the chapter are to (1) outline the genesis and mandate of the research station; (2) review the achievements of the research on upland rice; (3) assess the impacts of the achievements at local, regional and global levels; (4) analyze the major challenges of upland rice research and development and (5) lay out future plan of research on upland rice to address the emerging challenges.

2. GENESIS AND MANDATE OF THE NRRI RESEARCH STATION

Central Rainfed Upland Rice Research Station (CRURRS) was established in 1980 as an out-campus of ICAR-National Rice Research Institute (NRRI), Cuttack to address the specific requirements of the rainfed, unfavourable (drought prone uplands) rice ecosystem. In 1983, this centre became fully operative as a research station of NRRI, Cuttack. Initially it was named as Central Rainfed Rice Research Station. Later on, with the establishment of another research station of NRRI to address rainfed lowland rice ecology at Kharagpur, West Bengal, more specific mandate on 'upland' was assigned and it became Central Rainfed Upland Rice Research Station. The station started functioning in the present administrative cum research building on 5th May 1996 with 48 ha of experimental farm land. The station has a multidisciplinary team of scientists, technicians, a farm superintendent, and administrative and supporting staff. The initial research work was focused on varietal development, agronomical management and water harvesting. The station released its first variety Vandana (RR167-982) in 1992 for uplands of Bihar. Later on Vandana was also released for Odisha in 2002, became most popular upland rice variety because of its drought tolerance and now grown in all the states of Eastern India. Till date, 15 rice varieties were developed and released by CRURRS. The station developed new and improved technologies for profitable and sustainable farming of the target ecology. The station is also engaged in imparting training to the students and stakeholders throughout India on upland rice management.

Central Rainfed Upland Rice Research Station began working on the target of rice improvement in the mid-eighties with specific mandates to (i) develop suitable technologies to increase rice productivity and sustainability through applied and strategic research and disseminate them; (ii) collect, maintain and evaluate upland rice germplasm and characterize upland situations and (iii) develop mixed and sequence cropping systems

Subsequently (1987 onwards) three more activities were included for need driven broadening of the mandate i.e., research activities for adjacent ecologies such as rainfed lowlands/ irrigated lands; socio-economic studies on small and marginal rainfed upland rice farmers and documentation of information on upland rice-based cropping systems.

Research in the station concentrated on five major areas, viz., genetic resources, varietal improvement, crop resources management, stress (biotic and abiotic) management and cropping systems improvement. CRURRS became the lead center for upland rice research in the ICAR-IRRI collaborative Eastern India Rainfed Project during 1988-1991 and also the Indian key site for the Upland Rice Research Consortium (an ADB funded initiative managed by the IRRI) activities during 1991-1999. Farmer interface was strengthened with Farmers' Participatory Research during 1997-99.

3. ACHIEVEMENTS

3.1. Varieties developed

The research station has developed 15 suitable rice varieties (Details of the varieties have been presented in Table 1).

3.2. Crop production technologies

The package of practices of the improved upland varieties and appropriate cropping systems were developed for sustaining increased productivity of rainfed sub-systems prevalent in the target ecology:

1. Row seeding: An optimum seed rate of 40-80 kg ha^{-1} depending on row seeding method and implements used has been recommended as compared to farmers' practice of 150-250 kg ha^{-1} (broadcasted).

Table1. Rice varieties developed at CRURRS, Hazaribag.

Variety	Parentage	Year of release/ notification	Area of adaptability	Salient features
Vandana (RR-197-962)	C-22 x Kalakeri (*indicax aus*)	1992 & 2002 (SVRC)	Bihar, Jharkhand, Odisha	Duration 90 days; tall, LB; yield 2.5-3.0 tha^{-1} and 3.5-4.5 tha^{-1} under direct seeded & transplanted conditions, respectively; weed competitive; drought tolerant, deep root system; moderately resistant to blast & brown spot.
Sneha (RR19-2)	Annada/ CR 143-2-2 (*indicax aus*)	1992(SVRC)	Odisha	Duration 75 days; semi-dwarf; LB; yield 2.0-2.5 tha^{-1}; resistant to rice bug and rice tungro.
Anjali (RR 347-166)	Sneha x RR 149-1129 (*indicax indica*)	2002 (CVRC)	Uttar Pradesh, Bihar, Jharkhand, Assam, Tripura	Duration 90-95 days; tall, SB; yield 3.5 tha^{-1} in favourable uplands, moderately resistant to leafblast and brown spot.
Sadabahar (CR 306-37-13)	BRRI SAIL/ IR 10181-58 -3-1 (*indicax indica*)	2003 & 2004 (SVRC)	Jharkhand	Duration 105 days; intermediate height, LB; yield 3.2 tha^{-1}; moderately resistant to sheath blight.
Hazaridhan (CR314-5-10)	IR42/ IR5853-118-5 (*indicax indica*)	2003 & 2004 (SVRC)	Jharkhand	Duration 115-120 days; semi-dwarf; LS; yield 4.0-4.5 tha^{-1}; drought tolerant at vegetative stage; resistant to blast and moderately resistant to bacterial leaf blight.
Virendra (CRR 347-2)	Sneha/ RR 149-1129 (*indicax indica*)	2006& 2007 (CVRC)	Odisha, Gujarat	Duration 95 days; tall, SB; yield 2.75 tha^{-1}; resistant to gall midge;moderately resistant to leaf blast and brown spot.

Contd...

Variety	Parentage	Year of release/ notification	Area of adaptability	Salient features
Abhishek (RR 272-829)	Natural cross of CR 314-5-10 (*OF*) (*indica*)	2006& 2007 (CVRC)	Uttar Pradesh, Bihar, Jharkhand, Assam	Duration 120-125 days; Semi-dwarf (95-110 cm); SB; yield 4.5-5 tha^{-1}; resistant to rice blast,moderately resistant to brown spot and gall midge.
CR Dhan 40 (CRR 383-22)	N 22 / RR 20-5 (*aus*x *indica*)	2008 (CVRC)	Jharkhand, Maharashtra	Duration 100 days; tall, SB, yield 3.0 -3.5 tha^{-1}; drought tolerant; resistant to gall midge; moderately resistant to leafblast, brown spot, sheath blight, leaf folder.
Sahbhagi Dhan (IR74371-70-1-1-CRR-1)	IR55419-04*2 / Way Rarem (*indica*x *indica*)	2009& 2011 (CVRC)	Odisha, Jharkhand	Duration 105 days; intermediate height, LB; yield 3.8-4.5 tha^{-1} and 1-2 tha^{-1} under moderate and severe drought stress, respectively; resistant to leaf blast, moderately resistant to brown spot, sheath rot, sheath blight and leaf folder.
CR Dhan 103 (CRR 451-1-B-2-1)	Vandana / IR 64 (*indicaxindica*)	2014 (SVRC)	Jharkhand (yet to be notified)	Duration 95 days; tall; LS; yield 2.5-3.0tha^{-1}; drought tolerant; resistant to blast; moderately resistant to brown spot, very good grain quality.
IR64Drt1 (IR87707-445-B-B-B)	AdaySel/*3 IR64 (*ausxindica*)	2014& 2015 (CVRC)	Tamil Nadu, Andhra Pradesh, Telengana, Madhya Pradesh, Chhattisgarh, Jharkhand	Duration 120-125 days; semi-dwarf; LS; yield 5.5-6.0 tha^{-1}, 25% and 30% yield advantage over IR64 under severe and moderate moisture stress, respectively; drought tolerant; similar to IR64 in disease and pest reaction.
Purna (CRR356-29)	Annada/ RR151-3 (*indicaxindica*)	2017 (SVRC)	Gujarat	Duration 90 days; tall, SB; yield2.5-3.0tha^{-1}; drought tolerant, moderately resistant to leaf blast and brown spot, moderately resistant to stem borer and leaf folder.

Contd...

Variety	Parentage	Year of release/ notification	Area of adaptability	Salient features
Gangavati (CRR 363-36)	Ageti Gaurav x Kalinga III (*indicaxindica*)	2017 (SVRC)	Karnataka	Duration 85 days;tall, LS; yield 2.0-2.5 tha^{-1}; resistant to brown spot & moderately resistant to leaf blast. resistantto gall midge-1, stem borer &moderately resistant to GM Bio.4 & 5 and leaf folder, aromatic and extra LS grains.
Tripura Khara Dhan-1 (IR87707-446-B-B-B)	AdaySel/*3 IR64 (*ausxindica*)	2018 (SVRC)	Tripura	Duration 120-125 days; semi-dwarf; LS; Yield 5.3 tha^{-1} (3.36% higher than IR64), 11% and 24% yield advantage over IR64 under severe and moderate moisture stress, respectively; drought tolerant; similar to IR64 in disease and pest reaction.
Tripura Khara Dhan-2 (IR87707-182-B-B-B)	AdaySel/*3 IR64 (*ausxindica*)	2018 (SVRC)	Tripura	Duration 115-120 days; semi-dwarf; LS; Yield 5.2 tha^{-1} (2.09% higher than IR64), 17% and 22% yield advantage over IR64 under severe and moderate moisture stress, respectively; drought tolerant; similar to IR64 in disease and pest reaction.

2. Fertilizer management: Under unfavorable upland a dose of 40:30:30 (NPK) and favorable uplands 60-80:30: 30 (NPK) beside at least 500 kg FYM ha^{-1} is recommended.
3. Nitrogen (N) application schedule: Split application of N following ¼; ½ and ¼ schedule is recommended with first top dressing at maximum tillering followed by second at PI stage.

3.3. Weed management technology

Most critical period for crop-weed competition was determined to be first 30 days period. Pre-emergence application of butachlor @ 1.5 kg ai ha^{-1} followed by application of bispyribac sodium 10% SC@ 200 ml ha^{-1} at 21-25 DAS coupled with recommended N and P schedule proved best strategy for integrated weed management in rainfed upland rice.

3.4. Cropping systems technologies

3.4.1. Intercropping

The following suitable intercropping systems were identified for rainfed uplands, among them, rice +pigeon pea is the most profitable system.

i) Upland rice (Vandana) inter-cropped with pigeon pea (BR 65) in 4:1 row ratio proved the most advantageous system, with average yield of 2.06 t ha^{-1} of rice and 0.6 t ha^{-1} of pigeon pea and a net return of Rs. 4020 ha^{-1} compared with total variable costs and return of 2.72 $rupee^{-1}$ invested (Singh et al. 2014).

ii) Rice (Vandana/Kalinga III) + finger millet (A 404); row ratio 2:2

iii) Rice (Vandana/Kalinga III) + ground nut (BG 3); row ratio 4:2; occurrence of tikka disease was less in the inter-cropping than the sole crop.

iv) Rice (Vandana) + Okra (Prabhani Kranti); row ratio 4:1

v) Rice (Vandana) + Sesame (T 13); row ratio 4:1

vi) Application of lime either once in 3 years @1.5 t ha^{-1} or in alternate years @1.0 t ha^{-1} or every year @ 0.5 t ha^{-1} proved beneficial in rice + pigeon pea inter-cropping.

3.4.2. Mixed cropping

Mixed cropping of broadcasted rice with sowing pigeon pea in furrows opened 75 cm apart proved at par with rice + pigeon pea intercropping in 4:1 row ratio.

3.5. Arbuscular Mycorrhiza Fungi (AMF) technology

The following AM-supportive crop culture components have been recommended for improving activities of native AMF and P nutrition in upland direct seeded rice.

a) Two off season tillage at not less than 12-13 weeks interval allowed regaining optimum native AMF population in soil for effective activities in the next crop. Most suitable schedule is one after harvest tillage (October) followed by one summer tillage (May) (Maiti et al. 2011a).

b) Two rice-based cropping systems (two years) improved both total P acquisition of rice and productivity through enhancing native AMF activities;

   i) Maize relay cropped by horse gram in first year followed by upland rice in second year.

   ii) Pigeon pea / groundnut in first year followed by rice in second year (Maiti et al. 2011b).

c) Application of on-farm produced native AMF based inoculums @ 250 kg ha^{-1} further enhanced P uptake for which improved, farmers' friendly production protocol has been developed (Toppo et al. 2016)

d) Optimum level of P fertilizers application, under AMF-supportive crop culture components could be reduced by 33% from recommended dose.

3.6. Disease management technologies

3.6.1. Management Strategies for Brown spot (*Bipolaris oryzae*)

- Use of resistant cultivars (Kalinga III)
- Balanced fertilization and increasing level of Phosphorus (0-50 kg P_2O_5 ha^{-1}) reduced the brown spot incidence.
- Seed treatment with *Trichoderma* sp. @5 g kg^{-1} seed or Carbendazim @ 2 g kg^{-1} seed followed by a need-based spray of Carbendazim 50% WP (@ 2g/l) or Tebuconazole 50%+ Trifloxystrobin 25% w/w WG (Nativo 75 WP) (0.4 g L^{-1}) or Propiconazole (25 EC) (Tilt 25EC) @1 ml L^{-1}.

3.6.2. Management Strategies for Blast (*Magnaporthe grisea*)

- Use of resistant cultivars (Sahbhagi Dhan, IR64 Drt1 etc.)
- Seed treatment with *Trichoderma* sp. @ 5g (1 x 10^8 cfu g^{-1})/kg seed or *Pseudomonas fluorescens @ 5 g (1* x 10^{12} cfu g^{-1})/kg seed.
- Seed dressing with Tricyclazole75 WP followed by granular application of Kitazin48 EC at tillering effectively controlled blast with significant improvement in yields in IR 50 and HR 12, grown under favourable uplands.
- Need based application of systemic fungicides Tebuconazole 50% + Trifloxystrobin 25% w/w WG @ 0.4 g L^{-1} at heading can be effective in reducing the disease severity.

3.6.3. Management Strategies for Sheath rot (*Sarocladium oryzae)*

- Use of mechanically separated seeds using 20% common salt solution

- Split application of N fertilizer as per recommendation.
- Need based foliar application of Carbendazim 50 WP @ 1 g L^{-1}

3.6.4. Management Strategies for False smut (*Ustilaginoidea virens)*

- Early transplanting (by 3rd week of July)
- Moderate level of fertilization (80:40:40)
- Preventive spray of Hexaconazole@ 2 ml ai L^{-1} at PI stage

3.6.5. Integrated Pest Management for unfavorable uplands

- Select varieties of 90-100 days (e.g. Vandana and Anjali) duration with moderate resistance to blast and brown spot.
- Use healthy seeds (mechanically separate seeds using 20% salt solution) to manage sheath rot. Seed treatment with Carbendazim 50 WP / Trycyclazole 75 WP @2 g kg^{-1}.
- Line sowing of seeds by June last week.
- Split application of N fertilizer: [10 kg N (22 kg urea) basal + 20 kg N (44 kg urea) at 30 days after emergence (DAE) + 10 kg N (22 kg urea) at 45 DAE]
- Early post emergence (1-2 days after germination) application of butachlor (weedicide) @ 1.5 kg ai ha^{-1} (Machate 50 EC 3L ha^{-1}) under moist soil condition. This is to be followed by one need-based spray of bispyribac-Na 10% SC @ 200 ml ha^{-1} after 21-25 days after germination.
- Need-based application of Carbafuran 1 kg a.i. ha^{-1} (33 kg Furadon 3G ha^{-1}) 20-25 days after germination under drought situation to reduce termite damage.
- Need based application of monocrotophos @ 0.5 L a.i. ha^{-1} for stem borer and rice bug
- Need based application of Mancozeb (Dithane M 45 @ 1.2 kg ha^{-1}) for brown spot at action threshold level (ATL) 8-10% leaf infection.
- Need based application of ediphenphos @ 0.5 L a.i./ha (Hinosan 50 EC @1 L/ha^{-1}) under drought to protect crop from neck blast

3.7. Knowledge generation

3.7.1. Germplasm characterization

- Isozyme variation classified 64 upland rice germplasm into *indica* (35, mostly improved) and *aus* group (22, both traditional and improved). The *aus* group appears to be less diverse than the *indica* group (Courtois et al., 1997).
- Broad-spectrum blast resistance gene, *Pi9* was detected in only 6 accessions from eastern India out of 47 germplasm screened. Rare occurrence of *Pi9*

gene in the germplasm suggests that its introgression is very limited in *indica* rice (Imam et al., 2013).

- Among 32 rice germplasm from Sikkim, 13 were positive for blast resistance gene *Piz,* 6 each for *Pizt* & *Pik*, 7 for *Pik-p* and 16 for *Pik-h*. Atte thima was positive for three of *Pik* multiple genes and Dudhraj & Nepali dhan, were detected with both *Pita3* and *Pita/Pita-2* genes. However, presence of only *Piz-t*, *Pita/Pita-2* and *Pi9* gene ensured a resistant reaction in UBN. *Pi9* was detected in two cultivated germplasm, Kalchati and Bachithima (Imam et al., 2014).

- *Pi2* gene was identified in 4 landraces from Sikkim and one gora accession. Existence of *Pi2* gene in independent *indica* landraces from the eastern Indian region suggested that the gene might have originated and evolved in *indica* rice and exists in different allelic forms in blast endemic zones of eastern India (Shamshad et al., 2015).

- The frequency of bacterial blight (BB) resistance genes (*Xa*) in rice germplasm from Eastern India is as follows: *Xa1*/>/*Xa7*/>/*Xa4*/>/*Xa10*/>/*Xa11*. It was suggested that *Xa7*, *Xa8*and *Xa11* should be considered along with *xa5* + *xa13* + *Xa21* for BB resistance breeding in Eastern parts of India (Banerjee et al., 2018).

- Jhum rice germplasm of Tripura were found to contain many drought releated QTLs but poor in blast resistance genes. Only 3 accessions possessed both drought-related QTLs and blast resistance genes which can be useful in upland rice breeding programmes (Anupam et al., 2017).

- Molecular diversity among gora accessions identified all gora accessions as *aus* cultivar group. However, white gora accessions were closer to the *indicas* (Fig. 1). One black gora accession was found to be positive for blast resistant genes viz.; *Pi2, Piz* and *Pita2* and some brown & white gora accessions also possess one or more DTY QTLs.

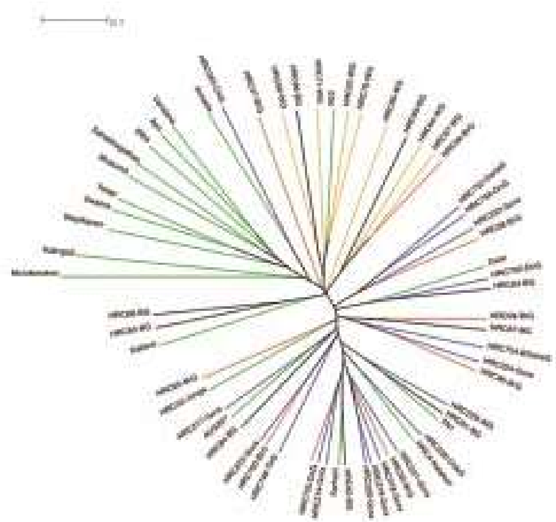

Fig. 1. Phylogenetic analysis with the Gora cultivars identified these as *aus* types. The White gora cultivars were genetically similar with the *indicas*.

- Phylogenetic analysis grouped the popular upland varieties and landraces from eastern India into varietal groups specific to *indica, aus* and *japonica,* where most of the released varieties are *indica* type (Fig. 2). *Pup1* (Phosphourus uptake) locus was detected in 13 upland varieties and landraces.

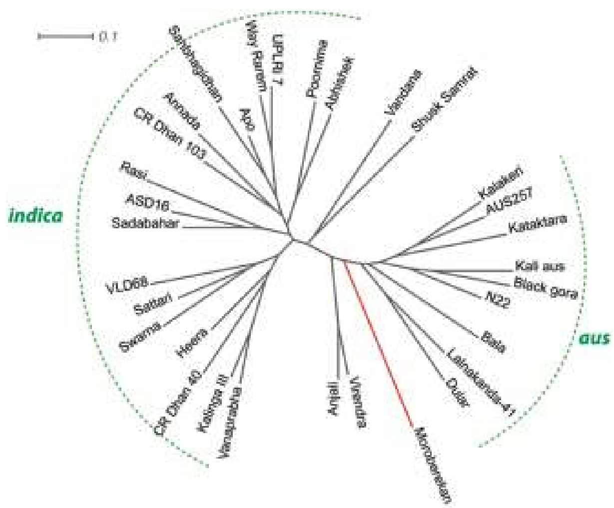

Fig. 2. Genetic diversity among upland rice varieties and landraces based on SSR markers associated with qDTYs.

3.7.2. Genetical studies

Morphological characters

- Novel floral abnormalities which help in out-crossing such as open floret (*of*), open glume, palealess and sterile mutant were developed through induced mutation and it was identified that these characters are governed by single recessive genes (Prasad and Sinha, 1993; Chauhan et al. 1996).
- Non-additive gene action were found to be involved in the inheritance of grain yield and associated traits. However, for 1000-grain weight additive component was important. Dominant alleles were predominant among the parents for days to flower, plant height, tillers per plant, panicle length and spikelet fertility. For other 1000-grain weight and grain yield an excess recessive alleles were indicated (Sinha et al. 2006).

Quality characters

- Moisture stress at the time of anthesis and grain filling reduces head rice recovery and increase grain chalkiness (Das et al. 2005).

Genotype x environment interactions and breeding implications

- For both favourable and unfavourable environments, indirect selection under moderate-input conditions was less efficient than direct selection for grain yield in low-input conditions, indicating upland breeding programs to adopt selection for grain yield under both moderate- and low-input conditions (Mandal et al. 2009).

Drought tolerance

- Rice cv. Vandana exhibited higher reproductive-stage drought tolerance and stomatal diffusive resistance than Brown gora under moisture-stressed conditions (Chauhan et al. 1996).
- Tropical *japonica* varieties were superior to *aus* and *indica* groups in root characters except for Annada (*indica*) and Kalakeri (*aus*), which were at par with the *japonicas* (Sinha et al. 2000).
- The *aus* genotypes (Kalakeri and Sathi 34-36) were efficient in translocating stem reserved carbohydrate to grains as compared to *indica* or *japonica* genotypes (Sinha et al. 2000).
- In IR 64/Azucena doubled-haploid (DH) population, 11 QTLs were identified for leaf rolling, 10 for leaf drying and 3 for growth rate under stress. Few leaf rolling and leaf drying QTLs were mapped in the same place as QTLs controlling root morphology (Courtois et al. 2000).
- The effect of *qDTY*12.1, large-effect QTL for grain yield under drought stress identified in Vandana/ Way Rarem population was validated in the target environment of eastern India, confirmed its large and consistent effect on grain yield under upland drought stress conditions, in a wide range of environments (Bernier et al. 2009).
- Performance of Vandana-*qDTY12.1* NIL*s* was not affected by soil texture but showed a notable response to drought stress severity. The effects of *qDTY12.1* on water uptake were most apparent under mild to moderate stress but not in very severe drought or well watered treatments, whereas the lateral root and transpiration efficiency responses were observed under a range of conditions. These results highlight the varying response of *qDTY12.1* across upland environments and the complexity of multiple mechanisms acting together to confer an effect on rice yield under drought (Henry et al. 2014).
- Characterization of qDTY-NILs (*qDTY2.2* + *qDTY4.1*) of different combinations in IR64 background highlight the complex interactions among major-effect drought-yield QTLs and the drought-response traits they confer, and the need to evaluate the optimal combinations of QTLs that complement each other when present in a common genetic background (Henry et al. 2014).

- Rice variety Sahbhagi Dhan possessed many important traits such as high emergence rates under direct-seeded germination-stage stress, a high proportion of total root length as lateral roots, high harvest index under drought, and high yield stability across wet seasons, which were identified as important traits for rice adaptation to the fluctuating soil moisture conditions of rainfed fields (Anantha et al. 2015).

3.7.3. Weed dynamics

- Mussoorie rock phosphate (MRP) was found advantageous over single super phosphate (SSP) in acidic uplands (pH 5.5) in terms of reducing weed biomass.
- Continuous use of Butachlor and pretilachlor allowed the buildup of the jungle rice (*Echinochloa colona* (L) Link. Pendimethalin favoured profuse growth of goat weed (*Ageratum conyzoides* L.) and annual sedges (*Cyperus* spp.).
- Inter-specific competition under rice: pigeon pea / cowpea intercropping coupled with complementarity increased crop stand ability to smother weeds and so, intercropping systems were found to be beneficial in terms of weed management (Singh et al. 2008).

3.7.4. Phosphorus dynamics and AMF

- The long-term Phosphorus trial revealed that rice yield increased with P levels (up to 7 ppm soil P) without definite trend until the 3rd year. P application @ 24 kg P ha^{-1} helped in reducing the effect of drought, increasing the productivity and P-use efficiency of rainfed upland rice.
- Long-term study revealed that native AM association is more effective in promoting P acquisition by associated (AM) plant under moisture stress conditions (Maiti et al. 2013).

3.7.5 Genetics of disease resistance & pathogen population structure analyses

- Two recessive genes were identified controlling resistance to brown spot in resistant donors Kalinga III and Ch45 (Prasad et al. 1998). In another study, 3 QTLs were mapped to chr.1, 2 & 11which were identified governing brown spot resistance in Kalinga III/ Moroberekan population, the resistant allele coming from Kalinga III.
- Assessment of molecular diversity and mating type analysis of *Magnaporthe oryzae* indicated that sexual recombination might be the one reason for lineage diversity in *M. oryzae* in North-East and Eastern India (Imam et al., 2014). *Pi9, Pita2, Piz5(Pi2), Piz and Pi1* have broader spectrum of resistance as revealed by their low frequency of infection (0-23%). A combination of *Pi-9* and *Pita2* excluded all the pathotypes from eastern India.
- Virulence analyses of 47 isolates from eastern India revealed that many isolates possessing alleles of *Avr* genes were able to infect monogenic lines

harbouring cognate R genes suggesting that such isolates might possess alternate mechanisms to escape host surveillance (Imam et al. 2015).

- *Pi* 5(t) and a number of QTLs associated with partial resistance to blast were mapped on the same chromosomal regions (chr. 6, 11 and 12) in Co 39/Moroberekan population. Efforts were then made to incorporate blast resistance QTLs from Moroberekan into popular upland rice cultivar Vandana using advanced backcrosses (Wu et al. 2003).
- The blast resistance gene (*Pi9*) was less variable in terms of disease reaction in landraces due the fact that the landraces are exposed to a smaller spectrum of pathogen variability across the country (Imam et al. 2016).
- Loop-mediated isothermal amplification (LAMP) protocol has been standardized for rapid and reliable detection of *Ustilagonoidea virens* (false smut) isolates prevailing in eastern India. The LAMP primer set designed from the *U. virens* hypothetical protein genes produced reliable amplification and holds promise for false smut detection using LAMP assay.

4. PUBLICATIONS

The number of research articles published in journal with >6.0 NAAS score is 60 and with <6.0 NAAS score 113. This station has also published an edited book on 'Upland Rice in India' and 7 research bulletins, besides a number popular articles & technology bulletin (both in English and Hindi) and contributed numerous book chapters. During last five years (2014-15 to 2018-19), however, out of 48 publications, 3 were in journals with above NAAS score of 10, 8 were in that of between 8-10 score, 14 were in between 6-8 score.

5. HUMAN RESOURCE DEVELOPMENT

The Hazaribag research station of NRRI is also serving as educational training center for the students, researchers and extension workers. The station has a strong collaboration with Vinoba Bhave University, Hazaribag. So far seven PhD students registered in V.B. University worked under the guidance of scientists of the station for obtaining Ph.D. degree. During the last three years 10 M.Sc., students in the disciplines of Genetics and Agronomy from IARI-Jharkhand did their dissertation work at this station. A number of SRFs (15) have worked in various projects on Drought, Blast, AMF, Farming System and Participatory Research at the research station. This station also offered training of different duration to post-graduate and under graduate students. Three M.Sc. students from Ranchi University and seven B.Sc. students from St. Xavier's College, Ranchi have successfully completed 3 months training program on rice biotechnology.

6. IMPACTS

Since its inception, the station is actively engaged in improving livelihood of rainfed rice farmers by developing suitable technologies to increase sustainable productivity of rice and rice based cropping systems through applied and strategic research and their dissemination. In this mission the research station has developed suitable fifteen rice varieties, their package of practices including crop protection and appropriate rice based cropping systems for increasing productivity of rainfed sub-systems prevalent in the target ecology and as per need and capability of farming community. Adoption of these technologies has led to moderate productivity increases, estimated at 15-20% in different rainfed upland rice growing regions.

The first upland rice variety released from CRURRS, Hazaribag in 1992 is Vandana. This variety was released for the plateau region of Bihar (including Jharkhand). Anjali is the first CVRC released variety from Hazaribag station in 2002, recommended for five states viz., Jharkhand, Bihar, Odisha, Assam and Tripura. Seed production program was initiated at CRURRS, Hazaribag with the implementation of revolving fund scheme on 'Seed production of upland rice varieties' in 1997 involving Vandana and 3 more upland varieties (Kalinga III, Sneha and Heera) released from the main institute, NRRI, Cuttack. With the release of more varieties from the Hazaribag station the seed production program was strengthened and at present breeder seeds of 11 rice

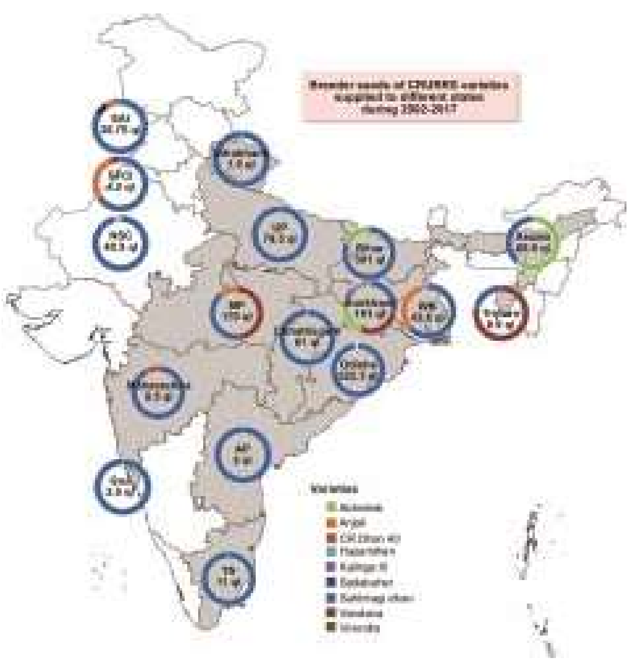

Fig. 3. Breeder seed indent from different states for CRURRS varieties during 2002-17.

varieties are being produced. During the early period (2002-2011) the total amount of breeder seed indent from DAC was about 170.0 quintals against which the station had produced and supplied 638 quintals breeder seeds including local demand. With the changes in government policy and implementation of some of the government scheme for promotion of new varieties since 2012 there is a jump in the indent for breeder seeds of the new varieties. Till 2017, about 2295 quintals of breeder seeds against indent of 1728 quintals comprising all varieties developed at Hazaribag station were produced and supplied. The quantities of seed produced for these varieties as per indents received from different states through DAC during the period 2002-2017 have been presented in Fig. 3. In addition to breeder seeds the station also produced and distributed truthfully labeled seeds to cater to the needs of local farmers. The total seed production during this period is about 4854 quintals, which is more than double of the breeder seed production. The prominent varieties for which seeds were produced at CRURRS, Hazaribag are Vandana, Sahbhagi Dhan, Abhishek and Anjali.

CRURRS has been conducting Front Line Demonstrations (FLD) with farmers' participation since 1995 for dissemination of the technologies developed at the station. During 1995 to 2008, FLDs were conducted in eight districts of Jharkhand (Hazaribag, Ranchi, Koderma, Chatra, Koderma, Giridih, Deoghar and Bokaro) covering 330 ha of area (20-30 ha per year). The technologies demonstrated were rice varieties (Vandana, Anjali, Sadabahar), crop establishment, weed management, fertilizer management, seed management and cropping system. Eighty seven percent of the farmers in Jharkhand found the variety Vandana to be superior to Brown gora (local check) in terms of yielding ability, disease & pest reaction, cooking characteristics and taste. FLD with Vandana in 3 villages in Hazaribag showed its ability to produce equally well under unfavorable and favorable uplands recording average yields of 1.64 and 2.84 t ha^{-1} as compared to 0.80 t ha^{-1} by Brown Gora. Over the years under these demonstrations Vandana yielded 0.9 to 2.8 t ha^{-1}, Anjali 1.9 to 3.2 t ha^{-1}, Sadabahar 3.0 to 3.5 t ha^{-1} as compared to 0.4 to 1.65 t ha^{-1} yield of Brown Gora. Anjali was also demonstrated extensively in Jharkhand under CURE program during 2005-07. During three years of demonstration at Kuchu village in Ranchi district and Amin village of Chatra district the area coverage by Anjali variety become double and also spread to the neighboring villages from farmer to farmer with participating NGOs. From 2009 onwards the varieties under FLD changed with development and release of new drought tolerant varieties viz., CR Dhan 40, Abhishek and Sahbhagi Dhan. During 2009 to 2016 these varieties were demonstrated in 7 districts (Hazaribag, Koderma, Chatra, Ramgarh, Saraikela, Dumka and Jamtara) covering on an average 30 ha area per year. In most of these demonstrations improved varieties significantly out-yielded the local varieties and found the acceptability of the farmers because of their earliness, ability to yield with less water, producing more straw for the cattle and better eating quality. CR Dhan

40 recorded a yield of 2.6 to 4.25 t ha^{-1}, Sahbhagi Dhan yielded 3.0 to 4.18 t ha^{-1} and Abhishek 3.4 to 5.8 t ha^{-1}. During 2012 *kharif* season in Chatra district total rainfall received during the cropping season at three villages (Chauria, Parsawan and Tilra) district was approximately 600 mm while in village Arabhusai it was 700 mm. At Chauria village for 22 days there was no rain corresponding to the panicle initiation stage. In spite of that, Sahbhagi Dhan produced a yield of 2.70, 3.54 and 2.44 t ha^{-1} at Chauria, Parsawan and Tilra, respectively and 3.39 t ha^{-1} at Arabhusai village. On-farm demonstration of CRURRS bred varieties was also conducted by other organizations for their popularization. In a successful FLD of variety Abhishek by RKMA Divyan-KVK, Ranchi reported 68.66% yield improvement over local variety and mentioned that livelihood security of the small and marginal farmers in Jharkhand can be improved through adoption of this variety (Singh and Chandra, 2010). Sahbhagi Dhan and CR Dhan 40 were also selected for promotion in 4 districts (Chatra, Ranchi, Khunti & Deoghar) through cluster demonstration in about 100 ha area under National Food Security Mission Program during 2013-14. The yield of CR Dhan 40 ranged from 2.50 to 3.90 t ha^{-1} in 2013 and 2.8 to 3.5 t ha^{-1} in 2014 under direct seeded condition (Table 2). Sahbhagi Dhan yielded better than CR Dhan 40 ranged from 2.3 to 6.7 t ha^{-1} in 2013 and 3.0 to 4.1 t ha^{-1} in 2014. Farmers were fascinated with performance of the new varieties and showed their intention for adoption. It has been estimated by our institute (NRRI) that area under varieties developed by Hazaribag station in Jharkhand is about 323.35 thousand ha contributing 1086.93 thousand tones to its production during 2017 (Pathak et al. 2018).

With the given mandate, CRURRS, Hazaribag has developed varieties for all the major upland rice growing states (given in details in the variety released section). Though variety Vandana was released for Bihar (including Jharkhand) and Odisha but at one time it was being cultivated in uplands of all the states in Eastern India. During the year 2001, 4528 mini-kits (2 kg each) of rice variety Vandana were distributed in different states of eastern India

Table 2. Average productivity of Sahbhagi Dhan and CR Dhan 40 in NFSM districts of Jharkhand during 2013-14.

Variety	District	No. of farmers	Area (ha)	Yield range (t ha^{-1})	Avg. yield (t ha^{-1})
Sahbhagi Dhan	Chatra (2013)	158	76	2.5-6.7	3.8 ±0.64
	Chatra (2014)	57	43.5	3.2-4.6	3.8
	Deoghar (2014)	23	11.2	2.7-3.6	3.1
	Khunti (2014)	103	19.6	1.7-3.0	2.3±0.28
	Ranchi (2013)	53	23.2	2.3-3.9	2.7±0.31
CR Dhan 40	Chatra (2013)	7	5.5	2.5-3.9	3.34
	Chatra (2014)	3	1.5	3.1-3.6	3.4
	Deoghar (2014)	11	4.1	2.4-3.4	3.0

Table 3. State-wise average productivity of Sahbhagi Dhan and yield advantage over other varieties (Adapted from NFSM report).

States	Total area Sahbhagi Dhan (ha)	Productivty Sahbhagi Dhan (t ha^{-1})	Productivity neighbour's field (t ha^{-1})	Yield advantage (t ha^{-1})	Produce used as (%)
West Bengal	50	4.47	2.86	1.07	12.46
Uttar Pradesh	900	4.50	3.70	0.80	8.04
Odisha	850	3.57	2.56	1.01	4.85
Bihar	700	4.50	3.22	1.29	8.9
Jharkhand	600	4.41	2.2	1.2	3
Total/Average	3100	4.29	2.9	1.07	7.4

viz., Jharkhand (2028), Odisha (1000), M.P. (500), Chhattisgarh (500) and U.P. (100). As a result of mini-kit demonstration, farmers of other states could realize the potential of this variety under rainfed upland condition and breeder seed indent for this variety started coming from other states for which it was not notified. Under NFSM, Sahbhagi Dhan was demonstrated in 1700 hectares in Odisha, West Bengal, Jharkhand, UP and Bihar. The variety performed exceptionally well under normal as well as drought or less rainfall conditions with overwhelming response from the farmers. In Purulia district of West Bengal, the variety yielded exceptionally good and surprised the farmers about its yield potential in 105 days duration under both good rainfall as well as scanty rainfall conditions. The average yield of Sahbhagi Dhan was 4.47 t ha^{-1} in 105 days as compared to Lalat which yielded 2.86 t ha^{-1} in 120 days (Table 3.). About 12.5 % of the produce of this variety was saved by the farmers as seed for the use during the next crop season. However, under the favourable rainfed conditions, the benefits of the variety are enormous. In UP, this variety yielded 4.5 t ha^{-1} in 105 days as compared to 3.7 t ha^{-1} of Sarju52 which is the most popular variety of eastern Uttar Pradesh. About 8 % of the produce of Sahbhagi Dhan has been saved by the farmers for personal use or exchanged with the fellow farmers in the ratio of 1:10. Equally good response was received from the tribal district of Mayurbhanj in Odisha. The late duration varieties in these areas have yielded less (2.56 t ha^{-1}) than Sahbhagi Dhan (3.57 t ha^{-1}). At present Sahbhagi Dhan is one of the most popular varieties of the country being cultivated in 12 states and the indent for breeder seed production is 383.7 quintals (2018), which is highest among all varieties.

Varieties developed at this station were used as checks in the national coordinated trials. Vandana and Anjali were the regional and national checks for very early direct seeded (VE-DS) trial of ACRIP. After merging of VE & E-DS trials Sahbhagi Dhan is being used as national check for this trial and Vandana is continuing as regional check. Anjali was also used as national check for early transplanted trial under AICRIP. Two elite breeding lines developed at this station have released as varieties by other institutes. CRR 356-29 (IET18654) has been released as Purna by Navsari Agricultural University, Gujarat and CRR 363-36 (IET19251) has been released as Gangavati Ageti by University of Agricultural Sciences, Raichur for Karnataka. Varieties and breeding lines developed at this research station are also being used as donors in the breeding program by scientists from other institutes. Vandana and Sahbhagi Dhanare have been well recognized nationally for their drought tolerance traits.

First upland rice variety developed from this station, Vandana has been extensively tested in many countries through IRRI coordinated INGER network under International Upland Observational Nursery (IURON). Vandana was also used as check in this trial and subjected to many genetical studies in India and abroad. The first major effect grain yield under drought stress QTLs (qDTY12.1) was identified in a population involving Vandana (Bernier et al., 2007). In the subsequent studies it was found that Vandana possess two minor drought tolerance QTLs (qDTY2.3 & qDTY3.2), which interacts with qDTY12.1 to provide increased drought tolerance and wider adaptability (Dixit et al., 2012). Vandana is also known to possess another drought tolerance QTL, qDTY6.1 (Venuprasad et a., 2011). The phenomenal success of Sahbhagi Dhan in India led to its release in other countries such as "SukhaDhan3" in Nepal, and "BRRI Dhan56" in Bangladesh (Kumar et *al*, 2012). In those countries also it is performing very well under drought-prone condition assuring farmers' livelihood security.

7. MAJOR PROJECTS AND LINKAGES

First collaborative research program of CRURRS was started with Birsa Agricultural College, Ranchi under Rajendra Agricultural University way back in mid 80's. The IFAD (International Fund for Agricultural Development) funded project on technology validation ("Eastern India Rainfed Rice Project" during 1987-1997) and technology adoption ("Accelerating technology adoption to improve rural livelihoods in rainfed eastern Gangetic plains" during 2004-2006) were operational in two phases having its one of the global sites at CRURRS, Hazaribag in the similar domain. CRURRS also acted as one of the global sites for "Upland Rice Research Consortium" (1991-1999) coordinated by IRRI, Philippines. It was also the key site for Plateau uplands of "Consortium for Unfavorable Rice Environment" coordinated by IRRI and funded by ADB during 2004-07. CRURRS have linkages with IRRI in a number of collaborative projects such as, Farmers' Participatory Breeding (1997-1999), Upland Rice Shuttle Breeding Network (2002-2008), Developing and disseminating resilient and productive rice varieties for drought-prone environments in India (2005-2008), Detecting and fine-mapping QTLs with major effects on rice yield under drought stress for deployment via MAB (2007-10) and Stress Tolerant Rice for Poor Farmers' of Africa and South Asia (STRASA) in 3 phases (2008-2019). Beside IRRI, CRURRS has linkages with other international institutes like ICRISAT, Hyderabad and CIRAD, France.

In the national scenario, Hazaribag station is well connected with other divisions of the institute (NRRI) through several institute and externally aided projects since beginning. CRURRS also implemented two NATP (a. Socio-economic dynamics of rice production system in Eastern India, and b. Study on Weed & pest incidence dynamics in relation to ecologies and its impact on economic losses for developing effective control measures) and two NAIP (a. Allele mining and expression profiling of resistance and avirulence genes in rice-blast pathosystem for development of race non-specific disease resistance and developing sustainable farming systems models) projects under ICAR during 1999-2003 and 2008-13, respectively. A number of others ICAR projects under AP Cess, RFS, Extramural, CRP, ICAR Network projects were also implemented in collaboration with other ICAR institutes (IIRR, ICAR RC NEHR, VPKAS, ICAR RC ER etc.) and SAUs. The CRURRS is also a partner for DBT funded mega project 'From QTL to Variety:..' involving 14 institutes in the country and coordinated by ICAR-National Institute of Plant Biotechnology, New Delhi in two phases (2010-15 & 2018-21). Besides this, the station had other DBT funded project on 'Identification of molecular markers for enhanced AM response and MAS of high AM responsive varieties for efficient P nutrition of upland rice (2009-13)' and 'Identification of major QTLs for grain yield under drought stress in 'Jhum' rice varieties of NER for use in MAB to improve yield under drought (2011-14)'.The outstanding, time bound and result oriented activities of this research station have attracted interest from various institutions of national and international repute for collaboration and funding in research projects.

8. ASPIRATIONS

Global climatic models predict that the earth is warming up and occurrence of drought as well as floods would be increasingly frequent in the coming years with changes in the rainfall pattern. Rainfed farmers in uplands and plateaus face drought while those in low-lying areas face floods and sometimes both. Farming systems, therefore, has to be resilient to the changing weather patterns. Though there is gradual reduction in upland rice area due to urbanization and crop diversification, in the coming days the technologies developed for rainfed uplands will be more relevant to the adjoining ecologies in the changing climate scenario. Drought proofing rice is a major thrust at CRURRS, Hazaribag. With a collaborated approach the station aspires to achieve the following in next few years.

- Developing high yielding climate-resilient rice varieties with good grain quality and multiple stress resistance. The current research goal has been set to achieve 5.0 and 7.0 t ha^{-1} yield under rainfed upland and rainfed drought-prone shallow lowland, respectively.
- Considering the constraints of rainfed agriculture, upland rice research is focused on developing rice varieties and production systems that need

lesser inputs such as water, fertilizer and pesticide. Thus, the new varieties will be enriched with drought tolerance, high-value traits, and genes that protect against and mitigate the effect of new pests and diseases.

- Employ a consumer-driven breeding approach to encourage improvements in grain quality and address issues in yield gap and nutrition.
- Establish a concerted process to examine the proof of concept and the value of traits important to rainfed upland rice systems using cutting edge techniques and collaborative approaches.
- Strengthening the research on utilization of native beneficial soil microorganisms such as non-symbiotic N fixers, P-solubilizing organisms, Arbuscular mycorrhiza fungi, etc., that facilitate nutrient uptake by the crop and sustain the soil health.
- Intensifying research on agro-meteorology to link with the best climate, population and economic models to develop accurate fore-sighting and modeling. The micro-level characterization of upland rice environments in relation to yield loss will help in tailoring and operationalize potential solutions on the needs of locations-specific rice cultivation.
- Device sustainable moisture conservation strategy through crop-soil management practices and water-harvesting structures.
- Reinvigorate weed research for environmentally safe and effective control of weeds in upland rice and rice-based farming systems as a major component of IPM strategy. Use of suitable drills and simple inter-cropping equipment to facilitate row seeding, mechanical weeding and fertilizer placement requires further attention for popularization.
- Monitoring the rice pest and pathogen landscape and develop suitable strategies for controlling new virulent races. Generating molecular data and tools on identification of new pathogen isolates and pathogen evolution.
- To work in collaboration with the national and international partners to resolve challenges in upland rice production and improving the livelihood of farming communities.
- To train and motivate young students and researchers to meet the future challenges of food security through improving the rice productivity.

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