ICAR-National Rice Research Institute: Activities, Achievements and Aspirations

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SUMMARY

ICAR-National Rice Research Institute (NRRI), Cuttack has contributed immensely in country's Green Revolution, ensuring food security and enhancing farmers' income. It has released 133 varieties and hybrids of rice so far. Currently, 20% of NRRI varieties are indented for breeder seed production. India grows NRRI varieties in 18% of its rice area with 17% of rice production, which fetches Rs. 48,643 crores of gross return annually. For ensuring nutritional security, the Institute has recently released, first time in the world, two high-protein (more than 10.3% protein) rice varieties (CR Dhan 310 and CR Dhan 311). Two climate-smart varieties (CR Dhan 801 and CR Dhan 802), which are tolerant to both submergence and drought and few biotic stresses have also been released, again unique achievement in the world, to face the challenges of climate change. The Institute has deposited more than 35,600 accessions in the National Gene Bank as long-term storage and more than 20,000 accessions preserved as medium-term storage in NRRI-Gene Bank. It has developed microbial formulations for enhancing nitrogen and phosphorus use efficiency; calibrated and validated simulation models for optimizing crop management; identified options for eco-friendly and economic use rice residues; fabricated more than 30 equipments for small and marginal farmers; optimized and demonstrated integrated farming system models and developed technologies and strategies for climate change adaptation and mitigation. More than 1,25,000 genotypes were screened to find out novel sources of resistance against rice pests. It has identified resistant genotypes against bacterial leaf blight and brown plant hopper. It developed integrated pest management technologies and identified plant essential oils as eco-friendly alternatives for pesticides and phosphine fumigant against stored grain pest. For promotion of technologies, it has developed riceXpert App, which is available in English, Hindi and Odia with the provision of voice recording and response system. The Institute has initiated programmes such as Self–Sufficient Sustainable Seed System for Rice (4S4R) system; Farmer's Farm Innovation Resources Science and Technology (Farmer's FIRST); Mera Gaon Mera Gaurav (MGMG) and Front Line Demonstration (FLD) to enrich and update farmers with advances in rice science to improve their livelihood. During the last five years it has reached out to 144 villages; benefitted more than 2,7000 farm families; established 5 Farmers' Producer Companies; signed MoU with more than 50 companies; reached more than 60000 stakeholders with agro-advisory services; trained 5000 persons on rice-based technologies and agri-entrepreneurship

and guided 120 MSc and 30 PhD students. Recently, the Institute has developed state-of-the-art infra-structure and collaborating closely with other national and international agencies in emerging areas of rice research. The Institute is working on to develop and popularize super-yielding (more than 10 t ha^{-1}) varieties and agro-technologies for higher productivity, profitability, climate resilience and sustainability of rice farming.

1. INTRODUCTION

Rice, the world's most important food crop, is the staple food for about four billion people i.e., half of the humankind on the planet (Table 1). Rice fields cover around 160 million hectares in a wide range of climatic conditions spanning from 44°N in North Korea to 35°S in Australia. It is cultivated from 6 feet below sea level (such as in Kerala, India) to 2700 feet above sea level in the Himalayas. The crop occupies a significant position in the culture and heritage of many Asian countries.

Rice is staple food for about 800 million population of India (Table 1). It plays a major role in diet, economy, employment, culture and history. It is the staple food for more than 65% of Indian population contributing approximately 40% to the total foodgrain production, thereby, occupying a pivotal role in the food and livelihood security of people. India grows rice in 43 million ha with production of 112 million tons of milled rice and average productivity of 2.6 t

Table 1. Global and Indian scenarios of rice.

Parameters	World	India
1. Production (Mt)	500 (milled rice), 750 (paddy), 1875 (residues)	112 (milled rice), 170 (paddy), 425 (residues)
2. Feeding people (billion)	4 (56% of population)	0.8 (65% of population)
3. Area (Mha)	166 (10% crop land)	43 (22% crop land)
4. Grown by families (million)	144 (25% of farmers)	67 (56% of farmers)
5. Livelihood to rural poor (million)	400 (40% of poor)	150 (40% of poor)
6. Annual value (US$ billion)	206 (13% of crop value)	53 (17% of crop value)
7. Irrigation wateruse (km^3 yr^{-1})	880 (35% of total)	200 (29% of total)
8. Fertilizer use (Mt yr^{-1})	25 (15% of total)	6.5 (37% of total)
9. Methane emission (Mt yr^{-1})	25 (12% of agriculture)	3.5 (18% of agriculture)

Source: Updated from Pathak et al. (2018b) ha^{-1}. The crop is grown in highly diverse conditions ranging from hills to coasts. Primarily a *kharif* crop, it is cultivated round the year in one or the other parts of the country. Area under rice has remained almost unchanged over the years, but production has increased more than five times (Fig. 1). With this, India has not only achieved self-sufficiency in rice but also produces surplus to export. The leading rice producing states are West Bengal, Uttar Pradesh, Punjab, Odisha, Andhra Pradesh, Bihar and Chhattisgarh. About 40% of the rice area in India is rainfed and more than 70% of which is in eastern India. Out of the total rainfed area, 23% are rainfed upland and 77% are rainfed lowland. The entire rainfed upland and 52% rainfed lowlands are drought prone. About 17% of rainfed lowlands are flood prone.

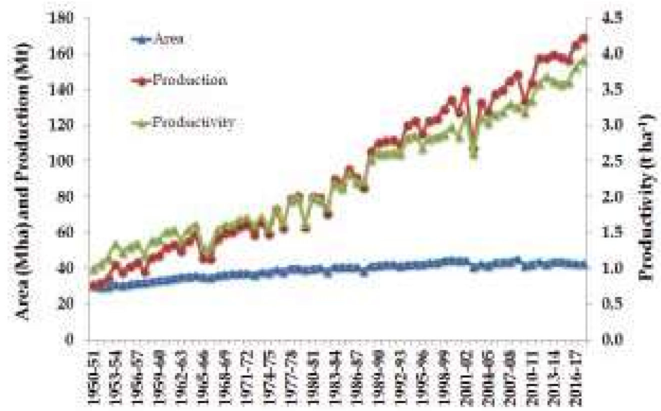

Fig. 1. Area, production and productivity of rice in India over the years.

Sustainable rice production is the key to achieving Sustainable Development Goals (SDGs), particularly for country like India (Fig. 2). We need to enhance productivity, profitability, input use efficiency and climate resilience in rice systems to achieve the SDGs.

ICAR-National Rice Research Institute (NRRI) is a premier research and development institute in the country. It is located at Cuttack about 35 km from Bhubaneswar airport and 7 km from the Cuttack railway station on the Cuttack-Paradeep State Highway. The institute lies approximately between 85^{0}55’48" E to 85^{0}56’48" longitudes and 20^{0}26’35" N to 20^{0}27’35" N latitudes with the general elevation of the farm being 24m above the MSL. The annual rainfall at Cuttack is 1200 mm to 1500 mm, received mostly during June to October (*kharif or wet season)* from the southwest monsoon. Minimal rainfall is received from November to May (*rabi* or *dry* season). The administrative arrangements of the Institute is presented in Fig. 3.

The Institute works on genetic improvement, production, protection, physiology and biochemistry and promotion of rice crop, which feeds more than half of the world population. The Institute, established in the year 1946 as a consequence Bengal Famine caused by the pathogen *Helminthosporium*

Fig. 2. Rice and Sustainable Development Goals (SDGs).

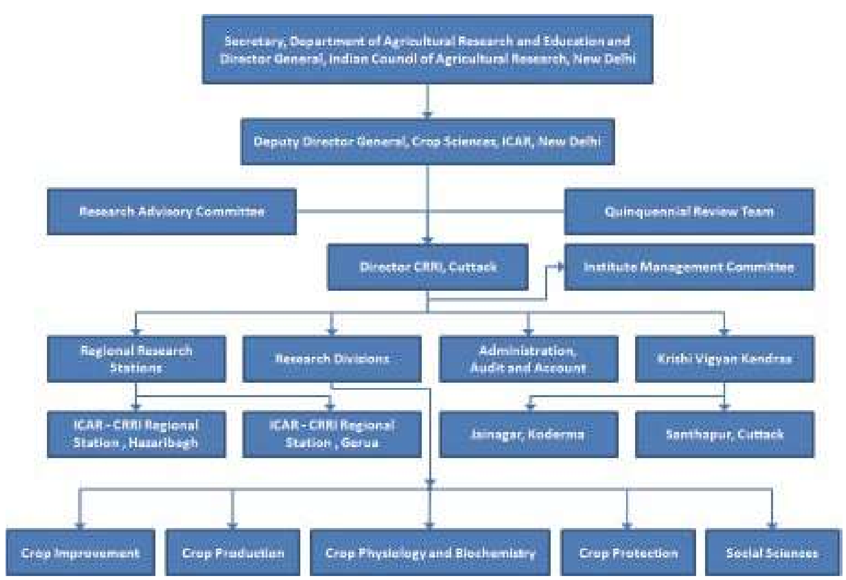

Fig. 3. Organogram of ICAR-National Rice Research Institute, Cuttack, Odisha.

oryzae (now *Bipolaris oryzae*), has got a significant place in the national history for its significant contributions in Green Revolution and ensuring national food security and enhancing farmers income. The year 2019 marks the 73rd year of the institute's journey towards a seasoned research institute which has evolved itself during its long odysseys and served immensely to the global and national interests. The 73 years long odyssey of National Rice Research Institute amount to development of rice varieties and various technologies for production and protection of rice crop, resource conservation, climate resilience, environmental conservation, biodiversity conservation, farm mechanization, human resource development, information and communication technologies and others, which are adjuvant to many of the national and global programs. The chapter highlights the significant achievements and impacts of the institute and its aspiration in years to come. The details of activities, achievements and aspirations have been presented in the respective chapters.

2. VISION, MISSION AND THRUST AREAS OF RESEARCH

The vision of the Institute is to ensure sustainable food and nutritional security and equitable prosperity of our Nation through rice science. It works with the mission to develop and disseminate eco-friendly technologies to enhance productivity, profitability and sustainability of rice cultivation. The mandates of the Institute include the following:

- Conduct basic, applied and adaptive research on crop improvement and resource management for increasing and stabilizing rice productivity in different rice ecosystems with special emphasis on rainfed ecosystems and the related abiotic stresses.
- Generation of appropriate technology through applied research for increasing and sustaining productivity and income from rice and rice-based cropping/farming systems in all the ecosystems in view of decline in per capita availability of land.
- Collection, evaluation, conservation and exchange of rice germplasm and distribution of improved plant materials to different national and regional research centres.
- Development of technology for integrated pest, disease and nutrient management for various farming situations.
- Characterization of rice environment in the country and evaluation of physical, biological, socio-economic and institutional constraints to rice production under different agro-ecological conditions and farmers' situations and develop remedial measures for their amelioration.

- ❖ Maintain database on rice ecology, ecosystems, farming situations and comprehensive rice statistics for the country as a whole in relation to their potential productivity and profitability.
- ❖ Impart training to rice research workers, trainers and subject matter/ extension specialists on improved rice production and rice-based cropping and farming systems.
- ❖ Collect and maintain information on all aspects of rice and rice-based cropping and farming systems in the country.

The Institute has the following thrust areas of research.

- ❖ Exploration of rice germplasm from unexplored areas and their characterization; trait-specific germplasm evaluation and their utilization for gene discovery, allele mining and genetic improvement.
- ❖ Designing, developing and testing of new plant types, next generation rice and hybrid rice with enhanced yield potential.
- ❖ Identification and deployment of genes for input use efficiency, tolerance to multiple abiotic/biotic stresses and productivity traits.
- ❖ Intensification of research on molecular host parasite/pathogen interaction and understanding the pest genomes for biotype evolution, off-season survival and ontogeny for devising suitable control strategy.
- ❖ Developing nutritionally enhanced rice varieties with increased content of pro-vitamin A, vitamin E, iron, zinc and protein.
- ❖ Development of climate resilient production technologies for different rice ecologies; designing and commercialization of efficient farm machineries suitable for small farms.
- ❖ Development of cost effective and environmentally sustainable rice-based integrated cropping/farming systems for raising farm productivity and farmer' income.

3. ACHIEVEMENTS OF NRRI

3.1. Ensuring national food security

The Institute has released 133 varieties and hybrids of rice so far (Fig. 4). About 13% of the rice varieties released in the country have been released by NRRI. But the farmers have accepted more of NRRI varieties. Currently, 55 NRRI varieties out of 250 in the country i.e., 20% are indented for breeder seed production through Department of Agriculture and Cooperation (DAC), Ministry of Agriculture and Farmers' Welfare, Govt. of India. The Institute produces about 120 tons of breeder seed annually out of 460 tons i.e., 26% of the requirement of the country (Fig. 5).

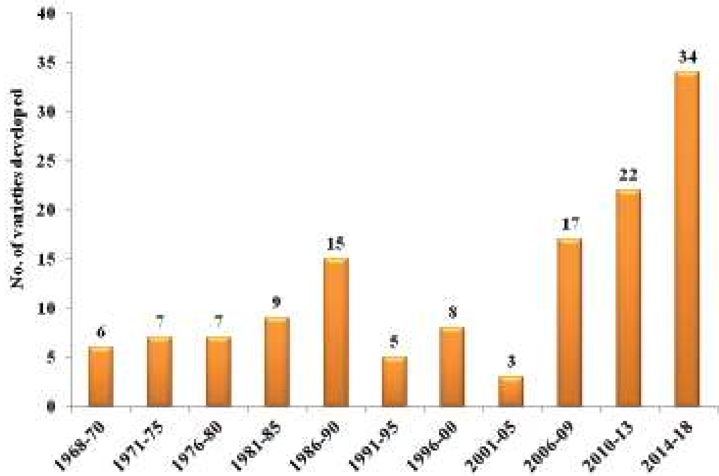

Fig. 4. Varieties developed by ICAR-National Rice Research Institute, Cuttack over the years.

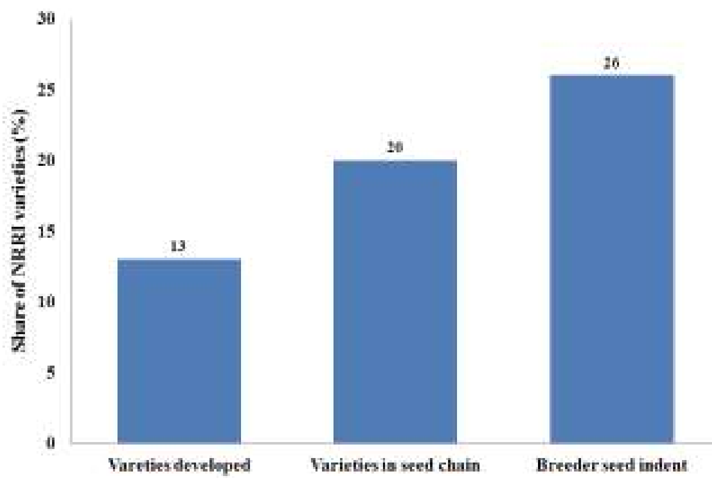

Fig. 5. Share of NRRI varieties to total rice varieties in India.

3.1.1. NRRI varieties cover 18% area and 17% production of rice in India

It was estimated that the area covered by NRRI varieties in the country during 2017-18 based on the amount of quality seeds provided to the farmers through the following ways: breeder seed indent to the DAC; breeder seed and truthfully-labeled seed supplied by the NRRI farm; participatory seed production by NRRI; seed distributed in various programmes and projects of the Institute; front-line demonstrations and on-farm testing; seed of NRRI varieties supplied by the private entrepreneurs and disseminated from farmers to farmers. A survey was conducted during July-August, 2018 to validate the estimated areas under NRRI varieties. The District Agriculture Officers of Odisha and West Bengal provided the data on coverage of NRRI varieties in their respective districts. Additionally, an expert consultation was organized to validate the estimates.

Out of 43 Mha, NRRI varieties covered about 8.0 Mha i.e., 18.0% of rice area of the country during 2017-18 (Fig. 6). The leading states growing NRRI varieties are West Bengal (2.25 Mha), Odisha (2.17 Mha) and Assam (0.97 Mha). Other states with sizable area under NRRI varieties include Uttar Pradesh, Tamil Nadu, Andhra Pradesh, Bihar, Jharkhand and Chhattisgarh. The NRRI varieties have been popular among the farmers and even become ruling varieties in some of these states. For example, Shatabdi is a leading variety in West Bengal, Pooja in Odisha, Naveen in Assam and Tripura, and Savitri in Tamil Nadu. Annual production of rice with NRRI varieties in the country is 18.5Mt i.e., 17% of total rice production of the country.

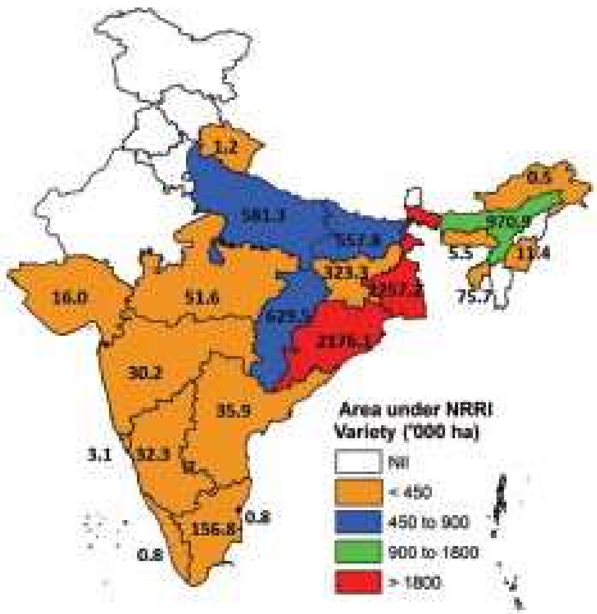

Fig. 6. Area covered by NRRI varieties in India.

3.2. *Strengthening nutritional security*

Although rice is deficient in protein (7-8%), due to higher digestibility and better nutritive value of glutelins, major fraction of seed protein of rice is nutritionally superior to other cereals. Therefore, the impact of increasing the protein content in rice would be enormous, particularly in the scenario where more than one third of world's children are affected by protein-energy malnutrition (PEM). In addition, if rice varieties are fortified with zinc along with high protein, it helps to combat the Zn-malnutrition of people dependent on rice-based diet.

3.2.1. High protein, nutrient-rich rice varieties of NRRI

Using a high grain protein content donor (ARC10075) several introgression lines in the high yielding varieties such as Swarna and Naveen were developed by ICAR-National Rice Research Institute, Cuttack and tested in multi-locations. Most of them had significantly higher level of lysine, threonine, leucine, isoleucine, valine, phenylalanine, alanine, proline, glutamic acid, arginine and total amino acid as compared to recurrent high yielding parents. Among them a high yielding (4.5 t ha^{-1}) derived lines in Naveen background, CR Dhan 310 has been released as the first biofortified high protein (10.2%) rice variety by Central Variety Release Committee (CVRC) and notified for cultivation in Odisha, Uttar Pradesh and Madhya Pradesh.

Subsequently, another nutrient-rich variety, CR Dhan 311 (Mukul) with high protein (10.1%) and moderately high Zn (20 ppm) content has been released by the State Variety Release Committee (SVRC), Odisha and notified by Govt. of India in 2019. These high protein varieties had significantly higher glutelin content than Naveen. Using SNP genotyping of a backcross derived mapping population from ARC10075/Naveen, a consistent QTL (*qGPC1.1*) on chromosome 1 was identified over the environments, encoding a glutelin family protein. High protein varieties CR Dhan 310 and CR Dhan 311 also contained this QTL. High protein rice varieties can be easily distinguished from the low protein recurrent parent, like Naveen with the help of the Xanthoproteic test. Both the varieties have high head rice recovery (>60%) and acceptable grain and cooking quality with intermediate amylose content (22-24%). The high protein varieties have been well accepted by the farmers due to their resemblance for grain and plant type with its recurrent parent, Naveen, a popular variety in Odisha, West Bengal, Tripura, Assam, Jharkhand and Goa.

3.2.2. CR Dhan 310 (IET24780: CR2829-PLN-37)

It was released at national level as first high protein rice variety for the states of Odisha, Uttar Pradesh and Madhya Pradesh. It has medium duration (120-125 days), semi-dwarf plant type (110 cm) with medium slender and good grain quality (Table 2). It is suitable for irrigated and favorable shallow rainfed areas. National average of grain yield is 4.5t ha^{-1} and it contains average 10.2% protein in polished rice.

3.2.3. CR Dhan 311 (Mukul), IET 24772: CR2829-PLN-100

It was released at national level as nutrient rich rice and notified by Govt. of India. It has high protein content (10.1%) and moderately high level of Zn content (20 ppm) in 10% polished rice. It has medium duration (120-125 days), semi-dwarf plant type (115 cm) with long bold grain and good cooking and eating quality (Table 2). It is suitable for irrigated and favorable shallow rainfed areas. National average of grain yield is 4.3 t ha^{-1} and in Odisha it is 5.5 t ha^{-1}.

Table 2. Characteristics of CR Dhan 310 and CR Dhan 311.

Characters	CR Dhan 310	CR Dhan 311
Plant height (cm)	110	115
Plant type	Semi-dwarf	Semi-dwarf
No. of effective tillers/plant	12	10
No. of panicle m^{-2}	311	256
Days to 50% flowering	97	95
Seed to seed duration (day)	125	123
Panicle type	Compact	Compact
Panicle exertion	Well exerted	Well exerted
Awning	Absent	Absent
Apiculuscolour	Straw	Straw
Lemma paleacolour	Straw	Straw
1000 grain weight (g)	24	26
Kernel length (mm)	5.49	6.26
Kernel breadth (mm)	2.06	2.21
L/B ratio	2.66	2.83
Grain type	Medium slender	Long bold
Chalkiness	Very occasionally	Very occasionally
Milling recovery (%)	71.9	69.0
Head rice recovery (%)	64.7	60.1
Alkali spreading value	5.0	5.0
Amylose content (%)	25.1	23.7
Gel consistency (mm)	37	24

Source: Chattopadhyay et al. (2019)

3.3. Increasing farmers' income

Rs. 48,643 crores gross return i.e., 13% of India's gross return from rice is generated with NRRI varieties. Annual incremental production of rice with NRRI varieties is 1.4 Mt with incremental gain in farmers' income is Rs. 2,432 crores (Pathak et al., 2018a).

3.4. Enhancing climate resilience

Considering the challenges of climate change, NRRI has developed rice varieties which perform better under different biotic and abiotic stress situation and thereby minimizes farmers' risk. Some of these climate-smart varieties are given in Table 3.The Institute developed CR Dhan 801 and CR Dhan 802 possessing submergence as well as drought tolerance ability in the background of mega-variety 'Swarna'. Globally these varieties are unique and developed first time in rice research. These have been notified for release by the Govt. of India on 19th February, 2019.

Table 3. Climate-smart rice varieties released by NRRI, Cuttack.

Stress	Variety	Duration (days)	Grain type*	Yield (t ha^{-1})
Submergence &drought	CR Dhan 801	140-145	SB	6.3
	CR Dhan 802 (Subhas)	142	SB	6.5
Drought	Satyabhama	110	MS	2.3-4.7
	Ankit	110	MS	3.98
	Sahbhagi Dhan	105	LB	3.5-4.0
	IR 64 Drt 1	120	LS	5.5-6.0
Submergence	Swarna-Sub1	145	MS	5.2
	Varsha Dhan	160	LB	3.5-4.0
	CR Dhan 502 (Jayanti Dhan)	135	LS	4.0
	CR Dhan 500	155	MS	4.0
	CR Dhan 408	160	LB	4.5
	CR Dhan 409	160	LS	5.0
	Jalamani	160	MS	4.6
Salinity	Lunishree	145	LS	4.75
	Luna Suvarna	150	MS	3.5-4.0
	Luna Sankhi	110	MS	4.6
	Luna Barial	150	SB	4.1

**SB, Short Bold; MS, Medium Slender; LB, Long Bold; LS, Long Slender*

The varieties CR Dhan 801 and CR Dhan 802 contain *Sub1* gene for submergence tolerance and *qDTY1.1*, *qDTY2.1* and *qDTY3.1* yield QTLs under drought stress, which were stacked in the background of Swarna variety using marker-assisted backcross breeding. Genome recovery of recipient parent was more than 95%. They are weakly photosensitive with average maturity duration of 140-145 days. The varieties are resistant to infestations of stem borer (both dead heart and white ear), leaf folder, plant hoppers and case worm while moderately resistant to bacterial blight, sheath rot and rice tungro virus. These have good hulling, milling and head rice recovery as like the recipient parent Swarna and possess intermediate amylose content, short bold grain and other desirable grain quality parameters. Cultivation practices, pest and disease control as well as harvesting and processing of these varieties are similar to other commonly grown high-yielding varieties of rice.

3.4.1. Climate-smart Rice Variety CR Dhan 801 (IET 25667)

The variety was developed from the breeding materials of cross IR81896-B-B-195 / 2* Swarna-Sub1 // IR91659-54-35. The variety has been released for the states of Odisha, West Bengal, Uttar Pradesh, Andhra Pradesh and Telangana. It has short bold grain with a test weight of 20.5 g (Table 4). It gives about 6.3 t ha^{-1} yield under normal condition and 4.0 t ha^{-1} under submergence while 2.9 t ha^{-1} under drought conditions.

3.4.2. Climate-smart Rice Variety CR Dhan 802 (Subhas: IET 25673):

The variety was developed from the breeding materials of cross Swarna-Sub1*4/IR81896-B-B-195. This has been christened 'Subhas' after Cuttack-born freedom fighter and illustrious son of India Netaji Subhas Chandra Bose. The variety has been released for the states of Madhya Pradesh and Bihar. It has short bold grain with a test weight of 19.0 g (Table 4). It produces an average yield of 6.5 t ha^{-1} under normal condition and 4.3 t ha^{-1} under submergence while 2.3 t ha^{-1} under drought conditions.

Table 4. Characteristics of climate-smart rice varieties CR Dhan 801 and CR Dhan 802.

Character	CR Dhan 801	CR Dhan 802
Plant height	87	102
Flowering	112	110
Maturity duration	140-145	140-145
1000-grain weight (g)	20.5	19.0
Lodging	Non-lodging	Non-lodging
Panicle type	Intermediate	Intermediate
Panicle exertion	Well-exerted	Well exerted
Awn	Awnless	Awnless
Hulling (%)	79.6	77.85
Milling (%)	69.9	70.2
Head rice recovery (%)	66.2	64.25
Kernel length (mm)	5.15	5.0
Kernel breadth (mm)	2.22	2.16
L/B ratio	2.31	2.31
Grain type	SB	SB
Grain chalkiness	VOC	VOC
Alkali spreading value	4.0	4.5
Amylose content (%)	25.13	25.0
Gel consistency (mm)	39	39.5

Source: Pradhan et al. (2019)

3.5. Water saving rice varieties

The Institute has developed "aerobic" rice varieties, which can grow with less water and conserve a significant amount of water with significantly higher yields. Some of the water-saving aerobic rice varieties of NRRI are listed in Table 5.

Table 5. Water-saving, aerobic rice varieties released by NRRI, Cuttack.

Variety	Duration	Grain type*	Yield (t ha^{-1})
CR Dhan 200	118	SB	4.5
CR Dhan 201	118	LS	4.0
CR Dhan 202	115	LB	4.0
CR Dhan 203	110	LS	4.0
CR Dhan 205	110	SB	4.1
CR Dhan 206	115	SB	4.0
CR Dhan 207	115	MS	4.0
CR Dhan 209	115	LS	4.0

**SB, Short Bold; MS, Medium Slender; LB, Long Bold; LS, Long Slender*

3.6. Fertilizer saving technologies

Customized Leaf Colour Chart (CLCC) was developed by NRRI to apply nitrogen fertilizer at right time and right dose to reduce loss of N and increase its use efficiency. The tool is getting popular in different states of the country. The Institute also developed urea briquette and its applicator, which places the briquettes at a suitable place in soil thereby reducing loss.

3.7. Resource conserving technologies

The Institute has been in the forefront of developing and refining resource conservation technologies for lowland rice in eastern India. Many of the earlier works of the NRRI was focused on improving the use efficiency of the natural resources, increasing productivity of rice and reducing GHG emission along with building up of carbon by developing the technologies related to direct seeding, system of rice intensification, cropping system research involving legume crops, rice residue management, minimum tillage and zero tillage both under transplanted and direct seeded conditions. The institute also worked upon designing and development of farm equipment for small and medium farmers for sowing and weeding.

3.8. Integrated farming system models

The Institute has developed the concept, design and production technology of rice-fish diversified farming system for improvement of farm productivity, total income and employment in rainfed lowlands. The technology has been adopted by farmers of Odisha, West Bengal, Eastern Uttar Pradesh and Assam. The Institute has three adoptable models: (1) Rice-fish diversified farming system for semi-deep (upto 50 cm water depth), (2) Multi-tier rice-fish horticulture crop based farming system for deep water (up to 1 m or more water depth) and (3) Rice-based integrated farming system for irrigated lowlands. These rice-based farming systems models have been validated and upscaled in farmers field through farmers participatory mode (FPM). These systems with higher land and water productivity ensure food, nutrition and livelihood security for the farming communities, particularly for the small and marginal farmers along with employment generation through engagement of family members in the farming.

Interactions among the rice and non-rice enterprises for increased productivity, bio resource flow, resource recycling and environmental impact has been assessed. Fish productivity was more when integrated with rice rather than sole fish in tank. It was further increased with wider spacing of rice over closed spacing or random planting. Continuous addition of fish excreta in the rice fish system increased the organic carbon of the soil. Emission of methane (CH_4) increased with fish in rice field but nitrous oxide (N_2O) fluxes were relatively low during the entire cropping period except towards maturity when the water recedes living the field dry. Fish acts as effective bio-control agent for major rice pests like hoppers, case worm, stem borer, gall midge, leaf folder and snails. Insecticides (phosphamidon, monocrotophos, quinalphos, ethofenprox, carbofuran) though did not kill the reared fishes (common carp, catla, mrigal), instantly, but showed varying degree of deleterious effects on growth, survival and yield. Efficient species of fish are *Ctenopharyn godonidella*, *Puntius gonionotus, Oreochromis mossambicus, Trichogaster pectoralis* and *Cyprinus carpi* for controlling weeds directly by feeding or indirectly increasing water turbidity, doing mechanical injury and constant flooding.

Sunflower is one of the most promising crops after rice with 2-3 limited irrigations by utilizing the water stored in pond.Watermelon was another promising crop in this system when sown during middle of January in pits with spot irrigation. Eastern India is having potential to harvest rainwater during peak monsoon period (July-September) that stored in the pond refuge can help to grow several winter vegetables like pumpkin, bitter gourd, lady's finger and chilli either on bunds or in main rice field. Other crops viz., pulses like black gram and green gram or oilseeds viz., sunflower, groundnut and sesamum can be grown during the dry season (January-early April) with limited irrigation by stored water.

3.9. Biodiversity conservation and utilization

The institute has preserved e"35000 rice genotypes, which are collected from different parts of the country. The institute is not only involved in genotype collection and preservation, but also in their rejuvenation and characterization. A total of around 53,311 germplasm were rejuvenated and characterized through morphological analysis. Also, the unique germplasms were identified and registered by the institute with Plant Germplasm Registration Committee (PGRC), NBPGR, New Delhi having the unique trait of tolerance to both vegetative and reproductive stage drought stress. Salkathi (IC 0256801), a local landrace was registered as Brown Plant Hopper (BPH) resistant rice germplasm and also to multiple insect pests of rice besides BPH.

3.10. Crop protection technologies

Pest and diseases are the regular visitors to crops, which accounts for a significant loss to the farmer and crops as well. The Institute standardized several processes and formulations i.e., artificial inoculation method of false smut pathogen isolation; a screening technique for rice bakanae disease; dose of riboflavin to induce resistance in rice against bacterial blight; DNA barcoding of several insect pests of rice and their natural enemies; formulated phosphine fumigant against stored grain pest. The institute conceptualized some green products and converted them into technologies for crop protection. These include alternate solar energy light trap; silver nano particles (Ag-NPs) effective against *Xanthomonas oryzae* and *Rhizoctonia solani* and *Trichoderma* sp., a growth promoter with ability to kill soil and seed borne pathogens. Resistant genotypes for bakane (FL-478, ASD-18, Vandana); sheath blight (CR-1014); BLB (Jalamagna); WBPH (AC34222, AC34264, AC38468 and AC42425); BPH (Salkathi and Dhobanumberi) and gall midge (Aganni and INRC 3021) have also been identified.

3.11. Farm mechanization

ICAR-NRRI Cuttack is the strong proponent of farm mechanization in the country and designed several farmer friendly and cost-effective farm equipment for different agricultural operations from sowing to harvesting and processing (Fig. 7). Various small agricultural equipment developed by the institute have tremendous potential to mechanize the small and marginal holdings of the country due to their handy nature and nominal costs.

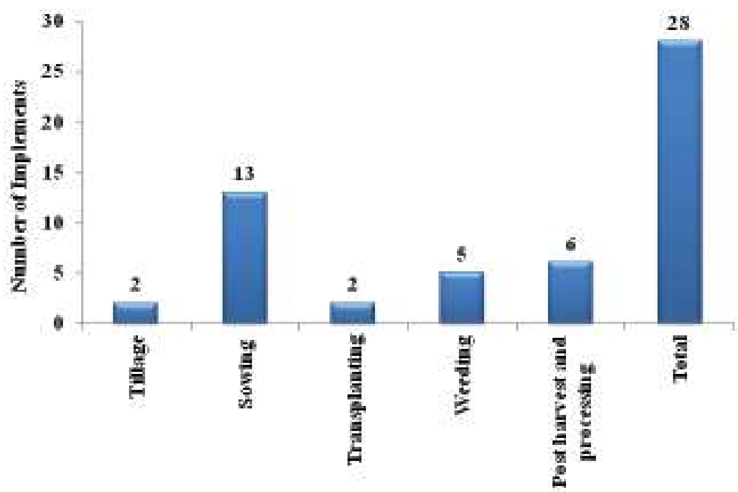

Fig. 7. Farm implements developed by NRRI for different agricultural operations.

3.12. Information and communication technology

Today the world is following the digital order, which has emerged as a prime driver for information and knowledge sharing. In line with the Government of India's "Digital India" drive, the Institute has developed an android app named as "riceXpert" with due consideration of farmers' needs. The "riceXpert" assists farmers not only in getting information on nutrient deficiency and toxicity, weed, pest and disease management but also provides information on accurate doses of fertilizers and pesticides via fertilizer and pesticide calculator embedded in it. Also, the app provides information on farm equipment for different operations and updates them on market platforms for inputs and produce. The riceXpert is available in three different languages namely Hindi, Odia and English for better penetration among the rural masses.

3.13. Making rural India self-sufficient in seed sector

Indian agriculture surprises the world by its stark contrast. Although it stood as a global leader in agricultural production, its productivity in many crops lies much below the world average. Unavailability of quality seeds with the farmers is one among the many reasons behind it. Therefore, the institute has conceptualized, developed and implemented a Self-sufficient Sustainable Seed System for Rice (4S4R) model with a prime intent to make rural India self-sufficient in the seed sector.

3.14. Microbial technologies

The Institute has developed microbial formulations for endophytic and rhizospheric nitrogen fixers, liquid formulations of two phosphates solubilizing bacteria (PSB), two exo-poly-saccharide producing bacteria and bio-control agents of soil-borne diseases. Technology capsule using native arbuscular mycorrhiza supportive crop-culture components has been developed for upland DSR to improve P nutrition.

3.15. Greenhouse gas emission, climate change adaptation and mitigation

Greenhouse gases emissions and climate change related works were initiated at NRRI since 1980s. Initial works mostly concentrated on estimation of methane (CH_4) emission from rice-based production systems and mitigation options of CH_4 emissions. Primarily, rice-rice, rice-pulse, rice-oilseeds and rice-fish systems were studied; both under rainfed and irrigated conditions. In general CH_4 emission was significantly low in rainfed as compared to irrigated system. On aerobic system, there was drastic reduction of CH_4 emission. Emission of nitrous oxide (N_2O) and carbon dioxide (CO_2) were mostly studied at ICAR-NRRI, Cuttack during 2004 onwards. Nitrous oxide emission in rice based system in eastern India varied from 0.22 to 1.75 kg ha^{-1}. In general low N_2O emission occurred in rice production system in lowland ecology primarily due to less favorable oxic-anoxic cycle, low N application, and continuous submergence. Carbon dioxide emission was reported in the range of 1000-1450 kg ha^{-1}.

4. HUMAN RESOURCES DEVELOPMENT

The institute provides training to farmers, students and officers of different national and international institutes and thereby assists them in their capacity building. The given figure provides a bird's eye view on a number of capacity building programmes organized and their beneficiaries in the last five years.

Currently, we have 50 MSc and PhD students enrolled among which 8 students are working with DST Inspire fellowship. From this year, NRRI-IRRI student fellowship programme has been initiated, in which IRRI will provide fellowships to 15 MSc and 10 PhD students. The institute observes Special Days, organizes workshops, national and international symposia and other discussion and promotional activities (Fig. 8).

Fig. 8. Number of training programmes and beneficiaries.

5. ACHIEVEMENTS IN BASIC SCIENCES

Additionally, the institute has attained eloquent achievements in basic sciences. Some of these achievements are hybrids and parental line improvement, development of molecular markers, development of genomic resources through resequencing, gene cloning and standardization of various scientific methods and testing of germplasms for different traits. Recently, the Institute identified varieties (Swarna and Mahsuri, for example) with intermediate glycemic index (GI) value (~60) and developed improved and reproducible *in vitro* method for determination of GI in rice. Explained the mechanism for submergence tolerance in FR 13A, Kalaputia and Swarna-Sub1 having highest volume of leaf gas film on both leaf surfaces. Na^+ and K^+ transporters for reproductive stage salt tolerance in rice have also been identified. Six ARC accessions (ARC 7336, ARC 7343, ARC 10260, ARC 10304, ARC 10314 and ARC 11124) and five high yielding varieties (Kalyani2, IR 64 MAS, Kalinga II, CSR 18 and Krishnahamsa) were identified as drought tolerant donors.

6. PUBLICATIONS

The Institute, in recent years, has made significant progress in terms of number and quality of research publications (Fig. 9). For the year 2018-19, average NAAS score of NRRI publications is 7.01 (average Impact Factor1.01). No. of publications per scientist per year is 1.88. Besides, several books, technical bulletins and leaflets have been published over the years. The Institute regularly publishes its Annual Report and Newsletter, which is published quarterly.

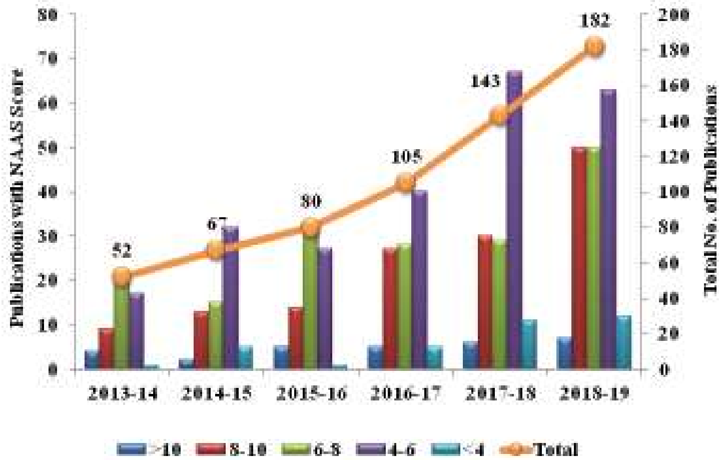

Fig. 9. Research publications of NRRI over the years.

7. SIGNIFICANT OUTCOMES

The Institute has attained significant milestones in each domain it ventured during its odysseys of 73 years. Over the years, the achievements of the institute have made significant impacts on the national agricultural canvass.

- Increased rice production in the country: Production of rice has increased to an all-time high of 112 Mt during 2017-18. Landmark NRRI varieties such as Mahsuri, Padma, Ratna, Savitri (CR 1009), CR 1014, Pooja, and Naveen have contributed immensely in increasing rice production in the country.
- Enhanced climate-resilience of rice production: The climate-resilient varieties (CR Dhan 801, CR Dhan 802, Sahabhagi Dhan) and management practices developed by the Institute ensured stability in rice production even during the adverse climatic years.
- Increased nutrient use efficiency and reduced greenhouse gas emission: Resource-conserving technologies involving coated fertilizer and customized leaf colour chart enhances 10-15% nitrogen use efficiency; decreases about 15-20% emission of greenhouse house and increases yield by 0.5-1.0 t ha^{-1}. The technology can reduce urea application by 25% and save up to Rs. 1500 crore in the fertilizer subsidy per annum.
- Increased employment and income of farmers: About 6.7 crore farm-families are dependent and 16 crores labourers are employed in cultivating rice in

the country. The rice-based farming system developed by the Institute provides 200-300 man-days per ha per annum. The rice value-chain involving all the stakeholders (farmers, self-help groups, seed producers, millers, Institute) and farmers' participatory seed production systems have increased productivity and income of farmers.

- Developed human resources in rice science: Every year about 75 students carry out their post-graduate research work in the Institute. It organizes training of State Govt. officials and progressive farmers of various states. The students, researchers and state Govt. officials trained in this Institute are catering to the needs of human resources in the country.

8. ASPIRATIONS OF NRRI

The current agricultural sector is encountered with a plethora of emerging challenges, which necessitate any scientific organization associated with the concerned sector to accommodate for new challenges and evolve itself to answer the emerging questions. In this context, the institute has aspired to accommodate for the looming problems of the future. The Institute is working on to develop and popularize super-yielding (more than 10 t ha^{-1} paddy) varieties and agro-technologies for higher productivity, profitability, climate resilience and sustainability of rice farming. Some of the aspirations of the Institute are given below.

- Enhancing rice productivity: It is estimated that the demand for rice will be 121 Mt by the year 2030, 130Mt by 2040 and 137 Mt by 2050. In order to achieve this, the production per unit area needs to be increased. However, due to competition from other crops, demand from urbanization and industrialization, there may be a decline of rice area by 6-7 Mha by 2050. Under such a scenario, the productivity target would be about 3.9 tha^{-1} milled rice.

- Value addition to rice product and its bi-products: Food habits are rapidly changing due to increased income and access to diversified food basket. In order to meet the future demand, NRRI needs to develop and popularise rice varieties suitable for bread making, speciality rice like diabetic rice, soak-n-eat rice, protein-rich, mineral rich rice, medicinal rice, and aromatic rice. Besides, the straw, husk and bran have to be efficiently utilized for commercial purposes for generation of high income through agro-industry ventures. Strengthening of the rice value chain in different dimensions like seed chain, grain chain and value chain for processed rice-based products would be other areas of focus.

- Enhancing water, nutrient, energy and labour use efficiency:Currently, 2500-3500 litre of water is used to produce 1 kg of rice in India. In order to meet the challenges of declining water resource base and competition from other sectors, the water productivity of rice needs to improve by bringing down the water productivity from the current level to the level of 2000 litres/kg of rice. Similarly, nitrogen use efficiency needs to be enhanced to 45-50% from current 35-40%; phosphorus use efficiency to 30-35% from current 20-25% in various rice production systems. In order to make rice cultivation as an efficient, competitive and profitable production system, the energy use efficiency has to be doubled from the current levels by deploying the modern resource conservation and energy efficient technologies. Rice production can remain a profitable proposition only if the current level of dependence on labour is reduced by one-third. This can only be achieved through mechanization of labour intensive components of rice farming, particularly in case of small farms.

- Climate resilient rice production technologies: Climate change impacts demand (i) adjustments in rice production methods and development of new rice strains that can withstand higher temperatures, (ii) developing multiple stress tolerant varieties that can withstand and perform under harsh climatic conditions, (iii) adoption of rice-based cropping system that is environment-friendly and has least environmental footprint, (iv) development of cultivation practices to maintain natural resource base and soil health for a sustainable rice production, (v) accelerating adaptation to climate change and reducing vulnerability of crop from risks and (vi) development and maintenance of synergy with producers and other stakeholders in a climate-smart framework for agricultural development that includes a range of innovative agricultural risk management measures. Development of genotype with multiple traits for abiotic and biotic stress tolerance; nutrient-rich and low glycemic index rice in a single genetic background would be desirable. Deployment of low greenhouse gas emission resource conservation technologies for reduced methane and N_2O emissions from rice fields would be essential for sustainable and ecologically safe rice farming.

- Tackling emerging pest problems in rice: Major thrust should be put forth to (i) identify multiple pest resistance genotypes, (ii) pest modeling and forecasting for timely pest management, (iii) to understand tri-trophic interaction of rice, pests and predators/parasites under climate change and (iv) to develop novel molecules and formulations for eco-friendly pest management.

- Networking and co-ordination for consolidation of gains: Space and information technology, virtual laboratories and classroom for communication and training from across the national and international institution required to be deployed for consolidating the gains in the field of rice science.

- Promotion of different rice varieties to new areas of the country: The NRRI rice varieties should have to be spread to newer areas of the country.

Institute's reach has to be expanded to the newer areas by promoting the recent rice varieties to different rice ecologies in other states.

- Breeding for demand-driven rice varieties: Evaluation of mismatch between quality parameters demanded by different stakeholders and quality parameters supplied by the existing varieties and varieties from the institute so that the mismatch can be bridged up for rapid expansion of NRRI rice varieties to different regions.
- Human Resource, Infrastructure and Skill Development: State of the art research facilities in the field of biotechnology, nanotechnology, climate science, soil and grain quality and toxicology will be strengthened at NRRI for basic/strategic and applied rice research, and impart training to create a pool of skilled manpower to handle R&D in rice.

References

Chattopadhyay K, Sharma SG, Bagchi TB and Mohapatra T (2019) CR Dhan 310 and CR Dhan 311: High Protein, Nutrient-Rich Rice Varieties of NRRI. ICAR-National Rice Research Institute, p. 1-4.

Pathak H, Pradhan SK, Parameswaran C, Mondal B, Jambhulkar NN, Tripathi R, Chakraborty M, Kumar GAK, Samal P and Sahu RK (2018a). Contributions of NRRI Rice Varieties to National Food Security and Farmers' Income. NRRI Research bulletin No. 16, ICAR-National Rice Research Institute, Cuttack, Odisha, 753006, India. pp 26+vi.

Pathak H, Samal P and Shahid M (2018b) Revitalizing rice-systems for enhancing productivity, profitability and climate resilience. In Pathak H et al. (Eds.) Rice Research for Enhancing Productivity, Profitability and Climate Resilience, ICAR-National Rice Research Institute, Cuttack, Odisha, pp 1-17.

Pradhan SK, Pandit E, Bose LK, Reddy JN, Pattanaik SSC, Meher J and Behera L (2019) CR Dhan 801 and CR Dhan 802: Climate-Smart Rice Varieties of NRRI. ICAR-National Rice Research Institute, p. 1-4.❄