National Rice Research Institute: Activities, Achievements and Aspirations

Editors

H Pathak, AK Nayak, D Maiti, GAK Kumar, JN Reddy, PC Rath, P Swain and R Bhagawati

ICAR-National Rice Research Institute
Cuttack 753 006, Odisha

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त्रिलोचन महापात्र, पीएच.डी.
एफएनए, एफएनएएससी, एफएनएएएस
सचिव एवं महानिदेशक

TRILOCHAN MOHAPATRA, Ph.D.
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FOREWORD

ICAR-National Rice Research Institute (earlier Central Rice Research Institute) in Cuttack, Odisha is the premier Institute of rice research in the country. Established in the year 1946 in the backdrop of the Great Bengal Famine, the Institute has steered groundbreaking research in development of high-yielding rice varieties that have contributed immensely to the achievement of self-sufficiency in rice production. It has contributed immensely in country's Green Revolution, ensuring food security and enhancing farmers' income. Till date the Institute has developed 133 high yielding rice varieties for different agro-ecologies. Out of 43 M ha of rice area, NRRI varieties covered about 8.0 M ha i.e., 18.0% of rice area of the country. Annual production of rice with NRRI varieties in the country is 27.8 million tons (Mt) and Rs. 48,643 crores gross return i.e., 13% of India's gross return from rice is generated with NRRI varieties.

For ensuring nutritional security, the Institute has recently released, first time in the world, two high-protein (more than 10% protein) rice varieties (CR Dhan 310, 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 to face the challenges of climate change.

In the field of basic sciences, the Institute has developed improved and reproducible *in vitro* method for determination of glycaemic index (GI) in rice and identified varieties with intermediate GI value. It has developed plant protection technologies, microbial formulations, customized leaf colour chart, machines for small and marginal farmers, and working on conservation agriculture, climate change, and assessment of carbon, water, nitrogen and energy footprints of rice systems. It has also developed alternate energy light trap, Trichoderma formulations and phosphine formulations for quarantine.

NRRI has developed a Mobile App 'riceXpert' to provide information to farmers in real time on insect pests, nutrients, weeds, nematodes and disease-related problems, rice varieties for different ecologies, farm implements for different field and post-harvest operations. The initiative "Mera Gaon Mera Gaurav" which has been launched to involve all the scientists of ICAR institutes and agricultural universities for effective and deeper reach of scientific farming to the villages is working very well in this Institute. Recently, new research infrastructure such as the Central Genomics and Quality Laboratory; Social Science Building, Administrative Building for Krishi Vigyan Kendra were established.

This publication on "National Rice Research Institute: Activities, Achievements and Aspirations" published by ICAR-National Rice Research Institute captured the achievements and aspirations of NRRI on rice research and development over the years. It highlights the genesis and evolution of NRRI and its achievements and aspirations in the fields of crop improvement; crop production; crop protection; physiology and biochemistry of rice crop; upland rice; lowland rice; human resources development and socio-economic analysis and impacts. The chapters comprehensively present the background of each new science and technology developed for effective management of rice crop in favorable and unfavorable ecologies and to address the emerging challenges of natural resources degradation and climate change.

I hope the publication will be useful for the policy makers, extension personnel, researchers, scholars and students involved in rice research. I congratulate the editors and authors for their contributions in bringing out this useful publication.

(T. MOHAPATRA)

Dated the 23rd May, 2019
New Delhi

Preface

Rice is the staple food for more than two thirds of Indian population contributing more than 40% to the total food grain production, thereby occupies a pivotal role in the food and livelihood security of people. The crop is grown under varying climatic and soil conditions under diverse ecologies spread over about 43 million hectares. Over the last six decades the productivity has increased by about five times and this growth in agricultural production has come mainly from yield increase and to a lesser extent from area expansion, which is projected to decline further. Rice productivity has to be further increased by using all the ingenuities of agricultural science. Increasing productivity, however, has become quite challenging in recent years due to degradation in natural resources such as soil, water and air along with shortage of labour and emerging problem of climate change. Future production of rice have to be done using less land, water and labour through more efficient, environment-friendly production systems that are more resilient to climate change and environment-friendly.

ICAR-National Rice Research Institute in Cuttack played a significant role in the agricultural development not only in Eastern region but at the national front. It was established in the year 1946 in the backdrop of the Great Bengal Famine of 1943. Since its inception, the Institute has been charged with the responsibility of conducting research on all aspects of rice and transfer of technology. The Institute has steered ground breaking research in development of high-yielding rice varieties that have contributed immensely to the achievement of self-sufficiency in rice production.

The objective of the publication '***National Rice Research Institute: Activities, Achievements and Aspirations'***, *published by ICAR-National Rice Research Institute (NRRI), Cuttack, Odisha is* to review the scientific and technological achievements of the Institute, assess its impacts on productivity, profitability and climate resilience of rice systems; and outline future plan and aspirations of the Institute.

Eleven chapters of the book cover the journey of NRRI since 1946 and salient achievements and impacts in national and international arenas. In general, the authors have captured the activities, achievements and aspirations of NRRI on rice research and development over the years. Specifically, the chapters highlight the genesis and evolution of NRRI; a few nostalgic anecdotes in the memory lane; and activities, achievements and aspirations in the fields of crop improvement; crop production; crop protection; physiology and biochemistry of rice crop; upland rice; lowland rice; human resources development and socio-economic analysis and impact assessment. The chapters comprehensively present the background of each new science and technology developed for effective management of rice crop in favorable and unfavorable ecologies.

In the course of preparing the book, the authors and editors have received help and support from different individuals. We are extremely grateful to each one of them. The editors take this opportunity to express their gratitude to all the authors for developing the chapters in a comprehensive and time-bound manner. Sincere thanks are due to the retired scientists of the Institute, who brought to light the rich history and path of evolution of NRRI and shared nostalgic memories to pass it onto the new generation. We thank Dr. T Mohapatra, Director General, Indian Council of Agricultural Research and Secretary, Department of Agricultural Research and Education for taking keen interest in bringing out this publication.

We hope that the publication would be useful to the researchers, particularly the younger ones, teachers, policy makers, planners, administrators, progressive farmers and students of rice sciences.

Editors

Content

Contd..

ICAR-National Rice Research Institute: Genesis and Evolution

D Panda and H Pathak

SUMMARY

People of India have been cultivating rice for about last 7000 years. It is the staple food for more than two thirds of the Indian population. Prior to 1950, rice cultivation was mostly monsoon dependent. Major abiotic stresses like drought and flood were often occurring due to deficit or excess rainfall. These abiotic stresses caused widespread crop failures, starvation deaths and even famines including the Great Orissa Famine (*Na' Anka Durbhiksha*) of 1866 with death toll of about 10 lakhs of people. Loss of rice crop in large areas due to pest and disease epidemics also caused famines, most disastrous of which was the Great Bengal Famine of 1943 with a death toll of about 20 lakhs of people. This famine broke out due to epiphytotic of brown spot disease of rice, adverse impact of the Second World War on the economy of the British Empire and failure of civil administration to mobilize food to the affected areas. At the backdrop of this famine, the Government of India decided to establish a Central Institute for Rice Research and appointed Dr. K. Ramiah as the Officer-on-Special Duty to select a suitable site for locating the Institute. He visited several rice growing states and shortlisted two sites-one at Coimbatore and the other at Cuttack. Having got aware about the list, Maharaja Krushna Chandra Gajapati, the then Prime Minister of Orissa promptly decided to hand over the State Agricultural Farm, Cuttack to the Central Government for establishment of the rice institute. Dr. Pranakrushna Parija, the then Director of Agriculture, Orissa placed full justification before Dr. Ramiah regarding suitability of Cuttack for locating the Institute. Finally, on the recommendation of Dr. K. Ramiah, the Government of India established the Central Rice Research Institute (CRRI) at Cuttack in 1946. Initially, the main objective of the Institute was to carry out basic and applied research on all aspects of rice leading to the development of better rice varieties and technology for enhancement of per hectare rice yield in the country. The other objectives of CRRI were to act as a centre of authoritative information and to train rice researchers, farmers and other stakeholders on all matters related to rice production.

The Institute started functioning by taking possession of the State Agricultural Farm, Cuttack, which was locally famous as Bidyadharpur farm. Initially the focus was laid on recruitment of personnel including 10 scientists, renovation of the existing infrastructure and creation of additional physical facilities for facilitating rice research. The research work was organized in 5 Divisions namely Botany, Chemistry, Agronomy, Entomology and Mycology. In due course of time, the numberof Divisions/Sections of research were

increased to twelve, which were again reorganized to 5 Divisions namely Crop Improvement, Crop Production, Crop Protection, Crop Physiology & Biochemistry and Social Science. A laboratory wing was created in 1958. Besides, a new administrative-cum-laboratory building was constructed in the early 1980s. The Institute was renamed as ICAR-National Rice Research Institute (NRRI) in 2015. Further infrastructure development has been made in 2018-19 with construction of a well-furnished Central Genomics and Quality Laboratory; Building for Social Sciences Division; Building for Krishi Vigyan Kendra at Santhapur, Cuttack; and an Auditorium. The sanctioned strength of scientists has been increased and now stabilized at 110.

In order to expand location-specific research two sub-stations namely, Central Rainfed Upland Rice Research Station at Hazaribag in Jharkhand and Regional Rainfed Lowland Rice Research Station at Gerua in Assam were established in 1980 and 1986, respectively. With a view to educate, empower and enhance income of the farmers two Krishi Vigyan Kendras-one at Santapur in Cuttack district of Odisha and the other at Jainagar in Koderma district of Jharkhand are functioning under NRRI.

During the entire period of 73 years of its existence, the Institute has developed 133 high-yielding rice varieties, several crop production & protection technologies and farm implements. With the contribution of researchers, extension workers and policy makers and hard work of the farmers, the rice production in the country has increased from 20 Million tonnes (Mt) in 1950 to 112Mt in 2017-18. The country is now annually exporting about 10 Mt of rice and earning about Rs. 50,0000 crores annually.

1. INTRODUCTION

Rice is being cultivated in India for at least 7000 years. A report by Zong et al. (2007) suggests that the history of domestication and cultivation of rice in China is as old as 7,700 years. Since there is a rich diversity of rice landraces in a vast region comprising of north-east India, adjoining parts of Burma, Thailand, Vietnam and South China, this region is believed to be the primary centre of origin of cultivated rice. Similarly, as there is a large diversity of landraces in Jeypore tract of undivided Koraput district of Orissa, it is considered as the secondary centre of origin of rice (Roy, 2017).

Rice is the most important food crop that sustains human life in India and many other countries of Asia and Africa. Recognising the importance of rice crop, the Imperial Council of Agricultural Research (presently the Indian Council of Agricultural Research), since its inception in 1929, had sponsored many rice breeding stations and research projects scattered over rice growing states of India to stimulate and foster rice research. However, the total production of rice was invariably short of the country's requirements during pre-independence era and even two decades after independence. Since rice production was mostly monsoon dependent, the crop production was adversely affected in unfavourable years of deficit or excess rainfall.The natural disasters such as drought, flood and cyclone had been resulting in shortage of food, starvation of people and even horrifying famines. Besides the abiotic stresses, biotic stresses such as incidence of insect pests and diseases, sometimes in epidemic dimensions, drastically decreased rice production bringing a lot of miseries to the people of India during the pre-independence period. Between 1860 and 1910 there were more than 20 famines. Most devastating of these famines was the Great Orissa Famine (*Na' Anka Durbhikshya*) of 1866 with death toll of about 10 lakh people that was about one third population of Cuttack, Puri and Balasore districts of Orissa. This famine occurred due to premature cessation of rain in September and October, lack of irrigation as well as defective colonial administration. All these famines became an eye opener for the Government of India to take remedial measures. Hence, many rice breeding and research stations were established all over India to undertake rice research, evolve improved rice varieties and to develop and adopt rice production technologies.

2. TRAGEDIES OF THE GREAT BENGAL FAMINE

The Great Bengal Famine broke out in 1943 due to very low production of rice in the previous year, 1942 in the then Bengal Province which comprised of West Bengal and the present country of Bangladesh. The shortfall in rice production in 1942 was mainly attributed to the epidemic of brown spot disease of rice crop caused by the fungal pathogen, *Helmionthorporium oryzae* Breda de Haan [*Cocliobolus miyabeanus (Ito* & *Karibayashi*) Drechsler *ex* Dastur] in Bengal province (Padmanabhan, S.Y. 1973). Comparison of weather parameters during the kharif season of 1942 with those of 1941, 1943 and 1944 revealed that the kharif season of 1942 had excessive rainfall in September, uniformly favourable temperatures of 20-30°C continuously for two months, unusual cloudy weather, higher rainfall and a higher minimum temperature in November. These unusual weather conditions were favourable for the occurrence of the brown spot epidemic in rice in the undivided Bengal.

Old Building of CRRI

New Building of CRRI

The Great Bengal Famine was so devastating that about two million people died of starvation. On the aftermath of epidemic of brown spot disease which was mainly responsible for outbreak of the famine, Dr. S.Y. Padmanabhan was appointed as Mycologist in Bengal in October, 1943. During his travel in Bengal he could observe dead bodies, starving and dying persons all along the way from Bahudurabad Ghat on the Brahmaputra to Dacca. This severe famine continued throughout October, November and December, 1943 in and around the important cities in Bengal, especially Calcutta and Dacca. The problem of acute food shortage was further aggravated due to the Second World War (1939-1945) involving many countries of the world including the British empire. The economy of the British Empire almost crumbled in the Second World War. As a result, the civil administration of British India failed to cope up with the wide spread severe food shortage. Due to the negligible marketable surplus of rice from 1942, price of rice in market went on increasing and it was beyond the reach of common people to purchase staple food grain. So, most of the rural people migrated to cities in search of employment. As they failed to get employment and food either in villages or in cities, they slowly succumbed to death due to starvation.

3. ESTABLISHMENT OF CENTRAL RICE RESEARCH INSTITUTE (CRRI)

Low production of rice in the country as a whole, outbreak of the Great Bengal Famine and unbearable tragedies of acute hunger and starvation of millions of common people during the early 1940's, in particular, prompted the Government of British India to actively consider establishment of Central Rice Research Institute at a suitable site in the rice belt of the country immediately after the second World War was over. There were several rice breeding and research stations functioning independently without any links with each other in different provinces of the country to meet demands of the local needs.The research facilities available in regional breeding stations and research centres were also inadequate to meet the challenges of low productivity and to deal with multidisciplinary research on all aspects of rice production at national level. In order to intensify rice research in the country, the Government of India at one time contemplated setting up of a Central Rice Committee to be financed by a cess on the crop. As the public opinion did not favour levying of cess on a major food crop like rice, the idea of establishing a separate Commodity Committee for rice was abandoned. Government of India finally took a decision in 1945 to establish Central Rice Research Institute under its auspices (CRRI, 1946).

In an immediate follow up action, the Government of India appointed Dr. Krishnaswamy Ramiah as the Officer on Special Duty in the Imperial Council of Agricultural Research to select a suitable site for locating the CRRI on the basis of his befitting contribution in rice research. A detailed biodata of Dr. Ramiah, popularly known as 'Rice Ramaiah', is available in the Annual Report of NRRI (2017-18).

As ascertained from the discussion with Dr. S. Patnaik, former Director, CRRI, Cuttack who served the Institute for 38 years (1952-1990), the following historical events and eminent personalities facilitated the process of site selection and establishment of the Central Rice Research Institute at Cuttack in 1946. Maharaja Krushna Chandra Gajapati became the Chief Minister of Orissa and created a Department of Agriculture which was earlier under the Directorate of Development. He appointed the eminent Botanist, Dr. Prana Krushna Parija as Director of Agriculture. Dr. Parija was simultaneously holding the position of Vice-Chancellor of the Utkal University. Both Dr. Parija and Dr. Ramiah were the alumni of Cambridge University. Maharaja K.C. Gajapati was also the Secretary General of Princes' Forum and Maharaja Sayaji Rao Gaikward of Baroda was its Chairman. As the Secretary General of the Princes' Forum, Maharaja Gajapati had several occasions to interact with members of the Executive Council of the Viceroy of India in connection with development affairs of the country. Sir C. N. Trivedi was the only Indian Member of this Executive Council. Subsequently, Sir C. N. Trivedi was appointed as the first Indian Governor of Orissa. At that time, the site selection process was almost at final stage. Dr. K. Ramiah selected two sites – one at Coimbatore and the other at Cuttack. When it was brought to the knowledge of Maharaja K. C. Gajapati, he impressed upon the Executive Council of the Viceroy to establish the Central Rice Research Institute at Cuttack and offered to transfer the State Agricultural Farm at Cuttack, popularly known as Bidyadharpur Farm with land area of 60 hectares and the existing infrastructure free of cost to the Government of India for establishing the Central Rice Research Institute.

Dr. P. K. Parija emphasized that Cuttack was more suitable for establishing the rice institute than the other shortlisted site because rice was the dominant food crop in high rainfall regions of eastern India including states of Assam, Orissa, West Bengal, south Bihar, Chhatisgarh, Jharkhand, eastern Uttar Pradesh and parts of south India including north Andhra Pradesh. Cuttack was receiving more than 1000 mm of rainfall during monsoon season from June to September. It was also receiving some more showers of rainfall in October and first fortnight of November. During monsoon season, no crop other than rice could successfully be grown in low and medium lands of Orissa and adjoining states. Moreover, Cuttack is situated in the heartland of rice belt of India. On the contrary, Coimbatore was receiving less than 800 mm

Founding Fathers of Central Rice Research Institute, Cuttack.

From left: Dr. KrishnaswamiRamiah, OSD, Site Selection for CRRI; Dr. Prana Krushna Parija, Director of Agriculture, Orissa; Maharaja Krushna Chandra Gajapati, Prime Minister of Orissa.

of rainfall spread over entire year and rice was mostly irrigated because of inadequacy of rain water. On the basis of this justification given by Dr. Parija and immediate willingness of the Government of Orissa to transfer the State Agricultural Farm at Cuttack free of cost to Government of India for establishing the Institute, Dr. K. Ramiah finally recommended Cuttack to be the suitable site for establishment of Central Rice Research Institute. This recommendation was accepted by the Executive Council of Viceroy of India. The Government of India finally accepted the recommendation to establish the Central Rice Research Institute at Cuttack in 1946 and appointed Dr. K. Ramiah as its Director in August, 1946 for a period of 5 years.

4. FUNCTIONING OF CRRI IN THE FORMATIVE YEARS (1946-1951)

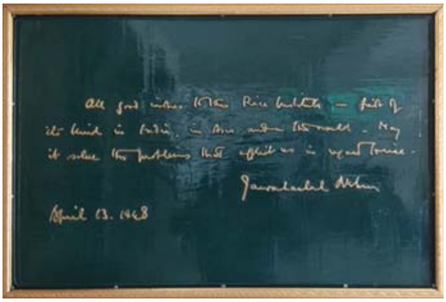
Dr. Ramiah joined the Institute on 27th of September1946 as its founder Director. The State Agricultural Farm, Cuttack in Orissa with its land area of 60 hectares, buildings and other infrastructure was taken over and arrangements were made afterwards to acquire additional land, contiguous to the existing farm. In the beginning, attention was devoted to fencing of the farm, constructing threshing floors, implement sheds, store rooms and preparation of plans and estimates for construction of laboratories and staff quarters. The layout of experimental fields with irrigation and drainage channels, roads and foot paths was also simultaneously undertaken. The necessary livestocks and deadstocks were also acquired.

Recruitment of scientific staff for the Institute was met with some difficulty. However, with the partition of the country into India and Pakistan, men became available out of the group of displaced persons who were previously working as agricultural scientists in areas which went over to Pakistan. The work of the Institute was organized under five divisions, viz. Botany, Chemistry, Agronomy, Entomology and Mycology, fully coordinated to address the researchable issues of rice production system from the all possible relevant angles.

Pandit Jawaharlal Nehru, the Honourable First Prime Minister of India visited the Institute on April 13, 1948 and gave his esteemed remarks "all good wishes to this Rice Institute - first of its kind in India, in Asia and in the world. May it solve the problems that afflict us in regard to rice". The plaque inscribed with these lines has been installed in the entrance of the main building of the Institute (*Please see below*).

The Institute had the opportunity to receive Pt. Nehru for the 2nd time on January 3, 1962 during which he visited the residential colony (Nehru Colony) and the Childrens' Park (Nehru Childrens' Park).

In Botany Division, focus was initially laid on rice germplasm collection of cultivated, semi-wild and wild species of *Oryzae* from various states.



Fortunately, the germplasm maintained by Dr. K. Ramiah in earlier years at the Paddy Breeding Station, Coimbatore was made available which were brought to start-up genetic stock at CRRI, Cuttack. Simultaneously, the conservation of the genetic stock and their utilization in plant breeding were undertaken. Regular yield trials were conducted with all the improved varieties collected from all over India including those available at Cuttack. It was from these trials the excellent performance of T 141 of Orissa was brought to light. In addition to selection and hybridisation, genetic studies were also undertaken mainly to determine linkage groups. Initially, in breeding new varieties, earliness of maturity and non-sensitivity to photoperiod were focused on. Experiments on response of rice varieties to chemical fertilizers with and without organic manures were also conducted. Plots for permanent manurial trials were laid out. The Chemistry Division of the Institute started investigations on the Chemistry of submerged soils and placement of fertilizers in reduced zone of waterlogged soil which was a pioneering work in India. Work in the Entomology Division was concentrated on two of the most important insect pests, the stem borer and gall fly, and their control. In the Mycology Division, work was concentrated on two fungal diseases, blast and brown spot. The Division also undertook work on screening of genetic stocks for disease resistance and hybridization to evolve resistant varieties.

As a member of the Standing Advisory Committee in Agriculture of FAO, Dr. Ramiah attended its annual conferences in different countries of the world in 1946, 1947 and 1948. The FAO decided to start an International Rice Commission (IRC) under its auspices for improvement of rice production in Asia and the far East. Representing India, Dr. Ramiah attended annual meetings of the IRC during 1948 to 1951. At the Burma meeting of IRC in 1950, his proposal to start an International Cooperative Rice Breeding Project was accepted by FAO and work was initiated at CRRI. Under this project an intensive programme of hybridizing *japonica* with *indica* rice was undertaken and the F_2 seeds were despatched to the different cooperating centres and rice research stations to select the most suitable types for their conditions. This programme brought limited success. However, from the seeds of hybridized population, sent from CRRI to different countries of the world and Institutions within India, the Regional Research Station, Aduturai in Madras state identified a promising culture and released it as ADT-27. In addition, rice varieties viz. Mahsuri and Malinja in Malaysia and Circna in Australia were identified from this programme and were released for cultivation. The FAO recognised the CRRI as an official centre for training persons selected from different countries in rice breeding. The Institute has been maintaining close contact and cooperation with the IRC of FAO since its inception. The IRC also recognised CRRI as one of the main centres for maintenance of rice germplasm of the world.

During 1946-1951, a scheme was initiated for popularising the use of chemical fertilizers for rice in Orissa. Although, canal water was available up to the end of April in major irrigation command areas, the land was left fallow and growing of a second crop (Rabi) of rice was unknown before. In such areas, suitable varieties of rice were successfully grown in Rabi season and the practice has since taken a deep root and made great progress (CRRI, 1956). In early 1960s, the Institute took up breeding for non-lodging types using the stiff strawed *javanica* and developed CR-1014; a super fine grain variety yielding 3-4 t ha^{-1} in intermediate deep water stagnation conditions from the cross between T90 and Urang Uragan (Roy, 2017). This variety became widely popular in many states of India.

5. LOCATION, SITE AND SOIL CHARACTERISTICS OF THE INSTITUTE

The Institute is situated at Cuttack in Orissa (now Odisha) with $20^0$25′ N latitude, 85^0 55′ E longitude and elevation of 23 m from mean sea level. It is located adjacent to the Cuttack-Paradeep State Highway, at a distance of 7 km from Cuttack Railway Station and 35 km from Bhubaneswar airport. The climate of the place is hot sub-humid with average annual rainfall of around 1500 mm. The rainfall during kharif season is more than 1000 mm.

The fields of the Institute farm are fairly level with less than 1% slope. The land has shallow ground water level. Thirty seven soil profile pits dug all over the farm showed that even at the end of May, sub-surface water appeared at a depth in the range of 0.45 m to 1.5 m. It has poor surface drainage as well as internal drainage. The farm is comprised of low and medium lands with negligible area of upland.

As per USDA Soil Taxonomy, 1999, soils belong to the order, Ínceptisols′ sub-order, Áquepts′ and great group, Endoaquepts. At soil series level, the soils of CRRI farm are classified as Typic Endoaquepts, Vertic Endoaquepts and Aeric Endoaquepts. As per FAO classification system, the soils are classified as Eutric Gleysols (Sarkar et al. 2003).

As soils of the Institute farm are of alluvial origin developed in the Mahanadi river delta, they are very deep. They are fairly fertile with medium to high organic matter content.

6. OBJECTIVES OF THE INSTITUTE

The Institute was established with the following major objectives:

1. To carry out research on basic and applied aspects in all disciplines of rice culture in order to develop rice production technologies for optimising per hectare yields of rice.
2. To conduct, co-ordinate and encourage adoptive research in rice growing tracts of the country before making site specific recommendations for use by the rice farmers.
3. To serve as a centre of authoritative information on all matters concerning rice production, protection and rice germplasm at national level.
4. To identify production constraints in regions through surveys and to suggest appropriate technologies for production.
5. To participate in communication and transfer of technology in respect of rice.
6. To train research and extension workers on rice production technologies in the country.

Retaining the basic theme of the original mandate, the objectives of the Institute have undergone slight modifications from time to time with the growth of the Institute. Currently, the research policies are guided by the recommendations of the Research Advisory Committee (RAC), Quinquennial Review Team (QRT) and the Institute Research Council (IRC). It also has an Institute Management Committee (IMC) to support implementation of its plans and programmes. In recent years greater attention has been paid on sustainable rice production technology development which includes productivity enhancement in quantity and quality of produce, profitability, feasibility, acceptability by farmers, environmental security and overall welfare of the farmers keeping in view the recent climate change events caused due to global warming.

7. GROWTH OF THE INSTITUTE

The land area of the experimental farm increased from the 60 ha to 117 ha with the acquisition of additional land contiguous to the farm area. The Institute initially started with 10 scientists, and later the strength increased to 40 in 1960s, 170 in 1980s, then reduced to 140 in 1990s, and 118 during 2000s. As on 2018-19 the strength is 100.

With the recruitment of scientific personnel as well as expansion and intensification of research, the demand for additional laboratory facilities grew and a laboratory wing was created in 1958. In due course of time, the infrastructures such as net houses, farm godown, and Engineering Workshop were constructed. The other facilities namely one conference hall, an auditorium, a committee room, a display hall (Museum), one library, a dispensary, a club house, one guest house, one farmers' hostel, one International Students Hostel, and Scientists' Home were created. The Institute also has other amenities like Post Office, Police Outpost, a pay counter of State Bank of India and service facilities for maintenance of civil, electrical and water supply structures. Besides, the new administrative-cum-laboratory building was constructed in early 1980s. Additional staff quarters were also constructed to accommodate nearly about 300 staff families belonging to various categories.

In order to cater to the needs of contemporary advanced research in 1990s, sophisticated instruments such as automatic amino acid analyser, ultra centrifuge, gas chromatograph, atomic absorption spectrophotometer, atomic mass spectrometer, liquid scintillation counter, aerobic chamber, liquid chromatography, infrared gas analyzer, infrared spectrophotometer, respirometer, fluorescent microscope, computers and many other commonly used equipments were installed over years. In addition, several externally aided projects including Asian Rice Biotechnology Network (ARBN), Rockefellor Foundation, Ford Foundation, Colombo Plan, Methane Emission, SARP, IRRI-CRRI collaborative CREMNET project, Indo-US collaborative project on N use efficiency, AP Cess Fund schemes and NATP projects were operated and many more advanced equipments were installed using funds available in these schemes and projects.

In the recent years from 2011-2019, further expansion of laboratories with instrumentation and other physical facilities has been made to carry out advanced rice research comparable to that of any national or international Institute. To cite a few such sophisticated laboratories, the construction of new Genomics Laboratory and Central Quality Control Laboratory buildings, well furnished and equipped with ultra-modern equipments, are worth mentioning. Since the existing auditorium and conference hall are not spacious enough to accommodate large number of participants of national and international symposia and farmer-scientist interaction meetings, the need for construction of a larger auditorium was recognised by the ICAR. For organizing such national and international conferences, symposia and farmers' meetings, a new auditorium to accommodate 500 participants is currently on the verge of completion in 2019.

The first sub-station of CRRI, Central Saline Rice Research Sub-Station was established in the heart of saline area of West Bengal at Port Canning in 1959 with the objective of developing suitable techniques for breeding salinity resistant rice varieties, to work out the physiology of resistance to salinity and to develop appropriate agronomic practices. This station was however later merged with the Central Soil Salinity Research Institute of ICAR in 1969 as one of its sub-stations, specifically meant for rice research in coastal saline areas (CRRI, 1996).

In order to expand location specific research on rainfed rice, two sub-stations, viz. Central Rainfed Upland Rice Research Station (CRURRS) at Hazaribag in Bihar (now Jharkhand) and Central Rainfed Lowland Rice Research Station (CRLRRS) at Kharagpur in West Bengal were established in 1980 and 1986, respectively. Subsequently, the CRLRRS was shifted to Gerua in Assam to cater to the typical lowland rice research needs of the north eastern region of the country.

Since multi-location rice research was considered essential mainly for testing the breeders' materials for yield and for assessing the resistance of the breeding materials to biotic stresses, the All India Coordinated Rice Improvement Project (AICRIP) was commissioned at Hyderabad in 1965. The AICRIP initially functioned as a part of CRRI for quite some years. Subsequently, the project Directorate of AICRIP was renamed as Directorate of Rice Research (DRR) which operated directly under ICAR as an independent Institute. The CRRI has been a major participant of the coordination. The DRR has further been renamed as Indian Institute of Rice Research in recent years.

With a view to educating, empowering and enhancing income of the farmers three Krishi Vigyan Kendras (KVKs)-one at Santapur, Cuttack district, the second at Annapurnapur, Kamakshanagar, Dhenkanal district and the third at Kalipad, Angul district were established in mid 1990s, which functioned directly under CRRI. Subsequently, out of these three KVKs, two KVKs one in Dhenkanal district and the other in Angul district were transferred to the administrative control of Orissa University of Agriculture Technology. The KVK at Santapur in Cuttack district has been functioning under CRRI since its inception. Recently, a lot of infrastructure development work in this KVK has been completed with the construction of new office building and well furnished laboratory buildings with provision of necessary physical facilities including laboratory equipments. Besides, one more KVK has been established at Jainagar of Koderma district in Jharkhand under the Central Rainfed Upland Rice Research Station (CRURRS) of CRRI. It caters to the needs of farmers of the concerned district in regard to their empowerment, enhancement of income and welfare of the farmers through integrated approach. The CRRI also carried out research and extension activities in Operation Research Projects, Lab to Land and Institute-Village Linkage (IVLs) programmes on transfer of technologies as out-reach programmes. In this connection, the Farmers First programme is currently in operation under NRRI.

The CRRI carried out on-farm research to develop and fine tune agricultural technologies for different rice-based cropping systems in various agro-ecological situations through the World Bank funded National Agricultural Technology Project (NATP) during the period from 1998-2003. CRRI functioned as the nodal agency for 35 on-farm research projects on Rainfed Rice-Based Production System (RRPS) at 35 main centres and more than 150 cooperating centres throughout the country. For this purpose, a separate NATP cell was created in CRRI and a Facilitator was identified and appointed by ICAR from among the senior Principal Scientists or the Director of the Institute to coordinate all these RRPS projects.

The Institute has also been pursuing academic and innovative research in different disciplines of rice science which would have far reaching impact on future rice crop improvement, crop production and protection programmes. The Institute has been recognized by several universities, as a centre for advanced research leading to award of doctoral degree. Hundreds of students and research fellows have been awarded with Ph.D. degrees through such innovative research in different disciplines under the guidance of scientists of the Institute including that of the sub-station CRURRS in Jharkhand. The Institute scientists have also published a large number of peer reviewed research papers in national and international journals of high repute. Besides, scientists of the Institute have also received several prestigious national and international awards and recognitions.

Although there were only five Divisions/Sections at the inception of the Institute, subsequently the number of Divisions/Sections increased to twelve viz. Plant Breeding and Genetics, Genetic Resources, Agronomy, Soil Science and Microbiology, Agricultural Engineering, Entomology, Plant Pathology, Physiology, Biochemistry, Agricultural Economics, Statistics and the Division of Extension, Communication and Training. As per the decision of ICAR, the Institute has again been reorganised into five Divisions viz. (i) Crop Improvement, (ii) Crop Production, (iii) Crop Protection, (iv) Plant Physiology and Biochemistry and (v) Social Science with the merger of related disciplines. Hence, currently there are five Heads of the Divisions in the Institute. Division-wise research achievements, impacts and aspirations are separately dealt in greater details in the subsequent chapters of this book.

8. IMPACTS OF RICE RESEARCH AND DEVELOPMENT DURING 1958-1984

During the period from 1950 to 1984, the rice production in India was increased by nearly 300% from about 20 Mt in 1950 to 60 Mt in 1983-84. Although rice has been cultivated in India for at least 7,000 years, more progress in improving production has been achieved in the last 35 years. The progress has been triggered off by a proper blend of (i) science-based technology developed by CRRI, SAUs and IRRI including provision of irrigation, fertilizers, and quality seeds of high yielding varieties, pesticides, farm implements through public and private sectors, (ii) credit through Cooperative and Banking sectors, (iii) favorable Government policies, and above all the farmers' sincere efforts which stimulated production.

The establishment of the IRRI in the Philippines in 1960 helped promote the concept of improving the plant type in *indica* rices based on the use of a gene for semi-dwarfing from a Taiwan variety. This helped in breeding high-yielding varieties capable of responding to higher levels of fertilizer application and good management. During the International Rice Year in 1966 the ICAR laid out one thousand national demonstrations to show that the century's old stagnation in *indica* rice yields can be broken. This marked the beginning of an accelerated advance in the improvement of the production and productivity of rice (Swaminathan, 1985). T.T. Chang (1961), the geneticist at IRRI, had come from Taiwan and he knew all about the success achieved by the breeders there in evolving TN1 and other high-yielding *indica* varieties of rice. Chang suggested the IRRI plant breeding scientists that they should introduce some of these semi-dwarf *indica* rice varieties from Taiwan for use as parental lines in their hybridization programme. The IRRI rice breeders, however, initially wasted little time in procuring seeds of these varieties. Subsiquently, Dr. P. R. Jennings, Head of varietal improvement programme made a series of crosses involving one of the semi-dwarf *indica* parental lines introduced from Taiwan.

9. CRRI AND GREEN REVOLUTION IN INDIA

Dr. H. K. Jain (2010), former Director of Indian Agricultural Research Institute, New Delhi vividly reviewed all aspects of rice revolution in his book "The Green Revolution: History, Impact and Future". As the plant breeders in the FAO sponsored *Indica-Japonica* Hybridization Project were struggling to achieve a major advance in *indica* rice yields in India and other countries, scientists in Taiwan had forged ahead in developing the world's first group of fertilizer responsive, semi-dwarf, high-yielding varieties of *indica* rice. The origin and development of these *indica* rice varieties have been reviewed by Athwal (1971). It all started with a traditional variety called Dee-geo-woo-gen, which farmers in Taiwan were growing in early years of the 20th century. It was very different in plant type showing dwarf stature, high tillering and stiff straw, which came to the notice of scientists at the Taiwan Agricultural Experiment Station much later. They used this variety in breeding programme. One of the products of these crosses, involving Dee-geo-woo-gen and Tsai-Yuan-Chung, was the variety Taichung Native 1, perhaps the first semi-dwarf, fertilizer responsive, high-yielding rice variety which became the prototype of a whole generation of *indica* rice varieties in many countries of Asia including India. The IRRI became a catalyst in this endeavour to revolutionise rice production through a change of direction of rice research in CRRI, SAUs of India and in many other countries of Asia.

The Government of India came to know about the progress of research in IRRI regarding development of rice varieties using Dee-geo-woo-gen through Sri K. K. Damle, the then Secretary, Ministry of Agriculture who was a Member of the Board of Trustees of IRRI. Further, Robert F. Chandler Jr., the first Director of IRRI during his regular visits to India had also briefed the Union Minister of Agriculture Sri C. Subramanium and the senior officers of the Government on this issue. One of the officers he briefed to was Sri B. Sivaraman, who later became the Secretary in the Ministry of Agriculture. Prior to his appointment in the Ministry of Agriculture, he had been the Chief Secretary of Orissa and visited CRRI, Cuttack to observe rice research programmes. One of the scientists he came in contact with was Dr. G.V. Chalam, Economic Botanist of Orissa who later became Deputy Director in the State's Department of Agriculture in the 1950s. Dr. Chalam was deputed to IRRI in 1964 for study in rice improvement programme. While at IRRI, he learnt about the outstanding performance of Taichung Native 1 and asked for 2 kg seeds of this variety for testing in India. The trial with Taichung Native 1 which Dr. Chalam organized was successful. Then the Ministry of Agriculture arranged to procure from IRRI one tonne seed of Taichung Native 1 with help of Dr. R.W. Cummings, the Field Director of the Rockefeller Foundation in New Delhi. When Dr. Chalam became the Chairman of National Seed Corporation, he managed to procure 5 tonnes of seeds of TN 1 in October 1965 and subsequently to import 60 tons of seeds of TN 1 and implemented distribution of these seeds for up-scaling coverage in India especially during dry season when the incidence of pests and diseases were less.

Dr. Robert F. Chandler, the first Director of IRRI, drew attention to Chang's contribution towards this new direction to the IRRI's rice breeding programme. He reported that TN 1 was released in Taiwan in 1956 and by 1960 it was widely grown by farmers there with an yield of 6-8 t ha^{-1} following good agronomic management including irrigation and application of large doses of fertilizers. Subsequently, the rice breeders in IRRI made several crosses in 1962 using the semi-dwarf varieties received from Taiwan as one of the parental lines. One of the crosses, to be specific the 8^{th} cross, was made between Dee-geo-woo-gen and Peta, a tall *indica* variety of Indonesian origin, known for its resistance to insect pests and diseases. After the required number of generations and yield trials, it was released from IRRI as IR 8. In India a set of 303 varieties and advanced generation lines were also received from IRRI at CRRI, Cuttack and also at Hyderabad. Dr. Seetharaman, the then Head of Genetics and Plant Breeding in CRRI found that 15 of the entries of the IR series recorded calculated yields around 9 t ha^{-1}. The entries which recorded the highest yield were those of the IR 8 series.

Taichung Native 1 introduced by Dr. G.V. Chalam in 1964 was the first high-yielding semi-dwarf variety which covered large rice area in India. It was however quickly replaced by IR 8 of IRRI. The scientists of CRRI had crossed TN 1 with a number of improved Indian varieties of tall type. One of these crosses made by Sh. M. J. Balakrishna Rao involved T141 and TN 1. A product of this cross was the semi-dwarf high-yielding variety Padma which was released by the Government of India in 1968. Padma (CR 28-25, IET 953) was of 120 days duration, short bold, medium resistance to blast and other major diseases and pests with yield of 3.5-4.0 t ha^{-1}. The Institute celebrated the Golden Jubilee of release of Padma in 2018 by releasing a golden plaque. The second variety named Jaya was developed by Dr. S.V.S. Shastry and his associates in AICRIP at Hyderabad. The variety Jaya became more successful and covered large areas in India replacing IR 8. These two varieties Jaya and Padma were more acceptable to farmers because of better grain quality and resistance to diseases and pests.

Dr. R. Seetharaman, Head of Plant Breeding and Genetics Division of CRRI organized a major research programme in early 1960s following the introduction of TN 1 and IR 8. Subsequently, the CRRI scientists including Dr Seetharaman, Dr Gangadharan and Dr B.K. Rao with their team developed 18 high-yielding semi-dwarf varieties which were released by Government of India. The varieties performed well not only in irrigated areas with favourable conditions but also suited well to various ecologies like upland, rainfed lowlands with intermediate and semi-deep water conditions. By the end of 20th century CRRI developed 59 high-yielding varieties of rice, many of them carrying the semi-dwarf gene. A number of CRRI varieties also became popular in other countries, viz. Afghanistan, Nepal, Pakistan and many countries of sub-Saharan Africa. By then, CRRI escalated its gene bank collection over 16,000 landraces and local varieties which were evaluated as sources of resistance to stresses. These donors of resistance were made available to rice breeders all over the country for use in their varietal development work.

Simultaneously Dr. S. Patnaik, former Director, CRRI, who was earlier invited to participate in the International Conference on Mineral Nutrition of Rice Plant at IRRI in 1964, collected 3 packets of seeds of semi-dwarf rice varieties: TN 1, Taiwan 3 and Chianung from Dr. A. Tanaka, Plant Physiologist of IRRI. On his return to CRRI, he multiplied them in the wet season of 1965. Dr. G. V. Chalam, the then Agricultural Commissioner of the Government of India and Dr. W. H. Freeman, Representative of Rockefellor Foundation in India visited CRRI, Cuttack and were impressed with the performance of these varieties at maturing stage in the field. Dr. Chalam requested to keep seeds of these varieties for minikit trials in India. In a follow up action, a total of 800 bags of 1 kg each of these 3 varieties (400 bags of TN 1, 200 bags of Taiwan 3 and 200 bags of Chianung) were collected by Dr. Chalam through his technician and were distributed in Orissa, West Bengal, Andhra Pradesh and Tamil Nadu for trials in agricultural farms and selected farmers' fields in 1966.

Dr. Chalam introduced the first high-yielding semi-dwarf rice variety TN 1 in India in 1964 for cultivation in Government Agricultural farms and farmers' fields. This was, however, not that TN 1 had found its way into India. In early 1960s, 67 rice varieties were received at CRRI, Cuttack from Taiwan under germplasm exchange program. Those were evaluated by Dr. R. H. Richharia, who was the then Director of CRRI. Interestingly TN 1 was one of these varieties included in this collection. Dr. Richharia was very much concerned about the susceptibility of these varieties to many pests and diseases. He was however, interested to use them as genetic resource for development of high yielding varieties of his own with a degree of resistance to pests and diseases. For him TN 1 was an important genetic resource rather than a readymade variety to be grown in farmers' fields. Dr. Richharia is best remembered for the vast collection of land races and traditional varieties of rice, which he made at CRRI (Richharia, 1979). However, the concerns of Dr. Richharia regarding the possible large incidence of pests and diseases in newly introduced semi-dwarf rice varieties were subsequently considered and intensive programmes of screening of land races and traditional varieties for resistance to various biotic and abiotic stresses were undertaken in CRRI, AICRIP and all other research stations of India under the network. The resistant enties were utilized in breeding programme. The resultant cultures were tested at various locations and finally different promising varieties having high yield potential and resistance to biotic and abiotic stresses were released. This has revolutionised rice production in the country. The evolution of IR 36 variety of rice in later years justified the concerns of Dr. Richharia because valuable resistance genes from landraces and traditional varieties have been incorporated in this high-yielding variety at IRRI.

10. CRRI- A SAVIOUR OF COASTAL ODISHA FARMERS POST-SUPERCYCLONE (1999)

The super cyclone occurred in Odisha during 28-30 October, 1999 with severe cyclonic wind and incessant rainfall. It caused a great loss of human life, loss of property and total loss of rice and other crops including plantations in the coastal Orissa. Sea water ingressed into the land area up to 20 km from the coast. All the affected people placed strong demands before the State and Central Government for immediate relief and long-term agricultural rehabilitation. The farmers were of the opinion that not even a blade of grass would grow on their land due to deposit of salts which was also confirmed by a research institute located at Bhubaneswar. So, Government of Orissa sent one S.O.S. letter to CRRI to survey the affected land area of the coastal belt, assess soil and water salinity and give recommendations for agricultural rehabilitation. The CRRI assigned this challenging job to a team of 3 scientists headed by Dr. D. Panda, who surveyed the entire affected land area including crop fields. A large number of soil and surface water samples from crop fields and ground water samples from tube wells, were collected and analysed in the laboratory. The scientific investigation revealed that soils and surface water of 93% of the area were non-saline i.e. normal, while only 7% of the area were saline, especially in depressions and ponds. The ground water collected from tube wells closer to sea coast were, however, saline. Most of the area remained non-saline because of incessant heavy rainfall for 24 hours following return of high tide to sea , which flushed off the deposited salts. Based on these results, a detailed report containing the analytical data, recommendations for cropping pattern and the package of practices of crop production was communicated to the Government of Odisha for implementation at farmers' level. The farmers followed the recommendations in their fields and harvested more than 4 t ha^{-1} of rice during

Rabi season, which partly compensated the crop loss in Super Cyclone. In fact, the soil fertility rather improved due to Super Cyclone because a thick layer of algae which was deposited during forceful inundation of the land with tidal water. Based on subsequent instructions from ICAR, CRRI undertook agricultural rehabilitation work extensively for a long period of about 5 years after Super Cyclone using Institute funds, by implementing NATP projects and also in collaboration with Ramakrishna Mission for economic upliftment of the farmers of the affected coastal belt of Orissa. When Sunami occurred in coastal Tamil Nadu in 2004, the Government of Tamil Nadu took help from the experiences of CRRI to deal with the situation.

11. A SUCCESSFUL 73-YEARS JOURNEY OF CRRI

In its illustrious journey of 73 years from 1946 to 2019, the Institute has been functioning as a light house radiating the knowledge generated from its basic, applied and adaptive rice research projects. More importantly, it has also been functioning as a rice research and development industry making its products of research available to the farmers and other stakeholders throughout the country and abroad. It has been made possible with the visionary leadership of 15 Directors including Padmabhushan Dr. K. Ramiah, the founder Director of CRRI and the dedication of the researchers, all supporting and administrative staff.

A brief account of history, development and the research achievements made during the initial period of ten years from 1946 to 1956 have been compiled in a booklet published by CRRI in 1956 (CRRI,1956). With the initiative of Dr. M.S. Randhawa, the former Vice President of Indian Council of Agricultural Research, the first book entitled "Rice in India" was written by Drs. R.L.M. Ghose, M. B. Ghatge and V. Subramanian which was published by ICAR in 1956. The second revised edition of this book was published in 1960. Dr. S.Y. Padmanabhan, the former Director of CRRI compiled an updated version of the book entitled "Rice Research in India" which was published by ICAR in 1985. Thereafter, the research achievements made in CRRI and other rice institutions of the country during the period of 40 years from 1960 to 2004 were compiled in 36 Chapters of the book entitled "Rice in Indian Perspective" contributed by various authors and edited by Sharma and Nayak (2005). Dr. H. Pathak, the current Director and his colleagues in 2018 compiled the contributions of CRRI and rice researchers in their book 'Rice Research for Enhancing Productivity, Profitability and Climate Resilience'. Besides, the details of the research programmes and the achievements made by the scientists of the Institute are regularly documented in the Annual Reports of the Institute.

The classical and innovative research carried out in the Institute include (i) *indica* x *japonica* hybridization leading to release of ADT 27 in India, Mahsuri and Malinja in Malyasia and Circna in Australia, (ii) collection of a large number of germplasm, their evaluation, conservation and utilization in rice breeding, (iii) pioneering work on water management in rice fields, (iv) Pankaj x Jagannath crosses for development of varieties in rainfed lowlands, (v) development of irrigated rice variety Ratna using genes from semi-dwarf rice variety and a tall *indica* rice variety, (vi) incorporation of *Sub-1* gene into rice variety Swarna and development of submergence tolerant variety Swarna *Sub-1* in collaboration with IRRI, (vii) knowledge development on chemistry of submerged soils, chemical kinetics of nutrient transformation, (viii) development of full proof technologies of efficient nutrient management in rice crop production and (ix) integrated management of pests and diseases in Crop Protection Division, (x) development drought and blast tolerant resilient varieties for special ecology of rainfed uplands, (xi) efficient P nutrition management through native microbial support system in acid soils of rainfed uplands (Ramiah,1971;Padmanabhan, 1973; Mohanty and Patnaik, 1976;Rao, 1978;Richharia, 1979; Vamadevan and Jha, 1985; Panda, 2005; Roy, 2017; Pathak et al. 2018).

Since the Institute was established at the backdrop of the Great Bengal Famine, it had the sacred mission of alleviation of hunger, elimination of starvation death and eradication of famine from India by providing rice research support to the nation. There had been many paradigm shifts in rice research, especially with the introduction of semi-dwarf rice varieties from Taiwan. Many semi-dwarf high-yielding rice varieties were developed from CRRI, IRRI and other rice research Institutions. Adoption of these varieties and technologies of scientific management of water, soil, manures, fertilizers and bio-fertilizers as well as scientific management of pests and diseases resulted in breakthroughs in rice productivity and production during the period from late 1960s to early 1980s. Due to the concurrent advancements in rice research in CRRI and wheat research in IARI, the era of green revolution ushered in India. Thus, the mission of self-reliance in food front has been achieved in our country.

During the last few decades, CRRI (presently NRRI) has played a pivotal role not only in ensuring food security to all the people of our country, but also in transforming it from a food importing country to a food exporting country. The Institute has developed 133 improved and high-yielding rice varieties including hybrids with stress tolerance till 2017-18. Very recently in March, 2019 the Institute has developed 9 more new high-yielding rice varieties with tolerance to drought, flood and cyclonic wind. Currently, rice is grown in about 43 Mha in India as compared to that of 28 Mha in 1950. About 85% of the area is now covered with high-yielding varieties. The annual rice production of the country has increased from 20 Mt in 1950 to 112 Mt in 2017-18 with the concerted efforts of researchers, farmers, extension agencies and policy makers. The country is annually exporting about 10 Mt of rice. Rice has now become one of the major foreign exchange earners.

We need not, however, be complacent with these achievements because rice yield and for that matter, yield of any crop is a function of gene and environment. Yield potential of any high-yielding rice variety developed even by the innovative breeding, can be realized only through sustainable management of land, soil, water, manures and fertilizers, adequate plant nutrition and protection of the crop from abiotic and biotic stresses. In this regard, Dr. M. S. Swaminathan has rightly said "The earth is a space ship with limited resources which, we may squander or pollute". Disproportionately higher crop production in intensive agriculture is normally associated with environmental degradations. As a consequence, the researchers and farmers are facing new challenges of climate change, low nutrient use efficiency, poor soil health, low water availability, lowering of the ground water table in semi-arid areas, increased emergence of pests and diseases and accumulation of pesticide residues in agricultural products. Besides, farmers are facing the problems of low profitability. Hence, NRRI is currently implementing the various research programmes in order to address the emerging problems and challenges.

In recognition of the outstanding contribution in the field of agricultural research and extension, several awards including Sardar Patel Outstanding ICAR Institution Award (2008) and ICAR-Best Annual Report Award (2016-17) were bestowed on the Institute. ICAR-NRRI is now progressing at an accelerated pace in respect of research infrastructure development as well as innovative rice research, keeping in view the farmers welfare.

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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.

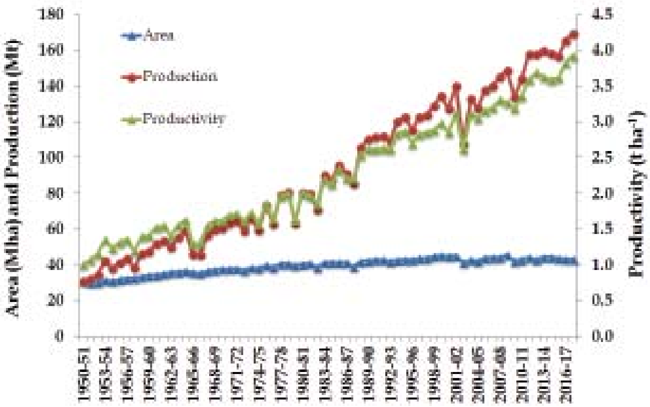

Fig. 1. Area, production and productivity of rice in India over the years.

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).

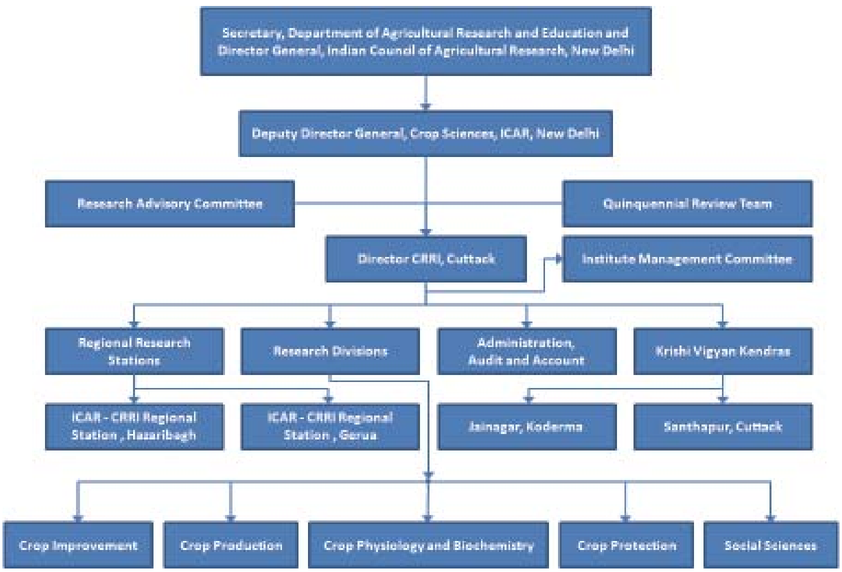

Fig. 3. Organogram of ICAR-National Rice Research Institute, Cuttack, Odisha.

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).

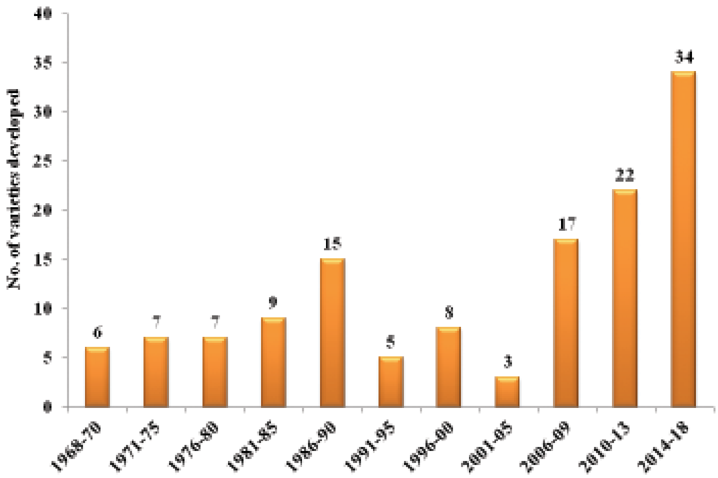

Fig. 4. Varieties developed by ICAR-National Rice Research Institute, Cuttack over the years.

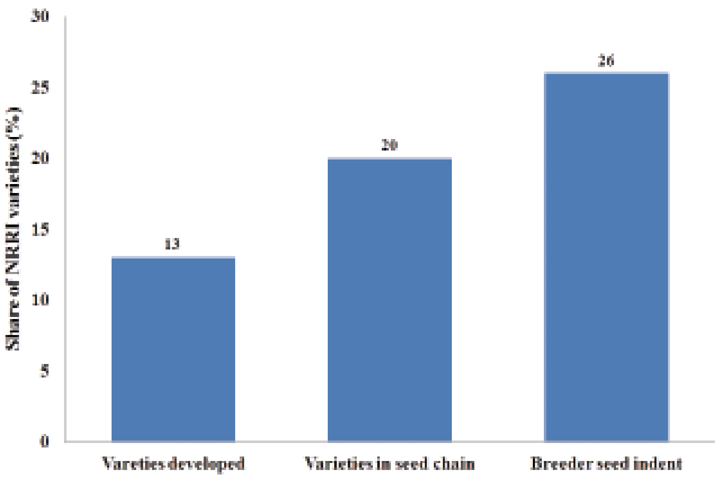

Fig. 5. Share of NRRI varieties to total rice varieties in India.

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.

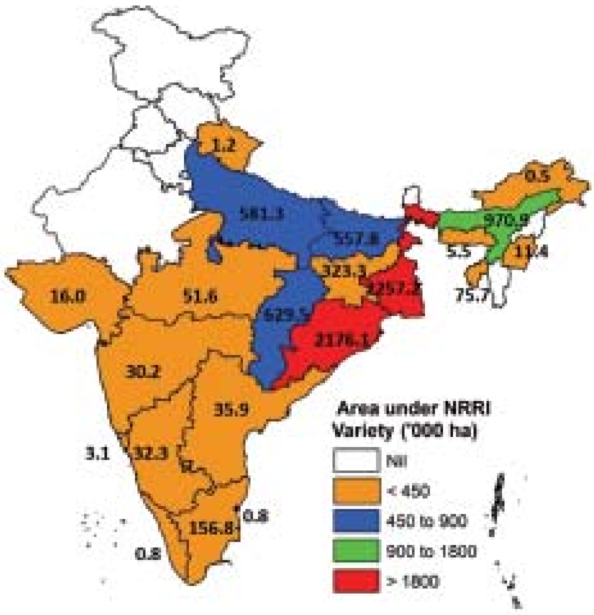

Fig. 6. Area covered by NRRI varieties in India.

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.

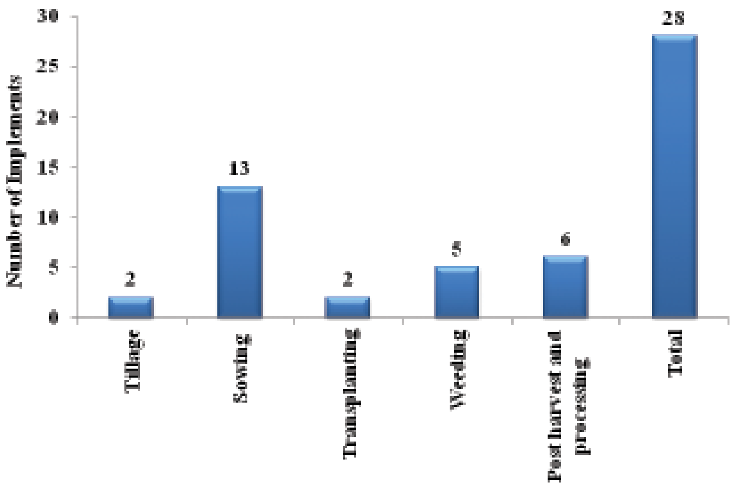

Fig. 7. Farm implements developed by NRRI for different agricultural operations.

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).

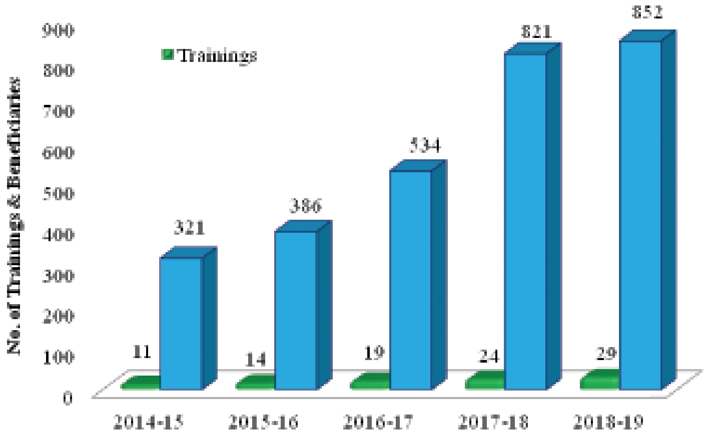

Fig. 8. Number of training programmes and beneficiaries.

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.

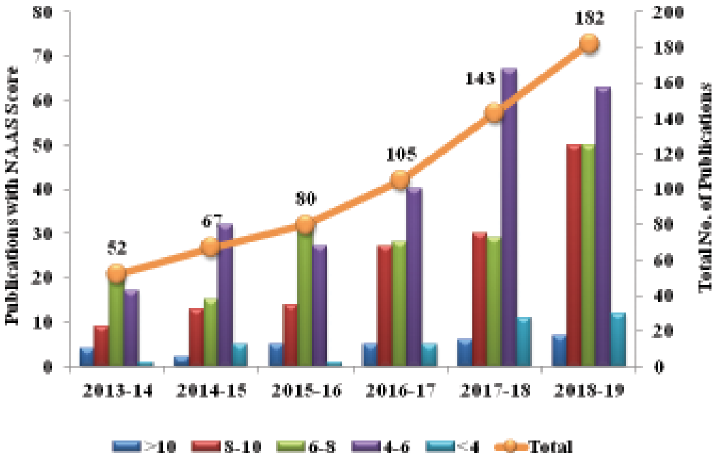

Fig. 9. Research publications of NRRI over the years.

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.

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Genetic Improvement of Rice: Activities, Achievements and Aspirations

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SUMMARY

Germplasm collection, maintenance, characterization and promotion for utilization in breeding program in national level have been major activity of the Division for the crop improvement programme. The Division has, so far, developed and released 134 varieties including three hybrids. For ensuring nutritional security, the Institute has recently released, first time in the world, two high-protein (more than 10.0%) 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 for the first time in the world, to address the challenges of climate change. Besides, 158 new entries were nominated in different AICRIP trials during 2018.Through commercialisation of these hybrids more than Rs. 1.5 crores has been earned for the Institute. Seed production of different categories are also another major activity of the Division. Every year on an average 1.0 ton of nucleus seed, 50.0 tons of breeder seed and 100.0 tons of truthfully labelled seeds are produced. Besides, identification of genes/QTLs for biotic stresses such as brown planthopper (BPH), sheath blight resistance and high yield enhancing genes, *Gn1a*, *OsSPL14* and *SCM2* were successfully pyramided into the background of MTU 1010, BPT 5204 and Swarna from donors such as Habataki, ST 12 and ST 6 using conventional breeding and genomic tools. The Division also standardized method for somatic embryogenesis in popular *indica* rice varieties which could be utilized in transgenics and CRISPR/Cas9 approach. It is working on to develop super-yielding (more than 10 t ha^{-1}) varieties with tolerance to biotic and abiotic stresses for higher productivity, profitability, climate resilience and sustainability of rice farming.

1. INTRODUCTION

Since inception, the major objective of NRRI remains to carry out basic and applied research on rice in all disciplines so as to improve productivity. The objectives have been broadened from time to time to address the newer challenges with aim to improve the income and livelihood of resource poor farmers who are depending mainly on rice cultivation under rainfed condition. To meet these objectives, many improved varieties were developed for different ecologies through pure line selection and several breeding lines were developed under *indica-japonica* hybridisation programme. Currently the major activities of the Division are to i) explore and collect the rice genetic resources from different parts of India, their maintenance, characterization and utilization, ii) produce Nucleus, Breeder and TL Seed and their quality control, iii) develop high yielding genotypes with multiple stress tolerance suitable for favourable and unfavourable rainfed lowlands, iv) genetic improvement of rice with novel attributes along with acceptable grain quality and biotic stress tolerance, v) develop Double Haploids (DHs) from elite *indica* rice hybrids and promising recombinants for yield related traits and mapping population, vi) identify and develop parents with good combining ability and develop heterotic hybrids with better grain quality in different duration and genetic backgrounds and vii) develop new generation rice for breaking yield ceiling. The Chapter presents the major activities and achievements of the Division and the aspirations towards higher productivity, profitability, climate resilience and sustainability of rice farming.

2. ACHIEVEMENTS OF THE DIVISION

The rice genetic resources are the basic material for improvement of the crop. The exploration, collection, morpho-agronomic characterization, screening/ evaluation, conservation and seed supply were part of the activities of erstwhile 'Botany Division' later named as 'Genetics Division' of the Institute. In 1984, this Division was renamed as 'Plant Breeding and Genetics Division' and a separate 'Genetic Resources Division' was created to look after all such activities on rice germplasm. It, however, was subsequently merged with the newly created 'Division of Crop Improvement' in 2001. Being the leading and premier national research institute, NRRI has been recognized as one of the National Active Germplasm Sites (NAGS).

Heterosis in rice was first documented at NRRI (Barwale, 1993). Studies were made on induced polyploidy and mutagenesis and it was possible to generate tetraploid Sitasail and SR26B genotypes (Misra et al. 1971). Tetraploid and long glumed rice was found to contain more protein than diploid rice with short glumed one.

Pachytene analysis technique unravelled the cause, nature of karyo-morphology, evolution and differentiation of species in genus *Oryza*. It was reported that genomes are homeologous and chromosome structural changes are the principal mechanisms of genome differentiation within that series. Total 12 primary trisomics were developed for the first time in the 'Sona' background, which led the path of chromosome engineering studies in rice

(Misra et al. 1985).This primary trisomics have been utilized for associating genes and linkage groups with respective chromosomes. Aneuploid stocks of rice are useful not only for genetic study but also for rice breeding.

Development of monosomic alien addition lines (MAALs) from the wild rice (*Oryza brachyantha* A. Chev. et Roehr.) for introgression of yellow stem borer resistance into cultivated rice was also achieved at NRRI (Mishra et al., 1971) which was later characterized with cross transferrable markers (Aveek et al., 2016). Mutation studies also led to the identification of several novel mutants (Sanchez and Khush 1992;Khush and Librojo 1984;Sanchez and Khush 1997; Nanda and Misra 1975; Misra et al. 1977).

The identification of the source for *Xa21* gene form wild *O. barthii* (Devadath 1983) conferring wide spectrum of resistance to BLB was first carried out at NRRI. This gene shows resistance to all the races of bacterial blight in India (Jachuck and Sampath 1966, Nayak et al. 1978).

2.1. Genetic Resources

The rice genetic resources are the basic material for improvement of the crop. The genus *Oryza* consists of 24 species, of which two are cultivated and rests are found wild in different parts of the world; all of them grow in the tropics only. Khush (1997) in IRRI confirmed that rice cultivation was started at least 7000 years ago and domesticated from its wild ancestor *O. rufipogon*. The perennial wild species was known earlier as *O. perennis* by all rice workers until Bor (1960) identified it as *O. rufipogon.* Sharma and Shastry (1965) assigned a new name *(O. nivara)* to *O. fatua, which* was not a validly published name for the annual wild species. The African wild rice, *Oryza barthii,* which was acquired and maintained at NRRI, was identified as tolerant to bactrial blight with new gene, *Xa*21. Weedy rice appears as hybrid swarms due to introgression of genes between wild and cultivated species in nature. In Asian rice, it is known as *Oryza spontanea* whereas in African context it is said as *O. stapfii.*

Dr. K. Ramiah, the founder Director had brought a set of 2,400 accessions of germplasm from Paddy Breeding Station, Coimbatore to start rice research at NRRI. Subsequently many exploration and collection programmes, introduction and acquisition through exchange activities have helped enrich the Gene Pool. Besides germplasm introduction, the other landmark activity of the Division was the Jeypore Botanical Survey (JBS). This programme was supported by an ICAR scheme and continued for five years (1955-59). It was led by Dr. S. Govindaswami and the mission was the first of its kind, ever organized in the world to collect rice germplasm. The team explored about 27,000 km^{2}and collected 1,745 cultivated and 150 wild rice accessions. A new species was described from this region and was given the name of *Oryza jeyporensis*, which did not exist later as a distinct species.

After establishment of NRRI in 1946, efforts were made to introduce some exotic germplasm from China, Japan, Taiwan and Russia, which were semi tall and nitrogen fertilizer responsive. Some cultivars of Chinese origin like CH 4, CH 45, CH 55, CH 62 and CH 63 proved to be very good donors for better yield and early maturity. Few varieties like CH 27, CH 47, CH 962, CH 971, CH 972 and CH 1039 were found suitable to grow in Kashmir valley. Contrary to the success of the Chinese varieties, the Japanese and Russian germplasm were found unsuitable under Indian condition. The International Rice Commission (IRC) recognized NRRI as a centre for multiplication and maintenance of world genetic stocks of rice mostly the FAO designated germplasm of five countries i.e. India, Indonesia, Japan, Pakistan and USA. In the process many varieties comprising *japonicas, indicas, bulus* and floating types of south and south-east Asian countries were introduced to the country. Further, NRRI was recognized as the main centre for the inter-racial *japonica-indica* hybridization programme during 1950-1964.In the process many exotic *japonicas* were introduced into India. In early 1960s, Dr. R.H. Richharia introduced 67 varieties from Taiwan, two or three cultures of those were dwarf types, were tested at NRRI and one of them was identified as Taichung Native 1 (TN 1), which later laid the foundation for ushering Green Revolution in the country.

Several joint explorations together with countries like Japan, France and Philippines were undertaken for collection of wild species of rice. Later in1975, a comprehensive exploration and collection programme was drawn for the whole country especially for the traditional rice growing areas of Karnataka, Maharashtra, Madhya Pradesh, Uttar Pradesh, Bihar, West Bengal and Odisha covering 30 districts of 7 states. This programme was popularly known as National Collection from States (NCS) and resulted in collection of 1038 accessions. Increased interest in herbal medicines during last few decades has necessitated collection of rice germplasm with special emphasis on their medicinal value from Bastar region of Chhattisgarh and Palakkad region of Kerala for the famous 'njavara' rice. Recently, FAO recognized Koraput region of Odisha for traditional rice cultivation and Kuttanad region of Kerala for below sea level farming in 2012 and 2013, respectively as Globally Important Agriculture Heritage Systems (GIAHS).

The cold storage system for conservation of rice germplasm was established at NRRI in 1984. After establishment of National Gene Bank at NBPGR, New Delhi, it was decided to deposit all the germplasm of NRRI at NBPGR in 1986. Since then, 35,619 rice accessions have been deposited in the long term storage (LTS) of -18^{0} C and with 3-4% RH. Under the aegis of the Indo-USAID collaborative project, a cold module was gifted to NRRI in 1997. The facility became operative in 1998 with a controlled temperature of 4^{o} ± 2^{o} C & 33 % ± 5 % RH and was found dependable. The Gene Bank facility thus created was meant for medium term storage (MTS) and the seeds were kept viable for 6-8 years. When accessions in the MTS drops below 50 g or if seed viability falls below 85%, then the seed is increased (rejuvenated). All the germplasm collections including wild and weedy rice are being characterized for agro-morphological traits based on 30 distinctive, uniformity and stability (DUS) characters as per the descriptors which include 19 qualitative and 11 quantitative characters at appropriate stages of plant growth and maturity. Sharing of rice germplasm also remains an important mandate of this Division for utilization in crop improvement programme. Germplasm are supplied to various institutes/organizations through proper signing of Material Transfer Agreement (MTA).

2.2. Cytogenetics of rice and its species

Food and Agriculture Organization (FAO) sponsored *indica* x *japonica* hybridization program was carried out by Dr. S. Sampath and his team during 1952-59. Cytological explanation for the spikelet sterility in *indica* x *japonica* hybrids (Sampath and Krishnaswamy 1948, Sampath and Mohanty 1954, Sampath 1960, 1964) established that it is a complex species. It has been reported that they can be crossed with each other despite their differences (Sampath 1961, Sampath and Seetharaman 1962). Dr. S. Sampath was selected as one among the three members of a Committee appointed on February 4, 1963 during the Symposium on Rice Genetics and Cytogenetics held at International Rice Research Institute to set a standard classification and nomenclature for the species in genus *Oryza* for adoption by all rice research workers worldwide.

2.3. Quality seed production and management

Genetically pure seed is the basic and important input for crop establishment and production. Good quality seed can contribute up to 30% increase in productivity. Therefore, a standing experts committee on seeds was appointed as early as in 1952 by ICAR to formulate a programme to strengthen the seed production and distribution system.

Since beginning NRRI has shouldered the responsibility to carry out the maintenance breeding programme for keeping the integrity and purity of the variety intact by producing Nucleus seed and Breeder seed particularly of these varieties developed by this Institution. It also continued to be one of the voluntary centres of ICAR for breeder seed production of paddy. In last ten years, the institute has produced 598.9 tons of breeder seed of 71 varieties, which were supplied to 15 states of the country, comprising of Government organizations and private companies as per the Government of India allocations. Besides, the institute is also producing TL seeds for distribution to farmers. Participatory seed production programme of the Institute started in 2012 under which 441.2 tons of truthfully labelled (TL) seed of 4 major popular rice varieties of the state was produced in the farmers' field under the supervision of NRRI Scientists and was made available to the farmers.

Presently, 48 rice varieties of the institute are under national seed chain, among them Swarna Sub-1, Pooja, Naveen, Shatabdi, CR Dhan 500, CR Dhan

201 and CR Dhan 303 are highly demanded varieties. The seed demand of high protein rice CR Dhan 310 & CR Dhan 311 (Mukul), high yielding variety CR Dhan 307 (Maudamani) and CR Dhan 800 (Swarna MAS) is picking up at a higher pace.

Along with seed production, seed science research is also a priority area for the institute. All the NRRI released varieties are already characterized for their duration of seed dormancy and viability. The other important seed traits viz., seed vigour and seed dimension are under investigation at molecular level.

With increasing awareness on role of quality seed, the Seed Replacement Rate (SRR) has gradually increased in the country. Like-wise with adaptation of newly developed climate smart and stress tolerant varieties the Variety Replacement Rate (VRR) of the country has also increased considerably in recent years. However, till now, only 30 to 35% of the farmers use their farm-saved seed for crop production either due to lack of awareness or poor accessibility of quality seed. Therefore, the quality seed production and distribution system are to be further strengthened in future to ensure the availability of quality seed for the total farming community.

2.4. Breeding for Biotic stress resistance

Rice suffers from several biotic and abiotic stresses that seriously affect its production. A wide range of pathogens, insects, nematodes and other pests attack the rice plant in different parts of the world. Magnitude and the type of damage caused by pests vary in different regions. Among them, diseases like blast, bacterial blight (BB), sheath blight (ShB) and insects like brown plant hopper (BPH),yellow stem borer (YSB) are of major concern in India as well as many other parts of the world. Despite the availability of several control mechanisms for mitigating pest damage, developing cultivars tolerant to major insect-pests and diseases prevalent in an area is the easiest, most economic and eco-friendly measure available to the farmers. At the same time, the system is highly dynamic in its nature due to continuous co-evolution of genes conferring resistance or susceptibility in hosts and their corresponding gene for virulence in pests. Genes conferring resistance are distributed across primary, secondary and tertiary gene pool of the crop. Judicious use of these genes and genetic resources to minimize losses caused by pests remains an important challenge for rice researchers worldwide.

In India, systematic research efforts to impart host plant resistance in rice has been undergoing since past 70 years. The biotic stress breeding programme at the NRRI has evolved over time depending on the dynamic pest profile of the crop and advances in the technologies available. The institute was established in 1946 in the backdrop of the Bengal famine caused due to *Helminthosporium* brown leaf spot. Hence during the first two decades, the emphasis was given to identify brown spot resistant genotypes for developing tolerant/resistant varieties. Eventually, breeding for tolerance against blast and yellow stem borer (YSB) was also taken up. With the introduction of high yielding semi-dwarf varieties like TN 1 during early 60's, bacterial blight became a severe threat to rice production. The 1970's and 1980's saw the major focus being directed towards breeding for bacterial blight tolerance. With the outbreak of brown plant hopper in the late 1970's, breeding for BPH tolerance had also taken a centre stage. Sheath blight, though very severe even during 1960's in countries like the Philippines, was not economically important in India until recently. However, consequent upon reports of severe incidences of ShB from different pats of the country in recent years, search for resistance sources has geared up.

2.4.1. Bacterial blight (*Xanthomonas oryzae* pv. *oryzae*) resistance

The *Xa21* gene, imparting resistance to BB, was identified at NRRI in the wild species *Oryza longistaminata*, which was highly effective against all races in South and South-Eastern Asia. The gene was later mapped and cloned at IRRI and is being extensively utilized by breeders across the globe. Varietal improvement programme was also initiated to improve the BLB resistance using popular high yielding varieties as recurrent parents and resistant genotypes viz., Ajaya (*xa5*), IRBB 8 (*xa8*) and IRBB 60 (*xa5, xa13 and Xa21*) as donors through pedigree breeding coupled with artificial screening.

Resistance genes (*xa5*, *xa13* and *Xa21;* either singly or in different combinations) pyramided lines were developed through marker assisted backcross breeding in the genetic background of Swarna and IR64 under the Asian Rice Biotechnology Network (Reddy et. al. 1997). Two lines CRMAS 2231-37 (IET 20668) and CRMAS 2231-48 (IET 20669) in the background of IR 64 were found promising for BB endemic areas of Uttarakhand & Andhra Pradesh and Uttarakhand & Haryana, respectively, while one line CRMAS 2232-85 (IET 20672) in the background of Swarna was recommended for the endemic areas of Gujarat and Maharashtra. Pradhan et al. (2015) introgressed three BLB resistance genes (*xa5, xa13* and *Xa21*) by marker-assisted backcrossing, in the background of the popular, but highly BLB susceptible deep water variety, Jalmagna. The pyramided lines showed a high level of BLB resistance and a significant yield advantage over Jalmagna. Lines carrying two BB gene combinations (*Xa21*+*xa13* and *Xa21*+*xa5*) were also developed in the background of Jalmagna (Pradhan et al. 2016). The pyramided lines showed increased resistance to BB isolates prevalent in the region. The parental line improvement for BB resistance has been successfully undertaken in case of popular rice hybrid of NRRI, Rajalaxmi, by introgressing four resistance genes (*Xa4*, *xa5, xa13,* and *Xa21*) through Marker-assisted backcross (MAB) breeding (Dash *et al*. 2016).

Varietal improvement program at NRRI for BB resistance resulted in the release of Improved Lalat [CRMAS 2621-7-1 (IET 21066)], Improved Tapaswini [CRMAS 2622-7-6 (IET 21070)] and CR Dhan 800 in the genetic background of popular rice varieties Lalat, Tapaswini and Swarna, respectively. Improved Lalat and Improved Tapaswini carry four genes (*Xa4, xa5, xa13* and *Xa21*) while CRDhan 800 has three resistance genes *Xa21, xa13* and *xa5*. All have been effective for growing in the "bacterial blight" endemic areas of Odisha.

2.4.2. Rice blast (*Magnaporthe oryzae*) resistance

Marker assisted backcross breeding strategy was applied for pyramiding blast resistance genes (*Pi2* and *Pi9*), into Vandana and Kalinga III through the crosses (Kalinga III/C101A51 (*Pi-2(t)*)/Kalinga III/*O. minuta* der. WHD IS 75-127(*Pi-9(t)*) and Vandana/C101A51//Vandana /*O. minuta* der. WHD IS 75-127). Many lines in the background of Vandana and Kalinga III were developed. Among the promising lines, CR 2619-2, CR 2619-5, CR 2619-6, CR 2619-7, CR 2619-8 and CR 2619-9 are in the background of Vandana while CR 2620-1, CR 2620-2, CR 2620-3 and CR 2620-4 are in Kalinga III background. The promising lines were tested in Disease Screening Nursery (DSN) under AICRIP for multi-location trials. The lines are in the pipeline for release as variety.

In an attempts to find out the status of twelve major blast resistance genes (*Pib*, *Piz*, *Piz-t*, *Pik*, *Pik-p*, *Pikm*, *Pik-h*, *Pita/Pita*-2, *Pi2*, *Pi9*, *Pi1* and *Pi5)* and their diversity among eighty released rice varieties of NRRI, it was observed that presence of resistant genes varied from 4 to 12 and the frequencies of the resistance genes ranged from 0 to100% (Yadav et al. 2017). Among the 80 varieties screened, 19 were resistant, 21 were moderately resistant and 40 were susceptible to the disease.

2.4.3. Sheath blight (*Rhizoctonia solani* Kuhn) tolerance/resistance

Screening experiments conducted at the NRRI using the local strains of the pathogen has shown that international check genotypes for ShB tolerance like Jasmine 85 and Teqing are susceptible to the local strains. Only two genotypes, Tetep and CR 1014, showed consistently moderate resistant for sheath blight. Conventional breeding has been less effective for the development of ShB tolerant genotypes because of the polygenic nature of the trait. In the segregating generations of the crosses made using CR 1014 as the donor for ShB tolerance, selection of superior recombinants has been difficult since ShB tolerance has tight linkage with plant height. A novel ShB QTL on chromosome 1 was identified from an $F_{2:3}$populations derived from the cross Swarna Sub1 x CR 1014, which need to be fine mapped and its effects in different genetic backgrounds need to be validated.

2.4.4. Brown plant hopper (*Nilaparvata lugens* Stål) resistance

Several landraces showing very high degree of resistance were used for breeding varieties resistant to BPH. The breeding lines CR 3005-77-2 (Samba Mahsuri/ Salkathi), CR 3006-8-2 (Pusa 44/Salkathi), CR 3005-230-5 (Samba Mahsuri/ Salkathi), CR 2711-76 (Tapaswini/Dhobanumberi) were found to be promising in plant hopper screening trials of AICRIP, 2011 and 2012. Molecular mapping of resistance genes/QTLs from these two landraces- Salkathi and Dhobanumberi is underway. Two QTLs designated as *qBph4.3* and *qBph4.4* were identified from Salkathi landrace among which *QBph4.3* is novel (Mohanty et al. 2017). Transfer of these two QTLs into two popular susceptible varieties Naveen and Pooja are in progress. Recently, Prahlada et al. (2017) at IRRI identified a single dominant gene, *BPH31* on the long arm of chromosome 3 in CR2711-76.

2.4.5. Yellow stem borer (*Scirpophaga incertulas*) tolerance/resistance in rice

Since gene(s) for resistance to YSB has not been found in the primary gene pool of rice, efforts were made to incorporate alien genes from wild species belonging to the secondary and tertiary gene pool, which are reservoirs of such traits. Wild rice germplasm has been screened against YSB. *O. brachyantha, O. officinalis, O. ridleyi* and *Porteresia coarctata* were found to be resistant/tolerant against the pest. Subsequently, backcross population of *O. sativa* cv. Savitri / *O. brachyantha* was developed to transfer YSB resistance to the cultivated rice (Behura et al. 2011). The cytogenetic analysis of the chromosomal variants led to the development of monosomic alien addition lines (MAALs). Of the 8 MAALs screened, MAAL 11 was found to be moderately resistant to YSB.

2.5. Breeding for Abiotic stress tolerance

2.5.1.Upland ecosystem

This ecosystem occupies an area of 8 Mha of which 6.2 Mha are in eastern region of the country. Moisture stress is an important limitation for achieving higher yield from this ecology. The main breeding objectives for development of upland rice varieties are early maturity duration (100-105 days) with drought tolerance, weed competitiveness and high yield. Upland varieties should also show biotic stress resistance to blast, brown spot, gundhi bug and termite attack. Many traditional *aus* cultivars from eastern India possess several desirable characters. The traits like early vigour, droopy leaves, deeper roots, moderate tillering and high grain weight are seen in *aus* genotypes. The common upland genotypes used as donor were Brown Gora, Black Gora, N22, C22, Lalnakanda 41, Kalakeri, Salumpkit, Ch 45, Dular, Annada, CR 143-2-2 and IRAT 112. They have provided good recombinants with *indicas*. The varieties developed for this ecosystem by the Institute are Bala, Sattari,Kalinga-III, Neela, Annada, Heera, Kalyani-II, Tara, Vanaprava, Sneha,Phalguni, Satyabhama and Ankit. More focused research on this aspet was initiated by the sub-station (Central Rainfed Upland Rice Research Station; CRURRS) of NRRI at Hazaribag (Jharkhand) where from following varieties have been developed; Vandana, DhalaHeera, Anjali, Sadabahar, Virendra, CR Dhan 40, Sahabhagidhan. Aerobic varietiesdeveloped at NRRIare CR Dhan 200(Pyari), CR Dhan 201, CR Dhan 202, CR Dhan 203 (Sachala), CR Dhan 204, CR Dhan 205, CR Dhan 206, CR Dhan 207 (Srimati) and CR Dhan 209 (Priya) which are suitable for drought prone ecology with assured irrigation.

2.5.2.Lowland ecosystem

Lowland is broadly classified into 3 classes based on duration and depth of water logging. The major class is shallow lowland with water depth of 0-30 cm during growth stages of the crop. This ecology is prone to intermittent flash floods and drought during growth stages. Direct seeding is also a common practice of cultivation in which proper land levelling is rarely achieved. Thus, anaerobic germination trait in the variety is desirable. For this submergence tolerant line, FR13A was selected from landrace Dhalaputia. Other landraces possessing submergence tolerance viz., Khoda, Khadara, Kalaputia etc. werealso selected as donor lines. Submergence tolerance has been incorporated in varieties like Pooja, Sarala, Gayatri, Varshadhan and Pratikhya. Currently, the Institute is focussing on development of climate resilient varieties by combining multiple abiotic stress tolerance genes/QTLs into popular varieties.CR Dhan 801 and CR Dhan 802 are two new climate-smart varieties possessing both submergence and drought tolerance in the background of "Swarna". The varieties released by the Institute for the ecosystem are Anamika, Ramakrishna, Samalei, Savitri (Ponmani), Moti, Padmini, Dharitri, CR 1002, Seema, Pooja, Ketikijoha, NuaKalajeera, NuaDhusura, Reeta, NuaChinikamini, Sumit, Swarna-*Sub1*, CR Dhan 407, CR Dhan 408 (Chakaakhi), CR Dhan409 (Pradhan Dhan),CR Dhan 800, CR Dhan801 and CR Dhan 802.

2.5.3. Semi-deep and deep water ecosystem

The semi-deep water ecology consists of low lying areas with water depth up to 75 cm and remain water logged for about a month while in deep water ecosystem it goes up to one-meter water depth and remains submerged for more than a month. By screening thousands of traditional landraces, several tolerant sources of different genetic background have been identified and several rice varieties suitable for deep and semi-deep water ecosystem are developed. The varieties released for water logged ecosystem are Utkalaprava, CR 1014, Gayatri, Kalashree, Panidhan, Tulasi, Sarala, Durga, Varshadhan, Hanseswari, CR Dhan 501, CR Dhan 502 (Jayantidhan), CR Dhan 503 (Jalamani), CR Dhan 505, CR Dhan 506, CR Dhan 507 (Prasant), CR Dhan 509, CR Dhan 510 and CR Dhan 511.

2.5.4. Ecosystem with salinity and water logging

For high throughput evaluation of rice germplasm and breeding lines for salinity tolerance at seedling and reproductive stages, dug-out cavity structures made of brick-mortar-concrete materials and filled with artificially prepared or natural transported saline soil havebeen designed and constructed at NRRI which (the prototype of structure and protocol for similating desired level of saliity) have subsequently been replicated at many research Institutions (Nayak et al. 2017). Novel screening protocol to promoteprecise screening for salt tolerance at reproductive stage was standardized and validated (Chattopadhyay et al. 2018a). Nine multi-environmental QTLs for salinity tolerance at reproduction stage were detected usingIR64/AC41585 population for different component traits such as spikelet degeneration, spikelet sterility and K^+ concentration in flag leaf on Chromosome 1, 2, 3, 4 and 11.

Landraces from Sunderbans region of West Bengal were found diverse in respect of salt tolerance. Salt tolerant cultivars from this area such as Kamini, Talmugur, etc. were found to haveallelic difference from the widely used *Saltol*-introgression line, FL 478 in the *Saltol* - QTL region (Chattopadhyay et al. 2013a). Raspanjar was found as one of the good performing landraces under salinity stress in coastal Odisha (Patnaik and Sinha, 1972). Unlike Pokkali, Raspanjar was efficient in maintaining higher level of K^+ despite high Na+ influx in shoot which are found to belocated distant from Pokkali in 3-D plot on SSR data. Swarna *Sub1* × Raspanjar and Savitri × SR 26B produced more transgression segregants for tolerance at seedling stage and were found ideal combination (Chattopadhyay et al. 2014). NRRI also identified few unique germplasm for reproductive stage tolerance viz. AC41585, AC39394 (Chattopadhyay et al. 2013b).

2.5.5. Coastal ecosystem

Different breeding methodologies were developed since early 1970s at NRRIto get improved high yielding genotypes with salinity tolerance (De and Sreedharan, 1991) and suitable for the target ecosystem. Lunishree, the first high yielding variety for coastal saline area was developed and released in 1992. This is a gamma irradiated mutant from Nonasail (Sridhar, 1996). CR Dhan 402 (Luna Sampad, IET 19470) and CR Dhan 403 (Luna Suvarna, IET 18697) in 2010 and Luna Barial (CR Dhan 406, IET 19472) in 2012 were released by the Odisha State Sub-Committee on Crop Standards (State Varietal Release Committee) for cultivation during wet season in coastal saline areas of Odisha. Luna Sankhi has been developed by ICAR-NRRI in collaboration with IRRI, Philippines and released in 2012 by SVRC, Odisha for dry season cultivation in coastal saline areas (Chattopadhyay et al. 2018b).

2.5.6. On farm evaluation of climate resilient rice varieties for unfavourable ecology

On-farm trials were conducted in Ersama block of Jagatsingpur district (Odisha) using suitable rice varieties, selected nutrient management practices. They were evaluated and the most promising options were validated in farmers' participatory mode. Among different integrated nutrient management practices, *Sesbania* green manuring (GM) for intermediate lowlands (0-50 cm water depth), *Sesbania* GM + prilled urea (PU) and Sesbania GM + *Azolla* for shallow lowlands (0-30 cm water depth) in the wet season, and *Azolla* + PU in the dry season were found to be promising. Substantial yield improvements (91% in wet and 75% in dry season) could be achieved by combining salt-tolerant varieties with improved nutrient and other crop management practices (Saha et al. 2008). During widespread survey and demonstrations of climate resilient rice varieties in coastal region it was felt that salinity and stagnant flooding in combination affect the rice production in greater extent (Chattopadhyya et al., 2016). Adoption of rice cultivars tolerant to flooding and salinity gave yield advantage of 0.44 to 2.14 t ha^{-1} compared to traditional rice cultivars. Luna Suvarna in salinity affected area, Varshadhan in water-logged area and Swarna *Sub 1* and Savitri *Sub 1* in submergence prone areas were found promising in Sunderbans, West Bengal.

2.5.7. High and low temperatures stress tolerance in rice

High temperature stress is prominent in dry season rice cultivation. The Institute has identified many tolerant germplasm lines to high temperature stress (Pradhan et al. 2016). CR3621-6-1-3-1-1, CR3820-2-1-5-1-2, CR3813-4-4-4-2-2, CR3820-4-5-3-1-3, AC 39890, AC 39973, AC 39790, Annapurna, Maudamani (CR Dhan 307) and N22 showed spikelet fertility of >40% under high temperature stress and categorized as highly tolerant while these lines exhibited>80% under normal situation. The strongly associated marker RM547 tagged with fertility under stress and the markers like RM228, RM205, RM247, RM242, INDEL3 and RM314 indirectly controlling temperature stress tolerance were detected through both mixed linear model and general linear model TASSEL analysis (Pradhan et al. 2016). Low temperature stress, on the other hand, limits yield in dry season boro rice and wet season hill and high altitude rice. Many germplasm have been identified as tolerant to cold stress by the Institute (Pradhan et al.2015c; Pandit et al. 2017). Chilling tolerant varieties can be developed by pyramiding of low temperature stress tolerance QTLs associated with markers like RM1347, RM328, RM152, RM341, RM50, RM2634, RM4112, RM5310, RM7179, RM3701, RM104, RM9, RM1211, RM245, RM3602, RM493, RM1335, RM282, and RM5704 which aresignificantly associated with chilling stress of 8^{0}C to 4^{0}C for 7–21 days duration. The primers linked to the seedling stage cold tolerance QTLs were also identified namely qCTS9, qCTS-2, qCTS6.1, qSCT2, qSCT11, qSCT1a, qCTS-3.1, qCTS11.1, qCTS12.1, qCTS-1b, and CTB2 (Pandit et al. 2017). CR Dhan 601, CR Boro Dhan 2 and Rajalaxmi have beenreleased for boro cultivation (cold tolerance) while Maudamani (CR Dhan 307) is moderately tolerant to both the stresses.

2.6. Irrigated ecosystem

The quantum leap in productivity was possible mostly by introduction of dwarfing genes in tall varieties. During 1956, Chinese local landrace Ai-zi-zhan and subsequently Dee-geo-woo-gen, Taichung Native 1, and I-geo-tse were used as source of dwarfing gene in breeding to improve tropical landraces. In 1966, the first semi-dwarf, high-yielding modern rice variety, was introduced for the tropical irrigated lowlands which created history, called green revolution (Khushet al.2001).The development of IR8 at IRRI increased the yield potential of the irrigated rice varieties substantially in tropics. Subsequently, tropical varieties of enormous yielding capacity, viz., Jaya and Padma in India and Bg. 90-2 in Sri Lanka were developed using the dwarfing genes. In Korea, Tongil-type rice varieties were developed in 1971 from a *japanica/indica* cross (Chung and Heu1980), which showed 30% yield increment compared to *japonica* varieties. The dwarf plant type was basically attributed to'sd1' gene in Dee-geo-woo-gen and others was a milestone in breeding high yielding varieties. There was phenomenal modification in plant architecture, viz., dwarf height, more tillering, sturdy stem and erect leaves. The competency further improved due to photo-insensitiveness and fertilizer responsiveness with an enhanced productivity potential. There was continuous effort to improve it further, however, there was less progress for productivity enhancement, rather there was shifting of target towards stability of yield with incorporation of substantial biotic and abiotic stress resistance/tolerance supplemented with quality improvement along with reduction in duration. However, somewhat stagnant yield of semi-dwarf *indica* inbreds have been observed since the release of IR8 (Peng et al.2008).

In this context, several high yielding rice varieties have been developed for mid early, mid or late duration with seed to seed 125-145 days. These varieties are endowed with characters of dwarfism. However, in this process, several crucial characters viz., dormancy, submergence tolerance, photo and thermo-sensitivity were depleted. Loss of photo-insensitivity was a blessing for intensive agriculture and for improvement of productivity per unit time (Krishnamurty et al. 1992). Apart from this, synchronous flowering/maturity was another desirable character in this ecology. More than 1200 high yielding varieties (HYVs) have been developed in India. Out of these, 132 varieties have so far been developed by ICAR-NRRI, Cuttack for different ecologies including 52 varieties for irrigated ecology (Pathak et al. 2018).

2.7. Hybrid rice

In India, hybrid technology was adopted in project mode during 1989 when Indian Council of Agricultural Research (ICAR) launched a special goal oriented and time bound project on 'Promotion of Research and Development Efforts on Hybrids in Selected Crops' at 12 network centres. After four years of meticulous research (1989-93), first hybrid rice was released in Andhra Pradesh in 1993 and India became the second country after China to develop and commercialize hybrid rice. So far, 101 rice hybrids (33from public organizations and 68 from private sectors) have been developed, suitable for different ecologies and duration ranging from 115 to150 days which covers 3.0 Mha rice area (6.8% of total rice area) in India.

ICAR-NRRI has started breeding hybrid rice during late 1970s and could develop and commercialize three hybrids namely, Ajay, Rajalaxmi and CR Dhan 701 besides several CMS and good combining restorers under diversified genetic back-ground. They are now being utilized for maximizing genetic gain of hybrids in the country.

The primary success of hybrid technology was identified long back at ICAR-NRRI when Sampath and Mohanthy (1954) reported male sterility in reciprocal crosses of *indica/japonica* rice lines. In the beginning, ICAR-NRRI had acquired all the prerequisite materials (CMS lines viz. V 20A, Yar Ai Zhao A, Wu10A, MS 577A, *Pankhari*203A, V 41A, Er-JiunanA, respective maintainers, nine other maintainers and 13 restorers) from IRRI (NRRI Annual Report 1981-82). Systematic hybrid rice breeding was initiated in interdisciplinary mode with objectives to develop desirable parental lines viz., cytoplasmic genetic male sterile (CGMS) lines, maintainers and restorers for development of rice hybrids for irrigated and shallow submergence. CR Dhan 701 is the country's first long duration hybrid, substitute for popular variety Swarna. Besides, NRRI has developed several promising CMS lines, which have stable male sterility (WA, Kalinga-I and *O. perennis*etc. cytoplasmic background), maintainers and effective restorers. More than 45 CMS lines in diverse genetic and cytoplasmic background have been developed amongst, Sarasa A, Pusa 33A (WA), Annada A (WA), Kiran A (WA), Deepa A (WA), Manipuri A (WA), Moti A (WA), Krishna A *(O. perennis),* Krishna A (Kalinga I), Mirai (Kalinga I), Padmini A, PS 92A and Sahbhagi Dhan A etc. are prominent. The medium duration CMS, CRMS 31A (WA) and CRMS 32A (Kalinga-I) are utilized more for hybrid development at NRRI and elsewhere in the country. The CRMS 24A and CRMS 40A, developed under the nucleus background of Moti and Padmini are found suitable for late duration hybrid breeding. Moreover, short duration CMS, CRMS 8A, CRMS 51A and CRMS 52A and CRMS 53A having drought tolerance are also being used for development of hybrids for drought prone ecosystem.

The latest release CR Dhan 701 (CRHR32) was found suitable for irrigated-shallow lowland of Bihar, Gujarat and Odisha having MS grain type with an average yield capacity of 7.5 t ha^{-1}. This hybrid shows substantial tolerance to low light intensity, thus having great scope in eastern Indian states where low light limits the potential expression of hybrids/varieties during wet season. Rajalaxmi (125-130 days) was developed utilizing native CMS line CRMS 32A, released by SVRC 2006/CVRC 2010 for irrigated-shallow lowland of Odisha and *boro* ecosystem of Odisha and Assam as it has seedling stage cold tolerance. Ajay is a medium duration hybrid with long slender grain, released for cultivation in irrigated-shallow lowlands of Odisha. As these hybrids are adaptable for eastern Indian climatic conditions with assured remuneration, 12 private seed agencies over five states have signed MoUs and taken license to commercialize them.

To make this technology more sustainable and amenable to farmers, trait development strategy among the parental lines becomes mandatory. The parents of hybrids Ajay, Rajalaxmi and CR Dhan 701 have been improved for bacterial blight, the most devastating disease of rice (Das et al. 2016). The submergence and salinity are the major abiotic stresses occur frequently in rain-fed shallow lowland area and cause substantial yield loss in rice. Hence, to cope up with the problems, and make hybrid rice more sustainable during these adversities, ICAR-NRRI has successfully stacked submergence and salinity tolerant QTLs in the seed parents of CRMS 31A and CRMS 32A. To enhance the seed producibility, introgression of stigma exsertion trait from *O. longistaminata* into CRMS 31A and CRMS 32A, are under progress. To excavate the genetic region responding heterosis in rice, transcriptomic analysis of hybrids Rajalaxmi and Ajay are completed and interpreted. Availability of restorers for WA-CMS lines is very stumpy in nature, only 15% of total rice genotypes are having the ability to restore complete fertility in WA-CMS based hybrid rice (Katara et al. 2017). Hence, good combiner genotypes having partial fertility restorers Mahalaxmi and Gayatri were improved by introgressing fertility restorer gene(s) *Rf3*&*Rf4* through MABB approach. Further, to make clear cut identity and ensure pure seed of parents/hybrids, 12 signature markers that unambiguously distinguish 32 rice hybrids were developed, which can be utilized for DNA fingerprinting and genetic purity testing of hybrids.

Hybrid rice technology is impressive as it enhances farm productivity of 15-25% more than HYVs. Given its yield advantage and economic importance, 101 rice hybrids have been commercialized in the country, which creates a huge seed industry world-wide. Moreover, this venture also has great entrepreneurship opportunity, creates additional employment for 100-105-man days ha^{-1} in seed production. Hybrids developed in the country are being commercialized under public-private partnership (PPP) mode. Three NRRI bred hybrids are being commercialized with 19 private seed agencies as total 38 MoUs were signed which could generate direct revenue of Rs. 182.00 lakhs (2010-2018) to the Institute.

2.8. Genetic improvement of rice for aroma, nutrition and grain quality

Since inception of the institute, grain quality has remained a focus of researchers, besides yield, dragging the major attention in breeding programs. During 1950s to 60s when *indica –japonica* hybridization program was at its peak, studies were undertaken on traits that could be easily phenotyped, like grain type, grain colour, head rice recovery, milling percentage, etc. Breeding program for fine grain was initiated as early as 1953. Initially, the method of pedigree breeding was chosen for improvement of grain characters of otherwise popular varieties like Ptb10. Later, mutation breeding became the method of choice for altering the grain traits of popular varieties like TN1, Taichung 65 and CR2001. Head rice recovery percentage which has now been accepted as one of the major criteria to decide the release of varieties through AICRIP, was first undertaken as a trait of investigation during 1960s. The nature, texture and type of chalkiness of endosperm were reported to affect the HRR%. These endosperm traits were found to be highly affected by the genetic factors of the variety. Crop harvesting at 30-40 DAF with 20-23% grain moisture content and shade drying to 11-13% moisture, yielded highest hulling recovery by reducing the development of sun cracks in the kernels during field drying. Inheritance studies on complex traits like cooking quality and protein content were undertaken in bi-parental populations and were concluded as to be governed by multiple genes. The role of minor genes in trait expression was also reported. Genetic studies on kernel colour were undertaken in the segregating generations of GEB24 and Ptb10 and linkage of the trait with others were also established. However, breeding initiatives for the complex traits like palatability, sensory traits, cooking quality, value added products, etc. could not become possible due to the difficulty and technical constrains involved in phenotyping of the traits. Traits that could be easily phenotyped, like grain type, aroma, were subjected to improvement keeping yield in the centre.

The existing genetic diversity for short-grained aromatic genotypes in eastern India appealed the plant breeders to enhance the yield potential of the popular landraces. This was initiated with the vision to improve the economic status of farmers by cultivating and preserving them despite the replacement pressure created by high yielding varieties. The initial improvement was through pure line selection of landraces like Dhusara, Chinikamini, Kalajeera yielding <1.5 t ha^{-1}. The varieties purified from the landraces were renamed as Nuadhusara, Nuachinikamini, Nuakalajeera respectively, which could yield 4.5t/ha, improving the yield potential by three times. Moreover, the varieties fetched higher remuneration in the market due to their qualities. Later came the phase of creation of variability through hybridization. Marker assisted pedigree breeding led to the development of CR Sugandh Dhan-907 by crossing Pusa 44 and Dubaraj, a landrace belonging to Chhattisgarh (Patnaiket al. 2015). Participatory plant breeding was integrated with the molecular breeding for better genetic gain in Kalajeera, Machhakanta and Haladichudi (Roy et al. 2017). Subsequently, aromatic, long grained, non-basmati varieties like Poorna bhog and Geetanjali were developed and released through mutation of basmati genotypes. Among these, Geetanjali variety has been used for establishment of rice value chain in Odisha and Poorna bhog is gaining popularity. Phenotypic descriptors with molecular markers were used to characterize the short grain aromatic landraces of eastern India (Roy et al. 2014 & 2016). A greater insight into the origin and their population structure was derived by integrating the analysis of both nuclear and chloroplast DNA sequence variations (Roy et al. 2016).

Protein in rice has ever been a major concern due to its lowest grain protein content among cereals. Positive correlation of bran and aleurone layers with protein and thiamine content was identified and high protein content genotypes were found to have a cellular patch in spermoderm (NRRI Annual Reports, 1949-50 and 1950-51). Studies on variation in protein content and aleurone layer thickness were undertaken in 450 representative genotypes of *japonica, indica* and *javanica* rice. Existence of positive correlation between aleurone layer thickness and percent protein content in kernels was reported earlier. Protein content in rice kernels varies from 6.1% to 10.1% while the aleurone layer thickness varied from 11.2ì to 75.0ì. Moreover, protein content in *japonica* rice was found to be higher than in white kernelled *indica* types. Inheritance of protein content was studied by the Rice Technology Section established during 1963 and they recorded frequency of occurrence of high protein genotypes among different duration classes of rice varieties in temperate and tropical zones. Due to 4-5% milling, a loss of 11-12% protein as compared to brown rice was recorded during 1966. Studies on inheritance of protein content suggested the role of polygenes in trait expression while appearance of transgressive segregants in F_2, suggested the possibility to breed pure lines for higher protein content than in parents. Near infrared spectroscopy (NIR) was therefore calibrated and validated for large scale and high throughput phenotyping of GPC (Bagchiet al. 2015). Breeding for high protein rice was initiated involving two landraces from Assam. High protein trait was transferred to high yielding backgrounds of Naveen and Swarna through backcross breeding to release the first high protein variety in Naveen background as CR Dhan 310 (released by CVRC for Odisha, Uttar Pradesh and Madhya Pradesh) with 10.3% GPC in 2016. Another variety CR Dhan 311 has been released by State Variety Release Committee of Odisha in the name of 'Mukul' with GPC of 10.1% and Zn content of 20 ppm. By using a backcross derived mapping population, a consistent QTL (qGPC1.1) over the seasons have also been identified (DARE/ICAR Annual Report 2015-16 and 2016-17 and NRRI Annual Report 2014-15). Quality breeding has come across several phases and has a long way to go with the objective to ensure the nutritional and economic security. With more quality traits coming under non destructive phenotyping, their genetic improvement will further be accelerated.

2.9. Genetic improvement of direct seeded rice

Several studies have reported that grain yield under transplanted system has edge over dry direct seeded rice. On the contrary, no significant differences were observed between the two systems (Mahender et al. 2015). In recent years, ICAR-NRRI has played a significant role in the development of rice varieties for the dry direct aerobic condition with yield potential of 4.0 - 4.5 t/ha. As these aerobic rice varieties require minimum maintenance and save labour they are getting popular across eastern states of West Bengal, Jharkhand, Odisha and Chhattisgarh. On the other hand, developing a hybrid for dry direct system would be beneficial. As hybrids are heterotic in nature, they yield higher in favourable conditions and marginal lands. Recently, two rice hybrids viz. GK-5022 and KPH 272 were released by private companies for the dry direct aerobic condition with yield potential of 4.0-4.2t/ha.

To surpass the gain of transplanted rice, understanding of direct seeded environment and traits adaptable for that environment need to be addressed. Good seed vigour, high mesocotyl length with anaerobic germination is very much essential to break the earth crust to have uniform emergence. However, anaerobic germination will address the problem of water stagnation in the improperly levelled field. Rice has the fibrous root system and developed for the transplanted condition. Over several decades, the below-ground portion for rice plant has been neglected. Attaining vigorous seedling growth and improving root parameters are necessary to improve nutrient acquisition and to compete against the weeds under direct seeded condition. Increase in nodal root in the early phase of the cropping period and deep root with more branching will facilitate the nutrient uptake under limited moisture. Erect leaves, thin and strong culm will have proper assimilation of photosynthates. That would address the problem of improving water productivity and helps in more spikelet fertility and high grain yield. ICAR-NRRI in collaboration with International Rice Research Institute, Philippines, has developed a comprehensive breeding program to develop new generation rice for direct seeded condition by introgressing the above discussed QTLs/genes (Table 1).

Table 1. Donors, QTLs, genes, trait information used to improve dry direct seeded rice.

Donors	QTLs/Gene	Trait	Reference
IR93312-30-101-20-13-66-6	$qAG_{9.1}$, $qAG_{9.2}$	Anaerobic germination	Angaji *et al.*(2010)
IR94226-B-177-B	$qNR_{5.1}$, $qEVV_{9.1}$, $qRHD_{1.1}$	High nutrient uptake (N,P, Fe, Zn), Early vigor, nodal root,	Sandhu *et al.*(2015)
WAB 880-1-27-9-2	$qNR_{5.1}$	High nutrient uptake (N,P, Fe, Zn)	Sandhu *et al.*(2015)
IR94225-B-82-B	$qGYDS_{1.1}$, $qGYDS_{6.1}$, $qGYDS_{9.1,}$ $qGYDS_{10.1,}$	Grain yield DS	Sandhu *et al.*(2015)
IR91648-B-289-B	$qLDG_{3.1}$, $qLDG_{4.1}$	Lodging resistance	Dixit *et al.*(2015)
IR91648-B-336-B	qCS1.1	Lodging resistance	Yadav *et al.* (2017)
IR91648-B-13-B	qEUE3.1	Early uniform emergence	Singh *et al.* (2017)
IR91648-B-32-B-B	qEUE11.1	Early uniform emergence	Dixit *et al.*(2015)

Thus, the stacking of multiple QTLs/gene in single background for nutrient use efficiency, lodging resistance, seedling vigor, anaerobic germination, yield related QTLs could assist in development of dry direct seeded rice varieties with greater productivity and would drastically reduce the input cost and water which ultimately leads to greater economic returns to the farmers.

2.10. Biotechnological applications in rice improvement

2.10.1. Doubled haploids

The ICAR-NRRI, Cuttack initiated the work on doubled haploid technique in 1997 to overcome the constraints associated with the rice hybrids such as (1) high seed cost(2) high sensitivity to unpredictable environmental condition and (3) asynchronous flowering. Since doubled haploid approach can effectively address the problems associated with hybrid rice through production of high yielding doubled haploids with uniform grain quality, the basic studies on *indica* rice anther culture assumes great significance.

Considerable progress has been made as evidenced by release of two DHs as new varieties named Satyakrishna and Phalguni in 2008 and 2010, respectively. Satyakrishna (CRDhan 10) has been developed from hybrid PHB-71 and is best cultivated in shallow irrigated low lands. Its maturity duration is 135 days. Satyakrishna is semi dwarf (105 cm) and possesses long slender grains with yield potential of 4.5-5 tha^{-1} in *kharif*and 5-6tha^{-1}in *rabi.* Phalguni was obtained from the popular hybrid KRH-2 and is cultivated in bunded upland and irrigated land. It is 105 cm tall and matures in 117 days. It also possesses long slender grains with resistance to leaf folder and leaf blast and moderate resistance to sheath rot, rice tungro virus, gall midge, brown spot and sheath blight. In 2013, attempt was made to standardize androgenic protocols in two *indica* rice hybrids i.e. CRHR32 (an elite long duration rice hybrid of NRRI, Cuttack) and BS6444G (a popular rice hybrid of Bayer Seed Pvt. Ltd.) for generation of doubled haploids. Further, anther culture was used for development of mapping population from Savitri (a high yielding *indica* rice variety) x Pokkali (a salt tolerant *indica* rice genotype) for identification of salt tolerant QTL/gene. Besides, two crosses of B X B and R X R were taken for generation of DHs using anther culture for parental line improvement to be used in development of rice hybrid. However, the production of albino shoots (60-100%) in all the cultures proved to be detrimental for optimization of androgenic response. Therefore, NRRI attempted to develop a protocol for suppression of albinism, which is also a frustrating feature. This led to standardization of 100% albino free shoot regeneration method in *indica* rice; patent and filed 1355/KOL/2015 entitled "Method for albino free shoot regeneration in rice through anther culture".

Subsequently, the improved protocol could generate 150, 200, 117, 73 and 30 DHs from CRHR32, BS6444G, Savitri X Pokkali, B X B and R X R respectively and surprisingly no haploids were observed in BS6444G, which showed 100%

spontaneous doubling. After proper assessment of ploidy status of the regenerants, 20 and 13 DH lines developed from CRHR32 and BS6444G respectively, were selected based on the morpho-agronomic characters and advanced for replicated trial for 5 consecutive seasons (*kharif* 2014-2018). Further, 6 promising DH lines derived each from CRHR32 and BS6444G showed promising grain yield and quality. Six promising DH lines developed from CRHR32 and BS6444G were nominated for AICRP trial.

All the 6 DH lines of BS6444G showing promising yield (BS6444G) were found to be aromatic confirmed by PCR and sequencing of *badh2*.A combination of BLB resistance genes (*Xa21*+ *Xa4*+ *Xa7*+ *xa5*) were also confirmed in 2 DH lines developed from BS6444G through molecular markers and bioassay. Besides, four DHs each derived from CRHR32 and BS6444G showed superior grain quality as compared to other DHs. Moreover, 4 DH lines derived from rice hybrid, CRHR32, were identified containing high protein (11.59-12.11%). Furthermore, isocytorestorer lines were developed through test cross of the 13 DHs (BS6444G) carrying positive Rf4 genes with the CMS, with an average of 500-600 grains per panicle.

A systematic study was carried out to find out the salinity tolerant lines during germination in different salinity levels for which 117 DHs derived from F_1s of Savitri (popular HYV) and Pokkali (salinity tolerant) were screened. This resulted in the identification of 4 candidate genes such as LOC_Os01g09550 (no apical meristem protein), LOC_Os01g09560 (mitochondrial processing peptidase subunit alpha),LOC_Os12g06560 (putative protein) and LOC_Os12g06570 (cyclic nucleotide-gated ion channel) using BSA. Subsequently, an efficient androgenic protocol was developed for another popular quality *indica* rice hybrid, 27P63 (M/s Pioneer, Hyderabad) and generated 345 green plants. After proper examination of ploidy status with further confirmation of 325 DHs using molecular markers, field evaluation was made for identification of superior lines using morpho-agronomic characters from which 92 DHs were selected for further evaluation out of which 25 DHs were found superior in terms of grain yield and quality.

About 15 years efforts of NRRI have overcome some of the problems that have enabled high frequency generation of doubled haploids from a number of commercial and experimental hybrids. Now, this expertise attracts the researchers from public sector institutions and private companies engaged in rice breeding to undertake training in this area. It is high time that country should take full advantage of this technology to apply at commercial scale.

2.10.2.Transgenics

Biotechnology research at the NRRI was initiated in the year 1999-2000 with an objective to build suitable capabilities for rice tissue and protoplast culture. Work was initiated on use of RFLP/RAPD and other DNA markers for genome analysis for rice improvement and genetic analysis of gall-midge resistance. A working molecular plant-pathology laboratory was also set up with the objective of marker-assisted selection for pathogen resistance.

During 2000-2001, a chymotrypsin inhibitor gene construct (pSKB: pMasJ35S-potato chymotrypsin inhibitor-nospolyA) was mobilized into an *Agrobacterium tumifaciens* strain LBA4404. *Agrobacterium* transformation of *indica* rice Pusa Basmati 1 was performed using 25 days-old-calli and resistant calli were placed for regeneration. Of the 38 putative regenerants produced, 34 plants were positive for the gus both through histochemical and PCR assays. In the year 2001-02, further attempts were made for genetic transformation of *indica* rice lines, Pusa Basmati 1 and Swarna. Three-week-old callus derived from the mature seeds used for *Agrobacterium tumifaciens* (LBA 4404) mediated transformation plasmid construct having potato chymotrypsin gene cloned under 35 S dual promoter and a nos terminator. A total 65 putative transgenics were obtained from Pusa Basmati 1 and 11 putative transgenics from Swarna. Molecular analysis confirmed the presence of *GUS* (reporter gene) and *hpt* (marker gene) genes. Work was also reported on standardization of callusing and regeneration protocols in Savitri, Naveen and Tapaswani for genetic transformation with *CrylAc*and*Xa21*, and chitinase genes through biolistic approach. Satisfactory callusing (51 to 86 %) was reported on MS medium with 2,4-D (2.0 mg/1) and kinetin (0.5 mg/1). For obtaining required level of regeneration, MS medium with BAP (1.0 mg/1), kinetin (1.0 mg/1) and NAA (0.25 mg/1), MS medium with BAP (2.0 mg/1) and NAA (0.25 mg/1) and MS medium with kinetin (2.0 mg/I) and NAA (0.25 mg/1) were examined.

During 2002-03, transformation of Swarna with a potato trypsin inhibitor gene was accomplished. Southern analysis confirmed the presence of trypsin inhibitor gene in the putative transgenic rice lines. Later in 2004-05, transgenic lines expressing a *pin ii* gene were developed in the genetic background of PusaBasmati-1 and Swama and these lines were subjected to the insect bioassays against YSB and leaf folder, and two transgenic lines from both PusaBasmati-1 and Swama showed higher levels of resistance to both the insects. In the year 2007-08, putative transgenics containing *Cry 1AB* gene were developed using both biolistic and *Agrobacterium*-mediated approaches for conferring resistance against yellow stem borer (YSB). A *Trichoderma* derived chitinase gene conferring resistance against rice sheath blight and *DREB1A*gene for conferring tolerance against drought were also used for rice transformation. The plants were grown to maturity and no morphological abnormalities were observed. In the year 2007-08, work was initiated to develop transgenic rice line over-expressing ferritin cDNA. Binary vector carrying ferritin cDNA was mobilized into *Agrobacterium tumefaciens* strain EHA105.

In another attempt to develop transgenic Swarna line with *Cry1Aabc* gene for YSB resistance, 150 callisurvivedafter selection. In another experiment, highly embryogenic calli derived from Gayatri and Swarna were co-cultivated with Agro strain LBA 4404 having pDREB1A and 120 and 150 calli, respectively, of the genotypes are on pre-regeneration media.

The high yielding variety Naveen was later used for transformation of NADP-Malate dehydrogenase gene using embryogenic callus. The regenerated shoots arising from calli on regeneration media were transferred to rooting media and rooted plantlets were transferred to soil for further analysis which is underway.

Transgenics were also developed with phosphomannose isomerase (*pmi*) gene in the genetic background of an elite *indica* rice cultivar, Pusa Basmati-1 and with zinc transporter gene into *indica* rice cultivars PB-1 and BPT 5204. A Swarna line with *Pennisetum glaucum* eukaryotic translation initiation factor 4A (*PG-eif4A*) was developed for increased salinity tolerance at germination and seedling stage. Enhanced activity of antioxidant enzymes (SOD and APX) was observed in PG-eif4A over expressed transgenic lines of Swarna. Rice variety Naveen was also transformed with NADP–Malic Enzyme gene and higher transformation efficiency was achieved. The GUS expression of the transformants confirmed the existence of the desired gene in the callus and the putative transgenic plant developed was used for further analysis.

3. IMPACTS OF THE DIVISION

The hybrids developed from this Division have been licensed and are being commercialised through various Seed companies (Table 2) and the farmers are getting benefitted.

Besides the hybrid technology, one patent entitled "Protocol standardized for albino free shoot regeneration in *indica* rice to hasten breeding cycle" has been filed in Indian Patent Office vide File No. 1355/KOL/2015.NRRI has imparted training tothe researchers ofseveral instituteson the doubled haploid technique.

4. ASPIRATIONS

Germplasm is always a basic material for any crop improvement programs for sustainable agriculture. A road map depicting collection sites need to be prepared so that areas which are not covered in the map will be explored. Wild and primitive populations are the reserves of cryptic variability and hence, their capacity for adaptive response is high. Such genetic variation is as important as prevalent varietal diversity for genetic conservation. It is, therefore, important to collect and conserve them. It has been estimated that even 5% of rice germplasm conserved in different gene banks have not been utilized. Our research should be oriented towards developing a core collection which represents the diversity of entire collection and removes duplicate accessions that wouldenhance the use of germplasm by identifying diverse source of parents and also wouldease in evaluating the germplasm against biotic and abiotic stresses. Identifying trait-specific, genetically diverse parents i.e., salt tolerance, cold tolerance, drought tolerance, early/late heading, low chilling,

Table 2: Varieties and technologies commercialized during 2009-2018.

Sl. No.	Variety/hybrid/technology	Institute/company
1	Ajay (CRHR 7)-Hybrid	Nodai Seed India Pvt. Ltd., Gurgaon
2	Rajalaxmi (CRHR 5)-Hybrid	Nodai Seed India Pvt. Ltd., Gurgaon
3	Ajay (CRHR 7)-Hybrid	Annapurna Seeds, Kolkata
4	Rajalaxmi (CRHR 5)-Hybrid	Annapurna Seeds, Kolkata
5	Ajay (CRHR 7)-Hybrid	Vikky Agrisciences Pvt. Ltd., Hyde3rabad
6	Rajalaxmi (CRHR 5)-Hybrid	Vikky Agrisciences Pvt. Ltd., Hyderabad
7	Ajay (CRHR 7)-Hybrid	Signet Crop Sciences, Pvt. Ltd., New Delhi
8	Rajalaxmi (CRHR 5)-Hybrid	Signet Crop Sciences, Pvt. Ltd., New Delhi
9	Parental lines of Ajay- Hybrid	IFSSA, Hyderabad
10	Parental lines of Rajalaxmi- Hybrid	IFSSA, Hyderabad
11	Ajay (CRHR-7)-Hybrid	Sansar Agropol Pvt. Ltd. Bhubaneswar
12	Rajalaxmi (CRHR-5) Hybrid	Sansar Agropol Pvt. Ltd. Bhubaneswar
13	Rajalaxmi-(CRHR 5)-Hybrid	Nath Biogene(I) Ltd., Aurangabad, Maharashtra
14	CR Dhan 701-(CRHR-32) –Hybrid	NathBiogene (I) Ltd., Aurangabad, Maharashtra
15	Ajay (CRHR-7)-Hybrid	PAN Seeds Pvt. Ltd., Kolkata
16	Rajalaxmi-(CRHR 5)-Hybrid	PAN Seeds Pvt. Ltd., Kolkata
17	Ajay (CRHR-7)-Hybrid	Vikkys Agrisciences Pvt. Ltd., Hyderabad
18	Rajalaxmi-(CRHR 5)-Hybrid	Delta Agrigenetics Pvt. Ltd., Hyderabad
19	CR Dhan 701-(CRHR-32) –Hybrid	Delta Agrigenetics Pvt. Ltd., Hyderabad
20	Ajay (CRHR-7)-Hybrid	Balaji Agri Biotech Pvt. Ltd. Paikmal, Odisha
21	Rajalaxmi-(CRHR 5)-Hybrid	Bharat Nursery Pvt. Ltd. Kolkata, West Bengal
22	Ajay (CRHR-7)-Hybrid	SaiShradha Agronomics and Husbandry Pvt. Ltd. Puri, Odisha

Contd...

Sl. No.	Variety/hybrid/technology	Institute/company
23	CR Dhan 701-(CRHR-32) -Hybrid	Sri Sai Swarupa Seeds Pvt. Ltd., Warangal, Andhra Pradesh
24	Rajalaxmi-(CRHR 5)-Hybrid	Vibha Agrotech Ltd., Hyderabad
25	CR Dhan 701-(CRHR-32) –Hybrid	Vibha Agrotech Ltd., Hyderabad
26	Rajalaxmi-(CRHR 5)-Hybrid	Sansar Agropol Pvt. Ltd., Bhubaneswar
27	Ajay (CRHR-7)-Hybrid	Sansar Agropol Pvt. Ltd., Bhubaneswar
28	CR Dhan 701-(CRHR-32) –Hybrid	GV Seeds, Hyderabad
29	Rajalaxmi-(CRHR 5)-Hybrid	GV Seeds, Hyderabad
30	CR Dhan 701-(CRHR-32) –Hybrid	Bioseed research India
31	CR Dhan 701-(CRHR-32) –Hybrid	Delta Agri Genetics Pvt. Ltd., Hyderabad
32	Rajalaxmi-(CRHR 5)-Hybrid	BharatiyaBeej Nigam Ltd.
33	CR Dhan 701-(CRHR-32) –Hybrid	Nath bio-genes PVT. LTD
34	Rajalaxmi-(CRHR 5)-Hybrid	Nath bio-genes PVT. LTD
35	Rajalaxmi-(CRHR 5)-Hybrid	PAN Seeds PVT. LTD.
36	Rajalaxmi-(CRHR 5)-Hybrid	Bharat Nursery Pvt Ltd., Kolkatta
37	Rajalaxmi-(CRHR 5)-Hybrid	Mahalaxmi Seeds Corporation, Begusarai, Bihar
38	CR Dhan 701-(CRHR-32) –Hybrid	Jay Shankar Agro Inputs Pvt. Ltd. Delhi

tolerance/resistance to particular pests/diseases, adaptability to water logged habitats, tillering capacity, root system, leafiness, etc., apart from quality characteristics are the primary need of the plant breeder for trait enhancement. A rice seed file depicting photograph of individual germplasm may be prepared for identification of germplasm and avoiding misrepresentation of germplasm. Morphological and molecular characterization of a core/minicore and trait specific subsets wouldfurther enhance the usefulness of the germplasm accessions. Work in this line has been initiated at this Institute (Jambhulkar et al. 2017).

Under changing climatic and agriculture scenario, rice hybrid is likely to face stiff competition to sustain in future. Despite having great potential to enhance production and productivity, it has not been adopted on large scale as was expected. This is due to several constraints like lack of acceptability of hybrids in some regions such as southern India, due to region specific choice grain quality requirement. Moderate (15–20%) yield advantage in hybrids is not economically very attractive and there is a need to increase the magnitude of heterosis further. Lower market price offered for the hybrid rice produce by millers/traders is acting as a deterrent for many farmers to take up hybrid rice cultivation. Higher seed cost is another restrain for large scale adoption and hence, there is a need to enhance the seed yield in hybrid rice seed production plots in order to reduce seed cost. Efforts for creating awareness for technology transfer were inadequate in initial stages. Involvement of public sector seed corporations in large-scale seed production has been less than expected. Hybrids for aerobic/upland, *boro* season and long duration for shallow lowland conditions are to be developed. Most of the constraints mentioned above are being addressed with right earnestness through the on-going research projects and transfer of technology efforts.

5. CONCLUSIONS

Though rice germplasm are collected either through explorations or exchange programmes and conserved in the gene bank but information on their trait characteristics are not complete. Germplasm without characterization and evaluation data are meaningless as per as their utilization aspect in crop improvement programme is concerned. Therefore, systematic characterization, evaluation and documentation of important traits against each germplasm are required to be done for better utilization by the breeders. The database on agro-morphological characters of all the germplasm conserved in gene banks need to be prepared. Also a National/central rice data base be prepared in collaboration with the research centres working in collaboration with NBPGR. Research work should be oriented towards developing a core collection for better management and utilization of the germplasm. Human resource development by imparting training to persons engaged in PGR activities is required for proper utilisation and conservation of germplasm.

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Production Technologies of Rice: Activities, Achievements and Aspirations

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SUMMARY

The Crop Production Division of ICAR-National Rice Research Institute (NRRI) works on basic, applied and adaptive research on resource management for increasing and stabilizing rice productivity. Since the inception of the Institute, the division is contributing towards developing new science and technologies for improving factor productivity, efficient utilization of water, fertilizers and other agricultural inputs to decrease the cost of cultivation, maximize profit and secure cleaner environment. Over the last six decades the division has developed a number of production technologies including crop establishment methods, spacing, dose and time of fertilizer application that constitute part of modern agronomy for rice production. Farm machineries developed and validated has helped not only to fuel mechanization of small field size of small and marginal farms but also reduced cost of cultivations. Technology and products developed utilizing microbial resources *viz.* N fixers, P solubilizes, entomopathogenic formulation, and pesticides degraders have helped in enhancing productivity and sustainability of rice production system. Besides measuring greenhouse gas emission from rice fields, developed technologies for rice production using less land, water and labor through more efficient, environment-friendly production systems that are more resilient to climate change and also contribute less to greenhouse gas emission. The Chapter provides an insight about the activities, achievements, impacts and aspirations of the Crop Production Division, NRRI.

1. INTRODUCTION

Crop Production Division of ICAR-National Rice Research Institute owns the responsibility of conducting basic, applied and adaptive research on resource management for increasing and stabilizing rice productivity in all ecologies with special emphasis on rainfed ecosystem and the related abiotic stresses. Research on crop production mainly focused on factor productivity improvement leading to efficient utilization of water, fertilizers and other agricultural inputs with aim to decrease the cost of cultivation, maximize profit and yet secure cleaner environment. Research on rice-based cropping/farming systems and crop diversification, *boro* rice, flood-prone rice, organic scented rice, aerobic rice, climate resilient production technologies, soil resilience and integrated crop management were the other focus areas of research. Characterization of rice environment of the country and evaluation of physical, biological, socio-economic and institutional constraints to rice production system under different agro-ecological conditions have also been carried out. Several technologies have been generated through applied research with major emphasis on handicapped rainfed ecologies which has ensured increased and sustained productivity, nutrient use efficiency and income from rice and rice-based cropping/farming systems. Division has played a leading role in preparing greenhouse gas emission inventories and production technology to reduce its footprint from rice farming in India, which helped the country in climate change negotiations at International level. Farm mechanization research was conducted to make farm operations cheaper, faster, easier and more productive. Post-harvest technology and value addition keeping the requirements of consumption, internal trade and exports also formed an integral part of agricultural engineering research. This chapter is an attempt to compile the rice research on production technology development covering the genesis, development and objectives of Crop Production Division; review its achievements and impacts at local, regional and global levels; analyze the major challenges of rice research and development with regard to natural resource management; and outline the future plan of the Division to address the challenges.

2. GENESIS OF THE DIVISION

Research on crop production aspect initiated with the disciplines of Agronomy and Agricultural Chemistry, which were created with the inception of the institute in the year 1946. The discipline Agricultural Engineering was added during the Second Five Year Plan period. A sub-station was opened at Canning, West Bengal during the Second Five Year Plan to study the problems of rice growing in saline soils. This was transferred to the Central Soil Salinity Research Institute in 1959. The blue-green algae scheme was established at the Institute in 1961 to conduct investigations on collection, survey and identification of nitrogen-fixing blue-green algae, evaluation of relative nitrogen fixing capacity of the various species, factors favoring their activity and their field application in rice production. Subsequently, this scheme took the shape of discipline of soil microbiology to include work on bacterial nitrogen fixers in addition to blue-green algae, microbiological studies on the rice rhizosphere, nature of organic matter of tropical rice soils. In the Fourth Five Year Plan, the different research disciplines at the Institute was organized into major divisions and research sections for conducting production oriented basic and applied research with emphasis on multi-discipline participation. With this crop production related disciplines were grouped under the division of Crops and Soils, which included sections viz. General Agronomy, Irrigation Agronomy, Soil Physics, Soil Chemistry, Microbiology and Agricultural Engineering.

Subsequently, disciplines related to crop production were reoriented and designated as Agronomy, Soil Science & Microbiology, Agricultural Engineering and Fish & Fisheries. Again, in the year 2006, all these sections were merged together retaining their research identity to form the current Crop Production Division.

3. ACTIVITIES OF THE DIVISION

Studies on rice in relation to its environment with suitable modifications of some of the environmental condition which govern crop establishment, weed control, maintenance of soil fertility, water use with improved cultural practices for maximizing rice production have been the objectives of Agronomy section. The Soil Science section deals with management of nutrients through integration of chemical, organic and biological sources for rice and rice based cropping system targeting soil productivity enhancement through assessing and enhancing soil quality and resilience with reference to sustainable crop production. Management of problem soils, optimization of soil tillage, simulation and system analysis techniques for site specific nitrogen management, sensor-based monitoring of greenhouse gas are also part of the ongoing research programme. Microbial resource mapping, diversity analysis and molecular characterization of beneficial microbes having roles in pesticide biodegradation, biogeochemical cycling of nutrients, entomo-pathogenic and abiotic stress moderating action in rice soils are the major research activities of the Soil Microbiology unit. Agricultural engineering section comprising three disciplines namely: (i) Farm machinery and power (ii) Soil and water conservation and (iii) Agricultural process engineering. Small farm mechanization through design and development of efficient tools and implements that reduces human drudgery, time and cost of operation is the focus area of farm machinery and power engineering. In addition to the improvisation in field operations, focus was also given to better water management practices for economic and efficient use of available water. Besides mechanization in crop production, improvised post production techniques such as cleaning, grading, drying, processing and storage to improve the quality of food grains and by-products are being developed. The various other activities of the section are (i) Design and development, (ii) Testing and evaluation, (iii) Consultancy to farmers, manufacturers and rice processing units, (iv) Instrumentation, (v) Repair and maintenance of farm implements, tube wells, pumps and farm structure, and (vi) Training to farmers, artisans, entrepreneurs.

Theme areas of research being undertaken at the division are nutrient management for enhancing productivity and resource use efficiency in rice; assessing energy and water footprints and increasing water productivity in rice-based systems in Mahanadi Delta; agroecology-based intensification of rice-based cropping system for enhancing productivity and profitability; integrated rice-based farming systems for enhancing climate resilience and profitability in eastern India; increasing productivity and input-use efficiency in rice-based production systems with resource conserving technologies; assessing weed dynamics in rice and evaluating germplasms and new herbicides for its management; economic and environment-friendly use of rice straw; mechanization of rice-based cropping systems for higher productivity and energy use efficiency; harnessing microbial resources for alleviating abiotic and biotic stresses for improving soil health.

4. ACHIEVEMENTS OF THE DIVISION

4.1. Crop establishment

With the release of a number of high yielding varieties during 1960s covering duration range of 100-160 days, farmers can now have variety of a particular duration according to their needs. Besides, breeding projects were in progress to evolve varieties for specific condition such as lowlands, saline conditions, etc. and it was expected that the area under high yielding varieties might go up considerably in the near future. Since time of planting has a great influence on the rice yield, practices which can reduce the preparatory tillage and direct seeding methods and weed control through herbicides were considered important in saving time, and agronomic investigations on these aspects were taken up. A method of direct seeding of sprouted seed in rabi under ideal fertilizer and water management and efficient weed control measures were found optimum, yielding at par with transplanted rice

Due to inadequate control of irrigation and drainage, successive cultivation of rice in wetlands was the general practice. The division has played a significant role in determining the schedule of planting and identifying the sequence for an economic rice based cropping system. These efforts demonstrated the feasibility of economically growing cotton, groundnut, gram, green gram, wheat and linseed in sequence with rice under irrigated condition. In addition, possibility of growing two crops of rice in succession during a year with a green manure crop in between was shown in areas where irrigation facilities are available and the winter temperature are not low. Under irrigated conditions, possibility of successfully growing three crops of rice constituting early, medium and early duration varieties in succession was also determined. Introduction of Jute in rotation with rice was shown to be highly economical.

With the introduction of high yielding, semi dwarf varieties in mid-sixties, comprehensive investigations were undertaken to devise ideal management practices for realizing maximum rice yield. Agronomic practices for growing high yielding varieties developed at this institute have been adopted in the country for increasing rice yield. These form the basis for high production of rice till date.

The possibility of growing newly developed scented Basmati type rice in Orissa for augmenting farmers income was explored. Varieties Kasturi, Ranbir

Basmati and IET 8579 performed well both in dry and wet seasons with yields around 2.5 t ha^{-1}. The optimum population requirement in wet season ranged from 33 to 50 hills m^{-2}. Early planting in July gave 13% higher yield over delayed planting in September.

Off season tillage in the month of January and/or summer ploughing in March with a tractor drawn cultivator ensured a better crop stand of the direct sown rice by providing fine tilth and early weed control than the conventional practice of ploughing just before sowing during mid-May. In a study on spacing, it was observed that rice crop sown at the spacing of 20x15 cm (333000 plants ha^{-1}) gave significantly higher yield (2.82 t ha^{-1}) than that grown under the spacing of 20 x10 cm (500000 plants ha^{-1}), 30x15 cm (222000 plants ha^{-1}) and 40x15 cm (166666 plants ha^{-1}). However, under DSR, drilling seed @ 40 to 60 kg ha^{-1} at a 20 cm rows spacing has been shown to be adequate and enabled adoption of better weed and fertilizer management. Using manual self-propelled seed driller, the seed rate can further be reduced to 25 kg ha^{-1}. Wet direct seeding (WDS) can be done in the well puddled field with sprouted seed using both manual as well as self-propelled drum seeder at a seed rate of 20-25 kg ha^{-1}. In transplanted rice, field preparation is similar to WDS followed by transplanting of 3-4 weeks old seedlings at required spacing. Seedlings for transplanting are grown in a separate nursery bed. Nowadays mechanical transplanters are gaining popularity due to low labor requirement. Under this method mat type nursery is prepared with a seed rate of about 20-25 kg ha^{-1} and 18-20 days old seedlings are transplanted in well puddled field having about 2-3 cm standing water. The seed rate can be further reduced by SRI method with 5-8 kg ha^{-1} and seedlings can be transplanted at 25x25 cm spacing by following alternate wetting and drying moisture regime. For transplanted rice, line transplanting with 25x15 cm spacing, 21 to 30 days older seedlings performed better as compared to other seedling age. However, 60 days older seedlings performed better in the area prone to submergence for a period of 10 days during early vegetative stage (30 days after transplanting), while in SRI method of cultivation 12 to 14 days old seedlings performed better under irrigated shallow lowlands of eastern India (Lal et al., 2016).

Poor seedling emergence and establishment and weeds are major constraint for adopting direct seeding in rice. Crop establishment is critical especially in rainfed lowlands where floods can occur immediately after sowing, creating anaerobic conditions during germination and early seedling growth. A study was conducted to determine the effectiveness of AG1 QTL in improving germination of two IR64-AG NILs sown under flooded conditions. The study also evaluated selected agronomic practices anticipated to further enhance crop establishment in flooded soils. IR64-AG NILs showed 81% and 217% higher plant populations over IR64-Sub1 and IR64, respectively, and this was also reflected as significantly higher grain yields. Agronomic manipulations like higher seed rate (60 kg ha^{-1}) and drum seeding improved seedling growth after germination and emergence, increasing plant height, leaf area, number of tillers and biomass accumulation (Lal et al. 2018).

Study on crop and varietal diversification of rainfed rice based cropping systems were carried out and it was found that tiller occurrence, biomass accumulation, dry matter remobilization, crop growth rate, and ultimately yield was significantly decreased under late transplanting. Naveen and Swarna transplanted on 1st July gave 13.1% and 36.4% higher yield compared to that of transplanted on 1st August. In the dry season, toria was profitable when sown earlier and if sowing was delayed green gram was suitable (Lal et al., 2017).

4.2. Cropping pattern/system

The early work on cropping patterns was mainly focused on double cropping and the crops such as cotton, groundnut, wheat, gram, linseed, pulse and berseem were found to be successfully grown after harvest of early rice in uplands and medium lands while jute followed by a photo-sensitive long duration tall *indica* was feasible in low lands. Later on, with the availability of short duration high yielding varieties, cropping pattern included multiple cropping i.e. about three crops in a year viz. 'rice- potato-rice', 'rice-hybrid maize-rice' and 'jute-rice-groundnut' on irrigable high and medium lands. Feasibility and maximization of yields with double cropping with jute-rice through the use of improved varieties and manipulation of sowing date, fertilizer application and harvest dates were demonstrated by collaborative investigations with Jute Agricultural Research Institute, Barrackpore that resulted in an increase of 100% over the national average yield of jute while a yield of 3500 to 4000 kg ha^{-1} of rice could be obtained by following the jute crop with rice variety Jagannath in low lands and CR Dhan 44 in high lands.

Efforts were made to grow summer rice in canal irrigated area in eastern India with varieties like Ptb 10, Mtu15 and GEB 24. This led to quantum jump of area under rabi rice (dry season) as second crop since 1955-56 onwards. In areas where rains during September and October are scanty (and the total rainfall is of the order of 450 mm), it was recommended to grow winter crop like safflower, horse gram, mustard, niger and black gram on these lands provided they are sown not later than mid-October. Inter-cropping of rice with pigeon pea (1:4) proved beneficial as an insurance against crop failures.

In the flood-prone areas where time of occurrence and duration of flood is unpredictable during July-September, capsularis jute (JRC 7447) can be grown between May and September, followed by photosensitive late duration rice (CR 1014, T 141) planted in third week of September as second crop in wet season. Growing sweet potato (85-16), green gram (Pusa 105), maize (Ganga 5), groundnut and sunflower under limited irrigation condition in the dry season after the harvest of long duration rice was also successfully demonstrated. Varieties suitable for such situation were: green gram (Pusa 105), black gram (LBG 20), pigeon pea (ICPL151 and ICPL 87, DA 6, DA16, DA

7, UPAS 120) and mustard (Varuna, Pusa bold, Pusa Bahar and Pusa Basant). However, in flood-prone lowlands with deposition of silts, green gram (Pusa 105 and ML 267) and fodder cowpea (Russian Giant) with application of a moderate dose of phosphorus (20 kg P_2O_5 ha^{-1}) can be grown profitably. In flood prone shallow lowlands, though Swarna Sub1 results higher yield than Naveen and Sahbhagi Dhan, the yield of subsequent crops toria, green gram and black gram are better when grown after Naveen and Sahbhagi Dhan due to timely sowing and higher residual moisture availability.

In uplands of western Odisha under red soil, traditional monocrop of rice could be replaced with intercropping of pigeon pea (ICPL 87 and ICPL 151) with groundnut (TMV 2 or AK 12-24) in 3:1 or groundnut with okra (4:1). In the lowlands of this region, pigeon pea and rice intercropping in 3:1 was more remunerative. Mixed and intercropping of rice and diversification of cropping system can insure against the risk associated with rice monoculture. With the selection of appropriate rice varieties, mixed cropping with red gram, green gram, mustard and lentil can also be practiced in uplands.

Recently, rice–rice systems have been suffering from yield fatigue; the productivity and sustainability of these systems can be increased by crop and cultivar diversification with rice or non-rice crops. Among three rice based cropping systems such as rice–potato–sesame, rice–maize–cowpea and rice–groundnut–green gram evaluated, highest production efficiency and lowland utilization efficiency were observed in rice-potato-sesame cropping system although rice-maize-cowpea system was found to be the most economical system. Eastern India, very often encounters with the problems of abiotic stresses such as drought and flooding alternately and sometimes both in the same year either at vegetative stage or at reproductive stage. Choice of kharif crop and variety component of rice based cropping system is really challenging. A study with six crop/variety combinations revealed that rice (Gayatri)–green gram system was the most energy efficient, followed by rice (Naveen)–black gram–horse gram system. However, under certain abnormal weather conditions, energy-efficient cropping systems may not be viable in terms of productivity and subsistence of farmers; in this situation, rice (Swarna)–rice (Annada)–black gram system is a better option. This system is less energy efficient but under abnormal weather conditions it is an alternative option for livelihood security (Lal et al. 2015a).

The rice equivalent yield (REY) of groundnut was significantly higher (58.0%) compared to maize in rabi. In groundnut, straw mulched plots also recorded higher pod yield compared to RDF applied plots. In summer season, significantly higher yield of cowpea was recorded in rice- maize-cowpea system compared to rice-groundnut-cowpea system. The total productivity of the rice-groundnut-cowpea system was significantly higher compared to that of rice-maize-cowpea system.

In order to arrest yield decline in continuous aerobic rice-rice system that occurs due to soil sickness because of root knot nematode infestation and problems of nutrient availability particularly N, P, Zn and Fe, rabi (dry season) component of aerobic rice-rice system was diversified by growing non-rice crops in alternate year (1:1) and every two years (2:1) with four non rice crops i.e., maize, groundnut, green gram and cowpea. It was found that after 10 seasons of aerobic rice, the grain yield of rice has been reduced by 18.3%. Rice-green gram followed by rice-groundnut rotation performed better and could able to arrest the yield declines significantly.

4.3. Farming system

National Rice Research Institute, Cuttack has developed adoptable technologies of rice-fish diversified farming system to improve and stabilize farm productivity and income from rainfed water logged lowland areas for the farm size ranged from one acre to one hectare. Field design included wide bunds (Dykes) all around, a pond refuge connected with trenches on two sides (water harvesting cum fish refuge system) and guarded outlet. Three different farming system models suited to particular area have been developed which are as follows (Poonam et al., 2019).

4.3.1. Rice-fish–horticulture-livestock based integrated farming system for rainfed lowlands (semi-deep areas upto 50 cm water depth)

The farming system model can annually produce about 16-18 t of food crops, 0.6 t of fish and prawn, 0.55 t of meat, 8,000-12,000 eggs besides flowers, fuel wood and animal feeds as rice straw and other crop residues from one-hectare farm. The net income would be around Rs. 76,000 in the first year, which is likely to be increased to 1,30,000 in the sixth year. This system thus increases farm productivity by about fifteen times and net income by 20 folds over the traditional rice farming in rainfed lowlands. It also generates additional farm employment of around 250-300 man-days hectare^{-1} year^{-1}.

4.3.2. Multitier rice-fish-horticulture-agroforestry-based farming system for deep water areas (50-100 cm water depth)

This farming system model can annually produce about 14-15 t of food crops, 1.0 t of fish and prawn, 0.5-0.8 t of meat, 10000–12000 of eggs, in addition to flowers and 3-5 t of animal feed from one-hectare area. The productivity of food crops further increased to 16-17 t besides, 10-12 t of fiber/fuel wood from eight year onwards due to addition of produce from perennial fruit crops and agroforestry components. The net income would be around 1,00,000 per ha in the first year. This will increase to Rs. 1,50,000 or more from the eight year onwards.

4.3.3. Rice based integrated farming system for irrigated lowlands

Rice based integrated farming system model of 1 acre could produce about 800-1000 kg of grain per year. Entire produce is sufficient to cater the need of small farm family. The straw is used for the cattle feed, mushroom base and roof of the farm house. Rest of the straw is sold to earn Rs. 500-1000 per year. After two to three months of rearing, fish fry worth Rs. 4000-5000 is sold to other farmers. Fish are harvested according to the need after the size becomes 250-300 g after 6 months or 0.5-1.0 kg after a year. The income from fish rearing in the system is Rs. 20,000. Pulses (green gram, black gram and pigeon pea) taken on the slope and bunds are just enough to meet the protein requirement of the farm family.

4.4. Nutrient Management

Nutrient management for enhancing rice productivity and ensuring environmental sustainability has always been a priority area. Most of the initial work before advent of semi dwarf high yielding varieties mainly focused on understanding chemistry and physics of submerged rice soil and its impact on nutrient dynamics and subsequent crop uptake.

Work on the mineral nutrition of *indica* rice was initiated in 1955-56 with the joining of Dr. A. Tanaka of the Hokkaido University, Japan, on a cultural exchange programme for one year. The japonica rice varieties responded to high rates of nitrogen whereas the grain yields in *indica* varieties decreased at these rates. Solution-culture studies to elucidate basic information about the reasons for this showed that the reduction of grain yield in the *indica* was due to an unbalanced nitrogen metabolism during the reproductive growth period, due to accumulation of non-protein nitrogen, resulting in high sterility as compared to the high responsive japonicas.

Study on the nutrients absorbed during different growth periods of *indica* rice showed that in the early duration varieties, nitrogen absorbed during the vegetative growth period was most efficiently utilized for grain production, whereas in the medium and late duration ones, there were two peaks of this efficiency during the vegetative and reproductive growth stages. For phosphorus and potassium there was, however, only one peak for all the duration groups. This information had shown the need for basal application of phosphorus and potassium and for fractional application of nitrogen for the medium and late duration *indica*. In solution and pot culture studies symptoms of nitrogen, phosphate, potash, calcium and magnesium deficiencies in rice were documented.

The cumulative effects of various fertilization treatments on weed species composition and diversity along with rice growth and yield were investigated in the long-term fertilizer experiment. Organic manure (FYM) and P fertilization affects the weed community more than N and K fertilization. Balanced fertilization of NPK reduced weed species richness and density during rice growth, because of the competition for soil nutrients between rice and weeds. Addition/omission of any of the major nutrients resulted in selective dominance or disappearance of some of the weed species (Lal et al. 2014).

The soil organic carbon and nitrogen fractions and soil organic carbon (SOC) sequestration was studied in the long-term fertility experiment and it was found that SOC and nitrogen stocks changed positively across the fertilizer and manure treatments over the control. Chemical fertilizer with manure input significantly increased SOC concentration and stocks and total nitrogen content. Higher SOC stock in control as compared to the initial value was observed during the period of the experiment due to the C input added through the incorporation of only roots and stubble (Nayak et al. 2019). Carbon input only from left over rice roots and stubble is sufficient to complement the C loss through organic matter decomposition in lowland rice particularly in sub-humid tropics and can sequester atmospheric carbon into the soil (Shahid et al. 2017a).

Application of rice husk biochar (0.5-10 t ha^{-1}) has been effective in C-enrichment in soil in the form of total organic C. An increase in rice grain yield (1–24%, depending on rate of biochar application) was observed with increasing rates of rice husk biochar by enhancing the soil fertility (Munda et al., 2018).

4.4.1. Nitrogen

During pre-semi-dwarf era, studies on nutrient dynamics in soil revealed that the losses of nitrogen from submerged soil occur due to oxidation of ammonium nitrogen from the surface-applied ammonium sulphate in the surface soils and its subsequent de-nitrification in the reduced sub-surface layer amounting to 30-40% loss of applied N. In addition, 10-12% losses of nitrogen were shown to occur in run-off water, particularly, when there was a heavy downpour of rain within 24-48 hours after fertilizer application. It was demonstrated that these nitrogen losses can be considerably reduced by deep placement or sub-surface application of the fertilizer in the reduced layer of the soil which enhances the fertilizer efficiency, and, thereby augments rice yield. Based on this, different methods of sub-surface application under diverse soil-water conditions were recommended. The importance of soil drying before cultivation to increase the ammonifying capacity of soil was emphasized particularly for intensive cultivation areas where two or three successive rice crops are to be grown on the same land.

With the launching of *indica-japonica* hybridization program at this institute in early fifties, comparative studies with the *indica* and *japonica* varieties were undertaken. These investigations showed that *indica* varieties were not able to utilize nitrogen as efficiently as the *japonica* varieties for grain production. The *indica* gave maximum grain yield at about 20-40 ppm nitrogen above which the yield was considerably reduced, while the japonicas continued to yield better even above 60 ppm nitrogen. In short duration varieties, where the reproductive stage closely followed the vegetative stage, the process of nitrogen absorption was continuous up to flowering suggesting that short duration varieties will be benefited by a single basal application of nitrogen. In medium and long duration varieties, where there is a time lag between the vegetative stage and the reproductive stage, nitrogen absorption was vigorous from the initial growth stage up to maximum tillering after which it slowed down. However, with the onset of ear initiation, there was again a vigorous uptake, indicating the need for a split application of nitrogen, one as basal at planting and the other about 20-25 days before flowering for the medium and late duration varieties.

A new method of urea application was developed to increase its efficiency by incubating it with 5-6 times of its weight of soil for 48-72 hours. During which, urea gets hydrolyzed to ammonium carbonate, and, thus chances of loss of nitrogen during this period are eliminated. During this period systematic studies using radio-tracer technology were initiated to quantify N dynamics in soil as well as crop N uptake pattern. The unaccounted loss in ^{15}N tagged prilled urea in low land rice ranged from 43-45% whereas it was 24-34% for urea supergranule. Studies on crop N uptake pattern with ^{15}N highlighted importance of stages of N application, basally applied N was found in vegetative parts and top dressed ^{15}N was used for grain filling. Methodologies for precisely quantifying nitrogen losses due to leaching, ammonia volatilization and de-nitrification losses in the field were developed. In alluvial soil with high ground water table and low hydraulic conductivity, leaching loss of nitrogen was not a concern, but de-nitrification and ammonia volatilization losses can be considerable. These were confirmed using ^{15}N tracer technique. Direct measurement of de-nitrification loss in lowland rice field using ^{15}N tagged urea fertilizer revealed that this loss can be more than 6-9% of the applied N. Of this, about 94% was in the form of N_2 and only 6% was as N_2O. Contrary to the earlier belief, de-nitrification started from the next day of fertilizer application and continued till the fourth week showing maximum loss during the first fortnight.

Study on quantification of N transformation indicated 30-40% of surface applied ammonium sulphate loss could be due to nitrification-denitrification processes and 10-12% of loss could be through run off and drainage. These observations led to recommendation of sub surface reduced zone N application and attempts were made to standardize the methods of sub surface application. In addition, N uptake pattern of rice cultivars in relation to crop growth stages of different durations were systematically analyzed for recommending time scheduling of N top dressing. Instead of single basal N application it was advised to go for two split application, one at the time of transplanting and another 20-25 days before flowering in case of medium and late duration crops.

Strategy for N management was standardized for rainfed lowland rice where N use efficiency is very low due to adverse soil-water condition. Single dose of N at the rate of 40 kg ha^{-1} was recommended in the condition where top dressing is not possible due to excessive water accumulation. Optimum dose of N for semi dwarf varieties in shallow submerged low land situation was found to be 80-100 kg ha^{-1} in wet season and 100-120 kg ha^{-1} in dry season. Slow release fertilizers (sulphur coated urea, neem coated urea and urea super granule etc.) evaluated for their potential for enhancing yield and N use efficiency of low land rice. Thorough incorporation of applied urea into wet soil by puddling and deep placement of urea mud balls in the reduced zone of submerged rice soil found to decrease N losses and improved N use efficiency in rice. Efficacy of different nitrification inhibitors were tested and it was observed that that hydroquinone was more effective in alluvial and laterite soils and alcoholic extract of neem cake was better in black soil than dicyandiarnide (Nayak and Panda 1999).

Grain yield of hybrid rice increased with increasing levels of fertilizers upto 135 kg N, 45 kg P_2O_5 and 90 kg K_2O ha^{-1} but declined with a further rise in fertilizer levels. The economic optimum levels of NPK for hybrid rice were 124 kg N, 41 kg P_2O_5 and 82 kg K_2O ha^{-1}. Nitrogen applied in 4 splits i.e. 25% as basal, 25% at 21 days after transplanting, 25% at panicle initiation and 25% panicle emergence was significantly higher yield than N applied in 3 splits in hybrid rice.

Significant variations in mineralization kinetics due to long term fertilization practices and higher potentially mineralizable C and N were recorded under combined application of chemical fertilizer and farm yard manure. Apart from that higher values of microbial and mineralization quotients were also observed under similar condition. This indicated that long term application of FYM along with inorganic fertilizer-maintained soil organic C pool and improved the N supplying capacity of soil in comparison to fertilizer alone and FYM alone (Mohanty et al. 2013).

A field study was conducted to examine the effect of different nitrogen (N) management strategies on nitrate leaching, nitrous oxide (N_2O) emission and N use efficiency in aerobic rice. The intermittent irrigation practices in unpuddled and unsaturated soil of aerobic rice resulted in leaching of 3.2–10.6% of applied N below 45 cm and N_2O-N emission of 0.23–0.43% of applied N, that could be a substantial loss from plant nutrition point of view. From this study it was observed that application of neem coated urea on the basis of leaf color chart reading is an efficient N management strategy that could reduce N_2O emission, NO_3-N leaching and improved yield and N use efficiency in aerobic rice (Mohanty et al. 2018).

A five-panel customized leaf colour chart (CLCC) was developed for real time nitrogen management in rice of different agro-ecologies to give cultivar specific recommendation of basal as well as top dressing of N for rainfed favorable low land, submerged and flood prone low land, rainfed upland, and irrigated rice (Nayak et al. 2013a). Results of on station and farmers' field experiment showed that at same level of N application yield advantages of 0.5-0.7 t ha^{-1} and 0.5-1.0 t ha^{-1} could be achieved following CLCC recommendation over RDF application and farmer's practice, respectively.

In collaboration with International Rice Research Institute a web based nutrient management tool rice crop manager (RCM) was developed for the rice growers of Odisha on the basis of principles of site-specific nutrient recommendation that could achieve grain yield advantage of 9.8 to 39.6 % with an average of 22.6% over farmer's practice (FFP).

Sub-surface application of urea briquette/ USG though has been proved to be an efficient N management technique it could not be widely adopted by farmers due to inherent problems of application associated with. Work was initiated to improve the strength of briquettes and reduce the breakability by mixing oils of neem (*Azadirachta indica*) and karanj (*Pongamia pinnata*). Apart from being good binding agent the oils used, contain active ingredients that reportedly inhibit nitrification activity in soil. The breaking percentage in oil mixed urea briquette was also reduced. In addition, easy to use hand operated briquette applicators (Manually pulled two row briquette applicator, Manually pulled three row urea briquette applicator, Urea briquette applicator mounted on cono-weeder for top dressing, injector type briquette applicator for both basal and top dressing) were also developed. Deep placement of urea briquettes manually or mechanical applicator resulted in the higher yield, N uptake and N use efficiency than broadcasting of urea granules. The highest yield was recorded when urea briquettes are deep placed manually following CLCC reading. Application of urea briquette using briquette applicator produced higher yield than broadcasting of urea granule but less yields than manual deep placement (Nayak et al. 2017a, Chatterjee et al. 2018).

The interaction effect of nitrogen (N) and silica (Si) application was also examined for the submergence tolerance in rice. Interaction of basal Si and post-flood N spray was the most promising method of nutrient application leading to significantly higher yield (Lal et al. 201b).

A study was undertaken to understand the response of age of seedlings and nitrogen application on submergence tolerance of rice with Sub1 and non-*Sub1* cultivars. The crop fertilized with post-flood nitrogen resulted in substantially better survival, leaf and root growth, photosynthesis, and yield, and the effect was more positive in older seedlings of Sub1 cultivars (Gautam et al. 2017).

The nutrient management strategy was devised for submergence tolerant varieties like Swarna *Sub1*, IR-64 Sub 1 to enhance productivity and reduce the yield loss. Application of additional (20%) basal P and post submergence N application either as soil application or foliar spray (48 h after de-submergence) along with additional potassium enhanced the submergence tolerance of both *Sub1* introgressed HYV and its recurrent parent (Gautam et al. 2014).

Homogenous management zones for precise NPK recommendations for rice growing areas of Odisha were delineated by classifying an area into several subsets based on homogeneous soil and plant attributes using fuzzy clustering approach. A site-specific N recommendation map was developed for Ersama Block, Odisha by using NUE and N uptake data obtained from trials involving omission plot techniques (Tripathi et al. 2015).

By following two approaches viz. geostatisical analysis using kriging and remote sensing using the moderate-resolution imaging spectroradiometer (MODIS) leaf area index (LAI) and normalized difference vegetation index (NDVI) satellite data, soil test–based N recommendation maps were developed (Tripathi et al. 2017).

4.4.2. Phosphorous

Pioneering studies on phosphorus transformation and management was undertaken during semi-dwarf era and it was reported that application of water-soluble P at puddling or flooding proved to be better. In acid soils, citrate-soluble and insoluble-P applied to moist aerobic soil two weeks before flooding, underwent transformation to Fe-P and Al-P, which under subsequent submergence increased P availability, because of reductant solubilization of Fe-P and hydrolytic solubilization of Al-P. This was confirmed by using ^{32}P tagged mono calcium-, di calcium- and tri calcium phosphate.

Studies on the transformation, availability and response with water and citrate soluble and insoluble phosphates in different soil types had shown that citric acid soluble phosphates and, to an extent, insoluble rock phosphates can be made as efficient as water soluble phosphates for acid soils by their application to moist soil about 2-3 weeks before flooding.

Phosphate rocks from middle-east and US, which had low P and high $CaCO_3$ applied two weeks before flooding to acid soils gave comparable result to water soluble P, but these were not effective in neutral and alkaline soil. On the other hand, indigenous phosphate rocks collected from different P mines all over the country, were found unsuitable for direct use even in acid soils, however, their thermal products with Na_2CO_3 were found to be suitable for direct use. Application of indigenous rock phosphates to green manure crop and its subsequent incorporation to rice soil was found to increase their efficiency, however, this needs continuous application of phosphate rocks at least for four years. Acidulation of phosphate rocks to an extent of 25% for acid soils and 50% for neutral and alkaline soils were sufficient for giving comparable result with water soluble P sources. Acidulation with HCl was as good as that of H_2SO_4 or HNO_3.

Soil phosphorus (P) fractionation, adsorption, and desorption isotherm, and rice yield and P uptake were investigated in flooded tropical rice-rice system in a 42-year manurial experiment. Long-term balanced fertilization lowers the bonding energy and adsorption capacity for P in soil as well as increasing its desorption potential. This process in turn increases P availability to plants and leads to increased P uptake and yield sustainability (Bhattacharyya et al. 2014a).

Application of extra 20% basal P to rice subjected to 14 days of flooding helped in improving the phenology, photosynthetic rate and yield attributes. This study suggests that productivity could be enhanced in areas where untimely flooding is anticipated by applying extra basal P (Gautam et al. 2014).

Application of additional P over the recommended dose to rice soil subjected to moisture stress enhanced the stress tolerance of rice by increasing relative leaf water content (RWC) at the same time decreasing electrolyte leakage (EL) as compared to the control (Kumar et al. 2019).

4.4.3. Potassium

Apart from the basic studies on transformation of potash in flooded soil, for the first time the exhaust potential of potash for rice crop was worked out. Potassium-fractions, thresholds of K release and fixation, quantity-intensity (Q/I) parameters of K, K-release kinetics, and K-fixation capacity were compared for their effectiveness in differentiating the effect of various nutrient management practices on K supplying capacity of an Aeric Endoaquept soil after 45 years of puddled rice cultivation. Forty-five years of different fertilization strategies in tropical lowland rice-rice system showed alteration of all K pools except total K. Among all the soil K parameters, release rate constants followed by RTC had higher correlations with rice grain yields (Das et al. 2018).

Spray of K at 2% solution during moisture stress at (-)60 kPa was having significant positive effect on mitigating the effect of drought as compared to the no spray. Further, it was observed that under submergence K application resulted in inhibition of lipid peroxidation and increase in catalase and peroxidase activities. Potassium at 60 kg ha^{-1} was more beneficial in terms of improving survival, photosynthesis and growth after recovery.

The impact of submergence on survival, chlorophyll, photosynthesis, post-recovery growth and anti-oxidant capacities in four rice cultivars namely IR 64, IR 64-Sub1, Swarna and Swarna-Sub1 having differential response to potassium application were examined. Potassium application improved the survival mainly because of maintenance of carbohydrates, chlorophyll and contributing to less lodging and leaf senescence. Potassium at higher levels was more beneficial (Gautam et al. 2016).

4.4.4. Secondary and micronutrients

Methodologies for extraction of S from flooded rice soil using Bray'1 extractant were standardized and available S status of soil was categorized as deficient (0-5 ppm), sufficient (5-40 ppm) and excess (>40 ppm) according to soil solution S content. Flooding increased availability of S up to 21 days in soils. Similarly, methodologies for extraction of Si from dry and flooded soil was worked out and 0.025 M citric acid extractable Si showed good correlation with crop Si uptake and indicated Si supplying power of soil.

Intensive laboratory and pot experiments on low productive problem soils like acid sulphate soils of Kerala and acid, red and laterite soils were carried out for their reclamation for increasing rice production. Low pH, high salt content, high Fe and Mn and low P and high soil reduction were found to be the causes of low production in acid sulphate soils. The ameliorating effect of lime, MnO_2 and NO_3 and $Fe(OH)_3$ on acid sulphate soils lasted for short period of only one cropping season. On the other hand, $MgCO_3$ and Mg silicate had somewhat longer lasting ameliorating effect. Problems with acid, red and laterite soils were due to high Fe and Al in soil with flooding and also nutrient stress like P and Zn deficiency and low organic matter. The soils were reclaimed by liming and suitable nutrient management practices.

With the introduction of high yielding rice varieties and intensive rice cultivation, problems due to micro-nutrient deficiency or toxicity have been increasingly noticed. Suitable methods of extraction and estimation of Fe, Mn, Zn, Cu, B and Mo were developed. Micro-nutrient nutrition of high-yielding rice varieties in relation to growth and duration of the crop was undertaken. Application of Zinc Sulphate to rice CR 260-77 increased the grain yield by about 10% and also enhanced the contents of Zn, Cu and Fe in the rice plants. The residual effect showed distinct difference in Zn content in maize, sunflower and groundnut crops in a rice based cropping system. Amount and pattern of micronutrients uptake by high yielding rice cultivars were investigated and peak uptake of Zn is found to be during vegetative stage while for Cu it is reproductive phase. The rice varieties Bhoi, Tapaswini, Mhamaya, Ranjit Savitri and Gayatri were found to be tolerant to soil Zn deficiency.

Several rice varieties were screened for tolerance to Fe toxicity in the field and some tolerant genotypes have been identified. These are Mahsuri, Sarasa, Bharati, Pusakal, IR 36, Mahanadi, Gajapati, Mahamaya, Sarathi, Chandrama, Vijeta, Udaya, Swarna, Borojohingia, Panikekoa, Purnendu, Ambika, Hanseswari, Radhi, Pooja, Bhuban, Lalat and Meher. The varieties susceptible to Fe toxicity although accumulated very high amount of Fe in the plant parts, it was not translocated to the grain. The paddy grains analysed 2-3 times more Fe and 4-5 times more Mn than the polished rice grain.

Institute developed agro-technology for the management of iron toxicity in lowland iron rich rice soils. The application of lime (75% LR) and limiting plant nutrients, such as K, Mn and Zn along with tolerant cultivars (Lalat and Naveen) were proved to be important components of iron toxicity management in iron toxic acid lateritic soils (Shahid et al. 2014; Shahid et al. 2017b).

The balance of micronutrients was studied in the long term fertility experiment and it was found that application of FYM alone or in combination with chemical fertilizer increased the diethylenetriamine pentaacetate (DTPA)-extractable Fe, Mn and Zn over the control treatment. Long-term application of chemical fertilizers together with FYM maintained the availability of micronutrients in soil and, thus, their uptake by rice crop (Shahid et al., 2016).

A foremost challenge in rice production is to identify suitable nutrient management strategy for reducing yield loss under water deficit stress (WDS) condition. Reduced relative water content and increased activity of osmolyte (proline) and antioxidant metabolites (catalase and peroxidase) due to application of Fe, and Si contributed to tolerate the WDS, which resulted in higher grain yield. We observed that in Si-applied plots the upright leaves prevent mutual shading and allow interception of more light below the canopy, thereby enhance whole plant photosynthesis and yield. Both Si and Fe increased the relative leaf water content in rice under water deficit stress (Kumar et al. 2019).

Boron (B) plays a very important role in the cell wall formation, sugar translocation, and reproduction of the rice crop and could play an important role in alleviating high temperature stress. Application of B results into higher grain yield under both ambient and high temperature condition. The results suggest that the exogenous application of boron had a substantial effect on cell membrane stability, sugar mobilization, pollen viability, and spikelet fertility, hence the yield (Shahid et al. 2018a).

Regional zones were delineated in a deccan plateau region of India by considering spatial variability of some soil properties and available micronutrients for efficient management of micronutrients (Shukla et al., 2018a). District wise secondary- and micro-nutrients map of Madhya Pradesh was prepared and published in the form of a book (Shukla et al. 2018b)

Fertilizer best management practices in rice for higher productivity and role of micronutrients in biotic and abiotic stress management and tolerance strategies in crops have been elucidated in form of review articles (Nayak et al. 2013b; 2018).

4.4.5. Integrated nutrient management

Research was initiated to devise integrated nutrient management strategies for low land rice with locally available organic resources with objective of attaining higher yield and at the same time sustaining the fertility of soil. Application of 75 kg N ha^{-1} using both organics (Sesbania aculeata/rostata or azolla compost or FYM) and inorganics (three spit urea) in 1:1 ratio produced higher yield from 5th years onwards. Application of FYM @ 5 t ha^{-1} and straw @ 10 t ha^{-1} was recommended for maintaining fertility of soil.

A long-term fertilizer experiment with rice-rice cropping system under combined application of organic manure and chemical fertilizer was initiated in 1969 and it was observed that continuous application of chemical fertilizers along with FYM resulted in improvement in soil physical and chemical as biological activity leading to higher soil quality index and greater sustainability (Shahid et al. 2013)

4.4.6. Application modeling

Work on development and use of simulation model was started 1986 under a collaborative project simulation and systems analysis for rice production (SARP). The crop growth simulation model ORYZA 1N was used for optimization of N for medium-long duration varieties and found that application of 80 kg N ha^{-1} in four splits at transplanting, active tillering, panicle initiation, and flowering was found optimum for long duration variety like Ranjit (Swain 2007).

Effect of resource conserving technologies (RCTs) on transplanted rice was studied using DSSAT model. The CERES-Rice model in DSSAT v 4.6 was used in this study. The DSSAT model was calibrated and validated using experimental data. The model predicted the phenological events of anthesis and maturity in rice accurately with low RMSE (1.0 and 0). There was a good agreement between observed and simulated values with low NRMSE (0.78 and 0%, respectively).

4.5. Water management

Different low water requiring vegetables and pulses were grown in Kuakhia area of Jajpur by creating water resources through drainage recycling and dugout pits. A water harvesting structure of capacity 40 m^2 was constructed with alpha DPA film lining along with having a micro water shed of 0.3 ha. The collected run-off water was utilized in the dry season to raise good tomato crop (44.3 t ha^{-1}) in an area of 286 m^2.

Under irrigation studies in cropping system, tomato as vegetable and groundnut as oilseed proved to be alternative possibility after rice with less amount of water and sometimes with residual moisture. A study on method of irrigation for tomato showed that in alternate furrow irrigation, water use efficiency was higher compared to flooding and all furrow irrigation with significant improvement in yield. In case of groundnut, critical stage of irrigation was found to be flowering and pod formation stage.

Water balance analysis of Cuttack, which falls under hot moist sub humid ecological sub region indicated a water surplus of 1046 mm in a normal rainfall year (2005) and during excess rainfall year (2003) it is around 1555 mm during the crop growing season. Even during a deficit rainfall year like 1996, there was a water surplus of 146 mm during the crop growing season indicating the opportunity for water harvesting and storage. The harvested water can be used for supplemental irrigation to mitigate the drought, extend crop growing season and irrigation for the dry season crops. Similarly, water balance components of Odisha districts were also worked out to aid in formulating

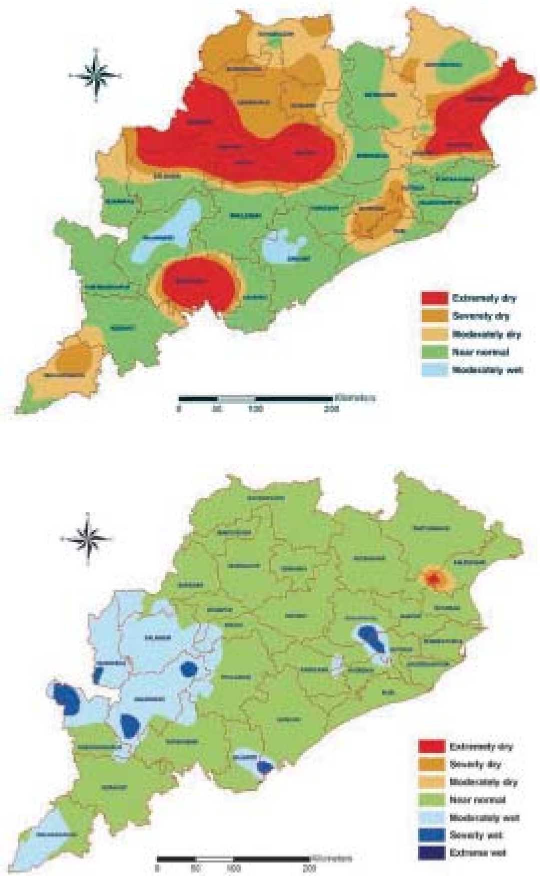

Fig. 1. Three months (July, August and September) SPI map of 2003 and 2008.

adaptation strategies for rice based cropping system. Using Standardized Precipitation Index (SPI), the severity and pattern of wetness/dryness in Odisha were examined at block level. The three month SPI maps of Odisha for September 2003 and 2008 were presented in Fig. 1 for comparison of normal and drought conditions. The frequency, area extent and severity of drought assessed from SPI will be useful in developing mitigation strategies of drought events in the region (Raja et al. 2014).

Among the irrigation schedule highest grain yield of 3.84 t ha^{-1} was achieved when aerobic rice was irrigated with 4 days interval during seedling and vegetative stage and was on par with that of yield recorded when irrigated at 6 days interval during seedling stage and 4 days interval during vegetative stage but significantly higher grain yield compared to irrigating the crop at 6 days interval during seedling and vegetative stage. Irrigation depth of 40 mm is optimal for scheduling irrigation in dry season for aerobic rice, that results in highest water productivity and grain yield at IW/CPE ratio of 1:2.

Precise measurement of evapotranspiration (ET) is required for developing better irrigation scheduling. Currently, eddy covariance (EC) approach is worldwide used as direct method for measuring ET. Out of all the four methods of estimating reference evapotranspiration (ETo), FAO-PM method was found to be better representative of ETo for this region.

Evapotranspiration of rice far exceeds PET or evaporation from free water surface as the ET process is governed not only by the energy balance process, but also by the aerodynamic phenomena. During *kharif* season the ET rates were relatively lower because of more humid atmosphere. The peak rate of ET was about 8 mm day^{-1} which is less than half of the peak rate observed during the rabi season. The difference between crop ET and evaporation from free water surface narrowed down during the *kharif* season.

During 1981, the total ET requirement of rice variety, *Ratna* for a period of 77 days in the main field in rabi season worked out to be 72.5 cm as against 48.3 cm lost from the bare free water surface under identical shallow submergence conditions. The corresponding figure for standard USDA open pan evaporation was 43.8 cm. These data clearly show crop effect on extra water utilization. Doubling the plant population rate increased the total ET by about 11%.

Planting in east-west direction resulted in slightly higher (1-2%) ET losses as compared to planting in north-south direction. Random planting resulted in about 6% higher ET losses as compared to row planting during the reproductive phase of crop in the month of April when atmosphere became relatively hotter. During Kharif season, the tall variety gave higher ET than that of the dwarf variety.

Irrigation requirement for groundnut (variety: AK 12-24), green gram (PDR 54), and black gram (T 9) in rice fallows was determined in rabi season. All these crops were sown on December 30, 1987. Groundnut produced significantly higher grain yield as compared to green gram and black gram. One irrigation at flowering gave the maximum yield (0.82 t ha^{-1}). The other crops (green gram and black gram) did not respond to irrigation, when yield increased only marginally with different supplemental irrigations over no irrigation (residual moisture) treatment.

The rajmash (*Phaseolus vulgaris*) (Var: PDR 14) crop responded significantly up to three irrigations given at seedling stage, grand growth period and pod initiation stage. Continuous submergence was superior to intermittent irrigation in terms of grain yield. Water requirement under continuous submergence was 1100 mm for extra-early variety CR 666-7 while it was 1200 mm for early varieties (CR 544-1-2 and CR 544-1-7) as against 600 and 700 mm respectively with intermittent irrigation.

Quantity of water required to produce 1 kg of rice was computed; water requirement to meet ET of the crop ranged between 1530 and 4200 L kg^{-1}. When total rainwater including field losses was considered, it ranged between 2675 and 6000 L kg^{-1}.

In rainfed areas land remains fallow after harvest of *kharif* rice due to shortage of water for irrigation. To create water resources during dry months rainwater was harvested and stored in renovated village ponds in Bhadrak, Balasore and Mayurbhanj districts. This water was used to provide supplementary irrigation to winter crops. Growing of sesamum and mung bean was feasible by the judicious use of summer showers.

The yield, evapotranspiration and water-use efficiency of several cultivars of rice-based winter and summer crops were evaluated. ET of oilseeds, such as mustard, sesamum and groundnut were 153 mm, 138 mm and 287 mm with WUE (in kg ha-mm^{-1}) of 5.56, 3.41 and 5.78, respectively. ET of mung bean, urd bean and chilli was 130 mm, 115 mm, 590 mm with WUE of 4.49, 4.43 and 15.4 kg ha-mm^{-1}. Similarly, ET and WUE of 10 vegetables, namely, tomato, potato, brinjal, okra, cabbage, cauliflower, pumpkin, cucumber, bitter gourd, and green pea were also determined.

Irrigation with marginally-saline water for four weeks during the vegetative growth did not cause a significant reduction in grain yield of rice; Annapurna recorded significantly higher survival, growth and grain yield (2.89 t ha^{-1}) as compared to Canning 7 (2.09 t ha^{-1}).

4.6. Weed Management

Weeds are the major biological constraint in rice cultivation. They do not only compete with rice for light, nutrients, water and space etc., but also create a favourable habitat for the growth of harmful insects, nematodes and pathogens. Certain weeds also secrete some toxic root exudates or leaf leachates, which depress the plant growth. These may lead to enormous losses by way of reduction in crop yields, input use efficiency, quality of the produce, wastage of human energy and increased expenditure. Further, changes in cultural practices by adopting direct-seeded rice farming lead to rapid changes in the abundance of rice weeds both at population and community level.

Investigations at the Institute showed 24, 36 and 41% yield losses due to weed competition during the first 1 month, 2 months and entire crop growth period, respectively in direct-seeded rice (DSR). An integrated weed management (IWM) approach was developed by rationally combining various preventive measures along with proper crop management practices followed by direct control measures by mechanical or chemical means or integrating both the practices in highly infested areas of direct seeded rice. This helps in reducing weed population below the economic threshold level during critical period of crop-weed completion (10-40 days) and is considered useful for improving and sustaining rice production.

4.6.1. Preventive measures

Mechanical separation by dipping rice seeds in 2% brine solution helps not only selection of high-density seeds but also removal of floating weed seeds. Selection of suitable rice varieties with weed-smothering character is another important option for realizing the desired rice yield particularly in uplands/ aerobic rice. Genotypes with intermediate plant height (110-120 cm), rapid seed germination, early vigour and moderate tillering are preferred. In general, semi-tall varieties like Vandana, Anjali and Kalinga III are better weed competitors than semi-dwarf varieties viz. Annada, Sneha and Heera in uplands. Genotypes Blackgora, Browngora, Soniya, NCS 132, NCS 134, Vandana, Kalinga III, AUS 257, AUS 196 and Agnisal and Narendra 97 are better weed competitive and could be used as potential donors in future breeding program. Leaving the land fallow after rice harvest encourages weed growth and, hence, the field should be ploughed for uprooting weeds to prevent the replenishment of fresh weed seeds.

4.6.2. Crop management practices

Poor land preparation is one of the major causes of increasing weed infestation. Deep ploughing once in three years during summer (April-May) helps in burying weed seeds into the deeper soil layers (below 8-10 cm) and prevents their germination. Weeds in the top soil layer that have germinated could be killed by shallow tillage with cultivator or rotovator at least 7-10 days before sowing. Stale seedbed technique is useful in aerobic soils and dry direct-sown rice for controlling weeds. In this method, sowing is withheld for at least 7-10 days after the final land preparation to allow germination of weed seeds and then emerging weeds are controlled either by shallow tillage (cultivated stale seed bed) or by applying non-selective herbicide like paraquat or glyphosate (chemical stale seed bed).

In DSR, proper crop establishment by optimizing the seed rate, time and method of seeding and spacing influences the pattern and intensity of weed competition. Sowing in 20-25 cm apart rows either by seed drill in dry-DSR or by drum seeder in wet-DSR with relatively moderate seed rate of 35-40 kg ha^{-1} ensures better crop stand and canopy cover and thereby reduces weed growth. Line seeding at 25 cm apart rows also facilitates mechanical weed control and other intercultural operations. Proper levelling and puddling of the field are important for proper water management which helps to suppress the initial weed infestation in wet-DSR and transplanted rice (TPR). In wet-DSR, the field should be kept in saturated condition for about a week after sowing to facilitate germination of rice seeds. Then, 2-3 cm standing water for the next 15 days and 3-5 cm standing water continuously up to panicle initiation stage should be maintained for reducing the weed infestation. It is recommended to apply half of the N fertilizer at 15-20 DAS and a quarter each at active tillering and panicle initiation stage that not only improves N-use efficiency but also increases weed control efficiency.

In transplanted rice (TPR), initial tillage one month before monsoon shower for removing perennial weeds coupled with shallow tillage 2 weeks before monsoon for encouraging germination of weeds to facilitate their incorporation during puddling reduces weed problem in the main field. Land levelling is important for proper water management and uniform crop stand establishment. Maintaining a water depth of 3-5 cm after transplanting till tillering initiation reduces population of weeds, particularly annual grasses and sedges. Transplanting of 20-25 days old seedlings with 3-5 leaves and closer spacing (15 x 20 or 15 x 15 cm) help to form a rapid canopy cover, which suppresses weed growth. However, wider spacing facilitates the operation of weeding implements. It is recommended to apply N in 3-4 split doses skipping the basal application.

In rainfed lowlands, growing short duration pulse/oilseed crops like horse gram, black gram, lentil, field pea, sesamum, linseed, safflower, castor, mustard/toria etc. after rice harvest with residual soil moisture helps in providing the vegetative cover and thereby prevents weed growth. However, these practices are feasible only when adequate soil moisture is available. In some areas, crops like jute and sesame with weed smothering effect can be raised as pre-*kharif* crop for reducing weeds in the subsequent rice crop. In irrigated areas, growing less water requiring non-rice crops such as wheat, potato, maize, groundnut, sunflower, barley, rapeseed and mustard during winter/dry season helps to reduce perennial and water-tolerant weeds.

4.6.3. Manual weed control

First 7-40 days is found the most critical period of crop-weed competition and the field should be kept weed-free during this period. Manual weeding twice at 2-3 weeks and 5-6 weeks after seeding/transplanting was recommended and is the most common practice in rice. But, it is labour intensive (80-120 man-days ha^{-1}), tedious, drudgery causing and expensive. Mechanical weed control by using implements is cost effective and has added advantage of improving soil aeration, root pruning and tillering, but it is feasible only when rice seedlings are planted at least in 25 cm apart rows. In light-textured soils (uplands and aerobic conditions), operation of finger weeder once at 20 days after sowing (DAS) combined with one manual weeding for removal of weeds within rice rows is effective in controlling weeds, reducing weeding cost and improving grain yield. In wet-DSR and TPR, operating manual cono-weeder or motorized weeder in 5-7 cm standing water helps to suppress the major weeds. However, these machines are not so effective when water depth is >10 cm. Manual weeding for removing weeds between or close to rice hills is needed after the operation of these machines. Integration of chemical weed control by application of early post-emergence herbicide, bispyribac sodium at 10-12 DAS/T followed by mechanical weed control by motorized weeder at 35 DAS/T was found most cost effective and eliminate manual weeding.

4.6.4. Chemical weed control

Chemical weed control is cheapest and alternative to manual/mechanical weeding. Herbicides can be applied either by spraying in a thin film of water or by broadcasting after mixing formulations with sand (30 kg ha^{-1}). The promising pre-emergence herbicides earlier recommended for DSR are pretilachlor (0.8 kg ha^{-1}), pendimethalin (0.75 kg ha^{-1}), anilophos (0.5 kg ha^{-1}), oxadiazon (0.75 kg ha^{-1}), pyrazosulfuron ethyl (20 g ha^{-1}), etc. These chemicals are effective only for first 18-20 days and a supplementary manual weeding at late vegetative stage is essential. Presently, these herbicides are not advised to apply in rice fields as their efficacy depends on soil moisture and is ineffective in dry soil conditions, further most of them are narrow spectrum and do not control established weeds. The application rate of pre-emergence t herbicides is also very high and most of them persist in soil for several weeks (6-10 weeks or more) and shows detrimental effect not only to rice crop but also to beneficial microorganisms in soil.

The low-dosage high-efficacy post-emergent herbicides/ herbicide mixtures having broad spectrum of weed control are expected to be the new intervention to suppress the weeds during critical period of crop-weed competition. The rate and time of application of these new generation herbicides/ herbicide mixtures were standardized in such a way that it may keep the weeds under control during first 5-6 weeks of rice crop establishment. Post-emergence application of bispyribac sodium (30 g ha^{-1}), fenoxaprop-p-ethyl (60 g ha^{-1}), cyhalofop butyl (60 g ha^{-1}) etc. are found effective in controlling the grassy weeds. Similarly, ethoxysulfuron (15 g ha^{-1}) is found very effective for controlling sedges. Metsulfuron methyl (10 g ha^{-1}) and penoxsulam are found effective for controlling broadleaved weeds. Some recently standardized herbicide mixtures at the Institute viz., metsulfuron methyl + chlormuron ethyl (ready-mix (4 g ha^{-1}), bensulfuron methyl + pretilachlor (ready-mix, 60+600 g ha^{-1}), penoxulam + cyhalofop butyl (ready-mix, 125 g ha^{-1}), XR 848 benzyl ester + cyhalofop butyl (ready-mix, 125 g ha^{-1}) as well as fenoxaprop-p ethyl + ethoxysulfuron (tank-mix, 50 + 15 g ha^{-1}) etc. are found effective for broad spectrum weed control in DSR and TPR. However, continuous use of a single herbicide may lead to build up of herbicide resistance in weeds and this can be prevented by following herbicide rotations.

4.6.5. Control of wild rice

Weedy rice causes significant yield reduction in eastern India and the problem is more acute in direct-sown rainfed lowlands. Use of clean certified seeds and clean machineries helps to reduce weedy rice seed bank in soil. Row seeding by using a seed-drill and use of rice varieties with pigmented (purple) base (Kalashree, Shyamali etc.) help in detecting them. Wet seeding with pre-germinated seeds also reduces the infestation. Transplanting rice seedlings in lines helps in destroying the germinating weedy rice plants at the time of final puddling and facilitates the detection and weeding of the plants emerging after the planting. In severely-infested areas, stale seed bed technique is another good option. Green manuring by *Sesbania sp.* in rainfed lowlands helps in successfully smothering weedy rice. Proper crop rotation by growing soybean, groundnut, maize, wheat, sunflower, sorghum, mung bean, etc. is effective as these crops allow alternative herbicide treatments and cultivation practices which would help to suppress weedy rice.

4.7. Resource conservation technology

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 (Shahid et al. 2018b).

Green manuring in situ with sunnhemp (*Crotalaria juncea*) and dhaincha (*Sesbania aculeata*) significantly improved growth and yield of transplanted rice. Giving the green manure crops 15 kg N ha^{-1} or 15 kg N and 30 kg P_2O_5 ha^{-1} further increased yield. Interaction between green manuring and N fertilizer revealed that a considerable quantity of fertilizer N (45–60 kg N ha^{-1}) applied to rice could be replaced by incorporation of green manure crops to which a small amount of fertilizer had been applied. Residual fertility in terms of organic carbon and available N, P and K increased under green manuring, whereas N fertilizer made no impact on fertility build up. Grain yield of wheat and gram increased when grown after rice in plots which had grown green manure (Sharma and Mittra 1988).

The beneficial residual effect, of cowpea grown in summer (March to May) and incorporated into the soil before the succeeding direct seeded rice crop in wet season (June-September) on uplands was reported. After picking pods, the foliage and stems of cowpea were incorporated. Succeeding rice crop, in wet season received a uniform application of 30 kg N ha^{-1}. Application of phosphorus at 20 or 40 kg ha^{-1} or nitrogen 5 kg ha^{-1} to cowpea crop increased its biomass over control.

Organic manuring of wet season rice with locally available materials (e.g. wheat straw, paddy straw, farmyard manure, water hyacinth compost, azolla, sunnhemp) was found to promote growth and yield significantly. There was a marked improvement in residual soil fertility, as estimated by organic carbon and available N, P and K content, with organic matter application after crop harvest, which increased grain yield of wheat, gram and rice grown during the subsequent dry season.

Organic C content of soil after the rice harvest increased significantly after straw application, whereas there was more available N after FYM. Increasing the rate of application of straw up to 15 t ha^{-1} increased organic C but not available N. Mineral N fertilizer had little effect on fertility build-up. Grain yields of wheat and gram (*Cicer arietinum*), grown after rice without any additional fertilizer, increased significantly. The residual N effect of the previous crop on wheat or gram yield was small and adding fertilizer directly is considered essential for higher productivity in these crops in a rice-based cropping system.

In a field experiment it was observed that wet tillage recorded significant yield advantage over the dry direct seeded practice, however, tillage depth had no significant effect on yield. During dry season, greengram cv. PDM 54 produced 48% higher yield in the plots where dry direct sown rice was grown in the preceding season.

A study conducted at NRRI on rice residue management revealed that substitution of chemical N (25%) with crop residue to provide 60 kg N ha^{-1} gave comparable grain and straw yields as that of chemical N. Superimposition of 60 kg chemical N ha^{-1} (urea) on 2.5 t ha^{-1} crop residue increased the grain and straw yield of rice over sole application of urea.

Different nutrient management options were tested on the rice-maize cropping system under conventional and zero/minimum tillage situations to develop conservation agriculture based nutrient management. The varieties Pooja (rice) and Super 36 (maize) were used in the experiment. About 7.7% grain yield reduction was observed in zero tillage rice compared to conventional tillage. Grain yield of maize did not differ significantly in zero tillage compared to conventional tillage. System productivity in terms of rice equivalent yield of zero tillage system was at par with that of conventional tillage in rice -maize cropping system.

Field experiment was conducted with different resource conservation technologies (RCTs) viz. minimum tillage, green manuring, brown manuring, wet direct seeding of rice, zero tilled dry direct seeded rice and paired row dry direct seeded rice. The grain yield varied in the range of 4.08 to 4.98 t ha^{-1} and the highest yield was obtained in the paired row dry direct seeded rice with dhaincha (*Sesbania aculeata*). The input and output energy varied in the range of 17.9-31.1 and 147.1- 190 GJ ha^{-1}, respectively with highest input energy in conventional system and lowest in zero tillage whereas highest output energy was in paired row dry direct seeded rice with dhaincha. The energy ratio (output/input) was also found highest in the paired row rice with dhaincha treatment. There was significant amount of energy savings and net C gain in paired row dry direct seeded rice with green manuring treatment. A best bet climate-smart resource conservation technology (CRCT) was developed and validated in the farmers field and recommended for higher yield, low energy and environment sustainability (Bhattacharyya et al. 2014b).

In an experiment conducted at National Rice Research Institute, Cuttack it was observed that SOC stock was significantly higher by 5.3-9.7% higher in zero tillage transplanted rice as compared to conventional rice cultivation. Labile carbon pools are highly sensitive to cultivation practices, on the contrary total carbon content does not change much. Therefore, carbon dynamics can be understood by observing the changes in labile carbon pools under various RCT practices (Dash et al. 2017).

Integrated effect of tillage, residue retention through mulching on GHG emission along with soil health, energy consumption and carbon footprints were examined together as conservation effective measure for sustainable and clean agricultural production. Zero tillage reduced the energy consumption by 56% and carbon footprints by 39% and besides that N_2O emission was 20% lower than conventional tillage. Apart from clean environment, soil health was also improved by adoption of zero tillage in terms of NPK status, labile pool of carbon and enzymatic activities (Lal et al. 2019b).

The cultivars 'Padmini' and 'Ketekijoha' were responsive towards organic sources of nutrients, while grain yield of 'Ketekijoha' was invariably better over 'Padmini' across the treatments and the highest was also observed under FYM + Green manure.

4.8. Climate change adaptation and mitigation

4.8.1. Quantification of GHGs emissions

Greenhouse gases (GHGs) emissions and climate change related work initiated at NRRI, Cuttack in 1980s. The studies primarily focused on GHGs quantification, monitoring, mitigation and climate change effects on rice production systems. 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 condition. In general CH_4 emission was significantly low in rainfed compared to irrigated system. In irrigated lowland rice-rice system, seasonal (one crop season), CH_4 emission varied from 38.8-71.5 kg ha^{-1} depending on fertilizer use and water management. On yearly basis CH_4 emission ranged from 107.3 to 109.3 kg ha^{-1} in rice-rice cropping system. In rice-fish production system CH_4 emission was as low as 45.4 kg ha^{-1} under rainfed condition, but it was estimated to 109.3 kg ha^{-1} in irrigated condition. On aerobic system, there was drastic reduction of CH_4 emission and it was reported to as low as 12.4 kg ha^{-1} (Mohanty et al., 2018). Nitrous oxide (N_2O) and carbon dioxide (CO_2) emissions and global warming potential (GWP) were mostly studied at ICAR-NRRI, Cuttack after 2004 onwards. Nitrous oxide emission in rice based system in eastern India varied from 0.22 to 1.75 kg ha^{-1} (Datta et al. 2009; Bhattacharyya et al. 2012a; Mohanty et al. 2018; Dash et al. 2017). 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 1000-1447.7 kg ha^{-1} (Bhattacharyya et al. 2012b). Based on the estimates at 18 locations under national methane campaign and at four centers, emission from irrigated and rainfed lowland system in India has been estimated to be around 4.0 million tons per year, which is much lower than the earlier US-EPA estimate of about 38 million tons per year (Adhya et al. 2000a).

4.8.2. Mitigation options of GHGs emissions

Various mitigation/adaptation options suggested for reduction of CH_4 and N_2O emissions in rice based production systems, which broadly included water and nutrient management, tillage manipulation, cropping system approach and addition of nitrification inhibitors. Rice-blackgram system could reduce 243% of CH_4 emission as compared to rice-rice system (Adhya et al. 2000b). On the other hand there is a potential to reduce CH_4 emission by approximately 399% in aerobic system than puddle transplanted rice on yearly basis (Mohanty et al., 2018). This was because aerobic system increases the redox-potential of soil which was not favorable for CH_4 production and methanogenesis. It also breaks the continuous submergences condition which usually prevailed in puddled lowland rice ecology. However, there is a possibility of increasing N_2O emission in the aerobic system if N management is not proper. However, incubation studies showed less reduction of CH_4 emission in aerobic conditions as compared to submergence (Table 1). Minimum and zero tillage could reduce CO_2 and CH_4 emissions by around 33 and 11.7 %, respectively as compared to conventional tillage (Neogi et al. 2014; Dash et al. 2017). This was due to lesser disturbance/ and or compactness of soil leads to reduction in soil respiration by heterotrophs and reduction in methanogenic activities in zero/minimum tillage condition.

Interestingly rice-fish farming system has the potential to reduce CH_4 emission by 112% as compared to rice-rice system (Datta et al., 2009) because of turbulence of soil-water interphase of the system which provides aeration and made the system relatively aerobic (relatively high redox potential) which retarded CH_4 production. However, N_2O emission was found relatively more (14.1%) in rice-fish farming system compared to rice-rice (Table 1) (Bhattacharyya et al., 2013a; Datta et al., 2009). Real time nitrogen management through customized leaf colour chart (CLCC) could mitigate the N_2O emission by 18.3% as compared to puddle transplanted rice.

4.8.3. Mass and energy exchange in rice ecosystem

Using open path eddy covariance (EC) system in a low land paddy during wet season, the value of cumulative net ecosystem exchange (NEE), gross primary production (GPP) and ecosystem respiration (RE) was reported as 448, 811 and 363 g C m^{-2} (Bhattacharyya et al. 2013b). In this experiment a positive carbon balance was also observed. In another study based on a year long data comprising wet and dry seasons, Bhattacharyya et al. (2014c) reported tropical low land rice ecosystem is a net carbon sink. They reported that the lowland rice had the potential to store about 0.91 Mg C ha^{-1} in wet season and 0.59 Mg C ha^{-1} in dry season. This study was further supported by Swain et al. (2016) who reported annual carbon storage of 1.04 Mg C ha^{-1} by lowland paddy. Net ecosystem methane exchanges (NEME) was found affected by air temperature, soil temperatures and radiation. The annual cumulative global warming potential in rice-rice system including fallows was 13,224.1 kg CO_2 equivalent ha^{-1}. Land surface energy fluxes were characterized and latent heat flux was found dominating over sensible heat flux (Chatterjee et al. 2019). The intercepted solar radiation was partitioned into latent heat flux (LE, 44–73%) followed by soil heat flux (G, 13–42%) and sensible heat flux (Hs 3–16%) in dry season rice (Swain et al. 2018). Energy imbalance in rice-rice ecology mainly occurred 1–3

Table 1. Greenhouse gases mitigation/ adaptation options in rice-based production systems.

Study type	Options	Reference/check	GHG	Reduction (%)
Field	Black gram-Rice	Rice-rice	CH_4	243.5
Field	N(urea) + DCD	Urea	CH_4	15.5
Field	Alternative flooding	Conventional Flooding (CF)	CH_4	18.3
Field	Rice	RF	CH_4	112.3
Field	Rice + Fish	Rice	N_2O	36
Incubation	Submergence	Aerobic	CO_2	21
Incubation	Aerobic	Submergence	CH_4	27
Field	Rice + Fish	Rice	N_2O	14.1
Field	FYM	RDF	N_2O	23.5
Field	Minimum tillage	Conventional Tillage (CT)	CO_2-C	33
Field	Minimum tillage	CT	CO_2-C	44
Field	Minimum tillage	CT	CO_2-C	23.3
Incubation	Submergence	Aerobic	CO2	212
Incubation	Aerobic	Submergence	CH_4	27
Field	Zero tillage	RDF	CH_4	11.7
Field	CLCC-N	RDF	N_2O	18.3
Field	Aerobic	Puddled transplanting	CH_4	399.2
Field	Puddled transplanted rice	Aerobic	N_2O	79.1
Field	-60 k Pa soil water potential (SWP)	Conventional flooding (CF)	CO_2	11.6
Field	-60 kPa SWP	CF	CH_4	171.46
Field	SWP	CF	GWP	43.2

days after the rainfall as the energy is advected in the fresh water (Chatterjee et al. 2019). The GWP and NEME depicted similar trend as soil enzymes and labile carbon pools. The mean NEE exhibited a more negative value with decrease in labile pools from panicle initiation to harvesting stage in the wet season.

4.8.4. Effect of anticipated climate change conditions on rice production system

Effect of anticipated climate change conditions (elevated CO_2 and temperature) on rice yield, biomass production, below ground carbon allocation, GHGs emission and microbial diversities were studied extensively. Dry matter accumulation in the above ground portion was measured higher under elevated carbon dioxide+ temperature (ECT) (84.5%) than that of under ambient chamber control (CC). Root biomass, leaf area index (LAI) and net carbon assimilation rates were increased significantly under elevated carbon dioxide (EC) than CC by 28, 19 and 40%, respectively. The grain yield was also found significantly higher under EC (22.6%) as compared to CC, although the higher temperature in ECT reduced the yield advantage by 3% than EC over 3 years.

A significant decrease in seasonal cumulative CH_4 emission (30–60.2%) was recorded at different soil water potential under elevated CO_2 and temperature as compared to conventional flooding. However, emission of CO_2 and N_2O were in reduced soil moisture potential (Kumar et al., 2016). As a result there was no significant reduction in global warming potential (GWP) was estimated as compared with CF.

Another important aspect, change in microbial diversity related to methanogenesis and methanotrophy were also studied under elevated CO_2 and temperature. The whole genome metagenomic sequence data of lowland rice exhibited the dominance of bacterial communities including Proteobacteria, Firmicutes, Acidobacteria, Actinobacteria and Planctomycetes. The acetoclastic pathway was found as the predominant pathway for methanogenesis, whereas, the serine pathway was found as the principal metabolic pathway for CH_4 oxidation in lowland rice. Rice rhizosphere showed higher structural diversities and functional activities in relation to N metabolism involving nitrogen fixation, assimilatory and dissimilatory nitrate reduction and denitrification under ECT than that of CC. Among the three pathways of N metabolism, dissimilarity pathways were predominant in lowland rice rhizosphere and more so under ECT (Bhattacharyya et al. 2019).

4.9. Ecosystem services

Ecosystem services (ES), are vital for the sustainable supply of food and fibre. The current trends of decline in the ability of agricultural ecosystems to provide ES pose great threat to food security worldwide. Ecosystem service valuation was done for different resource conservation technologies under direct seeded and transplanted conditions in a rice-green gram system taking into consideration the marketed ecosystem services and non-marketed ecosystem services. It was found that use of green manuring resulted in higher values of both marketed and non-marketed ES under transplanted (TPR) and direct seeded rice (DSR). Zero tillage under both TPR and DSR recorded higher ecosystem services as compared to conventional method due to higher soil fertility and carbon accumulation value.

Variations in ecosystem services in response to land use land cover change over 27 years in four agro-climatic zones (ACZ) of eastern India using satellite imagery for the year 1989, 1996, 2005, 2011 (Landsat TM) and 2016 (Landsat 8 OLI) were investigated. The value of ecosystem services per unit area followed the order of waterbodies > agricultural land > forests. A different set of indicators, e.g., by explicitly including diversity, could change the rank between these land uses, so the temporal trends within a land use are more important than the absolute values (Tripathi et al. 2019).

4.10. Microbiology research

Microbes plays a significant role in rice production system for nutrient availability and acquisition, control of insect pest and diseases, modifying rhizospheric and phyllospheric environment, moderating different abiotic stresses and acting as growth promoting substances. Division has developed several microbial formulations, technologies, product and processes which are discussed below briefly.

4.10.1. Beneficial microbes for stress, residue and nutrient management in rice

Liquid formulations of one each endophytic (*Azotobacter chroococcum* Avi2) and rhizospheric (*Azotobacter vinelandii* Az3) nitrogen-fixing bioinoculants for rice crop have been developed (Banik et al. 2019). Six entomopathogens (four bacterial: *B. thuringiensis* strain TB 160, 161, 261 and 263 and two fungal strains: *B. bassiana* strain TF6and *M. anisopliae* strain TF19)to manage rice leaf folder were identified and formulations of these strains were also filed for Indian patents with following numbers 264/KOL/2015, 263/KOL/2015, 261/KOL/2015, 262/KOL/2015, 260/KOL/2015, 265/KOL/2015, respectively. Role of antioxidant (ascorbic acid) has been analyzed in nitrogen fixing bacterium (*Azotobacter chroococcum* AVi2) under oxidative stress (different concentration of H_2O_2). Result indicated that 1 ppm of ascorbic acid enhanced the life span of *Azotobacter chroococcum* (AVi2) and its PGP efficiencies under oxidative stress. Recently, one efficient entomopathogenic bacterium (*Skermanella* sp.) was identified against rice leaf folder and pink stem borer (Panneerselvam et al. 2018). First time it was documented that the phosphorous tolerant rice varities (Kasalath and Dular) have a specific kind of AMF association. Arka Microbial consortium and Actino plus pachege have been standardized for low-land and aerobic rice production systems. Nine strains from paddy straw and composting pit were evaluated for their ability for decomposition of rice straw under microcosm experiment. The results indicated that actinobacteria isolates (DA10, DA13, and DA9) were 72.7-81.6% higher degradation of cellulose as compared to uninoculated control after one month of inoculation, whereas, it was 66.6-79.0% higher efficiency in case of fungal (DF15, DF7 and DF19) and bacterial isolates (DB12, DB20 and DB23). The bacteria, fungi and actinobacteria were identified as *Bacillus*, *Aspergillus*, *Trichoderma*, and *Streptomyces* spp., respectively. Long-term fertilizer experiment (LTFE) study proved for the first time that continuous application of N fertilizer alone over 47 years suppressed some of the bacterial phyla such as Fibrobacteres, Spirochaetes, TM7 & GNO4 in paddy soil (Kumar et al. 2018). Biolog Ecoplate-based functional microbial community under LTFE was analyzed which indicated that continuous application of nitrogen alone over 41 years decreased the functional soil microbial community, however microbial community increased with application of nitrogen with manure (Kumar et al. 2017a). Long-term aromatic rice cultivation over one decade decreased the frequency and diversity of diazotrophs in its rhizosphere (Kumar et al. 2017b).

Microbial consortium (*Bacillus*, *Aspergillus*, *Trichoderma*, and *Streptomyces* spp) has been formulated for sraw-residue management. Q-PCR-based eight functional genes such as *nifH* (nitrogen fixation), *amoA* (ammonia oxidation), *nirK* (denitrification), *nosZ* (denitrification), *npr* (amination), *phoD* (alkaline phosphatase), *soxB* (sulfur oxidation)and *acd S* (ACC deaminase) and four structural genes such as *Ps(Pseudomonas*), *cyano* (Cyanobacteria), *mcrA* (Methanogens) and *pmoA* (Methanotrophs) have been standardized. A unique combo-kit to screen plant-growth promoting microbes was developed, wherein six PGP traits can be rapidly analyzed simultaneously.

4.10.2. Prospects of Azolla and blue-green algae (*Cyanobacteria*)

Work on BGA at this Institute was started in early 1960's. In addition, investigations on Azolla work were also taken up in mid 1970's. Extensive studies covering basic aspects of these organisms and application of the findings for enhancing crop production were carried out.

A large number of N_2-fixing BGA was isolated from rice fields of the Institute farm and soil samples collected from different parts of the country. Predominant among them were species of *Aulosira, Anabaena, Nostoc, Cylindrospermum, Gloeotrichia and Aphanothece.* Most BGA were dominant in the moist soil and *Aphanothece* was abundant in all water regimes whereas *Aulosira* preferred clean standing water.

Occurrence of a long-tailed LPP type virus infecting, alga, *Plectonema boryanum* was reported in paddy fields for the first time. N-1 virus that infected *Nostoc muscorum* was inactivated in distilled water, saline solution and magnesium chloride solution and stabilized by monovalent and divalent cations. Virus particles were most stable at 45 ^{o}C and at pH of 6.7-10.5. Its adsorption rate was highest at exponential growth stage and decreased with ageing of algal culture. Virus resistant mutants of *N. muscorum* were isolated with frequency of $3.5x10^{-5}$. Gene transfer studies showed that nif ability was transferred from parent to mutant along with resistance markers.

Laboratory studies with *Fischerella muscicola* showed that sporulation frequency was higher in acidic than in alkaline pH. Phosphorus deficiency or application of nitrogenous fertilizers stimulated sporulation, urea-N being more effective than ammonium and nitrate-N. Dilution of the growth medium also enhanced sporulation. Antibiotics, streptomycin and chloramphenicol, stimulated sporulation initially, but suppressed it upon prolonged incubation. Increasing concentrations of glucose and fructose up to 1000 ppm, potassium permanganate and hydrogen peroxide up to 1.0 ppm, 2,4-D up to 60 ppm and sodium chloride up to 1000 ppm enhanced sporulation and their action was concentration-dependent. Certain heavy metals (Cr, Cd, Pb and Zn) and growth hormones (IAA and GA) also increased sporulation. Application of pesticides, benthiocarb, metacid and bavistin at the recommended doses favoured BGA sporulation under field conditions. Germination of *F. muscicola* spores was favoured by alkaline pH, red light and application of sugars, N fertilizers, IAA and GA.

Various types of mutants were isolated spontaneously and after chemical mutagenesis in several BGA. Mutants with loss of heterocysts (het^-) always lacked N_2-fixation (*nif*). MNNG-treated, chlorate resistant (Clr^R) mutants of *N. muscorum* and *Aulosira* sp., which were nitrate reductase defective (nar^{def}) or blocked (nar^-), showed heterocyst differentiation and N_2-fixation in presence of nitrate. MSX resistant (MSX^R) mutants of nar^- *N. muscorum* were partially blocked in glutamine synthetase, as evident from their low GS transferase activity in comparison to nar^- mutant and parent strain. MSX^R mutants of *Aulosira* sp. also showed low GS transferase activity and fixed N in presence of ammonium. Clr^RMSX^R mutants of this alga were nar^{def} GS^{def} and fixed N in presence of both nitrate and ammonium. Spontaneously isolated mutants of *N. muscorum* were characterized as het^- nif^- having short trichomes and abnormal cell morphology. They reverted into long forms having heterocysts but normal cell morphology was not restored. Amino acids, casein hydrolysate and vitamin B_6 failed to restore cell normalcy. Some other mutants showed loss of gas vacuoles, filament formation, sporulation and variations in colony morphology.

Aphanothece pallida and A. *castangei* were reported as N_2-fixers for the first time. The ARA of *Gloeocapsa decarticans* was higher in light, whereas *A. pallida* showed higher ARA in dark but required prior exposure to light. Addition of DCMU increased ARA of *A. pallida* under both short-term and long-term photo-incubation but decreased ARA of *G. decarticans* under long-term photo-incubation.

The BGA could be inoculated at 50-100 kg fresh wt or 6-10 kg dry wt ha^{-1} after 7 days of planting. Use of several BGA strains together was superior to single strain inoculum. Fresh inoculum grew better than dry BGA and local strains performed better than strains brought from distant places. Superphosphate at 20-40 kg P_2O_5 ha^{-1} and carbofuran at 75-90 g ha^{-1} encouraged growth of native and inoculated BGA. Field studies showed that application of BGA was on par with application of 20-25 kg N ha^{-1} as chemical fertilizer and increased yield by 15-60% over control.

Requirement of cobalt, molybdenum and vanadium for growth and N_2-fixation of BGA was established in the laboratory studies. Application of potassium, lime and molybdenum did not prove beneficial in field experiments. Gamaxene (BHC), lindane, diazinon and endrin reduced survival, growth and N_2-fixation of *Cylindrospermum* sp., *Aulosira fertilissima* and *Plectonema* *boryanum.* Growth of *Anabaenopsis raciborskii* and *Mycrocystis flasaque* was not inhibited by 2,4-D even at 150 ppm. Butachlor and benethiocrb at relatively low concentrations (10-15 ppm) reduced growth, N_2-fixation, uptake of phosphate and ammonium by *N. muscorum*. Inhibitory effects of the herbicides and N fertilizers could be minimized by increased application of P fertilizer. Their deleterious effects were also lowered by applying them together with insecticides.

Altogether, 102 strains belonging to seven species of *Azolla* from all over the world were maintained at NRRI. Wide variability was observed among these strain as regards growth and N_2-fixation. Among *A. pinnata* strains, growth of Vietnam green and Thailand strains was better. A strain of *A. caroliniana* grew better and fixed more N as compared to strains of other species. It was also tolerant to several pests and diseases. Morphology and cytology of some *Azolla* species were studied in detail. Plants consist of a branched floating stem, alternately arranged bilobed leaves and adventitious roots. *A. nilotica* and *A. filiculoides* showed vertical morphology and the other species showed horizontal morphology. Rhizome surface was pubescent in *A. pinnata* and glabrous in *A. mexicana* and *A. filiculoides*. Nipples on the surface of dorsal lobe were rounded in species of section *Euazolla* and prolate in species of section *Rhizosperma.* Besides reproductive features, use of vegetative characters like rhizome surface, structure and distribution of trichomes and total chromatin length for species identification was suggested. Chromosome number varied among species and strains. *A. mexicana, A. filiculoides,* India and Vietnam green strains of *A. pinnata* had a chromosome number (2n) of 48, 40, 44 and 66, respectively. Meiotic behaviour of microspore mother cell was also studied in these species.

About 5-10 cm depth of standing water, slightly acidic to neutral soil (pH 5-7) and moderate temperature (20-30 °C) are favourable for Azolla growth. However, strains tolerant to low or high temperatures are also available. Soils with high available phosphorus and low organic carbon and nitrogen are more suitable for its cultivation. Method of Azolla production in field was standardized. Well prepared field is divided into small sub-plots and 5-10 cm water depth is maintained. Fresh Azolla is inoculated at the rate of 50-400 g m^{-2}, depending on availability of inoculum. Inoculation at higher rates always helps in quick multiplication. Weekly application of superphosphate at 4-8 kg P_2O_5 ha^{-1} and carbofuran at 75-90 g ha^{-1} encourages growth. When thick mat is formed in about 2-3 weeks, half of the Azolla biomass produced is harvested and remaining half is left for further multiplication.

Almost all strains of *A. pinnata* and some strains of *A. caroliniana* formed sporocarps during November to March, when day length was short and temperature was relatively low at night. A strain of *A. mexicana* sporulated year-round. Vietnam green strain of *A. pinnata* formed only male sporocarps. Phosphorus deficiency and overcrowding enhanced sporulation. Growth hormones IAA, GA and kinetin also stimulated sporulation. Azolla could tolerate reasonably high levels of heavy metals like zinc, lead (each up to 250 ppm) and chromium (up to 5 ppm), although growth decreased gradually with their increasing concentrations. This finding suggests the possibility of using the fern for detoxification of heavy metal-polluted water bodies and rice fields.

A more efficient method of sporocarp collection from *Azolla* was developed where sporocarp balls were collected by repeated shaking and sieving of dried plant powder. Sporocarps germinated within 10-15 days after incubation. Light was required for germination. Nitrogen, phosphorus, amino acids and growth hormones like GA and kinetin increased germination. Young seedlings derived from sporocarps of different *Azolla* species showed interesting morphological differences.

Growth rate, maximum biomass and nitrogen content of *Azolla* provide estimate of its potential for agricultural use. Fresh weight of *Azolla* increased 2 to 6-fold every week. It fixed about 75 mg N g^{-1} dry wt. day^{-1}. Total nitrogen content was 3-5% on dry weight basis and 0.2-0.3% on fresh weight basis. Year-round multiplication yielded a maximum biomass of 347 t fresh wt. ha^{-1} which contained 868 kg N. The ARA studies have also confirmed its large N_2-fixing potentiality.

It could be used as both green manure and dual crop with rice, but dual cropping (inter-cropping) was more practicable and economical. Inoculation of fresh *Azolla* at 0.5-1.0 t biomass ha^{-1} before 15-20 days of planting for green manuring and after 7 days of planting for dual cropping is recommended. Dual cropping up to 3-4 weeks was beneficial for rice. Split application of superphosphate at 8-10 kg P_2O_5 ha^{-1} and carbofuran at 75-90 g ha^{-1} ensured rapid fern growth. Phosphorus need of *Azolla* could be met from recommended dose of P for rice by applying half the dose of P during *Azolla* cultivation. Green manuring supplied 20-40 kg N ha^{-1} and dual cropping 20-30 kg N ha^{-1}. Using *Azolla* as green manuring or dual cropping was on par with application of 30 kg N ha^{-1} through chemical fertilizer and increased grain yield of rice by 0.5-1.5 t ha^{-1} over control. Inoculum of 100-300 g m^{-2} for *Azolla* multiplication and 0.5-1.0 t ha^{-1} for green manuring or dual cropping has been recommended. Higher levels of inoculum helped in rapid *Azolla* growth and inoculum up to 3.0 t ha^{-1} could be used without any adverse effects on rice yield, provided water level is not high enough to allow rice leaves to be covered by *Azolla*.

Through latest sequencing technique, we reported for the first time that *Cylindrospermum* was the most abundant cyanobiont *in Azolla* rather than *Nostoc/Anabaena*/ others (Kumar et al. 2019). *Azolla microphyla* is considered as suitable feed for livestock, poultry, fish etc. based on nutrient profiling (Kumar et al. 2019). Besides cyanobacteria, twelve other nitrogen fixing bacterial strains from different *Azolla* spp., were also observed and most of them identified as *Acinetobacter* sp.

Azolla and blue-green algae (BGA) have significantly increased rice yield and maximum algal growth potential as biofertilizer for rice. On an average, BGA could supply 20-25 kg N ha^{-1} per season, whereas *Azolla* can supply 20-40 kg N ha^{-1} in 20-75 days. A large number of N_2-fixing BGA was isolated from rice field in the different parts of country. The following genera such as *Aulosira*, *Anabaena, Nostoc*, *Cylindrospermum*, *Gloeotrichia* and *Aphanothece* were found as predominant BGA. Out of the 102 strains of *Azolla*, 23 sporocarp producing strains were identified and standardized the soil based sporocarp formulations of one *Azolla* strain (*A. pinnata*).

4.10.3. Pesticides-Bacteria Interaction and nitrogen fixation by free-living bacteria

Research on pesticide soil microflora interactions was initiated in 1971 while that on nitrogen fixation by free-living bacteria was initiated in 1975. Nitrogen fixation by free-living Bacteria- employing sensitive ^{15}N tracers, it was demonstrated that flooded soils always exhibited higher nitrogenase activity than non-flooded soil. High levels of combined nitrogen inhibited and low levels stimulated the nitrogen fixation in paddy soils. In an isotopic study, employing ^{15}N, application of carbofuran, benomyl and gamma-HCH to submerged soils at 5 ppm level led to a significant increase in nitrogen fixation in a majority of five soils due to a stimulation of *Azospirillium* and anaerobic nitrogen fixers. Non-target effect of continuous application of chlorpyrifos on soil microbes, nematodes and its persistence under sub-humid tropical rice-rice cropping system was also analyzed (Kumar et al. 2017c)

4.10.4. Microbial degradation of pesticides

Repeated application of pesticides to soil led to development of microbial factors capable of degrading toxic pesticides to nontoxic metabolides. Chlorpyriphos degradation was more 35 °C (99.9%) after 15 d incubation (Das and Adhya 2015). Presence of the *linA* (471 bp) and *linB* (250 bp) genes of *Methylobacterium* were identified which utilizing â-HCH C-source and degraded 98-99% HCH in 5-6 days. Two endosulfan degrading bacteria were isolated and identified as *Pseudomonas olivians* and *Stenotrophomonas maltophila* each of them possessed single plasmid. A *sphingomonas* sp., isolated from flooded soil treated with HCH, exhibited an exceptional capacity to degrade not only alpha and gamma, but also thermo-dynamically stable beta-and delta-isomers of HCH under aerobic conditions (Chaurasia et al. 2013). The involvement of hydrogen sulphide, the end product of sulphate reduction, in the degradation of parathion in a flooded acid sulphate soil was published in Nature Journal (Wahid and Sethunathan 1979). A *Pseudomonas* sp. isolated from prarthion-treated flooded soil hydrolyzed prarthium to p-nitrophenol which was further metabolized to nitrite and CO_2.

4.11. *Agricultural Engineering*

For rice cultivation improved farm implements / machines were developed by ICAR-NRRI Cuttack and most of the implements were commercialized and popular among farmers due to its low cost and suitability for marginal and small farmers. To match the power source available with farmers; manual operated, bullock powered, power tiller operated, self-propelled type implements were developed. Among NRRI developed 32 machine/implements for rice cultivation; 2 were tillage implements, 11 Sowing implements / machines, 2 transplanting machines, 4 fertilizer applicators, 5 weeding implements/machines, and 8 Post harvest & Processing machines (Table 2).

Besides these some other technologies developed at the division are biogas plant, sun drying racks (paddy), Nanda bin (paddy storage) and solar rice bran stabilizer.

4.11.1. Energy requirements in agricultural sector and energy footprint of rice production

Studies on energy requirements are being carried out to identify energy efficient implements/system for the cultivation of paddy and other important crops of region. Studies are also being carried out to find out the energy utilization pattern and wasteful uses of energy on farmer's field in Orissa. Energy utilization in farmer's field for green gram, black gram, groundnut and sugarcane cultivation were also conducted. For all these crops, field preparation consumed maximum energy. There is need to make it energy efficient. Component-wise, with tractor as the source of power, diesel and fertilizer put together contributed 75% of total energy requirement for rice cultivation. With bullock as the source of power, bullock and human energy put together contributed about 55% of total energy required for rice cultivation.

Mainly three methods are employed for paddy rice cultivation in India, namely (i) dry direct sowing (ii) wet direct sowing and (iii) transplanting. These methods of crop establishment have different energy requirements for field preparation, crop establishment, weeding, harvesting etc. To achieve higher rice productivity along with environmental sustainability, energy foot prints involved in various farm operations related to rice cultivation was done to maximize the productivity by optimizing the energy used by various farm operations. Most energy efficient farm operation for DDSR are; Power Tiller/ Tractor - Cultivator (2 times) + Disc harrow (2 times); sowing with PT seed cum fertilizer drill / Tractor drawn seed cum fertilizer drill; weeding with single row power weeder + manual weeding; manual fertilizer application; chemical spray by power sprayer; harvesting by reaper and threshing by power operated drummy thresher/harvesting by combine harvester; transportation by tractor trolley. On similar trend energy efficient package for WDSR and transplanting was also recommended (Patel et al. 2017).

Table 2. ICAR-NRRI developed farm implements/machines.

Type of implement	Name of the implement
Tillage implements	Bullock drawn two gang notch type disc harrow
	Bullock drawn drum type disc harrow
Sowing implements	One row manual seed drill
	Two row manual seed drill
	Three row manual seed drill
	Three row manual puddle seeder
	Four row conical drum seeder
	Six row manual drum seeder
	Eight row manual drum seeder
	Power tiller operated Multicrop seed drill
	Power tiller operated Seed drill for rice and groundnut
	Self-propelled eight row seeder
	Five row self propelled hill seeder
Transplanter	Two row transplanter
	Four row transplanter
Urea briquette applicators	Two row urea briquette applicator
	Three row urea briquette applicator
	Injector type urea briquette applicator
	Urea briquette applicator attachment with rice transplanter
Weeding implements	Wheel finger weeder
	Finger weeder
	Star-Cono-Weeder
	Self-propelled single row weeder
	Two row wet land weeder
Post-Harvest and	Power operated paddy thresher
Processing machinery	Manual rice winnower
	Power rice winnower cum cleaner
	Chaff and husk stove
	Mini paddy parboiling unit
	NRRI RCC ring bin
	Solar fish dryer
	Domestic solar dryer

Source: Din et al. (2013)

5. PUBLICATIONS

During last five years (2014-18), the division has published a total of 205 research papers in national and international journals. Out of these, 9 papers have NAAS rating more than 10, 70 papers have more than 8, 53 papers have 6-8, 47 papers have less than 6 and 26 papers without any NAAS rating.

6. IMPACTS

6.1. Customized leaf colour chart

Since CLCC based N recommendation could increase N recovery efficiency from applied urea by 9.1-12.2 % as compared to conventional practice in transplanted rice it has the potential to save 18.5-27.3 % urea to produce same level of yield. Field trials also demonstrated application of 75% of recommended N on the basis of CLCC reading produced similar yield as that of 100% RDF, thereby saving 25% of fertilizer (Nayak et al. 2017b).

The CLCC is included in eNAM website of GOI for sale. There is growing awareness for using CLCC in different rice ecologies. As evident by State Govt (Odisha, Bihar, Chhattisgarh, Madhya Pradesh, Jharkhand, West Bengal and Uttar Pradesh) purchase of CLCC is about 84000 nos. Some of the foreign organisations such as IRRI purchased about 100 and Nepal purchase about 200 nos. Krishi vigyan kendras (KVK) have conducted about 158 front line demonstrations; Newspaper coverage: 2 times; TV talk= 2 times; Positive response of farmers regarding production and saving of N fertilizers; Future strategies to be designed and adopted by the R&D organisation with the collaborative efforts of both State and Central Ministry.

Customized leaf colour chart (CLCC) based N application enhanced yield by 10.3-13.3 % and 9.9-10.9 % over conventionally applied urea (RDF urea) in direct seeded (DSR) and transplanted rice (PTR), respectively. Yield enhancement with neem coated urea (NCU) when applied conventionally was 7.1-13.4% and 6.8-10.0% respectively. Whereas NCU when applied on the basis of CLCC, the yield enhancement over conventionally applied urea was 21.2-22.9 % and 14.6-15.9 % respectively for DSR and PTR.

6.2. Best management practices

In rice–rice cropping systems, application of FYM with NPK as balanced fertilization for 39 years resulted in annual 35-55% less emissions per unit yield over unbalanced fertilization. Though the GHGs emissions and GWP were higher under the combined application of FYM + NPK but emissions per unit grain yield were moderate under this treatment. Therefore, the combined application of FYM + NPK is a viable option in managing soil fertility, moderating GHG emissions and sustaining rice yield in tropical flooded soils.

6.3. Climate smart resource conservation technology

There was 32% savings in input energy and 55% gain in energy ratio in CRTC over control. The GHGs emission as a whole was considerably low in CRCT than conventional transplanting rice. There was decreasing global warming potential (GWP) and GWP/Yield ratio by 2.5% and 7%, respectively in CRCT as compared to control. Therefore, it is not only an energy saving and yield sustainable technology but also it can be used as a climate smart agricultural management option for environmental sustainability.

6.4. Agglomerated urea briquettes

The grain yield of rice was increased by 21.5% with the use of urea briquette amended with fly ash as compared to the urea briquette alone. Use of urea briquette amended with fly ash resulted in 8.9% reduction in nitrous oxide emission and decreased global warming potential by 26% as compared to the urea briquette alone.Application of urea briquette using briquette applicator produced 10% higher yield than broadcasting of urea granule.

6.5. Improved rice based integrated farming system

The rice based farming system models have been validated and upscaled in farmers fields through farmers participatory mode. 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 (Poonam et al. 2019).

6.6. Nutrient management in flood prone area

When N applied after desubmergence without basal P resulted in 16.7% yield reduction but when it combined with basal P then yield loss before submergence along with basal P resulted in yield reduction of 35.3% but when no basal P was supplied, yield subdued up to 44.7% indicating maximum damage was only 4.2% as compared to non-submerged condition.

The cost of production was lower when farmers field practices (FFP) was followed but the net returns and B: C ratio were higher when basal P, K and post-flood N management options were adopted because of higher grain yield under the treatment. Net returns were around 355 USD higher in basal P, K and post-flood N management over FFP, irrespective of the cultivar and locations. Further, net returns were increased by 4.4% and 2.9% in Swarna and Swarna-Sub1 when urea foliar spray was applied over N supply through urea broadcasting as post-flood.

6.7. Use of fly ash as soil ameliorant and source of plant nutrient

Application of fly ash @ 50 t ha^{-1} along with 75% RDF and 25% through FYM on N basis has recorded 38% higher yield as compared to the farmers practice

(40:20:0 kg N:P:K per ha). Application of fly ash @ 50 t ha^{-1} along with 75% RDF and 25% through FYM on N basis has resulted in 1.98 B:C ratio whereas the farmers practice (40:20:0 kg N:P:K per ha) resulted in 1.43:1 B:C ratio (Nayak et al., 2011, 2014).

6.8. Greenhouse gases (GHGs) emissions and climate change studies at ICAR-NRRI

More than five technologies recommended by this institute on mitigation cum adaptation of GHGs emissions and climate change are used in NICRA, climate resilient village in different parts of the country. Those five technologies are CLCC based N management, DSR in heavy textured soil, rice-fish farming system in lowland ecology, minimum tillage. Those technologies were also extensively demonstrated, evaluated and adapted in 3 districts (Cuttack, Ganjam, Jagatsinghpur) at Odisha.

6.9. Farm implements

ICAR-NRRI developed farm implements/machines for rice were commercialized through MOU with private manufacturers. Private manufacturers develop farm implements/machines and supplied to different states of the country. Till date about 10 numbers of farm implements have been commercialized and about 3715 number of units sold which cover 31,319 ha area. These implements have resulted in total cost saving of Rs. 12,11,40,453 and total energy saving of 40,97,832 MJ in comparison to manual operation.

6.10. Biofertilizers and biocontrol agents

The division has developed rice-specific endophytic bacterial (*Azotobacter chroococcum* Avi2), Cyanobacteria and *Azolla* formulations for nitrogen management in rice under sub-tropical condition which could replace ~25% of chemical nitrogen without compromising yield. *Azolla* is known biofertilizer for rice crop and its germplasm is being maintained at Microbiology net house since 1976 and is a source material for Odisha farmers, Government and private organizations. So far, 87 farmers from entire districts of Odisha, 102 Government personnel and 11 private organizations procured *Azolla* from our section.

On hundred two (102) strains of *Azolla* is being maintained at NRRI and is a source for research and extension materials at national level. So far, many organizations (n=19) covering eight states of India, procured *Azolla* stains from NRRI.

Six Indian patents on entomopathogens formulations for management of rice leaf folder were filed by the division with the following numbers 264/KOL/2015, 263/KOL/2015, 261/KOL/2015, 262/KOL/2015, 260/KOL/2015, 265/KOL/2015.

Deposited the well characterized beneficial microbes (n=13) in national level facility viz., microbial type culture collections (MTCC), Chandigarh; National fungal culture collections of India (NFCCI), Pune and Microbial Culture Collection, Pune which are the reference database for researchers as well as industrial personnel. Submitted nucleotides sequences of more than 229 cultured beneficial microbes and sequence read archives of more than 61 uncultured microbes in public domain (NCBI, New York USA), which are the reference database for worldwide researchers. Registered five lakh ninety one thousand nine hundred ninety four (591994) soil metagenome unclassified sequences to National Center for Biotechnology Information (NCBI).

7. ASPIRATIONS

Producing more from less resource will be the keyword for future agricultural production. Potential of conservation agriculture including zero or minimum tillage, direct-seeded rice, precision agriculture, site-specific nutrient management (SSNM), system of rice intensification (SRI), aerobic rice etc. through utilization of decision-support system will be consolidated through evidence-based research using artificial intelligence (AI), machine learning, robotics sensors and remote sensing. Nonetheless closing the energy cycle through recycling crop residues and organic farming employing newer agronomy would be the focus that result into sustainable development with right balance of productivity enhancement with reduced environmental footprint. Undertake basic and applied research for improvement and development of farm machinery for small rice farm mechanization will continue to remain as priority area of research.

Rice-specific microbial formulations related to nitrogen and phosphorous management need to be developed, validated and upscaled after showcasing the beneficial impact through awareness and demonstration. Exploring the possibility of potent extremophiles and endophytic microbes for nitrogen, phosphorous, potassium, sulfur, zinc and boron to increase nutrient use efficiency in rice ecosystem. *Azolla* potentials other than biofertilizer like livestock feed, microbial growth medium, energy production, secondary metabolite production, waste water treatment, biocontrol and bioremediation of heavy metals need to be explored. Rice residue burning is a national problem, hence a suitable microbial technology should be identified to decompose rice residue within short time. Mitigating greenhouse gas emission in rice is still a challenge; hence special emphasis should be given on anaerobic microbiological research. Omics and metaomics related microbiological research may be strengthened to alleviate abiotic and biotic stress management under rice ecology.

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शुक्ला अरविंद कुमार, तिवारी पंकज कुमार, बेहेरा संजीव कुमार, चन्द्र प्रकाश, रॉय एच के, टैगोर गोपाल, शर्मा बी एल, त्रिपाठी अजय, सिंह पूजा, नायक ए के, त्रिपाठी राहुल, पात्र ए के, चौधरी एस के, द्विवेदी बी एस, कुमार अनिल, पाठक प्रियंका, शर्मा संदीप कुमार, मीना एम सी, सिद्दीक शहाब, सिकनियाँ योगेश, शर्मा जी डी। 2018b। मध्य पादेश राज्य की मृदाओं में सूक्ष्म एवं गौण पोषक तत्वों का तालुकावारस्तर एवं प्रबंधनः एटलस. मृदा तथा पौधों में सूक्ष्म एवं गौण पोषक तत्वों एवं प्रदूषकों के शोध पर अखिल भारतीय समन्वित परियोजना। भाकृअनुप-भारतीय मृदा विज्ञान संस्थान, नविबाग, बैरसिया रोड, भोपाल, मध्य प्रदेश।1-268.

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Protection Technologies of Rice: Activities, Achievements and Aspirations

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SUMMARY

Crop Protection Division at NRRI is emphasizing on host plant resistance research using apt screening methodology for different insect pest and diseases. Studies on crop loss estimation, ecology, epidemiology, toxicology and integrated pest management (IPM) are integral components of investigation of the division since its inception. Methodology for large scale screening like uniform blast nursery (UBN) developed by the Division has been adopted worldwide. More than 1,25,000 genotypes were screened to find out novel sources of resistance against rice pests. Scientists have identified resistant genotypes against bacterial leaf blight (BLB) and brown plant hopper (BPH) which were used to find out novel genes. Novel quantitative trait loci (qBph4.3 and qBph4.4) associated with BPH resistance in the rice landrace "Salkathi" has been identified. Research on yield loss estimation and ecology of pests is being carried out here to understand the dynamics of rice pests. The scientists are also working on evaluation of different pesticides, use of biocontrol agents and indigenous technical knowledge (ITK) to offer options to farmers for the best pest management options. Developed IPM technologies are well accepted by the farmers. The contribution of the division in rice crop protection science is reflected through the quality publications by the scientists. The division is adopting new tools and techniques such as genomics, proteomics, genome editing, nanotechnology and space technology to provide more accurate and precise options to the farmers to tackle the complex and emerging pest situations in rice production systems.

1. INTRODUCTION

Pests, comprising of insects, diseases and nematodes are major constraints in increasing the productivity of rice in all ecosystems. The insect pest scenario of rice in India from 1965-2000 shows a gradual increase in the number of insect species from three during 1965 to twenty-one pests by 2017 (Jena et al. 2018). Likewise, brown spot and blast were the only prominent diseases in early 1960s, but additional ten diseases became economically important by 2017. The overall increase in number of economically important pests within a span of 52 years rings a bell of caution for analysing and identifying the factors responsible for such increase and also to bridge the gaps of management system so that the varieties can yield to their maximum potential. On an average, farmers loose 37 % of their rice yield to pests and diseases, and these losses can range between 24 and 41 % depending on the production situation (Sparks et al. 2012). At the national level, stem borers account for 30% of the losses while plant hoppers, gall midge, leaf folder and other pests are responsible for about 20%, 15%, 10% and 25%, respectively (Krishnaiah and Varma 2013).

Division has worked on various aspects of crop protection strategies and came out with technologies, products and processes to minimise the ever-challenging problems of rice pests. Presently, the Division is working to fulfil the current and upcoming challenges with following objectives:

- ❖ Exploration of new sources of donors for multiple resistance against different insect pests and diseases of rice and unravelling the mechanism thereof;
- ❖ Discerning the ever-changing bio-ecology of rice insect pests and diseases for climate smart protection strategies;
- ❖ Bio-intensive approaches for pest management in rice as a key component of Integrated Pest Management (IPM) technologies;
- ❖ Optimization of chemical pesticide-use for management of rice pests in different eco-systems and understanding the extent of pesticide pollution in rice ecosystems and its effects.

Scientists at NRRI, Cuttack has carried out investigations to understand the biology and ecology of major insect pests like stem borers, brown plant hopper (BPH), white backed plant hopper (WBPH) and gall midge. Epidemiology of diseases like blast and brown spot with physiological specialization enabling to forecast different diseases of common occurrence are also being studied by Plant Pathologists in the Division. Valuable resistant donors against these insect pests and diseases were identified at this institute and have been widely used by researchers in the country and abroad. The objective of the chapter is to revisit the work done by the Division in past, elaborate the impacts of the research to farming community and rice sciences at large and identify the future work plan to deal with new challenges in rice pest management.

2. GENESIS OF THE DIVISION

The outbreak of devastating epiphytotic brown spot disease of rice (*Helminthosporium* spp.) in the then Bengal province in 1942 caused heavy loss in rice production leading to Great Bengal Famine of 1943. The need to establish a national institute was felt for undertaking rice research on crop protection as well as on all aspects of rice, and thus the Central Rice Research Institute (CRRI) came into existence in 1946. The present day Crop Protection Division of the institute was started with two separate divisions namely, Entomology and Pathology. It was here that the concept of multi-locational evaluation of accessions to find out resistant genotypes was conceptualised in early 1950s and started with testing donors of blast resistance in different states for understanding the variability of blast fungus. A separate coordinated programme on this was initiated later. Methodology for large scale screening for blast resistance was developed and practiced at NRRI. The protocol has been adopted world over as Uniform Blast Nursery technique and is being widely used even today. Over the years, the division became stronger in the field of crop protection to tackle new challenges. The present format of Crop Protection Division came into shape in the year 2008 consisting of scientists from four disciplines, namely Entomology, Pathology, Nematology and Agricultural Chemicals. Presently the division has 21 scientists, 10 technical staffs, 2 skilled support staffs and one administrative staff, working relentlessly to manage the crop pests to achieve higher yield.

3. ACTIVITIES OF THE DIVISION

The Crop Protection Division is conducting basic, strategic and applied research on integrated management of rice pests to improve rice productivity, quality and profitability. Scientists from different disciplines of the division are involved in multidisciplinary research in collaboration with scientists of other divisions as well as from other institutes to generate basic and advance knowledge on relevant aspects. The Division is actively engaged in different major aspects of rice protection sciences e.g. (1) identification of genotypes with novel genes/QTLs against rice pests; (2) predicting the biology and severity of different pests in anticipated climate change scenario; environment friendly pest management using predators, parasitoids, microbial agents and plant based products for minimising the use of chemical pesticide. Major thrust has been given on multiple pest resistant genotypes, pest modelling and forecasting, tri-trophic interaction of rice, pests and predators/parasites under climate change, novel molecules and eco-friendly formulations for the management of field and stored grain pest. The Division is also involved in designing, validating and popularising pest-specific and ecology-based IPM modules for the farmers to ensure sustainability and profitability.

4. ACHIEVEMENTS

The Division has identified resistance donors against different pests and developed novel technologies to address the pest damages. Few important technologies are mentioned below:

4.1. Multi-use formulation of Trichoderma spp.

This technology relates to the development of talc based formulations of *Trichoderma* (Rice-Vit) to be used as a potential biofertilizer and biocontrol

Fig. 1. Effect of *Trichoderma* seed treatment on rice growth.

agent for direct seeded rice variety (Fig. 1). *Trichoderma* strains were isolated from novel habitats like tree bark, decaying woods etc. These products are safe to handle and cost effective. These may be used as invaluable input in the present day organic agriculture.

4.1.1. Alternate Energy (Solar) Light Trap (AELT)

Alternate Energy Light Trap comprising of light trap unit for attracting insects, a collector unit and an energy harnessing unit for harnessing alternative energy (sunlight) for powering the light trap unit (Fig. 2). The trap catches flying insects like leaf folder, stem borer moths, hoppers and other insects, thereby reduce population and subsequent progenies in the fields. No electricity and manpower is required to operate the device. The device reduces the usage of toxic chemical pesticide in the agricultural fields. It is an eco-friendly insect pest management device for cereals, pulses, oil seeds, vegetables, fruits and other fields of horticultural crops including plantation crops.

Fig. 2. Alternate energy light trap.

4.1.2. IPM module for rainfed upland ecology

Seed treatment (with fungicides), application of herbicide (pre-emergence) at 3 days after sowing and need based application of pesticide at maximum infestation and installation of pheromone traps for YSB resulted in effectively reducing crop damage by rice pests with highest B/C ratio.

4.1.3. IPM module for deepwater ecology

Cultural practices (deep summer ploughing, burning of stubbles), seed treatment with bactericides and any fungicides in water suspension for 6 hrs and basal application of granular pesticides reduced crop damage due to different pests (mainly BLB and yellow stem borer) and increased yield.

4.1.4. IPM module (bio-intensive) for irrigated ecology

Seed treatment and foliar spray of neem oil (0.5%) against hispa and leaf folder; soil application of neem and *Milletia pinnata* (karanja) seed powder at the beginning of infestation against yellow stem borer and gall midge and spray of extract of water pepper leaves for BPH and gundhi bug were recommended.

4.1.5. IPM module for scented rice

Foliar spray of tetracycline and Copper oxychloride against BLB, neem oil (1%), Karanja oil (1%) and water pepper leaf extract for BPH, mixed seed powder of neem, *Milletia pinnata* (karanja), or *Strychnosnux-vomica* (kochila) and kochila seed extract significantly controlled yellow stem borer.

4.1.6. riceXpert App

It is an android based mobile application (app.) and is presently tri-lingual (English, Hindi and Odia). The App will provide better diagnosis and management of insect pests, diseases, nematodes, weeds and nutrient deficiencies in rice to farmers. The App has other features like rice varieties, agricultural implements, news, expert consultation, weather information, rice news, government schemes and advisory services like Pest Solution and Fertilizer Calculator etc. Farmers can use this App as a diagnostic tool in their rice fields and make customize queries for quick solution of their problems through text, picture and voice that would be addressed by NRRI experts on real time basis (Mohapatra et al. 2018).

4.1.7. Indigenous Technical Knowledge (ITK) modules

The bio-intensive IPM was demonstrated in tribal areas of Odisha by NRRI, Cuttack, and was found most effective, economic and socially acceptable method of pest management for tribal farmers. Further, this was found to be the only feasible method of rice pest management for the farmers of unfavourable low land ecosystem. At the same time, ITK based IPM modules have the potency to reduce the pesticide load in irrigated ecosystem by preventing unnecessary pesticide application through proper monitoring and by the application of botanical products as an alternate to pesticides.

4.2. Knowledge generation

4.2.1. Host plant resistance

Various disciplines of the division always endeavored to find out new sources of resistance against different insect pests and diseases of rice. Large number of germplasm were screened over the years to find out novel donors against the rice pests. As per our annual reports of 1950-2018, the overall work has been summarized in Table 1 and 2.

Concerted efforts for identifying source of resistance started at Central Rice Research Institute, Cuttack in 1948. Since then, mechanism of resistance is being understood in rice. The antixenosis and antibiosis were studied in depth to understand the mechanism of resistance in rice pests. The yellow stem borer resistant variety, TKM 6, exhibited highest antibiosis as far as the larval survival and growth are concerned. In addition, susceptible cultivar Jaya possessed

Table 1. Varietal/landraces/genotypes screened against different insect pest at NRRI.

Insect pest	Scientific name	No. of genotypes screened	Number of resistant genotypes	Notable accession
Brown Plant hopper (BPH)	*Nilaparvata lugens*	14001	582	Salkathi, Dhobanumberi, Assamchudi, Baiganmanji, Champa, Champeisiali, Balibhanjana-T, Ganjeijota-P, Jalakanthi, Banaspati, Panidubi, Harishankar
White backed plant hopper (WBPH)	*Sogatella furcifera*	2365	60	AC 34222, AC 34264, AC 38468, AC 42425, AC 34270, Kalakalam, Malata, Babel, Lachha, Tripti
Gall Midge (GM)	*Orseolia oryzae*	15160	567	Aganni, INRC 3021, ARC 5984, Kakai (K1417), ARC 6248, IC 121824, IC 199557, IC 199558, IC 121850A1, B-127, B-140, B-143, B181, B-182
Yellow stem borer (YSB)	*Scirpophaga incertulas*	9606	88	TKM 6, SLO 12, B-514-32, B–506-2-18, B-2-12-14, Nalihazara, Dahijhil, Kendrajhali, Kusuma, Champeisali, Kanelaka, Achinha and Bahalmali
Green leaf hopper	*Nephotettix virescens*	772	30	Vikramarya, Nidhi, Samalai, Saraswati, Daya, Lalat and Radhi
Leaf folder	*Cnaphalocrocis medinalis*	1292	45	ARC14539B, GEB 24, HB 349, Raminad st3, Bundei, Harisankar, Sunakathi, Surjana, Juli and Sana chinamala
Gundhi bug	*Leptocorisa acuta*	161	9	CR 44-82, RR 50-3, TR 13-600, Badshabhog, Hamsa, CR 544-148-82,
Hispa	*Dicladispa armigera*	20	4	MO 1, MTU 15, Doddakhare and SR 26B
Aphid	*Rhopalosiphum rufiabdominale*	85	6	ZA/BCP-20, ZA/BCP-24, ZA/BCP-26, ZA/BCP-27, ZA/BCP-28, ZA/BCP- 32
Mite	*Steneotarsonemus spinki*	13	4	Vanaprabha, Heera, Annada and Vandana
Total	**43475**	**1395**		

Table 2. Varietal/landraces/genotypes screened against different diseases at NRRI.

Diseases	Genotypes screened	No. of resistant donors*	Notable accession
Blast	27954	3146 (R)	Zenith, Tetep, Tadukan,Dular, IR64, Sumit, Abhishek, Savitri, Co25, Co26, IR8
Brown spot	18220	1903 (R)	Co20, Bhagirathi, Sarala, Jyothi, PTB4, BAM10, Sudhir, Ashoka, ARC5846, HRC 702
Bacterial leaf blight	22837	1134 (R)	IR32, IR34, Naveen, Tetep, Tadukan, Dular, Zenith, CRHR 45, AC36369, CRHR 48
Sheath blight	13951	433 (MR)	CR BoroDhan 2, CR Dhan 801, CRHR 41, Sabita, Tarori Basmati, Sumit, Pusa-33,Ghanteswari, Tulajapur-1, IR-62

*R, Resistance; MR, Moderately resistance

higher amounts of total and reducing sugars, amino acids and starch whereas the resistant TKM 6 and PTB 18 had more amount of total phenols (Padhi and Rao 1978). It was found that the resistant gene, Gm4 identified from PTB10 was an ideal candidate for deployment in gene pyramiding (Mohaptra et al. 2014). Gene pyramiding of gall midge resistance genes (Gm1, Gm4) into an elite cultivar, Improved Tapaswini was completed. Out of the ten gene pyramids, ITGP7 (IT+Gm1+Gm4) showed high levels of resistance similar to resistant controls (Das et al. 2018).

NRRI has developed a polymerase chain reaction (PCR) based assay that distinguished five different biotypes of the Asian gall midge (biotype 1 to biotype 5). Five diagnostic PCR products were isolated, cloned, sequenced and converted to sequence characterized amplified regions (SCARs). It was found that Cuttack (Odisha) populations were found to be distinctly different from those of Warangal and Raipur (Behura et al. 2002). An important study established a karyological sexual dimorphism in rice gall midge. Six chromosomes are present in the metaphase ganglionic cells of larvae populations generating males and eight chromosome populations generating females (Sahu et al. 1996).

Salkathi and Dhobanumberi showed promising antibiosis against BPH; further novel quantitative trait loci associated with brown plant hopper resistance in the rice landrace Salkathi has been identified (qBph4.3 and qBph4.4.) (Mohanty et al. 2017). Utilizing these resistant accessions, different genotypes have been developed in the back ground of popular rice varieties

Tapaswini, Pusa 44 and Samba mashuri. Some genotypes like CR 2711-76, CR2712-227, CR2711-114, CR 2711-139, CR 2711-149, CR2712-2, CR 2712-11-1, CR 2712-11-13, CR 2712-229, CR 2713-8, CR 2714-2 were identified as highly resistant to BPH out of which CR2711-114, CR 2711-76, 2711-139, CR 2711-149, CR 3005-77-2, CR 3005-230-5 and CR 3006-8-2 were found highly promising in the co-ordinated trials of IIRR (earlier DRR), Hyderabad, (CRRI, 2013; AICRIP, DRR, 2006-2010). Cultivar CR2711-76 developed with the introgression of resistance from genotype Dhobanumberi in the background of high yielding cultivar Tapaswini at NRRI Cuttack, India, has a single dominant gene, Bph31.

The Division has identified highly tolerant variety "CR-1014" against sheath blight disease. This particular variety performed good against sheath blight over the years. Efforts were put into to identify new QTLs or genes present in it. The Division also actively participated in the developing of BLB resistance gene pyramided variety Jalamagna.

The variability in reaction of blast resistant accessions at different locations suggested the possible existence of different physiological races of the blast fungus. By 1964, the existence of 22 races of the blast fungus were classified using the international set of differentials. Later on, isolates of *P. oryzae* collected from different parts of India during the period 1962–68 were analysed and reported the occurrence of 31 pathogenic races of *P. oryzae* (Padmanabhan et al. 1970). Three varieties Tetep, Tadukan and Zenith were found resistant to all the races identified in India. Similarly, pathogenic specialization in bacterial blight pathogen was established. A set of Indian rice differentials were constituted and 6 pathotypes were identified (Nayak et al. 2008).

The genetic diversity at twenty-four most significant blast resistance gene loci using twenty-eight gene specific markers were investigated in landraces originated from nine diverse rice ecologies of India. The landraces harbour a range of five to nineteen genes representing blast resistance allele with the frequency varied from 4.96% to 100%. Five markers viz; K3957, Pikh, Pi2–i, RM212 and RM302 were strongly associated with blast disease with the phenotypic variance of 1.4% to 7.6% (Yadav et al. 2019). The genetic diversity of eighty released rice varieties of the institute (NRVs) were studied by screening them using molecular markers linked to twelve major blast resistance (R) genes. Out of seventeen markers, only five markers, 195R-1, Pi9-i, Pita3, YL155/YL87 and 40N23r corresponded to three broad spectrum *R* genes viz. Pi9, Pita/Pita2 and Pi5 were found to be significantly associated with the blast disease with explaining phenotypic variance from 3.5% to 7.7% (Yadav et al. 2017). Similarly, major blast resistance genes were investigated in landraces originating from north-eastern India. The genetic frequencies of the 18 major blast resistance genes were between 6.2% and 27.4%. Association analysis identified six markers, CRG4_2, RM72, tk59-2, pi21_79-3, RM1233 and RM6648 which are significantly associated with blast disease and explained a phenotypic variance of 1.1–6.5% (Susan et al. 2019). The associated genes could be used in marker-assisted rice breeding programmes for gene pyramiding to develop rice varietal resistance against blast disease.

4.2.2. Ecology and epidemiology

The pre-monsoon rains in India during April and May initiate gall midge activity in rice stubbles, self-sown rice, and other hosts leading to extensive damage to early planted rice crop. (Prakasa Rao 1975). In case of delayed monsoon, however, the late-planted crop suffers. Insect activity oscillates between last week of August and first week of October. Pest proliferates in active tillers of susceptible rice cultivars irrespective of planting time (Prakasa Rao et al. 1971). Depending on the severity of gall midge attack, yield loss was estimated between 3-70% (Chatterji et al. 1976) and was also estimated percent increase in gall midge incidence reduced the crop yield by 0.4-0.5% (Reddy 1967).

Stem borer occurs in both the wet and dry seasons. In the wet season, stem borer incidence is intense during October-November resulting in white ear head damage at the flowering stage, while in the dry season, the pest incidence occurs from February to April infesting the rice both at vegetative and heading stages. The stem borer incidence was negligible at the vegetative stage while the white ear head incidence was recorded as high as up to 22.6% (Jaya) and 27.2% (Padma) (Annual report, 1974). NRRI has developed a simple method of forecasting appearance of first brood of yellow stem borer, by either recording soil temperature at 5 cm depth in field (appearance of first brood of stem borer is correlated to soil temperature reaching 19°C at 5 cm depth) or by regular examination of the stubbles of the harvested crop for over-wintering larvae during December-January (Prakasa Rao 1984).

Hot and humid conditions with stagnant water in the fields with a maximum temperature of 28 to 29°C and humidity range of 85 to 90% were favourable for the incidence of leaf hoppers and plant hoppers. Rice hispa was abundant when temperature is in the range of 28 to 33°C with a relative humidity of 75 to 98%. During flowering season in October-November, prevalence of temperature between 27 and 28°C with a relative humidity of 80-82% favoured gundhi bug incidence.

Investigation on nematodes of rice and rice soils commenced in 1963 at this institute. Sampling methods and optimum time for survey and assessment of nematode fauna in rice and rice soil were devised (Israel et al. 1966; Das and Rao 1971). The nematode parasites of rice were identified and research started with identification of nematode resistant rice varieties and their mechanism of resistance (Jena and Rao 1971).

Four new nematodes viz. *Heterodera oryzae, Meloidogyne graminicola, Caloosiahetero cephala* and *Trichodorus* spp. were reported from rice. In 1978, *Heterodera oryzicola*, a new cyst nematode species infecting rice was identified and reported from Kerala, India (Rao and Jayaprakash 1978). The symptom of nematode injury in rice and losses due to their infestation were determined. The losses ranged from 20 to 23% in young crop. The principal nematode problems were identified. Population dynamics of rice nematodes in relation to soil factors were studied. Alternate hosts of rice nematodes were identified. Nematode management through crop rotation was studied and found that crop rotation with jute and soil population of *Hirschmanniella mucronata* were considerably reduced below threshold levels (Rao et al. 1984).

Two species of rice tarsonemid mites, *Steneotarsonemus spinki* and *Tarsonemus cuttacki* were found to be regular pest deteriorating paddy seed quality. For the first time in India, rice tarsonemid mite, *Tarsonemus cuttacki* was isolated from stored paddy from CRRI godowns (Rao and Prakash 1984). They also reported this mite from the infected panicles/grains. Biology of this mite was studied by Ghosh et al. (1993). For first time in India, population of *S. spinki* were recorded in rice ratoons, stubbles paddy field and weed, *Cynodon dactylon* (Rao and Prakash 1992).

4.2.3. Screening methodologies

No standard methods were available in the beginning for assessing the reaction of genotype to the major diseases like blast and brown spot. The need for evaluating the genetic stocks for blast resistance was felt as early as in 1955 in the sixth meeting of International Rice Commission working party on rice production and protection in which CRRI was an important member and played a vital role. CRRI, as a partof the three-member committee (Ceylon, India and Japan) set up by Food and Agricultural Organisation (FAO) in 1959 played a significant role in designing and developing the popular Uniform Blast Nursery technique for large scale testing and evaluation of genotypes for blast resistance that has been adopted and is still being practiced world-wide (Padmanabhan 1979).

Division's role in the establishment of the coordinated rice improvement programme in India traced to the multi-location trials used to be conducted to find out resistance donor against both brown spot and blast from its inception. The resistant varieties were tested in 46 centres all over India consecutively for three years during 1955-58. This was a significant precursor for the formulation of multi-location trials for evaluation of resistant donors and breeders' material (Padmanabhan 1979).

Pathologists of the division have standardized false smut pathogen isolation method (PSA media, 26±1°C for 21 days) and artificial inoculation technique (2 ml spore solution was injected in each tiller at late booting stage and the plant should be kept at 25±1°C for 5 days) to screen genotypes against this pathogen (NRRI Newsletter. 2016. 37(2):17). An artificial inoculation technique to screen large number of germplasm for their resistance against bakane was also stadardized. Inoculation of hot water treated seeds (52 °C for 10 min) with microconidial suspension @ 1.50 x 10^5/ml for 24 hours followed by drying the seeds for 4-6 hours and sowing in sterilized soil in trays under glass house conditions resulted in rapid development of disease symptoms. This technique is very useful for large scale screen of genotypes within 20-30 days.

Initially, the primary emphasis was put on developing a dependable screening method for assessing reaction of large population of plant material against bacterial blight and sheath blight. The methods like clipping the leaves and spraying the plants with the bacterial suspension or dipping the clipped leaves into the bacterial suspension led to development of now popular clip inoculation technique. A cut-leaf inoculation technique was developed in this institute for assessing reaction to sheath blight was successful and results were comparable to field screening (Fifty Years of Rice Research at CRRI (1945-1995), CRRI, Cuttack, India, 1996).

4.2.4. Leads in bio-agents and plant products

The role of indigenous parasitoids in the control of stem borer and gall midge and other pests of rice was studied and the period of activity and the extent of parasitization by important egg, larval and pupal parasitoids were determined. *Colluiris sp*. a carabid beetle and adults of *Casnoidea indica* was recorded for 1st time as predators on immature stages of gall midge and leaf folders. *Platygaster oryzae* (solitary), a parasitoid of gall midge was recorded for the first time during 1986.

Leaves of *Vitex negundo, Lippia geminta, Aegle marmelos, Ocimum canum,* crude extracts of garlic and pyrethrum found to be effective in protecting the stored paddy grains insects (Prakash and Rao 1996). A promising grain protectant "2-heptatriacontanone" was isolated and identified from begunia, *Vitex negundo*, leaves and evaluated against grain boring insects in stored rice (Prakash et al. 1990). Strong antifeedant action was observed by neem bark decoction to leaf eating larvae of leaf folder and cutworm. Aqueous and ethanolic extracts and essential oil preparations from leaves of *Agele marmelos and Ocimum sanctum* were toxic to blast fungus (Rout et al. 2013 and 2014).

Trichoderma isolated from tree bark is being used as growth promoter and kills soil and seed borne pathogens (patent file no. 1240/KOL/2015). First time it was proved that *Trichoderma erinaceum* obtained from tree bark could be incorporated in integrated rice crop management both as biocontrol agent and biofertilizer (Swain et al., 2018). Similarly, *Beauveria bassiana,* was found to kill *Nilaparvata lugens* (brown plant hopper), *Nephotetix virescens* (green leaf hopper), *Scirpophaga incertulas, Chilo auricilius, etc*. *Parnara* and *Sesamia* NPV viruses were isolated and characterized. The *Parasitorhabditis* sp. nematode was reared on an artificial diet developed for the purpose (Fifty Years of Rice Research at CRRI (1945-1995), CRRI, Cuttack, India, 1996).

Insect juvenile hormone, ZR-777 was found to inhibit metamorphosis of green leafhopper. ZR-515 at 0.5% concentration impaired embryonic development in *Angoumois* grain moth, a stored grain pest. Rice yellow stem borer (*Scirpophaga incertulas*) and rice leaf folder (*Cnapholocrocis medinalis*) were monitored by using dry funnel sleeve traps baited with 9 Z-hexdecenol and 11 Z-hexadecenol in 1:3 rati on and 13 Z-octadecenyl acetate and 11 Z-hexadecenyl acetate in 10:1 ratio, respectively (Fifty Years of Rice Research at CRRI (1945-1995), CRRI, Cuttack, India, 1996).

4.2.5. IPM and pesticides

Scientists of the division evaluated large number of pesticides to give recommendation to the farmers to manage rice pests. Recently, seed treatment of rice with thiamethoxam showed positive effects on seed emergence, increased plant root and shoot biomass (Annamalai et al., 2018). Seed treatment with chlorantraniliprole had shown no negative effect on seed emergence, shoot and root parameters (NRRI Annual Report 2017-18), no dead heart damage was reported till 40 days after seed treatment. Besides the bio-efficacy of the pesticides, resurgence of different pests was also investigated. For example, application of synthetic pyrethroids viz., decamethrin, cypermethrin, tetramethrin as foliar spray had shown yellow stem borer resurgence; a first time reported in India. Similarly, application of sub-lethal doses of phosphamidon continuously for 3 BPH generations resulted in females to lay more eggs than the control, with increament ranging from 3 to 11 times (Fifty Years of Rice Research at CRRI (1945-1995), CRRI, Cuttack, India, 1996).

Detailed investigation was carried out to know the persistence of different pesticides (pretilachlor, imidacloprid, fipronil, chlorantraniliprole, bispyribac sodium etc.) in rice ecosystem. In-vitro experiment has been carried out for number pesticides namely butachlor, bispyribac sodium, chlorantraniliprole, fipronil etc. to understand their distribution in different environmental matrices and effects on soil microbes. For example, chlorpyriphos degradation was faster under elevated CO_2 (Adak et al. 2016). Changes in microbial diversity indices confirmed that imidacloprid application significantly affected distribution of microbes. The extent of negative effect of imidacloprid depends on dose and exposure time (Mahapatra et al. 2017). Pretilachlor did not harm the soil microbes at field dose but microbes were affected at higher dose (Sahoo et al. 2016). Non-target effect of continuous application (7 seasons) of chlorpyrifos had no significant effect on population of heterotrophic aerobic, anaerobic, oligotrophic and copiotrophic bacteria, whereas, population of asymbiotic aerobic nitrogen fixer, nitrifiers, denitrifiers, gram positive and spore-forming bacteria were significantly reduced by nearly 0.25–2 fold in chlorpyriphos treatment (Kumar et al. 2017).

Indigenous green synthesis of silver nanoparticles (Ag-NPs) mediated by rice plant extracts has been undertaken by the division for the first time. They were characterized by UV-Vis spectrophotometer, FT-IR, DLS, SEM-EDS etc.

The synthesized Ag-NPs were effective against rice diseases *Xanthomonas oryzae* and *Rhizoctonia solani (*NRRI Annual Report 2015-16).

Use of phosphine in quarantine is limited in India, being a part of all India collaborative project, scientists came into conclusion that both phosphine formulations (77.5% G (Granule) & 56 % Tablet) were effective. Exposure to phosphine for 7 days can be recommended in quarantine to kill major store grain pests of rice. Seven days degassing period is safe for human consumption as phosphine residue in the rice samples was found to be within the MRL (<0.1 ppm). Based on the results, phosphine gas can be recommended for quarantine (NRRI Annual Report 2017-18).

5. PUBLICATIONS

Division of Crop protection has made tremendous progress not only in terms of research but also communicating the same for scientific fraternity through quality research journals with better NAAS score or impact factor. Over the years' not only total number of publications have increased but also publications in journals having higher NAAS score (>8) also increased. Last year (2017-18), divisional scientists have published total of 30 publications of which 11 publications are having NAAS score greater than 8. Few of the journals in which scientists have published with higher score are; Chemosphere, Microbiological Research, Ecotoxicology and Environmental Safety, Bulletin of Environmental Contamination and Toxicology, Biological Control, PLoS One, etc.

6. HUMAN RESOURCE DEVELOPMENT

Developing human resource is one of the important priorities of the Division. Since its inception Division has taken a keen interest in guiding various masters and doctoral students. Because of competent scientists and well established laboratories students from various universities are taking up their research at Crop Protection Division. Over the years, number of students who had taken up their research at Division and awarded degrees have increased. Till today, there are 11 doctoral and 32 master students awarded/pursuing with their degrees who took up their research at this division. Beside this, division imparts training to different stakeholders of rice farming namely, agricultural officers, farmers, etc. on integrated pest management.

7. LINKAGES

The division of crop protection is working vibrantly with various international and national agencies. Division is working in collaboration with IRRI Philippines through different projects. There is a strong convergence mode of research with other division of the institute. There have been collaborations with different ICAR institutes. Since, pesticides are one of the thrust area of the Division, we are working in close association with the various private partners too.

8. IMPACTS

The resistance of BLB in one of the wild rice accessions of *O. longistaminata* (earlier designated as O. *barthii*) was first identified at CRRI (Devadath, 1983). Dr. Khush took it to IRRI, from where it was taken to the University of California-Davis where the Xa21 gene was identified and cloned for developing BLB-resistant rice varieties (Patra et al. 2016). If we Google search with a key word "xa21 gene" 10,900 results which contain the particular key word are being retrieved as on 20.04.2019.

The bio-intensive IPM system has been introduced in the tribal areas by CRRI, Cuttack, through a DST Project (2007-2011). The application of insecticides in irrigated ecosystem, an unnecessary expenditure of about Rs. 800-1800/- during 2007 and 2008 besides polluting the environment by killing earthworms, was dropped by about 70% of the farmers during 2009 and 2010 and they have opted for botanical applications, particularly oil application against BPH (Annual report SP/TSP/2006).

Location specific package of practice for integrated pest management (IPM) in Mahanga block, Cuttack district, Odisha during 2013-2016 recorded tremendous adoption by farmers. The number of damaging pests decreased from 2012 to 2017 and even if more pests were observed during years like 2013, 2015 and 2016, their intensity decreased as protection strategy was taken at initial incidence. The overall protection cost (only material cost) was reduced by 91% by the year 2017 as compared to that of 2012. Yield increase was realized from an average of 3.70 tha^{-1} during 2012 to 5.83 tha^{-1} during 2016 with about 57.6% increase over the first year. The technologies like seed treatment, pest monitoring and application methods were adopted by the farmers of the nearby villages (Jena et al. 2017).

The *Trichoderma* based formulation Rice-Vit developed at ICAR-NRRI is having multifaceted impact on crop health. The *Trichoderma* sp. has been isolated from tree bark and having excellent plant growth promoting characters as well as it is having the capability to control the soil and seed borne pathogens (Swain et al. 2018). The formulation has been tested in Hazaribagh under drought condition and it has been recorded that the *Trichoderma* treated paddy gave 12% higher yield than that of the control one (NRRI Annual Report 2017). The formulation has been tested in Chandol of Kendrapara district in farmers field where higher yield and total biomass of paddy was recorded in treated plants. So, this formulation is having tremendous potentiality for better crop health management.

"riceXpert", the mobile app is having more than 22,000 users covering India (73%), Philippines (9%), Indonesia (3%), Pakistan (2%), Nigeria (1%) and other counties (12%). More than 1500 queries relating to rice insect pest, disease, weed, variety, farm implement, nutrient toxicity/deficiency and other aspects of rice have been received from the Indian users through e-rice advisory module of the app covering almost all rice growing states of India and the queries are being addressed by the panel of experts from and the solutions are being sent to them through SMS. Perusal of the month-wise statistics on the year 2018 downloads of riceXpert app revealed that August (1583) month recorded the highest users of the riceXpert app followed by September (1236) and October (1110).

9. ASPIRATIONS

The pioneering work of the division to identify the resistant donors based on rigorous phenotyping has to be translated into identification of genes/QTLs for resistance and their possible integration into elite variety which are underway and need to be further strengthened. Use of genome editing techniques will be amalgamated to obtain pest free rice crops. Proteomics and metabolomics techniques will be applied to understand plant-pest-natural enemies' interaction. Deeper understanding in molecular diagnosis to detect pathogen at initial stage can help framers to save the crop. Use of space technology in developing forecasting model would make the technology more precise and accurate. Nanotechnology would help to reduce the doses of pesticides and may help for targeted pesticide application. Site specific IPM modules incorporating ICTs will be developed to entrust farmers in decision making for better pest management. Novel pest management strategies like new biocontrol agents, RNAi techniques, novel peptides, chemical elicitors should be given importance.

10. CONCLUSIONS

The Division has screened more than 1,25,000 genotypes against number of disease and insect pests. Two genotypes, Salkathi and Dhobanumberi, have shown resistance against BPH. Similarly, the resistant genotype *Oryza longistaminata* against bacterial blight, has been dissected to identify novel gene *Xa21*. Division's role in phenotyping is worldwide acknowledged. The Division is associated with development of Uniform blast nursery, novel screening techniques related to host plant resistance and many others. Two products as patents, IPM technologies, ITKs have reached to farmers. Work on botanicals, biocontrol agents are widely accepted. Dissemination of rice technologies through riceXpertis is playing critical role to provide information at farmer's doorstep. The Division has amalgamated new technologies to counter the challenges posed by ever-changing pest scenario.

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Physiological and Biochemical Perspectives of Rice: Activities, Achievements and Aspirations

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SUMMARY

Since its inception in 1960, the Division of Crop Physiology and Biochemistry at NRRI has made significant contribution in the area of basic and applied physiology and biochemistry and improvement of nutritional quality of rice. In crop physiology, over the years major thrust was given on understanding the physiological, biochemical and molecular mechanism of tolerance to different abiotic stresses *viz.*, drought, salinity, submergence, waterlogging, heat, low light, etc. occurring simultaneously or in tandem during the cropping season. Screening of large numbers genotypes for multiple seasons resulted in identification of unique genotypes having novel sources of tolerance to one or more abiotic stresses, improved photosynthetic efficiency and improved plant types, which were used further for varietal development or for identification of novel QTLs. Besides this, significant progress has been made for improving photosynthetic efficiency for yield maximization in rice. These studies not only identified highly photosynthetically active rice genotypes, but also analysed the unique plant type features of these genotypes which can be transferred to other rice cultivars for enhancing their photosynthetic efficiency. Since, last few years, the work on developing C4 rice was initiated in the division with a vision to further enhance the photosynthetic efficiency and cutting the photorespiratory losses of currently grown rice cultivars. In biochemistry, since long efforts were made to identify rice genotypes with high grain protein content and understand their underlying mechanisms. Recently, this institute has released country's first high protein rice cultivar CR Dhan 310 having average grain protein content of more than 10%, using the genotypes identified at our division. Later one more variety, CR Dhan 311 was released for high grain protein and moderate Zn content, which was also developed using the genotypes identified at our division. The Division is also working on development of low Glycaemic Index (GI) rice suitable for diabetic people and multiple nutrient rich rice with improved bioavailability of essential minerals to counter wide spreading malnourishment in our country. The achievements of the division were documented in form of peer reviewed research articles in journals of national and international repute. Besides the core research activities, the Division has produced 22 and 9 PhD and MSc scholars, respectively. In this compilation major activities, achievements and aspirations of the Division are presented.

1. INTRODUCTION

Over the past three decades, the advent of modern high yielding rice varieties and associated 'Green Revolution' technologies have almost doubled the rice production globally. Several countries in South and Southeast Asia have not only achieved self-sufficiency in rice production, but also a few of them, including India, have become net exporters of rice. However, with the growing population, the demand for rice will also continue to grow. A challenges in the future would be to produce more rice from less land, with less water, less labour and lesser use of pesticides. This would require innovative research and technologies and policies that promote increased rice production. In the Division of Crop Physiology and Biochemistry, based on analysis of current status of rice production and review of the constraints, constant research efforts are undergoing for improvement of rice in terms of physiological and biochemical traits to meet the targeted production of rice. We are focussing our research on three aspects: 1) rice production under different abiotic stress environment (individual or multiple), 2) improvement of photosynthetic efficiency of rice and 3) improvement of nutritional and grain quality aspects of rice.

Abiotic stress can impose limitations on crop productivity and also limit land available for farming, often in regions that can ill afford such constraints, thus highlighting a greater need for understanding how plants respond to adverse conditions with the hope of improving tolerance of plants to environmental stresses. Most rice varieties are severely injured by abiotic stresses, with strong climatic impacts. Water deficit is a widespread challenge to sustainable agriculture. Evidence suggests that various pathways, mechanisms, and morphological modifications are among the most important factors in plant responses to dehydration. It is true that plants require water for growth but excess water that occurs during submergence or waterlogging is harmful or even lethal. A submerged plant is defined as a plant standing in water with at least part of the terminal above the water or completely covered with water, whereas waterlogging is defined as, a condition of the soil in which excess water limits gas diffusion in rhizosphere. Rice is also a salt-susceptible crop. Currently, one third of the world in agricultural land is affected by salinity. Salinity, both soil and water, has negative effect on rice production. Elevated levels of sodium in agricultural lands are becoming a serious threat to the world agriculture. This demand of increased food supply can be fulfilled only if we utilize all available land resources to their full potential. Understanding rice physiology to stress may help breeding for more tolerant varieties.

Photosynthesis is the process where plants capture energy from sunlight and convert it into biochemical energy, which is subsequently used to support nearly all life on Earth. Recent technological developments now provide us with the means to engineer changes to photosynthesis that would not have been possible previously. The concept is to switch rice from using the C_3

photosynthetic pathway, which is not very efficient, to using the more efficient C4 photosynthetic pathway. In most plants, including rice, CO_2 is first fixed into a compound with three carbon atoms, hence it is known as 'C3 photosynthesis'. The enzyme that fixes CO_2 into sugar reacts with oxygen in an energy-wasting process known as photorespiration, which occurs especially at higher temperate tropics where most rice is grown and causes a dramatic reduction in the amount of CO_2 to convert to sugar. C4 plants, on the other hand, have a naturally evolved way to minimise this energy wasting process by using an oxygen insensitive enzyme first to fix CO_2 and then efficiently convert CO_2 into sugar. This increased efficiency is accompanied by increased water and nitrogen use efficiency and improved adaptation to hotter and dryer environments. Several international consortia are currently working toward improving photosynthesis. Grafting the more efficient C4 photosynthetic pathway onto cereals that produce the most desirable grains in rice and wheat is a bold venture. A new bioengineering approach for boosting photosynthesis in rice plants could increase grain yield by an approach, called photorespiratory bypass. The genetically engineered plants would be greener and larger and showed increased photosynthetic efficiency and productivity under field conditions, with particular advantages in bright light.

As countries reach self-sufficiency in rice production, the demand by the consumer for better quality rice has increased. In our division, we are working on rice grain quality which includes combination of physical and chemical characteristics that are required for a specific use by the consumers. Thus, grain quality can be a combination of many factors such as smell (aroma), size, cooking characteristics, colour, nutritional value, percent whole grains, etc. Consumer preferences driven research on grain quality are underway in the division. Another research focus of our division is on rice grain protein, which is nutritionally superior over most of the other food cereals in terms of amino acid composition. The enrichment of rice grains with protein would have a positive effect on the health of billions of people around the globe particularly the poor and the malnourished. The Chapter provides a glimpse of rice physiology under different abiotic stress environments, the way of improving photosynthetic efficiency and grain and nutritional quality of rice.

2. GENESIS OF THE DIVISION

The Division of Plant Physiology was established at ICAR-National Rice Research Institute, Cuttack in June, 1960 as a separate section. The mandate of the Section was to study the physiology of rice under various abiotic stresses such as drought, salinity, submergence, water-logging and other environmental stresses. The Section envisaged identification and characterisation of tolerant genotypes, development of appropriate screening techniques and analysis of constraints for productivity especially under stress situations. The Section was upgraded to a Division during the 4^{th} Five Year Plan in 1972. During this period financial help was received in terms of different national and international projects, which strengthened and intensified the research work of the division. The Rockefeller Grant (prior to 1960), Colombo Plan (aid from Japan in 1974), PL-480 Project for Photosynthesis (1980-90), Canadian line of credit (1978), IRRI-Collaborative Program under IRWYN (1982-84), National Fellow Award (1984-88), Emeritus Scientist Award (1989-92) were few of them which immensely helped in developing divisional infrastructure, establishment of good research laboratories with modern equipment for achieving research goals. A Government of India certified 'Radio Tracer Laboratory' was also established in 1972 to support various work related to radio biology in the division.

Initially, physiological research on salt-tolerance in rice was carried out at the saline sub-station located at Canning, West Bengal. With the transfer of this sub-station to CSSRI, Karnal in 1972, work on salt tolerance was shifted to the main institute. Similarly, the physiological research on drought tolerance was initially started in at Cuttack, but after the establishment of Central Rainfed Upland Rice Research Station (a sub-staion of NRRI) at Hazaribagh, Jharkhand, majority of the drought research was shifted to that center from this Institute. Currently major focus of the Division is on understanding the mechanism of tolerance to individual and multiple abiotic stresses along with improvement of photosynthetic efficiency in rice and improving grain and nutritional quality in rice. Besides, investigations on physiological analysis of chemical regulation of growth, heterosis in hybrid rice derived from cytoplasmic male sterility (CMS) lines and simulation models for low light monsoon rice also progressed well in due course of time.

Work on rice biochemistry was initiated in 1970s. The objective was to study all aspects of rice quality with particular emphasis on consumers' preference. This covered varietal differences in hulling, cooking quality and nutrient content, loss of proteins and vitamins in milling, influence of various fertiliser and cultural practices on the protein content, influence of storage on the physical and chemical changes that take place in stored grains, effect of moisture content, aging, time and method of harvesting, drying etc. on the milling quality and the genetics of the various quality attributes. Subsequently during 1980-1996 the activity of Biochemistry division was concentrated on biochemical, technological, cooking and eating quality of rice, aromatic rice, protein quality, quantity and biosynthesis, biochemical mechanism associated with biotic and abiotic stresses, rice processing and by-product utilization etc. As per the suggestion of QRT (1997-2004) the Physiology and Biochemistry divisions were merged as Biochemistry, Physiology and Environmental Science Division. Subsequently on the basis of next QRT (2005-2012) recommendation the division of Biochemistry, Physiology and Environmental Sciences was renamed as Crop Physiology and Biochemistry Division to undertake research on the following aspects: i) study and development of health rice, ii) designing and tailoring new plant type of higher potential yield and iii) stress physiology.

3. OBJECTIVES OF THE DIVISION

Since beginning, the major goal of division was to conduct basic and strategic research on rice to enhance productivity and profitability by improving the production per unit area and per unit time under different environmental conditions. On this note, the research programmes of Physiology and Biochemistry of rice has three major thrust areas *viz*. rice grain and nutritional quality, abiotic stress physiology with special emphasis on mechanistic understanding and enhancing photosynthetic efficiency. The major research programmes of the division have the following objectives.

- Study rice grain quality in relation to GI, mineral (Fe/Zn) bioavailability and protein content.
- Identification of donor sources of relevant physiological traits and understanding the physiological/biochemical/molecular mechanisms underlying the plant responses to abiotic stresses
- Enhancement of photosynthetic efficiency by introduction of C4 pathway and minimizing photorespiration.

4. MAJOR ACHIEVEMENTS

4.1. Abiotic Stress Tolerance in Rice

As 60-70% of monsoon rice (*Kharif* season) is subjected to stresses like drought, salinity or water-logging, both laboratory and field investigations were conducted under defined conditions to isolate and characterise elite lines to develop simple screening techniques.

4.1.1. Drought Stress

Since beginning, drought tolerance studies were one of the thrust areas of the Division. More than 10,000 rice germplasm accessions comprising of upland rice, lowland rice, deep water rice, wild rice, advanced breeding lines and fixed lines were screened under field condition during the dry seasons. Among all the tested genotypes, around 250 lines were identified as vegetative stage drought tolerant characterized by SES score '1' following the standard international method (IRRI SES method on 1-9 scale) under forced drought stress with an available soil moisture content of 5–8%, soil moisture tension -40 to -50 kPa and ground water table down below 100 cm. Three rice germplasm lines named Mahulata (AC No. 35186), Brahman Nakhi (AC- 35678) and Sal-kaiin (AC- 34992) were registered as new sources of vegetative stage drought tolerance through Plant Germplasm Registration Committee (PGRC), ICAR-NBPGR, New Delhi. Another unique breeding line CR 143-2-2 developed at ICAR-NRRI was identified as both vegetative as well as reproductive stage drought tolerant rice variety having a yield potential of more than 1.2 t ha^{-1} under drought stress condition, was registered in ICAR-NBPGR, New Delhi.

Besides the cultivated rice genotypes, two wild rice accessions of *Oryza nivara* (IC -330470 and IC -330611) collected from West Bengal, were also identified as vegetative stage drought tolerant lines with a SES score of '0' & '1'. For reproductive stage drought stress, BVD-109 (2.15 t ha^{-1}), Kalakeri (2.08 t ha^{-1}), IC 416249 (2.02 t ha^{-1}) and CR 143-2-2 (1.90) are identified as promising genotypes with grain yield of 1.90 to 2.15 t ha^{-1}, while AC 27675, IC 516130, Udayagiri, Indira, Vandana and CR 143-2-2 showed better tolerance in terms of other morpho-physiological traits like relative water content (RWC), drought score, chlorophyll florescence traits etc.

In shallow rain-fed rice agro-ecosystems, drought stress can occur at any growth stage and can cause a significant yield reduction. During recent years, some rice varieties possessing reproductive-stage drought tolerance have recently been developed. Besides, tolerance to vegetative-stage drought stress is also required to improve rice productivity in drought-prone regions. We have evaluated a set of rice breeding lines for their response to a range of different types of vegetative-stage drought stress in order to propose standardized phenotyping protocols for conducting vegetative-stage drought stress screening. A soil water potential threshold of 20 kPa during the vegetative stage was identified as the target for effective selection under vegetative stage with grain yield reduction of about 50% compared to irrigated control trials. Genotypes identified as showing high yield under reproductive-stage drought stress were not necessarily the genotypes showing best performance under vegetative-stage drought stress (Swain et al. 2017). Alternatively, tolerance of both vegetative-stage and reproductive-stage drought stress could be accomplished by crossing donor lines, one of which is tolerant of vegetative-stage drought stress and one of which is tolerant of reproductive-stage drought stress. The development of improved varieties with combined tolerance of drought stress at multiple growth stages will help farmers in rain-fed rice-growing regions maintain stable yields across increasingly unpredictable climatic conditions

Maintaining high turgidity (RWC>70%) during severe stress with higher photosynthetic rate and faster recovering efficiency on re-irrigation were found to be the key traits for drought tolerance. Significant negative correlation between drought score vs. RWC (r= -0.78*), drought score vs. Fv/Fm (r= -0.610*) and significant positive correlation between RWC and Fv/Fm (r=0.710*) showed that plants having higher leaf water content were able to harvest most of the photon falling on the canopy and radiated back less amount of energy leading to overall lowered canopy temperature. The genotypes *viz*. AC-43025, AC-43037 and AC-42997, AC-43012 and CR 143-2-2 were identified to have highest water use efficiency coupled with slow transpiration rate above VPD 5 kPa. Low stomatal density and lower canopy temperature (34.02°C - 41.18 °C) in these genotypes resulted in higher biomass production using less water compared to susceptible check IR 64 (ICAR-NRRI Annual Report 2015-16).

Along with higher water use efficiency, lesser number of stomata and slower transpiration rate, improved root traits also play vital role in drought tolerance in rice. We identified twenty superior genotypes *viz*. Kalakeri, Mahulata, Zhu-11-26, CR 143-2-2, Lalnakanda-41, Annapurna, RR 433-2, Sambha-Mahsuri, EC306321, CR 2430-4, RMP-1, RR 366-5, AC- 26774, Sasyashree, Salumpikit, Lektimachi, AC 26773, Khitish, IET 18817, SGS-1 for higher values for more than one root trait. This was reflected in their better ability to tolerate vegetative stage drought stress. The genotypes AC-26685, AC-35679 and EC-205334 were found to have important root markers (MRL, RV, R/S, RW) responsible for drought tolerance. The root: shoot ratio, maximum root length to shoot length ratio and root volume were observed to be the most crucial morphological markers in determining drought tolerance in rice genotypes analyzed through biplot analysis (Dash et al. 2017). AC-42994, AC- 42997, AC-43020, CR-143-2-2, Ronga Bora and Bora were found to possess desirable root traits and these genotypes can be used in the breeding programme for enhancing drought tolerance in rice (Fig. 1).

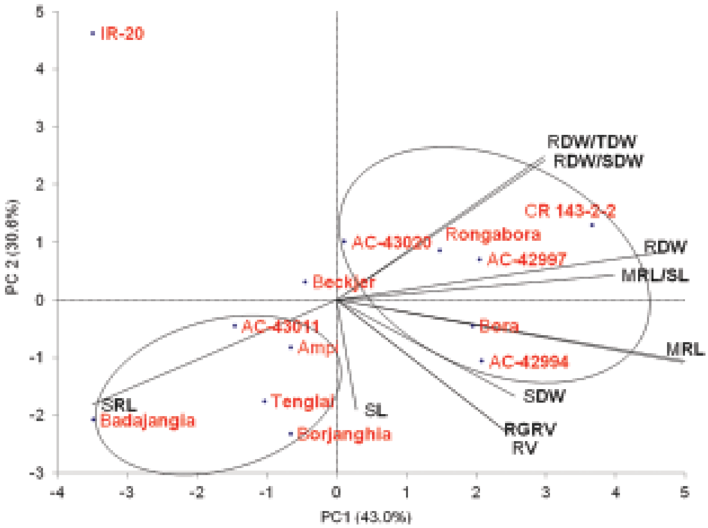

Fig. 1. Factorial plans with two principal components representing root traits averaged over three replications for selected rice genotypes under water limited condition sampled at 20 days stress period (severe stress). Variance explained by each dimension is shown as a percentage of total variance (indicated in axis legend). Coordinates correspond to the correlation coefficients between variables and principal components 1 and 2. *Black colour letters* indicate trait names and *red colour letters* indicate genotype names.

Source: Dash et al. (2017)

Similarly, studies showed significant negative correlation obtained between DSI with grain yield under stress (S) and positive correlation between DSI with yield under irrigated control (I) conditions indicated selection for this character under stress environment might result in decreasing susceptibility to stress. In general, the drought tolerant varieties were characterized by high germination in PEG (20,000) and coleoptile growth in D-mannitol (10 atm), stability to high temperature (40 °C) as apparent from less statolith starch disintegration in root. Besides, low destruction of chlorophyll, tillering in quick succession before onset of drought, fast recovery on re-watering, profuse root growth with high ramification of roots at greater depths (25 cm below), high leaf moisture content (RWC), high stem sugars and protein nitrogen in the plant tissue was also found in drought tolerant rice genotypes. Tillers produced till the end of drought were mostly productive whereas those developed during recovery phase had no influence on yield. The root length was high in ~~DR~~ drought tolerant varieties which was characterized by high peroxidase activity, high soluble sugar and lipid P in root enabling rapid rejuvenation of roots on relief of drought. Drought at panicle emergence stage was found to be more detrimental than at vegetative stage. The critical periods of injury being flowering >PI>tillering>milk stage. Certain varieties were consistently tolerant to drought especially at vegetative stage with very good recovery in terms of plant vigour after drought spell and also give satisfactory yield of ~2 to 2.5 t ha^{-1}. Among the high yielding varieties, Rasi, C 22, CR 113-84-2, CR 143-2-2, TNAU x T 65, Annada (MW 10) were identified to have considerable drought tolerance (Ramakrishnayya and Murty 1993).

4.1.1.1. Identified drought tolerant donors: Over the years, evaluation led to identification of few drought tolerant rice genotypes. Some of the noteworthy ones are AC-254, AC-263, AC-304, AC-511, AC-2298, AC-3035, AC-3111, AC-3577,AC-9066, AC-9387, ARC-7063, AC-45 (CH-45), AC-40083 (MTU-17), W-691, AC-467 (Lalnakanda-41), AC-35207 (Dular), AC-37077 (Dhan gora), AC-37127 (Black gora), AC-37291 (Kalakeri), AC-8205 (Surjamukhi), AC-34440 (Salumpikit), AC- 34256 (Kabiraj Sal), AC- 34296 (Bombay murgi), AC-35021 (Kalon dani) AC-35038 (Godhi akhi), AC-35046 (Nadi tikar), AC-35059, (Phutki bari), AC-35060 (Bhuska), AC- 35143 (Baihunda), AC-35452 (Karama), Mahulata, Brahman-nakhi, Sal-kain, CR 143-2-2, etc.

4.1.1.2. Water saving approaches for rice cultivation: Aerobic rice cultivation using alternate wetting and drying (AWD) method was found to be a potential method of rice cultivation with significant water saving during the crop growth period. Higher yield potential in rice hybrids under AWD and Aerobic conditions (more than 5.5 t ha^{-1}) with least yield loss (1.87 - 6.2%) indicated their adaptability to water shortage conditions. It might have been contributed by high biomass, high LAI (>4.22) higher moisture retention capacity (>70%) during the dry cycle with high chlorophyll content (> 3.0 mg g^{-1} FW) and high photosynthetic rate (30.2-35.6 μ mole CO_2 m^{-2} s^{-1}). Highest grain yield in CRHR

7, PA 6444, PHB 71, PA 6201 and (5.4 - 6.8 t ha^{-1}) under both AWD and normal irrigated conditions with least yield loss (1.87 - 6.2%) under AWD indicated their adaptability to water limited situations. Yield loss under AWD treatment was non-significant and total biomass reduced by 6-8 % without much change in harvest index. Thus aA better adaptable water saving technique was understood by alternate cyclic wetting and drying practice which enabled decreased requirement of irrigation water (about 33%) at the cost of 14 % yield loss in dry seasons and 3.2% yield loss in wet season.

4.1.2. Submergence and Waterlogging Stress

Erratic rainfall leading to excess water usually creates havoc for rice cultivation especially in the rain-fed shallow lowland ecology. For this we need genotypes that are capable to withstand stresses arising due to excess water. In this regard, Elite varieties (traditional and high yielding) for different water depths have been identified. These are AC 2624 (T 1237), MTU 16, Monoharsali, NC 1281 (traditional), IR 5, CR 70-91, TN1 x 65, CRM 10-4622 (HY) for shallow submergence (15-30 cm) and Intan, CN-540 (Suresh), IET 5638, IET 6206, C 4045 for intermediate depths (about 50 cm) (Sarkar 2016). Among the stages, flowering period was more sensitive for flood or submergence injury. However, CRM 10-4622, NC 1281 were relatively tolerant at all stages. It was found that waterlogging reduced chlorophyll and total sugar content in the plant with reduction in NR-A and RUBP Carboxylase activities. Under water-logging, the panicle number per unit area was reduced and the yield reduction is partially compensated by greater grain number per panicle. The adverse effect was more apparent on dry matter at harvest than on HI. Obviously, the panicle weight types were more efficient under water logged situations. Tillers above 40 cm in height at time of submergence survived better and hence varieties with greater number of primary tillers with optimum height were more efficient under submerged conditions eg. CN 540 (Suresh), IET 6205 (Reddy and Mitra 1985).

Significant progress has been made in submergence studies in rice at our institute. The genotype, FR13A (vernacular name 'Dhalaputia', Orissa, India) was identified from this institute as a true submergence tolerant genotype. FR13A is the source of submergence tolerance gene / QTL (*SUB1*) which imparts submergence tolerance. Extensive work was done with this genotype and mechanism of submergence tolerance is now fairly understood (Sarkar and Bhattacharya 2011). In other words, it can be said that NRRI (then CRRI) and Odisha presented the *SUB1* gene to the rest of the world. Genotypes with *SUB1* can withstand complete submergence depending on flood-water characteristics up to 1-2 weeks. One of the key finding for submergence tolerance of rice identified from here is that non-structural carbohydrates content before and after submergence is important for providing energy for maintenance of key metabolic processes during submergence and for regeneration and recovery of seedlings after submergence. Studies have shown that the differences in tolerance level were not necessarily associated with the initial carbohydrate status before submergence but were rather associated with the plant's ability to maintain high levels of stored energy through either slower utilization during submergence and/or greater underwater photosynthesis. The initial carbohydrate level before submergence was almost equal in rice cultivars Gangasiuli and Raghukunwar, but Gangasiuli showed better survival percentage (51%) than Raghukunwar (36%), with retention of higher chlorophyll and non-structural carbohydrate contents during submergence (Das et al. 2009).

Under submergence, varieties with high O_2 liberating power are more efficient and the tall tillers have such efficiency to withstand water-logging. Elongation of stem was associated with high pectin methyl esterase activity and air space in culm. However, in productive non lodging varieties moderate elongation with less activity of enzyme and lower air space was apparent. From stress management perspective, our studies showed foliar spray of IAA + GA, 10 days after planting (100 ppm) helped in leaf sheath elongation, better survival of the plants with 5-fold increase in grain yield at harvest. Close spacing and aged seedlings when transplanted could yield better under water logging. Direct seeded crop was better than transplanted crop because of the advantage in initial height of the tillers at submergence (Sharma 1994). Application of N- and P-fertilizer at seedling stage helped in greater elongation growth of tillers and tolerance to submergence. It was found that P enhanced acid phosphatase activity and submergence tolerance. Minimum elongation during submergence aided in survival due to greater preservation of non-structural carbohydrates (NSC) and application of Gibberellic acid (GA) showed to increase susceptibility, whereas GA biosynthesis inhibitor paclobutrazol increased the tolerance (Das et al. 2005). Seed priming with simple tap water and 2% Jamun (*Syzygium cumini* L.) leaf extract improved the grain yield both under anaerobic seeding and stress-free environment in Swarna and Swarna-Sub1.

The activities of antioxidant enzymes viz. superoxide dismutase, catalase and peroxidase were found protective in ensuring better regeneration/ rejuvenation capacity of rice seedlings during shift from anaerobic (submergence) to aerobic (normal) situations. A higher catalase activity seems to be important to withstand de-submergence injury (Sarkar et al. 2001). Evaluation of starch phosphorylase enzyme activity was indicative of its strong association with submergence tolerance. Submergence tolerant cultivars maintained greater non-structural carbohydrate (NSC) before and especially after submergence. Maintenance of underwater photosynthesis due to greater preservation of chloroplast functional and structural integrity also aided in survival. Cultivars with *Sub1A* QTL maintained greater quantities of non-structural carbohydrate contents especially after submergence and pursued the energy saving mode of carbohydrate utilization. Structural and functional integrity of photosystem II was better in cv. with *Sub1A*. Introgression of *Sub1A* had no adverse effects on yield (Panda et al. 2006). The tolerant tall varieties, Suresh and Utkal Prabha (CR 1030) are characterised by optimum air space in stem, high peroxidase and catalase activity and O_2 liberation by roots, greater chlorophyll especially Chl 'b' and high photosynthetic rate of the top leaves above water level. A novel genotype CRK-2-6, was identified as equally submergence tolerant to that of FR 13A but possesses better yield potential as well as superior grain quality. Dhulia, PD-27 and PD-33 were also identified as submergence tolerant rice genotypes. Besides a few germplasm lines IC-299929 and IC-300131 found to be tolerant to complete submergence for 14 days comparable to FR 13-A and better than Swarna-*Sub1* (Sarkar and Bhattacharya 2011).

Here are some of the most significant achievements of the division with respect to submergence and waterlogging tolerance studies.

- ❖ Data on submergence tolerance of more than six thousand germplasms were compiled and a core set and CRRI germplasm data base is prepared.
- ❖ Eight cultivars namely, Khoda (INGR 04001), Khadara (INGR 08108), Atiranga (INGR 08109), Kalaputia (INGR 08110), Gangasiuli (INGR 08111), Kusuma (INGR 08113), Bhundi (INGR 14025) and Kalaketi (INGR 14026) have been registered as submergence tolerant donors. Bhundi and Kalaketki tolerate three weeks of submergence.
- ❖ A chlorophyll fluorescence based non-destructive technique was developed and standardized to screen submergence tolerant varieties.
- ❖ Important germplasm lines tolerant to stagnant flooding are AC 42103, AC 42220, AC 42243 and AC 42254.
- ❖ AC39416 is tolerant to anaerobic germination, stagnant water flooding, drought and salinity.
- ❖ Kalaputia is tolerant to submergence, stagnant water flooding, and drought.

4.1.3. Anaerobic Germination and Germination Stage Oxygen Deficiency (GSOD) Tolerance

Besides submergence and waterlogging, excess water at the time germination is also detrimental for rice. Flash flood just after sowing imposes submergence stress by creating hypoxic condition (3% Oxygen) during germination as well as during vegetative stage. Interestingly, mode of overcoming hypoxic stress by rice plants seems to be different during germination and vegetative stages. The genes and QTLs reported for vegetative stage submergence tolerance are of no use to tolerate germination stage submergence and *vice-versa*. In general, rice coleoptile under water has been found to elongate about 1 mm h^{-1} to reach the atmosphere by rapid elongation of basal cells (up to 200 m in 12 h) immediately after emerging from embryo. However, anaerobic germination potential (AGP) varies greatly among different rice genotypes, which ultimately provide an edge to a few genotypes to perform better under oxygen deficient conditions over others. Screening over the years resulted in identification a few rice genotypes *viz*. Panikekoa, Dhulia, AC1631, AC 40413, AC 40602, AC 41658 and AC 41620 having superior anaerobic germination potential. Detailed mechanism and possible candidate gene(s) for anaerobic germination was identified in rice recently. Our studies showed effective operation of anaerobic respiration and nitrogen metabolism in tolerant rice genotypes led to more energy efficient metabolic system under oxygen limiting GSOD condition resulted in better ROS handling and cellular pH maintenance. Very recently we have registered AC41620 as a unique rice germplasm having high anaerobic germination potential (AGP) with a robust gene regulatory mechanism. We believe that it would be used as a donor for rice improvement programme to increase the AGP of direct seeded rice varieties (Vijayan et al. 2018).

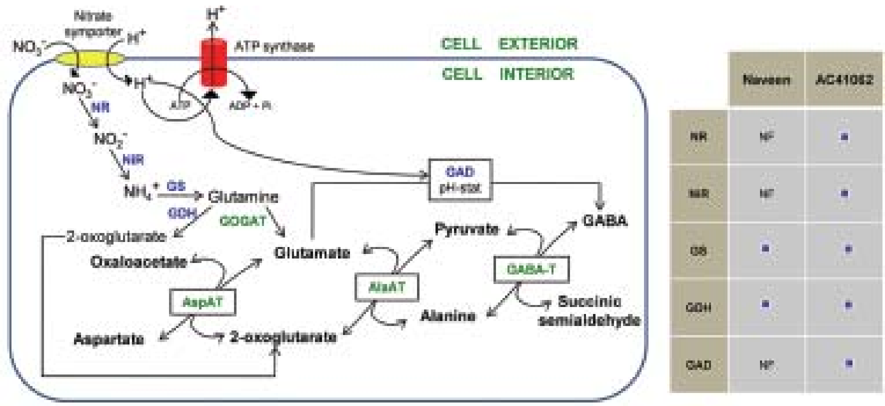

Fig. 2. A summarized network for nitrogen metabolism operative inside the cell also maintains the intracellular pH. In the network, the enzymes encoded by up-regulated genes are mentioned in blue colour and the enzymes encoded by genes which did not show any differential expression are mentioned in green.

Source: Vijayan et al. (2018)

4.1.4. Salinity stress

Work done for past few decades in the area of salt stress physiology indicated that rice is quite sensitive to salinity stress. In fact, it is the most sensitive among the cereals, having a threshold salinity level of only 3 dS m^{-1}. But, rice show considerable variability across different genotypes. Although it had been reported to be relatively tolerant during germination, active tillering and towards maturity, but shows sensitivity during early seedling and reproductive stages, which can reduce rice yield signicantly. It was found that the critical salt limit for 50% reduction in yield was 0.2% NaCl solution for salt susceptible genotypes like Co 13 and T 90 and 0.4% NaCl solution for salt tolerant lines J

349 and SR 26B. The adverse effects of salinity were more apparent in dry than in wet season. Under salt stress reduction in grain number per panicle due to increased spikelet sterility, was found to be the most affected yield component in rice. Varieties showing salt tolerance at seedling stage were not as productive under saline conditions at later stages (Janardhan and Murty 1970).

Under salinity Na, Ca, Mg, ash and Cl percent increases while that of K and P decreases, resulting in lower K/Na ratio. In salt tolerant varieties higher K/Na ratio was maintained. The N concentration increases with salinity, especially soluble N, and P content decreases in salt susceptible varieties. The uptake of P and N is also high in saline tolerant varieties (Kalarata, Damodar, Dasal, Getu, etc.). Forty-five rice landraces collected from coastal saline areas of Orissa and West Bengal were evaluated for salinity tolerance at seedling stage at an EC of 12 dS/m. Kamini, Talmugra, Paloi, Marisal, Rupsal, Ravana and Rahspanjar were found tolerant with per cent survival of 42.2 (Kamini) to 78.3 (Paloi), as against 87.9 for Pokkali (tolerant check). Nagalmutha was moderately tolerant with 22.2% survival. Studies showed that rice plants counteracted the deleterious effects of salinity and maintained greater photosynthetic activities and chloroplast structural and functional integrity by maintaining the appropriate levels of K and ascorbate in metabolically active tissues. Among the 55 salt-tolerant Pokkali collection present in the institute, it was found that accession no. AC39416 was tolerant to both salinity and waterlogging and accession no. AC41585 was tolerant to both vegetative and reproductive salt stress (Singh and Sarkar 2014).

Studies on combined stresses of salinity and partial flooding indicated that maintenance of sufficient levels of tissue K^+ and ascorbate content helps to counteract deleterious effect of salt stress. Our studies showed both photosynthetic rate and non-structural carbohydrate contents decreased due to saline treatment especially in susceptible cultivars. The significant reduction in photosynthetic rate after seven days of salt treatment was noticed. However, in Pokkali (AC No. 39416), photosynthetic rate did not decrease and the differences were non-significant compared to the controlled conditions. The reduction in variable fluorescence (Fv) and maximal photochemical efficiency (Fv/Fm) of light reaction were greater in IR 42 and FR 13A as compared to the tolerant genotypes. Other physiological characteristics changed greatly with imposition of salinity stress. Accumulation of greater quantities of H_2O_2 contents increased lipid peroxidation as MDA content showed highly significant position association with H_2O_2 content. Greater quantities of Na^+ in shoot increased H_2O_2 production whereas greater quantities of K^+ had inverse reaction which resulted lower production of MDA. Highly significant negative association was noticed between net photosynthetic rate (Pn) and H_2O_2 content and Pn and Na:K ratio. However, the association between Pn and K^+ content was positive. The data showed that under saline conditions accumulation of greater quantities of K^+ is beneficial (Sarkar et al. 2013).

One of our very recent study showed reproductive stage salt tolerance in rice is primarily governed by selective Na^+ and K^+ transport from root to upper plant part. Ionic discrimination at flag leaf governed by differential expression of Na^+ and K^+ specific transporters/ ion pumps was found to be associated with reduced panicle degeneration, spikelet sterility and reproductive stage salt-tolerance in rice. It was found that that higher expression of *HKT1;5*, *HAK5*, *HAK1* and *AKT1* in roots, and *NHX1* and *HKT1;1* in leaves governed selective ion transport in rice. It resulted in minimal Na^+ transport to flag leaf and developing panicle maintaining greater K^+/Na^+ ratio for reproductive stage salt tolerance. Increased expression of *AHA1* in leaf and *AHA7* in roots not only met the greater energy demand for selective salt ion exclusion, but also contributed to overall energy balance required for reproductive stage salt tolerance in rice.

The procedure for screening rice genotypes for salt tolerance at seedling stage has been well established and validated through number of experiments. But, unfortunately only a few protocols for screening of salt tolerance at reproductive stage are currently in use, which are based on both in-situ field evaluation and ex-situ evaluation under controlled condition. For this we have developed and standardized a novel screening protocol for precise phenotyping of salt-tolerance at reproductive stage in rice. In the new method, the setup was established with a piezometer placed in a perforated pot for continuous monitoring of soil EC and pH throughout the period of study. Further, fertilizer enriched soil was partially substituted by gravels for better stabilization and maintaining the uniformity of soil EC in pots without hindering the buffering capacity of the soil. The protocol having modified medium (soil: stone, 4:1) at 8 dS m^{-1} salinity level was validated using different rice genotypes having differential salt sensitivity. The method was found significantly efficient for easy maintenance of desired level of soil salinity and identification of genotypes tolerant to salinity at reproductive stage.

Similarly, another high precision screening protocol based on chlorophyll fluorescence imaging system was standardized for efficient phenotyping of rice genotypes for combined stresses of salinity and partial flooding. Among different fluorescence parameters such as maximal fluorescence (F_M), variable fluorescence ($F_V = F_M - F_0$), maximal photochemical efficiency of PS II (F_V/F_M) and quantum yield of non-regulated energy dissipation of PS II ($Y_{(NO)}$) were able to precisely distinguish genotypes based on their sensitivity to stress. Overall, we found suitability of chlorophyll fluorescence imaging technique for precise phenotyping of rice based on their sensitivity to combined effect of salt and partial submergence (Pradhan et al. 2018).

4.1.5. Low Light Stress

Light intensity is one of the most important environmental factors that determine the basic characteristics of rice production and productivity. However, continuous cloudy weather during the rainy season especially if it coincides with the grain-filling stage, induces a significant loss in rice yield and results in poor grain quality (Murty and Sahu, 1987). Our studies showed that low light at flowering was more detrimental. The adverse effect being in the order of reproductive stage > ripening stage > vegetative stage. Under low light, chlorophyll (Chl) content especially Chl 'b' increases with reduction in Chl a/b ratio. Among the varieties tested, Swarnaprabha (early), Vijaya (medium), Mahsuri (late) were found to be consistently better adapted to low light condition. The lowlight adapted varieties are characterised by high net photosynthetic rate (Pn) under low light, increased Chl b content and N uptake, slow senescence, low respiration and better shoot contribution to grain development. Vijaya is relatively more adapted to low light at ripening stage than at reproductive stage and its adaptability is associated with the above characters (Nayak and Murty 1979).

Foliar spray of 2, 4-D or kinetin, delayed senescence, enhanced apparent contribution rate from stem to panicle and reduced spikelet sterility under low light. The adverse effect of low light is more apparent in *Kharif* season than in *Rabi* season. Under low light the decline in photosynthetic rate is partly due to reduction in stomatal frequency and partly due to reduced stomatal conductance to CO_2. The simple characters like specific leaf weight (SLW) or leaf thickness at flowering under normal light condition is significantly associated with biomass or grain yield at harvest under low light suggesting the usefulness of this character as a preliminary selection parameter for low light adapted varieties even under normal conditions. Specific leaf weight (SLW) at flowering under normal light condition is significantly associated with biomass and grain yield at harvest under low light suggesting the usefulness of this character as selection criteria for low light adapted varieties even under normal condition (Nayak and Murty, 1980). Since expansion of leaf blade appears to be characteristic feature in increasing leaf area ratio under low light, least increase in this parameter (within 80 $cm^2 g^{-1}$) found to be an index for identifying cultivars adaptable to low light stress (Swain and Nayak 1996). Stomatal frequency and RUBISCO activity were reduced under low light. However, low light adapted varieties like Vijaya and Swarnaprabha were less affected in these traits. It was found that cultivars adapted to low light also had high Chl 'b' and high Pn under blue light. Light saturation for photosynthesis varied from 50 to 80 klx and the low light adapted varieties invariably showed low light saturation for Pn (30-40 klx). Some of the better adapted low light varieties identified are Ptb 10, Hamsa, T 90, Mahsuri, Pallavi, Swarna-prabha, Vijaya, NC 1281, Vajram and Hybrid, IR 54752A/Vajram. This hybrid has the potential for use in the low light monsoon areas (Murty et al. 1992). Among the three hybrids PHB-71, Rajalaxmi and Ajay tested under low light, Ajay had lowest yield loss over control.

The efficiency of some wild rice species was also tested to now their adaptability potential under low light stress. *O. rufipogon, O. punctata, O. barthii, O. eichingeri* and *O. nivara* were identified to be tolerant to low light stress

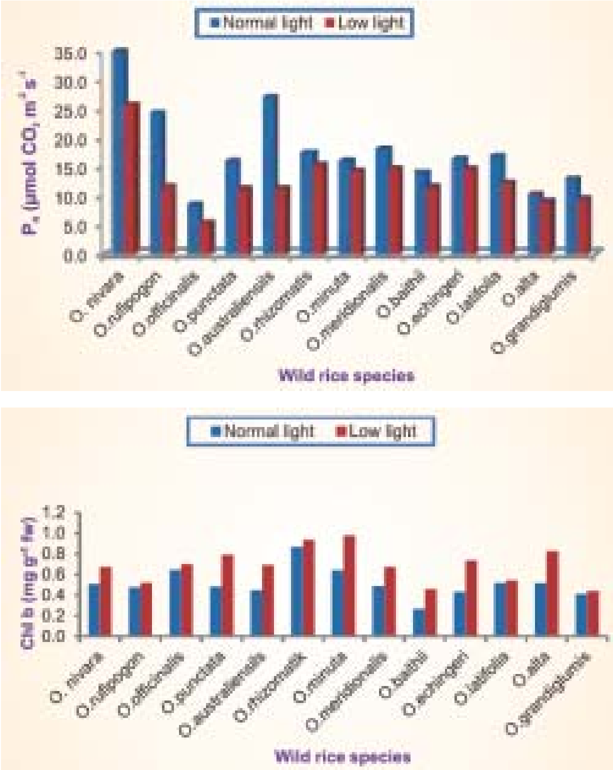

Fig. 3. Photosynthesis and chlorophyll 'b' content of different wild rice species under low light stress condition.

Source: NRRI Annual Report (2014-15)

among different species of rice (NRRI Annual Report 2014-15). Considering accumulation of more chlorophyll *b* and consequently low *Chl a/b* ratio under low light environment as the selection criteria for selecting the varieties for low light tolerance, the species *O. rufipogon (AC-100266), O. punctata (AC-100289), O. barthii (AC-100277) and O. echingeri (AC-100210) and O. nivara (AC-100298)* showed their tolerance to low light environment (Fig 3). Longer duration rice genotypes showed better photosynthesis and more chlorophyll b accumulation under low light environment. Besides, the wild rice species, some identified low light tolerant genotypes from cultivated rice are Satyam, Govinda, Vandana, Naveen, CRHR-32, Sahabhagidhan, Phalguni, Anjali, ADT-36, NC-0087, Udayagiri, Lalitgiri, Suphala, Kalinga-III, ASD-16, Saket, PB-1, Satyakrishna, Tapaswini, Chandrama, Pusa-33, Daya, Srabani, etc.

4.1.6. Heat stress

Work on heat tolerance in rice is at nascent stage in our division. Some preliminary work suggested pollen response can be used as a screening tool for heat tolerance. Among different genotypes tested, IR 8 was identified as most sensitive to temperature with a cumulative temperature response index (CTRI) of 6.8, while Annapurna as most tolerant with a CTRI of 7.5. High temperature stress resulted in reduction in chlorophyll, protein, seedling dry weight, membrane stability, but increase in relative injury (%), sugar content, peroxidase and catalase enzyme activities with significant differences in the changes in these parameters under increased duration of exposure to high temperature stress conditions. Annapurna and N-22 showed minimum yield reduction (19.3 to 21.5%) with low relative injury under high temperature stress with better partitioning of carbohydrate reserve from source to sink tissues. Accumulation of total sugar in the panicles of heat tolerant varieties (N-22) were much more pronounced than the heat susceptible Naveen. In Satabdi and Naveen, the carbohydrate concentration in grains was significantly lowered suggesting the impaired carbohydrate mobilization process existing in these.

4.2. Photosynthetic Enhancement of Rice

Utilization of light energy via photosynthetic processes plays key role and has considerable impact on biomass production and yield in rice. Important components of photosynthetic efficiency are considered to be canopy structure, nitrogen utilization, photosynthetic capacity and CO_2 diffusion rate. Modification of plant types or architecture is thought to be an important strategy to enhance the photosynthetic efficiency and potential yield of crops. Our studies showed photosynthetic rate increases with moderate N rate (90N) due to enhanced nitrogen per unit leaf area (N_{LA}) and decreases with population density because of reduced leaf thickness. Under field conditions, the canopy photosynthesis ~~Pn~~ increased up to 12 noon, remained stable till 2 P.M. (100-120 klx) and declined later indicating 100 klx as threshold light for canopy photosynthesis ~~Pn~~. However, a mid-day depression in individual leaf net photosynthetic rate (Pn) of top leaves was apparent which is associated with reduction in leaf hydration and stomatal conductance to CO_2 and increase in photorespiration and substrate accumulation (Swain et. al, 2006). Canopy photosynthesis (LA x Pn) also varied considerably (1.5-2 fold) and had association with dry matter and yield (r =0.66**). In general, leaf area and Pn, contributed 70% and 30% to grain yield indicating the importance of LAI for yield.

Net assimilation rate (NAR), which indicates the integrated field photosynthesis showed high association with specific leaf weight (SLW) suggesting the usefulness of the latter as a primary selection index for high NAR varieties. However, Ratna showed high Pn with relatively low photorespiration (PR). The tall Indica, Ptb 10 though efficient in Pn recorded high PR and dark respiration. Cultivars identified with low PR are: B 76, Adt 27, Tkm 6, IR 8, Ratna, Pankaj, Vijaya. Leaf thickness (SLWD), leaf vein frequency (LVF), stomatal conductance (Cs), Chl_{LA}, N_{LA} and leaf protein showed high association with Pn while leaf area and yield had a tendency for negative association. LAI increased with duration of the variety with N rate and under low light with consequent reduction in Pn and its associated characters, Cs, stomatal frequency (SF), N_{LA} etc. Nevertheless, cultivars like Swarnaprabha showed high LAI, combined with moderate Pn recording high canopy photosynthesis and grain yield. In general, short types were more efficient in translocation efficiency than talls. Cvs. Bala, Swarnaprabha (early), IET 1145 (medium) and Jagannath (late) are efficient in translocation. Translocation was not affected and even marginally increased under slight reduction in light intensity up to 30% normal light, while at lower light intensities, it was considerably impaired. High leaf N (beyond 2.5%) though enhanced Pn, reduced translocation of photosynthates. Maximum translocation of ^{14}C assimilates to panicle was evident 2 weeks after flowering. Assimilates produced during milk stage contributed 75% of total carbohydrates in grain. Varieties with high panicle Pn (~~eg.~~ Pallavi) exhibited better translocation. Varieties with high Pn are not always that efficient in translocation. Photosynthetic rate per se (Pn) is not that associated with yield while the product of photosynthetic surface (LAI) and Pn invariably showed high association with yield indicating the predominance of leaf area over leaf Pn in determining yield. Swarnaprabha though moderate in Pn recorded high photosynthetic productivity/yield due to larger leaf area, lower maintenance respiration and higher P/R ratio and translocation efficiency. In another study on photosynthesis of rice hybrids Baig et al (1998) reported F1 hybrid like IR62829A x Vajram showed higher readings in PN, PN/RM and PN x LAI at the flowering stage than IR62829A x Swarna. The parents Swarna and Vajram although moderate in Pn had highest Pn x LAI at flowering stage due to greater LAI. There was an increase in seedling stage photosynthesis in the paclobutrazol treated plants over the control as there was an increase in leaf chlorophyll content in the treated plants

Screening large number of cultivars/germplasm lines resulted in identification of a few elite line with high photosynthesis rate.

Table 1. List of elite rice cultivars/germplasm having high photosynthetic efficiency.

Type of variety	Duration	Name of varieties
High Yielding Varieties	Early	C 3383, CR 110-174, Pallavi, Kalinga I and Kalinga II, Saket-4, Co 41, Ratna.
	Medium	IET 734, Jayanti, Sona, Vijaya, Indira
	Late	Jagannath
Traditional Varieties	Early	Ptb 10, Asd 5, Mtu 15
	Medium	AC 4491
	Late	Mahsuri, SR 26B, GEB 24, Mtu 16, Latisail, CR 1014, Sigadis
Mutants		Club, Tainan 3 M, Brittle culm, Saturn striata.
Drought		CR 125-12-30, CR 143-2-2.
Tetraploid Lines		Sita, Indrasail.
Hybrids		IR 54752A/Vajram
Restorers		Anamica, IR 58, IR 9761-19-1
Maintainers		IR 19806-8-1-3-2

4.2.1. Efficient Utilisation of Solar Energy

Besides enhancement of single leaf photosynthesis, efficient solar energy utilization (Eu%) for biological yield (BY) and economic yield (EY) enhancement was studied in the division under PL-480 Project during 1980-91. The elite entries for Eu% (BY) are given below.

- HYV: Kalinga I and II, Saket 4, Vaigai, Suphala, Adt 32, Jagriti, Aswati, Co 41, IR 36, Prabhat, Madhu, Swarnaprabha (early), Savitri, Mahsuri, Madhukar, Jalgaon-5, Deepa (medium and late) (Rao et al 1985).
- Traditional: Ptb 10, Co 29, Ch 1039, N 22, Mtu 15, B 76, BR 34, Tkm 6, AC 3905 (early), T 141, GEB 24, Bamia, Bam 9, T 90, Belamancha, Naukoili (late) (Rao and Murty 1984).

It was found that solar energy utilization is higher in *Kharif* season than in *Rabi*. It increased up to flowering stage and was highest during the reproductive stage (PI to flowering). A tendency for increase in Eu% with duration of variety was apparent because of corresponding increase in leaf area index (LAI). The Eu% (BY) is associated with LAI, dry matter partitioning, amount of light (PAR) intercepted by the canopy and with yield while Eu% (EY) is related with post flowering DMP. The Eu% (BY) could be further enhanced in a cultivar by higher planting density and N rate through increase in LAI.

4.2.2. Development of C4 rice

Rice is a model C3 plant which operates Calvin cycle for fixation of atmospheric CO_2 into carbohydrate. It is well known fact that C4 plants are better in carbon fixation than C3 plants specially under limited CO_2 and nitrogen condition as well as under high temperature and drought. Therefore, C4 cycle operating plants are suitable for the changing climatic scenario to address the global food security issue. Hence, we took an initiative to transform rice into C4 plant with an objective to improve its photosynthetic efficiency and yield. We found that the highest expression level of Carbonic Anhydrase (*CA*), a key enzyme for C4 pathway in *Sorghum bicolour* and *PEPC* in *Setaria italica* plant. The highest expression level of *PPDK* and Malic Enzyme (*ME)* was found in *Seitaria italica* plant. Cloning of *Setaria italica* PPDK, *Setaria italica* ME, *Sorghum bicolour* CA and *Setaria italica* PEPC was done in pCambia binary vector. Transformation of *SiPPDK, SiME, SbCA* and *SiPEPC* and expression constructs to *Agrobacterium* strain *LBA4404* and their subsequent transformation into rice genome was done *E. coli* glycolate metabolic pathway genes in rice, (Glycolate dehydrogenase), *GDH* (3 subunit-*glcD*, *glcE*,& *glcF*), *(*Glyoxylate carboligase glyoxylate) *GCL* and *(*Tartronic semialdehyde reductase) *TSR* gene were PCR amplified from *E. coli* genomic DNA and sequence confirmed. Out of 5 genes, 3 were cloned in plant transformation vector for rice transformation.

4.3. Rice Production Physiology

Our research related to rice production physiology showed that timely top dressing of N (30% of total) just prior to 50 DAS helped in maintaining leaf N above 2%, enhanced N uptake and reduced tiller mortality. Thus application of N in 3 splits (40%, 30%, 30% at 20 and 50 DAS and at booting respectively) increased tillering, reduced tiller mortality and enhanced panicle weight and ultimate grain yield/tiller. It was found that grain filling in rice mostly depends on optimum source to sink ratio and climatic condition during ripening phase. Results indicated that per spikelet the optimum source is 2.5 cm^2 leaf area and 14 mg of stem tissue (fresh weight basis) at flowering stage, especially for early varieties like Ratna or Pallavi. Major constraints for productivity in wet season were low grain number per panicle in early duration type cultivars; high spikelet sterility (%) in medium duration type cultivars and low panicle number per unit area in late duration type cultivars. It was also shown that grain development mainly depends on accumulated reserve dry matter at flowering stage in *Kharif* season. Partitioning of dry matter to panicle is also poor due to high sterility resulting in low HI. Both leaf and panicle senescence is also faster resulting in lower post flowering photosynthate production and its mobilization to panicle. Nevertheless, taller genotype Pallavi with high panicle photosynthesis as compared to semi dwarfs like Ratna, showed high translocation and low sterility in low light monsoon (Debata and Murty 1982).

Net photosynthetic rate (Pn) was found to be low during wet season (WS) partly due to low leaf area, nitrogen (N_{LA}) stomatal conductance and high respiration losses. Yield during WS was obviously associated with LAI and DM at flowering (source size and efficiency) while spikelet or grain number/ m^2 (sink size) determined yield in dry season (DS). Varieties with high dry matter production or crop growth rate (CGR) at reproductive /ripening stages rather than at vegetative stage were more productive as dry matter produced at this stage is directly associated with sink potential (spikelet number and its filling). Besides efficient grain filling, high density grain% (HDG %) was also reported to be a desirable trait for higher production. The HDG (%) was generally higher in late than in early or medium duration types. Some of the genotypes identified for HDG (%) were Rasi, IR 50 (early), Jaya (medium), Swarnadhan or IET 5656 (late). Within a panicle, HDG % was higher in top portion than in middle or bottom portion and in primary than in secondary or tertiary rachis branches (Janardhan and Murty, 1977). Foliar spray of growth regulators found to enhance HDG (%) and the order being kinetin >GA_3> IAA >mixtalol.

Besides photosynthetic efficiency and dry matter production potential, grain filling or spikelet sterility was found to be one of the key for higher productivity. This trait was widely varied (16%-74%) among ~2500 genotypes tested during wet season. Some of the identified rice cultivars with low spikelet sterility were Pallavi, Selection TN1 x T 65, Sakti, Mahsuri (HYV); B 76, Bam 12, Ptb 18 and 21, H 4 (traditional). Spikelet sterility was mostly a post fertilization phenomena and was reported to be higher in wet than in dry season (2-3 fold variation). Low Light during flowering to 10 DAF, especially on the day of anthesis was critical. Variation in duration of different phenological phases was observed under direct seeded and transplanted conditions. The reproductive phase under direct seeded condition was 27 to 29 days whereas it was 22 to 25 days under transplanted condition. Transplanting of 45 days old seedlings exhibited higher dry matter accumulation during vegetative phase and also higher grain yield in comparison to transplanting of 30 days old seedlings. Biomass partitioning study revealed a similar partitioning pattern in leaf but variation in stems. In general, the rate coefficient (¡) in biomass partitioning in leaves was less than in stems. The trend indicated slow yet progressive decrease from panicle initiation (PI) to maturity and becoming almost negligible at maturity (Krishnan et al. 1998).

In general, partitioning from source to sink (panicle growth rate) was faster under direct seeded than in transplanted condition, but larger sink size emanated from transplanted conditions. Contribution pre-flowering stored carbohydrate to grain was more during the milky white stage > 43% that reduced to 35% towards ripening stage. However, pre and post flowering carbohydrate contributions were 39% and 61% respectively. A significant positive relation (r=0.89**) between dry matter accumulated between PI to flowering stage was associated with spikelet number under close spacing (10 x10 cm) with moderate nitrogen level (40-60 kg ha^{-1}) that was highly advantageous to exploit more number of filled grains (high density grain). Leaf area index (LAI) at flowering was linearly related with grain number (r=0.79**) indicating larger and functional source size at flowering eventually resulted in higher yield (sink size). Positive correlation of maintenance respiration with biomass production at early stages and negative correlation at post flowering stages indicated the possibility to identify cultivars having high biomass with less maintenance expenses even at high level of N supply and could be further exploited for breeding elite varieties (Swain et al. 2000).

4.3.1. Physiology of Hybrid Rice

Hybrids exhibited variation in terms of sink capacity and higher sink capacity in terms of panicle no. m^{-2} (CRHR 5), fertile grains $panicle^{-1}$ (CRHR7 and KRH2), low sink capacity but high partitioning rate (KRH-2 and PHB-71), high sink capacity but less partitioning rate (DRRH-1). 1000 grain weight and high translocation efficiency (HI > 0.50) with better grain filling rate (spikelet fertility > 80%) contributed to higher grain yield. Foliar application of GA_3 (30 ppm) in hybrid rice was found more effective in reducing spikelet sterility (20-30%) followed by IAA (17-22%) and Brassinolide (14-21%). Also GA_3 application being expensive, combination with other cheaper chemicals like Brassinolide was found equally effective in seed setting and grain yield, thus reducing the cost of seed production in hybrid rice (Baig et al. 1995, IRRN).

4.3.2. Physiological Efficiency of New Generation Rice (NGR)

The highest erecto-foliage leaf orientation coupled with higher LAI (5.0-6.3), highest leaf photosynthetic rate (35.2 - 49.1µ mole CO_2 $m^{-2}s^{-1}$), maximum photosynthetic quantum yield efficiency of PS II (Fv/Fm ratio of 0.770 - 0.808) with high performance index (2.21 - 3.84), high biomass (10-11 t ha^{-1}), high HI (0.52), high panicle number (340) and higher translocation efficiency with high grain filling percentage (>85 %) are key traits contributing for higher yield potential (more than 7-8 t ha^{-1}) with yield advantage of 0.5 - 1.0 t ha^{-1} over the checks in NGR lines.

Table 2. Elite Rice varieties identified for physiological efficiency.

Useful trait	Growing Condition	Elite Genotypes
High photosynthetic efficiency	Under normal light	Ptb 10, Mtu 15, Mahsuri, Co 41, Ratna, Saket-4, IR 58.
	Under low light	Ptb 10, Swarnaprava, Vijaya, Vajram
Low photorespiration		TKM 6, Triveni, Kanchan, Pusa 33, T(N) 1.
Low maintenance respiration		Rasi, T(N)1, Kanchan, Swarnaprava.
High translocation efficiency		Swarnaprava, IR 50.
High solar energy utilization	Biological Yield	Ptb 10, AC 4491, Bam 9, Swarnaprava, Saket 4.
	Economic Yield	Ptb 10, Pallavi, AC 4491
Nitrogen use efficiency at low inputs		Pallavi, Swarnaprava
Slow leaf and panicle senescence		Pallavi, Vijaya.
Low spikelet sterility		Pallavi, Saket.
High density grain (%)		IR 50, Swarnadhan.
Stresses	Low light	Ptb 10, Swarnaprava, Vajram
	Moisture deficiency	CR 143-2-2, Annada (MW10)
	Salinity	CSR 1,2,3.
	Water-logging	Utkalprava, Gayatri, Suresh, Tulashi
General high physiological efficiency		Ptb 10, (traditional) Swarnaprava (HYV)

4.4. Identification of unique rice germplasm and novel genetic information

Screening and evaluation of large numbers of genotypes for tolerance to different abiotic stresses, photosynthetic efficiency and grain and nutritional qualities led to identification of a few unique germplasm lines, which were registered through Plant Germplasm Registration Committee (PGRC), Indian Council of Agricultural Research, New Delhi. Some of the lines thus registered are,

- Unique rice germplasm Cherayi Pokkali (ICAR-NRRI Gene Bank Accession No. AC39416A) was identified and registered by PGRC (Registration number INGR19004) of ICAR. This rice germplasm is very unique as it possesses multiple abiotic stress tolerance, which is an utmost important character and can be used for developing climate resilient rice cultivars. AC 39416A is tolerant to drought, salinity and stagnant flooding at vegetative stage and moderately tolerant to germination stage oxygen deficiency (anaerobic seeding) and tolerance to combined stress of salinity and drought and water stagnation and salinity.
- Three rice germplasm lines Mahulata (AC No. 35186), Brahman Nakhi (AC- 35678) and Sal-kaiin (AC- 34992) as new sources of vegetative stage drought tolerance and one genotype CR 143-2-2 for both vegetative and reproductive stage drought tolerance having desirable root traits with high water use efficiency (WUE) are registered by PGRC, ICAR, New Delhi and are being utilized in different breeding programme.
- Unique Germplasm of Rice Khora-1 (ICAR-NRRI Gene Bank Accession No. AC41620) was identified and registered by PGRC (Registration number INGR19006) of ICAR. This rice germplasm is having exceptionally high anaerobic germination potential (AGP), a trait most important for rain-fed direct seeded rice. Also, a detailed analysis of underlying mechanism suggests existence of novel mechanism of AGP other than known role of AG QTLs in rice. This genotype is a potential source for developing novel AG (anaerobic germination) QTL(s) useful for direct seeded rice.
- Land races 'Bhundi' (INGR 14005) for Elongation ability and "Kalaketki" (INGR 14202) for Submergence tolerance, one unique germplasm AC41620 for high anaerobic germination ability and another unique germplasm AC39416 for multiple abiotic stress (salinity and stagnant flooding at vegetative stage and moderately tolerant to germination stage oxygen deficiency) were registered by PGRC, New Delhi.

Besides this few new gene sequences were identified and registered in NCBI gene bank, which can be used as basic source of information for transforming rice into a C4 plant. The sequences are

- *Sitaria etalica* Malic enzyme (NCBI Acc. No.MG999525)
- *Sitaria etalica* PPDK (NCBI Acc. No.MF593307)
- *Sitaria etalica* PEPC (NCBI Acc. No.MF967570)
- *Sorghum bicolor* Carbonic Anhydrase (NCBI Acc. No.MF593306)
- *Zea mays* PPDK (NCBI Acc. No.MF593305)

Other than this, we have generated global transcriptome database for multiple abiotic stress tolerance in rice. The gene expression data were submitted to GEO (Gene Expression Omnibus) of NCBI (National Center for

Biotechnology Information, NIH, USA) for its global public access. This database would help to understand the differential mechanism of tolerance in rice under waterlogging and salinity stresses by looking into expression profile of DEGs and uniquely expressed genes.

4.5. Rice Biochemistry

The prime determinant of consumer choice and marketability of a variety is its grain quality aspects. Thus, improving the nutritional quality of produce is imperative in the times of climate change to cater to the diverse dietary requirements of millions of people primarily dependent on rice. The division worked towards estimation and identification of germplasms with good nutritional profile for further breeding and improvement programs.

4.5.1. Grain Nutritional Quality

4.5.1.1. High Protein Rice: The nutritional status of a crop majorly depends on its protein content. Rice protein, when compared to other grains, is considered to be one of the highest quality proteins but although this cereal contributes to the diet of people around the world, milled rice is generally low in grain protein (6-7%). Since enrichment of rice grains with protein would have a positive effect on the nutritional profile, breeding programs for enhancing protein content was urgency.

To this effect, the Division contributed in evaluating around 3000 rice germplasm for grain protein content since 2004 and also found wide diversity for the trait (5-15%). Two low yielding germplasms from Assam rice collection (ARC10075, ARC10063) with high (13-15%) grain protein content in brown rice were identified. Cultivars with high protein content namely ARC 10075 (13%) and Heera (11.5%) were found to richer in nearly all amino acids. Heera was found to have highest amount of threonine, which is known to help maintain the health of the digestive system lining. Heera also had the highest amount of lysine, an essential amino acid. CR 2819-1-3 (12.08% CP), CR 2821-1-8 (11.9% CP), CR 2820-1-8 (11.8% CP) were identified as high protein F3 population along with high protein donor, ARC 10075-6 (11.75% CP). CR2821-1-5 (10% CP), CR2821-1-9 (10.8% CP) and CR2821-1-3 (10.0% CP) showed higher protein yield of 68 g m^{-2}, 46 g m^{-2} and 34 g m^{-2}, respectively than Naveen (30 g m^{-2}), Swarna (31 g m^{-2}) and IR 64 (24.1 g m^{-2}) (Govandaswamy et al. 1973).

The Institute has developed protein rich lines in high yielding backgrounds such as Naveen and Swarna suited for irrigated and favourable rainfed system namely CRDhan 310 (in Naveen Background) and CRDhan 311 (in Swarna background). The Twelve lines with high GPC and protein yield were subjected to protein fractionation. The glutelin fraction was enhanced compared to Swarna, while the Prolamin/Glutelin ratio was maintained. This indicated that the quality of grain protein also enhanced together with the amount of protein in high GPC breeding lines. Subsequently, a rapid method to distinguish between low and high protein rice grains was developed (Bagchi et al. 2016).

4.5.1.2. Glycaemic Index of Rice: Rice is nearly 90% carbohydrate on dry weight basis. Glycemic Index concept, as developed by David Jenkins, Thomas Wolever and colleagues ranks the quality of individual carbohydrate-rich foods on a scale of 1-100 by measuring how blood glucose levels rise after someone eats an amount of food that contains 50 grams of available carbohydrate. Foods are classified as low GI (GI, 55 or less), medium GI (GI, 56-69), and high GI (GI, 70 or more) types, when D-glucose is given a GI of 100. Refined, processed starches/ fruits have a higher GI. Whole grains, high fiber foods, whole fruits vegetables and legumes have lower GI. The GI value of rice varies widely (48-92) with an average value of 64 including the brown and milled rice. Rice contains less than 3% Resistant Starch or RS (mainly of type 5), which escapes digestion almost entirely and therefore its calories are unavailable for cells to use. The more the RS, the slower the digestion of rice and consequently the lower is the GI.

There is evidence to suggest that low GI diets reduce the incidence of diabetes, hyperlipidaemia and cardiovascular disease. GI values of milled rice of popular Indian varieties are higher (70-77) compared to those of brown rice (50-87) as per the 2008 international GI table. In this respect, an *in vitro* method for estimation of glycaemic index was developed and validated by the Division of Biochemistry. 102 varieties/germplasm from different ecologies were screened for glycaemic index (GI) using this in vitro method. Genotype PB177 was found to have the lowest GI (57.91). Large variation in the value of GI (57.50-76.40) and resistant starch (RS) (0.28-2.94%) was observed among 100 NRRI varieties. Among the genotypes studied, Shaktiman showed lowest GI (57.50) with relatively high RS (2.11%) while the highest value for GI (76.40) was found for Hue with lowest RS (0.28%).

4.5.1.3. Antioxidant Value of Rice: Antioxidants, the substances found in foods and dietary supplements help protect cellular constituents like proteins, lipids and DNA against the damage caused by free-radicals including reactive oxygen species (ROS), which are routinely produced during aerobic energy metabolism in our body. Brown rice (BR) or dehusked rice, which is obtained when paddy (rough rice) is subjected to hulling is rich in bioactive components such as dietary fiber, functional lipids, amino acids, vitamins, phytosterols, phenolic compounds, gamma-aminobutyric acid (GABA), minerals and many antioxidant molecules. To satisfy consumers' needs, the rice grain is usually milled into white rice, while the bran and husk are discarded. Most of the antioxidants are confined to the bran layer and endosperm and are absent from the milled rice. Pigmented rice is now gaining popularity because of its documented health benefits. In addition to its high protein, vitamin, and fiber content, it is a good source of a variety of phytochemicals including polyphenols, isoflavones, phytosterols, and anthocyanidins that have several beneficial functions in human health. The nutritional advantages offered by both brown and pigmented rice necessitate their inclusion in the daily diet to a greater extent. Hence, characterization of the colored and other rice for their antioxidant value needs to be a priority.

Research carried out in the division showed that the total anthocyanin content (TAC), total phenolic content (TPC) and antioxidant activity (ABTS) differed significantly among the pigmented genotypes with highest concentration of these parameters in the purple grain (Mamihungar), whereas no significant difference between the colour groups (red and purple) was observed for total flavonoid content (TFC), gamma-oryzanols and phytic acid content indicating that value of these parameters depends on genotypes and not on kernel color. A high correlation of TAC with TPC and ABTS suggests that the major phytochemicals responsible for the tested antioxidant activities are phenolic acids and anthocyanins. Estimation of the total phenolic content was found to be maximum in Lalbora (0.27mg/g GAE) and minimum in Mornodoiga (0.10 mg/g GAE). The free radical scavenging activity (RSA) of colored rice extracts was determined by the DPPH method to assess the antioxidant activity. The RSA was found to be highest in the rice Saathi and was lowest in Mugai.

4.5.1.4. Mineral Bioavailability: Fe and Zn are essential trace elements in human nutrition and their deficiencies are major public health threats worldwide. Unfortunately, rice does not furnish minerals adequately, because it contains only small amounts of Fe and Zn, and the loss of minerals (particularly Fe) during milling is high. In addition, rice contains phytic acid (PA), the most important anti-nutritional factor impeding availability of divalent cations. As an anti-nutrient, high levels of PA can affect the bioavailability of essential minerals such as Zn, Fe and Ca, as it is a strong chelator of divalent cations. The anti-nutritional properties of PA can be further extended to human health as it is considered to be the most important anti-nutritional factor contributing to the iron deficiency suffered by over 2 billion people worldwide. The undesirable properties of PA make the development and characterization of low phytate rice crops a high priority in agricultural research.

Studies carried out in the Division identified the NRRI rice cultivar CR Dhan 907 to be the richest in iron (20 ppm) followed by CR 3704 (14.1 ppm), the latter was also found to be rich in zinc (27.7 ppm). Studies were undertaken to enrich rice grains with iron and zinc, by which Fe content could be increased by 2-10 times and Zn by up to 2.6 times depending on variety. Rice variety Naveen was soaked in 1000 ppm of iron and zincs each and subjected to parboiling. The content of the two elements was determined in brown, milled and well washed milled rice prepared from the parboiled paddy grains. The washed milled rice grains of treated samples had 3-4 times more iron and zinc than the untreated control; for Fe, Control: 4.70 ppm and treated:19.05 ppm (in 1000 ppm Fe) and 19.47 ppm (in 1000 ppm Fe and Zn each); likewise, for Zn, control:14.5 ppm and treated 73.7 ppm (in 1000 ppm Zn) and 49.3 ppm in 1000 ppm Fe and Zn treated samples). The presence of iron and zinc was found to cause reduction in the absorption of the other element. A simple colorimetric protocol was also developed for mass screening of Fe in rice grain. Iron was first extracted from grain samples in dilute acid solution followed by heating on a boiling water bath. An aliquot of this solution was mixed with a colour forming reagent and the developed colour was measured in a spectrophotometer. The results were validated with a standard colorimetric method for iron estimation (R^2=0.739).

A simple colorimetric protocol was also developed for mass screening of phytate in rice grain. Phytate was first extracted from grain powder in dilute acid solution followed by heating on a boiling water bath. An aliquot of this solution was mixed with a colour forming reagent and the resulting colour was measured with a spectrophotometer. The results were validated with a standard colorimetric protocol of phytate estimation (R^2= 0.702). An inverse relationship was also found between PA content and Fe/Zn bioavailability among different varieties. The brown rice of Bindli, which had the lowest PA (0.82%) showed highest Zn bioavailability (12.51 ppm), while PB267, which had the highest amount of PA (2.62%) showed low bioavailability of Zn (8.94 ppm) and Fe (4.04 ppm).

4.5.1.5. Phytic acid content of rice including pigmented rice in brown rice grains: Iron and zinc are essential micronutrients for humans; their deficiency affects metabolism considerably with adverse effect on health. Rice does not provide these micronutrients adequately because the processing decreases their content in rice grains significantly. Not only this, presence of phytate in grain aggravates the problem as the interaction of phytic acid with proteins, vitamins and several minerals (Fe, Zn, Ca) further restricts their bioavailability. Phytic acid content was determined by an assay procedure specific for the measurement of phosphorus from phytic acid, myo-inositol (phosphate) and monophosphate esters by phytase and alkaline phosphatase using the phytic acid/total phosphorus assay kit (Megazyme International Ireland Limited). The 32 rice varieties already screened for Zn, Fe contents and the 22 colored rice varieties available in the institute were analyzed for phytic acid in the brown rice. The highest phytic acid content (2.83 g/100 g) was found in PB267 and lowest in Bindli (0.82 g/100 g) among the non- pigmented rice. In case of colored rice, lowest phytic acid was found in Mornodoiga (0.34 g/100 g), while the highest amount was found in Manipuri Black rice (2.97 g/100 g) followed by Mamihungar.

4.5.2. Grain Physico-Chemical Quality

The concept of rice grain quality varies with the consumer preference and the purpose (end use). But normally physical qualities like (grain size, shape and appearance), milling quality (the capacity to withstand the pressure of milling) and chemical quality which determines cooking characteristics and nutritional quality are the main determinants of rice grain quality. Though, the quality attributes are determined mainly by the genetic constitution, the environmental conditions and cultural practices have profound role in shaping the final product. Grain quality characteristics assume much more importance for rice compared to other food grains and are the prime determinants of market price, because most of the rice (almost 95% of production) is consumed as *cooked whole grain*. The current emphasis on quality rice is because of the increase in per capita income, which led to the increased demand for quality rice. Hence, breeding for improvement of grain quality has become a priority area of rice research.

Forty four promising aromatic, semi dwarf, high yielding breeding lines having medium slender grain developed from the crosses Swarna/Geetanjali (CR2937), CR689-116-2/Kalanamak (CR2938), Tillak Chandan/Kalanamak (CR2936), IR36/Basmati-370 (CR-2939), CRM 2203-4/Dubraj (CR2947) and BPT5204/Kalanamak (CR2941) were evaluated under Advance Yield Trial with Kalanamak and Badshabhog as checks and five cultures gave more than 5.00 t ha^{-1} yeild. The NRRI rice varieties Sarala and Gayatri were found to be the best for making popped rice as each of them exhibited ten times volume expansion.

Some popular rice cultivars from Nagaland and West Bengal were assessed for grain quality traits. It was found that the cultivar Nyakmok-V4 (Nagaland) and Kalabhat (W.B.) had very low amylose (9.59% and 5.32%, respectively). Long slender (LS) grain cv. Banskathi, which is very popular in the eastern parts of India and commands high market price showed an AC of 26.74% (high amylose rice) with GC = 38.2 mm.

Forty-four promising aromatic, semi dwarf, high yielding breeding lines having medium slender grain developed from the crosses Swarna/Geetanjali (CR2937), CR689-116-2/Kalanamak (CR2938), Tillak Chandan/Kalanamak (CR2936), IR36/Basmati-370 (CR-2939), CRM 2203-4/Dubraj (CR2947) and BPT5204/Kalanamak (CR2941) were evaluated under Advance Yield Trial with Kalanamak and Badshabhog as checks and five cultures gave more than 5.00 t ha^{-1}. Three promising aromatic genotypes CR2947-1, CR2738-2, CR2713-35, CR2934-39 and CR2934-35 having desirable quality traits were nominated for evaluation under IVT-ASG as new short grain entries for all India testing. One hundred single plants and 26 bulk populations belonging to F5 -F7 generations have been harvested in wet season. Duration of those lines varied from 120- 150 days. Average single plant yield was 40 g. Mean seed protein content of these genotypes was significantly higher (11.1%) than high yielding parents (9%). The F1 seeds from ARC10075/Swarna and ARC10075/ Naveen contained 14.5% crude protein. Highest seed yield/plant (71 g) was recorded in a line derived from Naveen/ARC10063 cross, but its protein content was low (8.85%). On the other hand, highest seed protein content (15.18%) was recorded in a line derived from ARC10075/Swarna cross with 36g seed yield. High protein yield/plant were recorded in CPL-C-2 (7.49 g), a line derived from IR64/ARC10063 and CPL-H-11 (7.29 g), a line derived from Naveen/ ARC10063 as compared to Swarna (4.27 g). Some genotypes such as CPLH-4 (5 and 12.04%) and CPL-B-3 (6 and 11.8%) were observed to have good alkali spreading value as well as high crude protein content. They could be preferred for their good cooking and nutritional quality. During the third cycle of purification, 153 panicle to row progenies of Kalajeera (three lines each) transplanted in 2011 wet season and no morphological variation was observed in the population. Six uniform Kalajeera pure lines with more than 19% amylose content were identified for seed production purpose.

The rice Aghoni was identified as a soak n eat rice earlier. With repeated cultivation at Cuttack, its soaking time increased from 40 min in 2008 to 90 min in 2010 at this institute. Later, two more *soak-n-eat* rice namely, Nalbora and Asham Biroin were identified in 2011 out of 32 Assam rice germplasm tested. A multi-location trial was initiated during 2012-13 in six states viz., Odisha, West Bengal, Assam, Bihar, Jharkhand and Meghalaya to identify regions most suited for cultivation of soak n eat rice, so that the harvested grains do not show increase in soaking time in subsequent generations. Out of the surplus received from four sites, increase in soaking time was noticed in samples of Aghoni and Nalbora obtained from Pusa (Bihar) and Ranchi (Jharkhand); there was no increase in the samples grown at Cuttack (Odisha) and Gerua (Assam). The grains of Asham Biroin not only showed increase in soaking time after the first harvest, but also retained a hard core and hence have been discarded.

4.5.3. Plant molecular biochemistry related to grain quality

Over the last few decades, the improvement in human nutrition and health in Asia has largely been attributable to stable and affordable rice supply. With almost sufficient production of rice, now the research focus is on better nutritional quality of rice with respect to micronutrient rich rice or rice with low anti-nutritional factors like Phytic acid (PA). Knowledge of the biosynthetic pathways related to micronutrients/anti-nutritional factors will permit genetic engineering of metabolic pathways to enhance the availability of micronutrients or to reduce anti-nutritional factors and hence help in improving the nutritional quality of rice grain. Phytic acid (PA) is the principle storage form of phosphorus in cereal grains including rice. PA acts as a strong chelator of metal cations to form phytate and is considered an anti-nutrient as it reduces the bioavailability of important micronutrients. With an aim to lower the amount of PA to an optimum level, this basic study has been carried out.

The enzyme IPKI plays a key role in the last step of PA biosynthesis. The rice *IPKI* gene (Os04g0661200) is highly expressed in developing rice grain and activation or suppression of this gene may result in alteration of PA biosynthesis and change in total phosphorus content in rice seeds. Expression analysis was done in developing grains of three rice cultivars (Bindli, Heera and PB267) having different levels of PA in grains. Lower level expression of *IPKI* was detected at the initial and final stages of grain development in all the three cultivars suggesting that the process of synthesis and accumulation of PA occurs during the mid-stage of grain filling. There was several fold increase in the expression level of *IPKI* in the middle stage in all the three genotypes.

Among these genotypes, PB267 showed highest expression of *IPKI* at the mid-stage of grain filling, which was positively correlated with their phytate content.

In an another study with an objective to enrich the micronutrient in rice grain the accumulation of ferritin protein and expression of corresponding gene was studied in two rice cultivars that differ in grain Fe content. Both Sharbati and Lalat, accumulated maximum ferritin protein in the flag leaf at 5 ppm of Fe in the growth medium beyond which the concentration declined; while the decline was gradual in Lalat up to 50 ppm, it was abrupt in Sharbati, showing almost complete inhibition at 15 ppm of Fe. Differential response of the cultivars to higher level of Fe might be due to the fact that the low Fe cultivar, Lalat, was perhaps inefficient in absorbing and translocating the element within the plant. Further the study was extended where the candidate genes of Fe homeostasis were studied for their expression in rice genotypes having different grain Fe content. Expression of the genes varied among the cultivars as well as different tissues within a cultivar.

Recently molecular analysis of 227 lines of Machhakanta and 234 lines of Haladichudi was done with 24 highly variable Rice Microsatellite (RM) markers. Out of 24 markers, fifteen and seven markers could detect polymorphism in Machhakanta and Haladichudi populations, respectively.

5. IMPACTS

5.1. Rice physiology

Newer technologies in respect of development of rice cultivars tolerant to submergence, multiple abiotic stress tolerance are arising day by day through sharing of materials and knowledge developed by the division through in-house and out-house project. Technologies developed in relation to seed and seedling qualities are being applied in farmers' field through IRRI-ICAR-NRRI collaborative programme namely Stress Tolerant Rice for Poor Farmers in Africa and South Asia (STRASA) as well as through National Initiative on Climate Resilient Agriculture (NICRA), ICAR, India. Swarna-Sub1 developed by IRRI, however, it was tested and released by this institute in India. Swarna-Sub1 now occupies millions of hectares of land in India.

Rice variety CR Dhan 206 was released in 2014 by SVRC Odisha for aerobic ecosystem, using Brahman-nakhi, a drought tolerant donor. This variety is of 115 days duration having yield potential of 3.95 t ha^{-1} with moderately resistant to leaf blast, brown spot, Sheath rot, stem borer and leaf folder. GEB-24 a traditional variety identified for high photosynthesis was used as a parent in breeding programme for development of high yielding variety Krishna in 1970. Another elite variety T 90 efficient for photosynthesis under low light was used as parent in development of high yielding variety Vijaya and Jayanti in 1970s and CR 1014 in 1988. TKM 6 identified for low photorespiration was used as a parent for development of variety Saket 4. Tinan 3 M- a mutant with high photosynthesis was used for development of Indira in 1980. Late variety Jagannath with high photosynthesis and Pankaj for low photorespiration was used for development of Savitri, Gayatri, Dharitri etc in 1980s which are still popular in many states. MTU 15 used for Annada in 1987, Vijaya for Kshira (1988) and Pooja (1999) still prevailed in seed chain as a best popular variety in Odisha. CR 1014 was used to develop Sarala, Durga, Tulasi, Tara, Panidhan etc. during 1988s. Sigadis, Latisail, CR1014, PTB10, CN 540, etc. were used in many crosses for development of high yielding varieties.

Drought tolerant genotypes C22 and Kalakeri were crossed to develop Vandana (1992 and 2000). Lalnakanda 41 used to develop CR 143-2-2, a unique breeding line having both vegetative and reproductive stage drought tolerance which also got registered by PGRC in 2017. Brahman-nakhi used for development of CR Dhan 206 (2014) which is getting popular in rainfed upland areas. Some of the drought tolerant identified lines viz, Annapurna, Selumpikit, CR 143-2-2, C 22, Lalnakanda 41, Browngora, Blackgora, Rasi, Kalinga III, MTU 17, Dular, two accessions of *O. nivara* (AC 100374, AC 100476) were used in many crosses for development of drought tolerant varieties. Some mutants were also developed from the identified lines for different traits. Mutant of identified lowlight tolerant variety Swarnaprabha was developed as Radhi in 1996, high photosynthesis variety CR 1014 was developed as Padmini in 1988 and drought tolerant variety Ch-45 was developed as Chandan in 2008.

Strategic research for identification of markers/traits associated with submergence, multiple abiotic stresses (salinity, stagnant flooding, anaerobic germination, and drought) could address the need of the day in developing suitable cultivars / technologies for flood prone as well as coastal areas of South and Southeast Asian countries. Several publications were made which were quoted by several workers working on the aspects as evident from citation indices. Cloning and introgression of *SUB1* into mega varieties provided a good protection against short-term submergence. Greater efforts are needed to further enhance tolerance to flash-floods as well as to stagnant long-term flooding, predominant in most flood-prone areas. Cultivars with multiple abiotic stresses tolerant are needed to address climate change effects. The new genetic resources are now the sources of identification of new genes/ technologies and for mechanistic studies.

Characterization of floodwater and impact of each parameter on survival improved our understanding and helped in developing better screening methodology and explaining reasons for variability in survival/mortality of a cultivar at different places. We have standardized screening technique based on the floodwater characteristics. Now it is possible to identify tolerant cultivars even in the laboratory and their performances at different locations could be predicted with greater accuracy. Dry- and wet-seeding methods are becoming more popular not only with rice farmers of rain-fed lowlands but also with the farmers of irrigated ecology as because they require less labour and time than transplanting. However, direct seeding has some inherent problems due to which sometimes farmers are reluctant to adopt this technique. Anaerobic germination tolerance can solve this problem to an great extent. Pioneer work in India on this aspect was done in the Division (Sarkar et al. 1999).

Physiological basis of tolerance to different abiotic stresses have made wider our understanding based on which rice cultivation technology is being developed. Different ecosystems require different types of cultivars. Now it is feasible to identify cultivars suitable for flash-floods/water-logging/anaerobic germination/salinity/multiple abiotic stresses tolerant based on the understandings and identification of physiological markers.

5.2. Rice biochemistry

Research conducted in the division aims at understanding the basic mechanisms underlying physiological and biochemical responses of crop. In addition, evaluation and intensive screening of germplasms for various nutritional parameters are carried out routinely to identify suitable donors for various quality traits for further improvement programs. Likewise, the division has contributed immensely to the varietal development program of the institute. Two varieties were released in 2016 by NRRI, Cuttack with high protein content using donors identified by Biochemistry division. High Protein rice CR DHAN 310 was released by Central Variety Release Committee (CVRC) in 2016. This is the first high protein (10.2%) rice variety in national level and has medium slender grains. This is an introgression line (CR 2829-PLN-37) in Naveen background. The average grain yield in national level was 4.5 t ha^{-1}. Another nutrient rich rice MUKUL (CR Dhan 311) (IET 24772: CR2829-PLN-100) was released by SVRC, Odisha in 2016. It has high protein (10.1%) and moderately high level of Zn (21 ppm) in Naveen background. It is medium early (125 days) with long bold grain. The average yield at national level was 4.1 t ha^{-1} and in Odisha- 5.5 t ha^{-1} (in AICRIP trials) and 4.6 t ha^{-1} (farmers' fields in Odisha).

6. PUBLICATIONS

Since inception our division had published numbers of peer reviewed research articles in journal of International and National repute. More than 400 research articles were in different journals, which promoted the basic concepts, newer knowledge and strategic researches in the field of abiotic stress tolerance in rice, enhancement of photosynthetic efficiency in rice, growth and production physiology, etc. The last ten years' publication trend of the division highlighted almost equal numbers of research papers in journals of NAAS score more than 8 (30), score of 6-8 (33) and score of less than 6 (34).

7. HUMAN RESOURCE DEVELOPMENT

In addition to the research work this division is also engaged for training and guidance to Junior Scientists/Research Scholars for PhD/MSc programs and professional trainings. Since inception a total of 22 research scholars obtained their PhD degree by working under the supervision of different scientists of this division. Also 9 student carried out their dissertation work under the guidance of the scientists of this division.

8. LINKAGES

Since inception Crop Physiology and Biochemistry attracted fairly good external linkages with different National and International research organization/ institute and/or funding bodies. The division received financial help in terms research grants, which strengthen and intensified the research work of the division. The Rockefeller Grant (prior to 1960), Colombo Plan (aid from Japan in 1974), PL-480 Project for Photosynthesis (1980-90), Canadian line of credit (1978), IRRI-Collaborative Program under IRWYN (1982-84), National Fellow Award (1984-88), Emeritus Scientist Award (1989-92) were few notables which helped in developing divisional infrastructure and also established good research linkages outside this institute. Besides, in last few decades this division had good research collaboration with International Rice Research Institute (IRRI), Philippines in terms of active participation in different IRRI-ICAR collaborative projects *viz*. STRASA and others.

9. ASPIRATIONS

From the beginning, the division is engaged in both basic and strategic research in relation to abiotic stress tolerance, photosynthetic efficiency, crop Ideotype concept, enhancement of nutritional and grain quality of rice. Till date, considerable progress had been made in these areas. However, we feel there are still plenty of research opportunities remained to be explored in the above mentioned aspects. In next few years our division would like to focus on some of the emerging and most important areas of research such as.

- Reduction of energy cost for various abiotic stress tolerance in plants which include stresses like salinity, submergence, drought, heat, germination stage oxygen deficiency etc.
- Understanding the plant behaviour and underlying mechanism of simultaneous multiple abiotic stress tolerance.
- Development of C4 rice for better photosynthetic efficiency and yield enhancement.
- Identification and characterization of CO_2 responsive and thermo-tolerant rice genotypes suitable for climate resilient rice cultivation.
- Identification and development of Diabetic Rice with low Glycaemic Index.
- Development of nutrient rice with high iron (Fe), zinc (Zn) and phytate content.

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Socio-economic Evaluation and Transfer of Technologies: Activities, Achievements and Aspirations

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SUMMARY

The Social Science Division of ICAR-National Rice Research Institute has undertaken several socio-economic studies, impact assessment programmes, capacity building measures and shared advanced technical knowledge with different stakeholders to enrich and update them with advances in agricultural science and bring a visible change in life of farmers engaged in rice farming. The Self–Sufficient Sustainable Seed System for Rice (4S4R) is one of such initiative of the Division. Effective interventions were made with farmers' Farm, Innovation, Resources, Science and Technology (FIRST) Programme, Mera Gaon Mera Gaurav (MGMG) Programme and Front Line Demonstration (FLD) Programme for diversifying the income portfolio of the farmers. During the last five years the division has reached out to 144 villages and benefitted >27000 farm families through various technological interventions; five Farmers' Producer Companies (FPCs) were successfully registered; >60000 visitors had given agro-advisory services and about 5000 participants were trained on different rice based technologies and agri-entrepreneurial aspects. In this Chapter, different activities and achievements of the Division have been compiled and aspirations highlighted.

1. INTRODUCTION

In Indian agricultural canvas, the challenges may vary from increasing population (>1.3 billion) to declining average operational land holding area (1.08 ha), indebted agricultural households (51.9% of agricultural households), sole dependency on agriculture (63.4% of households derive their income from agriculture), highest rate of urban land expansion (Seto et al. 2012), poor market infrastructure (6746 regulated markets out of 26519 total agricultural markets), limited reach of government program and schemes (MSP benefits about 20% of the total farmers) and so on. Underneath these challenges lie opportunities to partner with the locals in the identification of their most pressing needs and devise the sustainable solutions to the problems.

ICAR-National Rice Research Institute, as one of the pioneer research Institutes on rice, which is staple food for more than 60% of its population and provides livelihood to 150 million people of the country has an added advantage of reaching to the millions of the farmers, share croppers/tenants and landless poor through its high yielding varieties and rice-based technologies to answer the pressing problems. The Institute, through its dedicated Divisions, strives hard to maintain balance with the basic/ fundamental research and science on one hand and transfers the new knowledge and technologies to farmers to augment their well-being on another hand. Over the years, the Division has evolved itself by incorporating knowledge, techniques, methods and approaches from other subjects such as psychology, sociology, communication, entrepreneurship, information technology and so on. The Social Science Division also undertakes fundamental research for developing methodologies, models and approaches for rapid dissemination of institute's technologies to its users and getting feedback on it from the users. The Division also provides platform to evolve and develop the subject based on the objective-oriented research related to identified theme areas and interaction among the Extension professionals and to attain this objective, the Division had organized 1st International Extension Congress in year 2018. In this chapter, the genesis of the Social Science Division, its objectives, activities, achievements and the significant impacts that the Division has made over the years have been discussed and future aspirations of the Division have been highlighted.

2. GENESIS AND OBJECTIVES OF SOCIAL SCIENCE DIVISION

At the beginning, there existed distinct sections like Extension Communication and Training section and Economics and Statistics sections, which were working independently. Later these sections were clubbed under the Extension Communication and Training (ECT) Division in the year 2009 which later evolved into a full-fledged Social Science Division. In the Institute, social science activities got its significance since the Green Revolution period when the institute has released its first rice variety "Padma" in 1968 for farmers. The Division since its beginning is associated with the social scientists that have played a very key role in communicating new and advanced technical knowledge to rice growers of the country and also provided the feedback on the performance of the institute's technologies to the concerned Divisions for its improvement and the evolution of the new technologies. The Division serves the institute with its dedicated team of scientists from Extension, Economics & Statistics and technical officers and skilled manpower. The Division operates with the following objectives:

1. Development of socio-economic approaches, models and strategies for rapid transfer of technologies for sustainable rice production.
2. Characterization of resources, socio-economic and institutional constraint analysis, creation,

3. Demonstration of technologies in the farmers' field and evaluate and validate their performance.
4. Dissemination of rice production technologies through publications, advisory services, exhibition, workshop, interface, special days, etc.
5. 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.
6. Impart training to rice research workers, trainers and subject matter/ extension specialists on improved rice production and rice-based cropping and farming systems.

3. MAJOR ACTIVITIES OF THE DIVISION

The Division undertakes various activities, which are crucial for the conduct and performance of Institution. These activities can be broadly classified into two categories: research activities and supportive activities.

Research activities include translational research, impact assessment, database maintenance, capacity building for the visitors and trainees, human resource development; ICAR's face lifting activities like transfer of suitable technologies, expansion of the reach of the institute to new regions and providing agro-advisory services which assist the farmers in risk minimization. Albeit its involvement in various activities, it has performed well in the research front and the following section describes its research outputs and outcomes. The Division has undertaken different research projects under broader areas of development of approaches and models for technology dissemination, evaluation and testing, gender sensitivity, impact analysis, database updation, assessment and adoption of various rice production technologies, characterization of resources and innovations to add to rice research in the country and other areas of contemporary importance (Fig. 1).

Fig. 1. Major research projects and activities of the Division in last few years.

4. ACHIEVEMENTS OF THE DIVISION

4.1. Socio-economic approaches and methods for technology transfer

4.1.1. Development of model villages for sustainable and profitable rice farming

Approaches for development of the rice-based model village in the rainfed situation have been undertaken in *Gurujang-Guali* Cluster, *Tangi-Choudwar* Block of Cuttack district with two major interventions viz., varietal substitution of rice in different ecologies and crop diversification for improving the livelihood of the households. Strategies like broad-based participation through the inclusion of scheduled caste and women farmers and cultivation of vegetable under crop diversification after rice using available water were also tried. Assessment of returns from different cropping sequences introduced in the cluster indicated that rice-onion crop sequence was more remunerative than any other type of vegetables like bhindi, cucumber, tomato, pumpkin, bitter gourd in the rice-based cropping systems. Among various socio-economic characteristics; land holding size, non-farm income, labour force participation rate, provision for irrigation etc. were important factors apart from the improved traits of rice varieties like high yielding potential, low disease infestation and better grain quality for their adoption as well as shifting of crop choices by the farmers.

4.1.2. Gender-sensitive extension approaches in rice farming

Under this approach, intense gender sensitization was a pre-requisite which followed the capacity building of women rice growers through training, workshops, demonstrations, group discussions, counselling and exposure programmes. Both men and women got equal opportunity to exchange their experiences and feelings to garner community support to women rice growers in many critical areas of the gender gap.

Various interventions were taken up in *Sankilo* village of Cuttack district in order to design and test gender-sensitive approaches in rice farming. Demonstrations of seven rice varieties with improved technologies by 30 farm-women on 0.5 acre land each were conducted with women perspective. Besides, awareness training on IPM in rice, training-cum demonstrations in paddy-straw mushroom cultivation, NRRI rice parboiling unit and rice-husk stove, etc. was also conducted. It was assessed that almost all of the women farmers have participated in the activities like nursery management, uprooting, transplanting, water management, harvesting, threshing,winnowing, storage and value addition. In case of accessing resources/inputs for rice cultivation, majority of respondents were very successful like training (100%), land (93.33%), family labour (93.33%), threshing floor (93.33%), polythene bag (93.33%), etc. whereas, 30% did not succeed in accessing marketing and market information. It was also observed that majority had full control over rice chaff

(80%) and straw (70%) and the women growers perceived that their recognition in the family (100%), in the community (66.67%) and at the organizational level (60%) had increased.

4.1.3. Strategies for popularization of rice varieties

During the last five years the institute has developed 35 varieties; however, its spread was slow. Therefore, an approach was developed to popularize NRRI varieties and include it in DAC indent. Traditionally, state departments used to get information regarding new varieties from VIC document or institute. This was not enough to place breeder seed demand of newly released varieties in DAC indent. Generally, the demand for breeder seed of newly released varieties is created from block level, therefore, above approach was developed in which result demonstration was conducted at block level in farmers' field and Field day was observed in presence of state-level officials from Department of Agriculture. Based on the result, the state department placed DAC indent of recently released varieties.

4.1.4. A Self–Sufficient Sustainable Seed System for Rice (4S4R)

Water and quality seed are the two most important factors affecting Indian agriculture. The 4S4R model deals with seed. In case of seed, there are five important problems viz. the right quality of seed, right quantity of available seed, right time of supply of seed, right choice of varieties and right cost of production. Self-sufficient Sustainable Seed System for Rice (4S4R) model (Fig. 2) provides solutions to all these problems (Mishra et al. 2018).

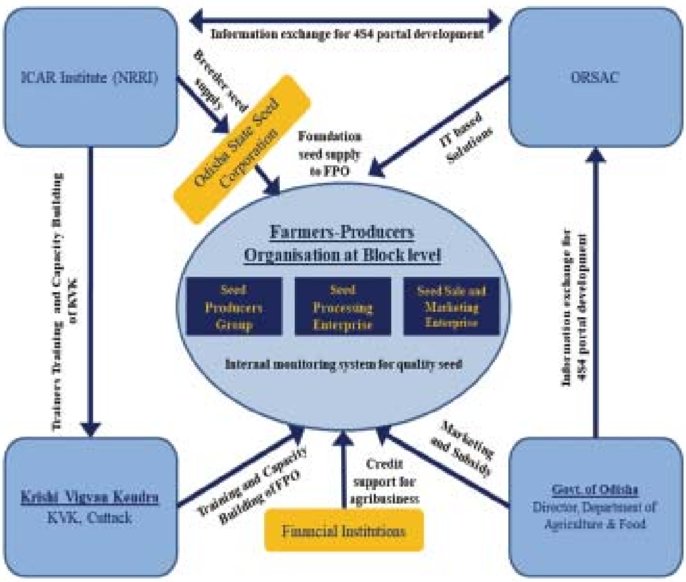

Fig. 2. Conceptual framework of self–sufficient sustainable seed system for rice (4S4R).

4.1.5. Rice Value Chain

The main objective of NRRI developed rice value chain (Fig. 3) was to promote large scale cultivation of high quality and speciality rice varieties of this institute in contiguous patches, and to undertake its processing and trading, so that the consumers have access to premium quality rice and all parties involved in the value chain are benefitted.

4.1.6. Rice-based climate-smart model village through convergence

Approaches for development of the rice-based model village in the rainfed situation have been undertaken in Gurujang-Guali Cluster, Tangi-Choudwar Block of Cuttack district during the last three years through convergence mode. Two major interventions namely, (i) varietal substitution of rice in different ecologies and (ii) crop diversification have been focused besides targeting holistic development of the village for improving the livelihood of the households (Das et al. 2017 and 2018).

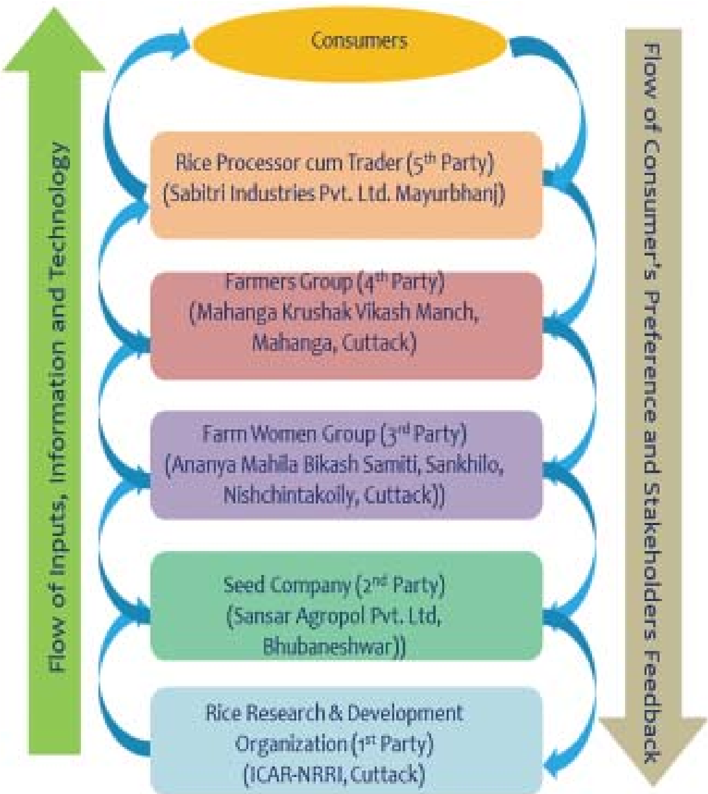

Fig. 3. Conceptual framework of NRRI rice value chain model.

4.2. Dissemination of rice-based technologies

4.2.1. Demonstration of NRRI rice varieties

Varieties like Rajalaxmi (7.3 t ha^{-1}), Ajay, Satyakrishna, Chandan, Sahbhagidhan, Phalguni, CR Dhan 300, Swarna*Sub1*, Naveen, Pyari, Luna Sankhi, Satyabhama, Lalat MAS, Chandrama, Geetanjali, Abhishek, IR 64 *Sub1*, Hazaridhan, Sadabahar, Hue, Kamesh, etc. were demonstrated during dry-season. While Rajalaxmi, Ketekijoha, NuaKalajira and Geetanjali, were demonstrated during the wet season. In the upland situation, the varieties Sahbhagidhan, Abhishek, Kamesh, and Hazaridhan were tested and under the irrigated situation, the varieties Satyakrishna, Phalguni, Chandrama, Chandan, Swarna*Sub1*, Naveen, Pyari, Lalat MAS, Satyabhama, IR 64 *Sub1* and IR 64 MAS, etc. were demonstrated. In the year 2018-19, NRRI rice varieties CR Dhan 305, 202 and IR64 *drt1* were demonstrated in Jharkhand state. The results of the crop cutting experiment indicates that IR 64 *drt 1* has outperformed (>15% yield advantage) Sahbhagi Dhan (Local Check) in the farmers field. In the state of Bihar, CR Dhan 201 has provided yield advantage of 6% over and above the local check Sahbhagi Dhan. In the state of West Bengal, NRRI varieties CR Dhan 307 (Local check- Swarna) and CR Dhan 304 (local check IR 64) have given the yield advantage of 29.46 and 19.39% respectively. In the state of Odisha, CR Dhan 304, CR Dhan 307, CR Dhan 508, CR Dhan 206 and CR Dhan 800 have given yield advantage of more than 15% as compared to the local checks (Fig. 4).

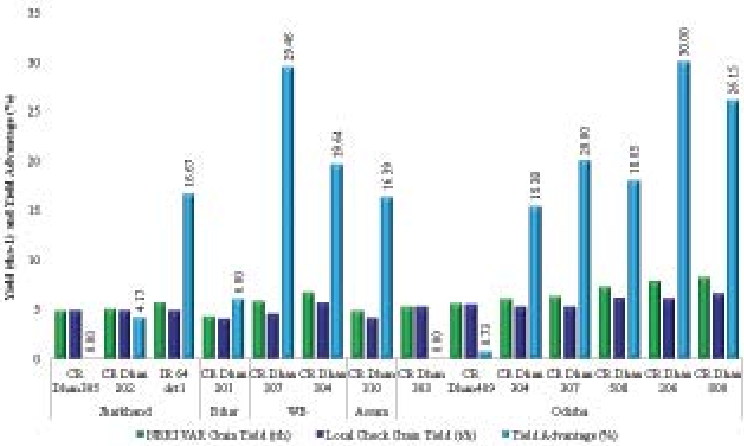

Fig. 4. Performance of NRRI rice varieties in comparison to popular local checks.

4.2.2. Dissemination of rice production technology through KVKs

On-farm trial (OFT) was conducted by KVK Santhapur on "Assessment of Bensulfuron methyl + Pretilachlor (Londex power) in transplanted rice" in an area of 2.5 ha involving 10 farmers. The most popular rice variety "Pooja" was taken by the farmers which yielded 5.20 t ha^{-1} in treated plot and 5.02 tha^{-1} in farmers' field. The yield increment was only 4.6% but the total savings was Rs. 7000 due to savings of labour cost in hand weeding. Several off-campus training programmes related to rice covering the topics "Scientific nursery raising for healthy seedlings", "Integrated nutrient management in rice", "Integrated weed management in rice and "Integrated pest management in rice" in different villages for 300 farmers, farm women and rural youth were conducted. On-farm trials on suitable weed management for DSR, newly released short duration varieties of rice for DSR and effect of brown manuring on the yield of paddy were conducted by KVK, Koderma. Demonstrations with variety Sahbhagi Dhan and Abhishek were conducted as well as several training courses were organized in integrated nutrient management, water harvesting, seed production technique, vermicompost production, balanced fertilization, System of Rice Intensification and advance agronomical practices for increasing oilseeds and pulses production, contingent crop and resource conservation technologies, etc. were demonstrated.

4.3. Impact evaluation of rice-based technologies

4.3.1. Assessment of adoption of rice production technologies

Adoption of NRRI varieties studied from a representative sample of 100 farmers having rice in the irrigated shallow to semi-deep lowland ecosystem and exposure to NRRI rice varieties were assessed and it was reported that the majority (88%) of the farmers adopted rice variety Gayatri, followed by Pooja (83%), Varsha Dhan (25%) and Sarala (25%). In terms of the area also, most widely grown variety was Gayatri (49%) followed by Pooja (35%).

4.3.2. Estimation of the area under NRRI varieties

The variety wise seed distribution and HYV area information for 5 years (2008-09 to 2012-13) were used to estimate the area under different rice varieties in the Indian states. West Bengal, Odisha, Assam, Chhattisgarh and Uttar Pradesh states have a significant area under NRRIs rice varieties (Pathak et al. 2018). The rice varieties with larger area coverage in Odisha state are Swarna, MTU-1001, Pooja, Lalat, MTU-1010, Pratikshya and Khandagiri and NRRI varieties covered 698,223 ha in the state and accounted for 20.4% of the total HYV area in the state. In Maharashtra state, rice is grown mainly during *Kharif* season and the mega varieties (covering more than 1 lakh ha area) of the state were MTU-1010, Indrayani, PKV-HMT, Ratna and Jaya. The NRRI variety Ratna was grown to the extent of 133,255 ha in the state and mainly confined to the Konkan region. In Madhya Pradesh also rice is grown predominantly during *Kharif* season and it was observed that the mega varieties of the state were IR-64, Kranti, IR-36 and MTU-1010. NRRI varieties were grown to the extent of 22,455 ha in the state. Information with respect to Tripura state revealed that varieties like Swarna, Pooja, Naveen, and NDR-97 covered maximum area under rice. NRRI released varieties were grown to the extent of

73100 ha in the state and accounted for 25% of total *kharif* HYV area and 48% of total *rabi/summer* rice area. Similarly, information for Chhattisgarh state revealed that the coverage of HYV rice in the state was 63%. The *rabi/summer* rice accounts for only 3.2% of the total area under rice. The rice varieties which covered maximum area were MTU-1010, Swarna, MTU-1001, Mahamaya, IR-64 and IR-36 and these varieties covered about 55400 ha in the state.

4.3.3. Evaluation of public-private partnership in adoption of rice transplanter in Odisha

Secondary data regarding the spread of rice transplanter revealed that public-private partnership (PPP) mode of promotion is effective for their adoption in Odisha. The rapid adoption stage is in progress and the number of transplanter purchased by farmers in PPP mode during the year 2013-14 was 634 from a mere three numbers during 2005-06. The transplanters are adopted by large farmers mainly in irrigated areas of Balasore, Cuttack, Kalahandi, Kendrapara, Puri, Sambalpur, Sonepur and Sundergarh districts to overcome labour shortage during the peak period. Among the models approved by the Government, the model promoted by VST Tillers and Tractors i.e., Yanji Shakti 2ZT-238-8 has been adopted by a majority of the farmers followed by the model promoted by Kubota Agriculture Machinery India Pvt. Ltd., i.e., NSP 4W due to aggressive marketing by these two firms. Further, analysis of primary data from 60 transplanter owners covering fifteen districts in Odisha revealed that the cost of transplanting by use of self-propelled transplanter was Rs. 6,750 ha^{-1} in inland Odisha in comparison to Rs. 12,650/- in manual transplanting. The labour-saving due to transplanter use was 53 man-days per ha over manual transplanting. Among the total farmers covered, the distribution of small and marginal farmers were 42% and 92% respectively in the state.

4.4. Entrepreneurship Development

4.4.1. Development of entrepreneurial modules for selected NRRI technologies

A Trainer's Training Module of five-week duration for entrepreneurship development on NRRI Rice Technology (TED-CRiT) on commercial (50 acre), medium (7.5 acre) and small (0.5 acre) rice-fish integrated farming systems models were developed which contained sub-modules such as entrepreneurial motivation, general management, finance management, production management, labour management, marketing management and business plan development etc. These modules were developed to train the potential entrepreneurs to undertake new startups in agricultural sector.

4.4.2. Development of community-based business modules in rice technologies

Under the activity-develop resource-characterization based T-EDP modules of NRRI technologies for community-level adoption, Sakhigopal block of Puri district was selected based on the reports of the extent of mechanization. The State Government has provided subsidy for the purchase of tractor (97), power tiller (76), reaper (43), power-driven equipment (118), rotavator (56), transplanter (6), combine harvester (1), special power driven equipment (15) and hydraulic trailer (31). Further, as part of developing T-EDP module, the business plan was developed and profitability projections were made.

4.5. Resource characterization, database and information management

4.5.1. Resources characterization to aid rice research

As part of designing resource-characterization based general simulation model of diffusion of rice technologies, adoption data were collected from 19 locales situated at 50 km grids from NRRI. The data were interpolated using the Inverse Distance Weighted (IDW) scheme which resulted in the generation of interpolated rice variety adoption maps and the results revealed that a large area of rice fields was predominantly covered by high yielding varieties of rice (08.35%), while the rest of rice fields (31.65%) were covered with local varieties. Using the grid data of adoption for various HYVs, maps were generated. It was found that Pooja was the most popular variety covering 17.69% of rice area followed by Sarala (6.54%) and Gayatri (6.38%). The diffusion of NRRI varieties was positively correlated with the easiness of labour availability. Further, the diffusion rate was regressed with labour availability, pesticide availability, distance of selling produce, percentage of lowland, percentage of medium deep-water land, percentage of irrigated land, percentage of coastal saline land and acreage of other HYVs and the results showed that 73.6% of variations can be explained by change in independent variables and almost 50% variation was attributed to change in labour availability and percentage of irrigated land.

4.5.2. Development and maintenance of rice knowledge management portal

NRRI developed a digital photo library on rice-related information such as various stages of rice plant growth, insect pests of rice, diseases of rice, implements/machinery used for production and post-harvest of rice, varieties, etc. as consortium partner of the portal. Besides, documents of Government schemes and extension programmes on rice were collected, digitized and uploaded in rice portal. Sixty one-minute spot films and one 17 minute documentary film were produced and made available on the portal. In order to make the portal popular, a capacity building workshop was organized for 60 participants from Odisha, Bihar, Jharkhand and Chhattisgarh at this Institute and they were exposed to the Rice Knowledge Management Portal and its utility in disseminating rice related information to the farming community.

4.6. Developing strategies to double farmers' income

The institute has developed a comprehensive document on strategies to double farmers' income in Odisha state (Pasupalak et al. 2018) and also suggested the strategies to double farmers' income in rice sector for India (Samal et al. 2017).

4.7. Capacity Building

The Division is also engaged in capacity building via different trainings, exposure visits and workshops for the visitors around the years. Figure 5 represents the number of training programmes organized and the participants benefitted out of these trainings in last five years.

The Social Science Division has played a key role in displaying the new technologies to the farmers through its participation in various exhibitions across the country. By its exhibits, the Division has opened a window for dissemination of NRRI technologies and thereby contributing in technology transfer and knowledge sharing in the society. Fig. 6 depicts the year wise participation in exhibition for last few years.

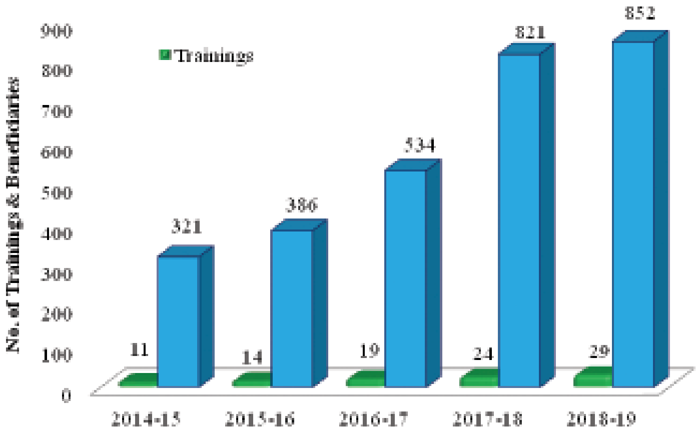

Fig. 5. Number of vocational training organized and the number of beneficiaries in the last five years.

4.8. Exhibition

The Social Science Division has played a key role in displaying the new technologies to the farmers through its participation in various exhibitions across the country. By its exhibits, the Division has opened a window for dissemination of NRRI technologies and thereby contributing in technology transfer and knowledge sharing in the society. Fig. 6 depicts the year wise participation in exhibition for last few years.

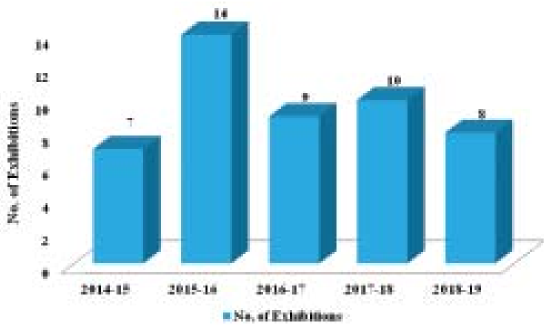

Fig. 6. Year-wise participation in the exhibition.

4.9 Research publications of the Division

The testament to the research work undertaken by the division is reflected in its publications. The publications from the Social Science Division has a range from research articles to book chapters, popular articles, technical bulletin, training compendium, extension bulletin etc. In last five years (2014-15 to 2018-19) the Division has published 52 research articles out of which 20 (38%) were published in impact factor journals with NAAS score >6. Also, the Division has published 14 book chapters, 12 popular articles, 3 technology bulletins, 24 training compendiums, 13 extension bulletins and presented papers in 20 symposia during the same period.

5. IMPACTS OF THE DIVISION

5.1. Socio-economic approaches and methods for technology transfer

Farmers in the villages where NRRI intervened with improved varieties and other improved production technologies were growing local rice varieties (e.g. Saruchina, Kalamata, Mathura) and harvesting very meagre yield. The improved varieties namely, Sahbhagi Dhan, Swarna-Sub1, Pooja, Ketekijoha, Varshadhan and Naveen were adopted by the farmers which produced almost doubled yield and they cover around 63% of the cultivated rice area. It was also reported that vegetables grown after rice provided better opportunities to the women for employment, family nutrition and income as indicated by the farmers.

Due to embracing of gender-sensitive approaches in rice farming through NRRI intervention, the women growers perceived that their recognition in the family (100%), in the community (66.67%) and at the organizational level (60%) increased. Similarly, there were major changes in the mindset of male members of family/society towards women-managed rice farming (90%) and need for their exposure to rice knowledge (93.33%). Remarkable changes in the behavior of women rice growers were found with regard to knowledge (100%), skill (93.33%), decision-making capacity (86.67%) and group effort (76.67%), respectively.

As a part of action research on empowerment of tribal women engaged in rice-based farming activities in Balasore district of Odisha, about 120 farm-women from three villages were organized into twelve Self Help Groups. Eight income-generating activities in rice-based farming systems were selected for empowering women depending on the capacities and opportunities they had. Extension methods *viz*., group approach, training, demonstration and advisory services were organized for the group on the identified interventions. An index to measure the extent of empowerment was developed by identifying nine relevant indicators and the overall gain in empowerment was found to be 25.6%, which was mainly due to the expansion of income generation activities.

The impact assessment of Swarna-*Sub1* was carried out in the submergence/ flood prone project area to assess the area spread and benefits accrued to farmers. Two surveys were conducted to assess the area spread, one before the introduction of the variety (during 2009) to assess the area under existing varieties and the other, four years after the introduction (during 2013) by interviewing 100 farmers. Until 2007 *Kharif* season, Swarna-*Sub1* was confined to one farmer in the mother trial. Encouraged by its performance, neighbouring 13 farmers have grown the variety in 3.5 ha area in rainfed shallow lowland during 2008 (Mondal et al. 2018). By 2012 *Kharif* season, the variety has covered 35.7% of the shallow lowland in the project area and almost all the farmers have adopted the variety. The varieties which were replaced by Swarna-*Sub1* were Swarna, Jangalajhata, Gayatri and Pooja because of its submergence tolerant ability and comparable grain quality. Further, data analysis revealed that Swarna-*Sub1* has a marginal advantage in yield and income over its competing varieties. The yield advantage was 8.9% and the net return obtained was 4% higher over the competing varieties. The additional return per ha obtained from Swarna-*Sub1*was Rs. 2,883/- and the reduction in the cost of production per quintal was Rs. 39/- in comparison to its competing varieties.

Feedback on the performance of different rice production technologies (RPTs) and government-sponsored programmes and schemes were collected randomly by accidental sampling from 220 rice farmers from various states which revealed that farmers were convinced about the better performance of 'System of Rice Intensification (SRI) method' (with mean weighted score (MWS) of 4.62 out of 5 in a 5-point scale) and 'Line transplanting' (MWS of 4.60) over the traditional random transplanting (MWS of 4.20). About the performance of various government-sponsored programmes and schemes, 'BGREI programme' was highest rated among the beneficiaries (MWS of 4.55) followed by 'procurement of paddy at minimum support price (MSP)' (MWS of 4.23) and training-cum-exposure programme of ATMA'.

5.2. NRRI's footprint across the country

The institute with its mandates on rainfed ecosystem undertakes research activities streamlined at technology development, backstopping and dissemination specific to rainfed rice ecologies in the country. Since its inception the institute has released 129 rice varieties and developed different technologies, which have inscribed its footprints across 20 states and millions of farm families.

5.3. Number of villages and farmers covered

Currently, the institute has covered 144 villages under different extension programmes like Mera Gaon Mera Gaurav (MGMG: 105 Villages), Farmers First Programme (FFP: 4 villages) and Front Line Demonstration Programme (FLD: 35 villages). In terms of farmers' coverage, the institute has covered around

27000 farm families in last five years. Under 4S4R, five Farmers Producer Companies have been registered under Company Registration Act 2013 and 70 FIGs have been created under these FPOs covering 1400 farmers. More than 26,000 farm families are covered by the two major programmes of the institute; under Farmers First Programme more than 1800 (Das et al. 2018) and under Mera Gaon Mera Gaurav Programme more than 25000 farm families are covered by the institute. Out of the total beneficiary, 26% belongs to SC/ST and 66% are small farmers.

5.4. Effect of trainings on behavior of the participants

The institute provides a number of training to farmers from all over countries on varies aspect of rice cultivation, ranging from seed production, grain production, nutrient, and disease and pest management to post-harvest processing and marketing of produce. Institute has conducted a survey to assess the impact of the training program conducted by NRRI by taking the trainees who attended the training program during the last three years i.e., 2014-15 to 2016-17. The impact study was conducted for training provided on 11 technologies and response of trainees was elucidated for adoption behaviour and change in behaviour (knowledge, skill and attitude). The results of the study indicate that for most of the training organized by the Division on behalf of institute, have brought >50% positive changes in the behavior of the participants. Trainings on use of improved implements, recommended doses of pesticides and seed rate indicates a <50% change in the behavior of the participants due to other reasons (Fig. 7).

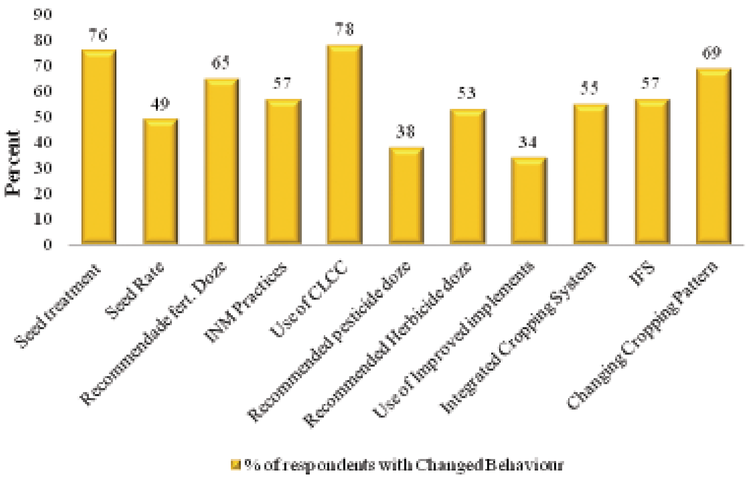

Fig. 7. Impact of training on the behavior of respondents.

The Division also reaches out to different stakeholders for dissemination of new knowledge and improved technologies. In the last decade, the institute has witnessed an increasing trend in the number of visitor's arrival and also the delivery of agro-advisory services to them. This visitor base has continued to increase over the years and multiplied itself more than twice from meagerly 3000 to about 7000 visitors per annum. Also, a sum total of more than 30000 farmers and students have been provided agro-advisory services and basic knowledge of agriculture, respectively (Fig. 8).

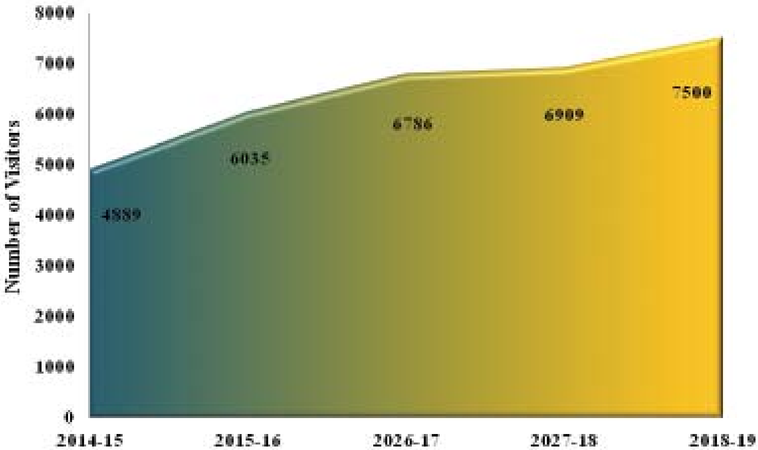

Fig. 8. Visitors in the Institute for the last five years.

6. ASPIRATIONS

Social science Division of institute is an institute's limb to reach out different stakeholders at different platforms for diversified purposes and activities. It is associated with transfer of NRRI technologies from lab to farms across the country, capacity building of different stakeholders on desired aspects of rice cultivation, processing, marketing etc. and showcasing the strength of institute at various local, regional, national and global platforms by participating in different exhibitions. Under this background, the social science Division has set up following aspirations for its futuristic work.

- Promotion of different rice varieties to new areas of the country: As many of the NRRI rice varieties are released by Central Varietal Release Committee (CVRC) and State Varietal Release Committee (SVRC) these varieties should have to be spread to newer paddy cultivation areas (in terms of Institute's reach) of the country. Therefore, it is pursued that the institute's reach has to be expanded to the newer areas by promoting the recent rice varieties to different rice ecologies in other states too.
- 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.

- To make Indian farms self-sufficiency in seeds, the 4S4R model would be up-scaled by taken up in the new districts of the existing state and to other states as well.
- Strengthening of value chain of rice in different dimensions like seed chain, grain chain and value chain for processed rice based products.
- Development of a system for real time data collection by using information and communication tools for farmers.
- To undertake the state level study on profitability of rice in different agro-ecological zones of the states.

7. CONCLUSION

Over the years, the Social Science Division has reached to about 90000 of different rice stakeholders spanning from farmers to the consumers including millers, private traders, and government officials from various departments through its diversified activities. As a result, it has contributed to the outreach of the institutions across different zones in the country. The division has a crucial stake in transfer of rice based technologies and knowledge creation via trainings and exhibitions across the country. The division is committed to undertake different socio-economic studies pertaining to rice growing families; resource characterization and mapping; accessing agro input footprints like water and fertilizer footprints, demand forecasting to assist policy makers, product profiling etc.

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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 (*indica*x *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 (*indica*x *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 (*indica*x *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 (*indica*x *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 (*indica*x *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 (*indica*x *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.

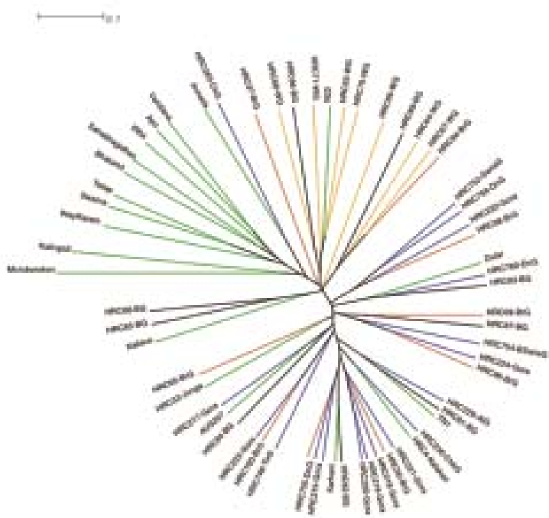

Fig. 1. Phylogenetic analysis with the Gora cultivars identified these as *aus* types. The White gora cultivars were genetically similar with the *indicas*.

❖ 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.

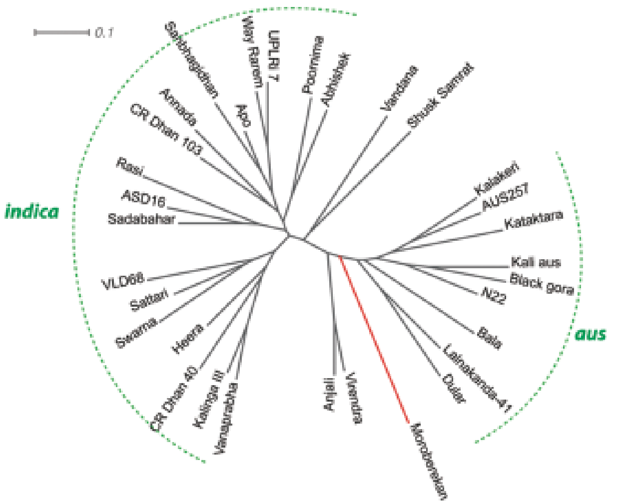

Fig. 2. Genetic diversity among upland rice varieties and landraces based on SSR markers associated with qDTYs.

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

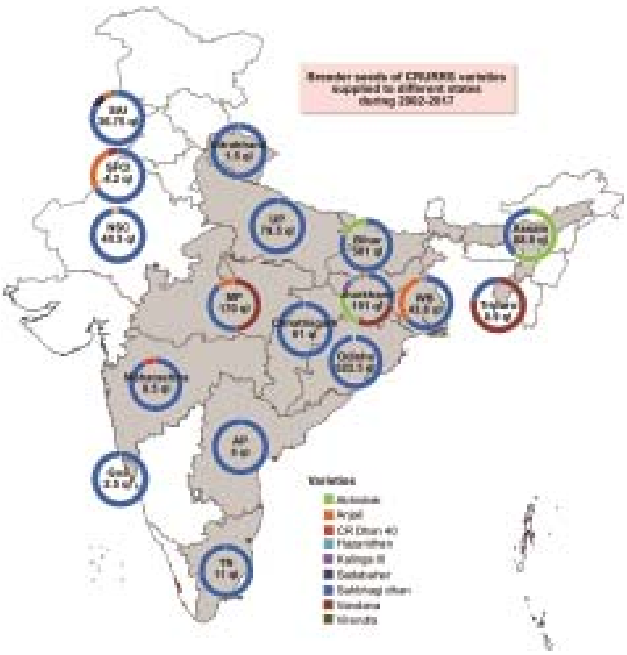

Fig. 3. Breeder seed indent from different states for CRURRS varieties during 2002-17.

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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Rainfed Lowland Rice:
Activities, Achievements and Aspirations

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SUMMARY

Flood/submergence is critical constraints to rice production in lowland and deep water areas. Most traditional varieties are low yielder. These varieties can neither elongate fast nor survive inundation and suffer from lodging when water table recedes. Most of the varieties are not adapted to flash flood inundation. In North East India, low productivity of crop during rainy season is due to low incidence of solar radiation coupled with fluctuating light intensity with over cast cloudy sky coinciding mostly with reproductive stage, the most sensitive stage to low light stress. Weather related constraints, poor drainage and mostly acidic soils with iron and aluminium toxicity are also other limiting factors in realizing higher productivity of rice under rainfed lowland situation in N.E. India. Similarly in Assam during late *sali* the crop suffers from sterility due low temperature at flowering and *boro* rice suffers from cold injury during the early vegetative stage. Continuous rain during harvest cause (i) grain germination on the plant (ii) incomplete drying and (iii) high humidity mediated deterioration of grain quality.

Efforts were initiated to address these issues by specific varietal development programme with definite targeted objectives in RRLRRS, Gerua, Assam. High yielding rice varieties like Chandrama, CR Dhan 601 and CR Dhan 909 were developed at this research station suitable for both *Sali* and *Boro* seasons which have become popular preferred varieties of Assam. Similarly several numbers of advanced breeding materials were generated which are in the pipeline of varietal development. Development of required production and protection technologies for each variety suitable for the target environment are underway.

1. INTRODUCTION

Rainfed lowland rice comprises five micro agro-ecologies, which are classified based on hydrology, physiography, soil structures and landscape. These sub-ecologies, as mentioned below, strongly influence choices of cultivars and management practices.

- Shallow, favourable ecology;
- Shallow, drought-prone ecology;

- ❖ Shallow, drought-and submergence-prone ecology;
- ❖ Shallow, submergence-prone ecology;
- ❖ Medium-deep and waterlogged ecology.

In rainfed lowland landscapes, upper, middle, and lower fields tend to have distinct hydrological and soil characteristics: upper fields tend to be drought-prone, middle fields drought and submergence-prone, and lower fields submergence-prone. There is strong relationship between landforms and adoption of modern varieties. Farmers on alluvial plain riverine bed areas (with more favourable hydrology) tended to adopt modern varieties more readily than farmers of drought or flood-prone lands. The adaptation of cultivars developed for rainfed areas are now evaluated based on landform. In eastern India, for example, rainfed rice land is categorized as highlands, mediumlands, and lowlands. Farmers in this area choose varieties and use cultural practices appropriate to the category of field.

High minimum temperatures and low solar radiation directly reduces rice yield potential in many rice growing rainfed lowland areas. For instance, rainfed rice yields are low in eastern India and have not increased significantly in recent years. Researchers attribute these low yields, in part, to the area's high minimum night temperatures at tillering and floral initiation combined with low levels of solar radiation during the growing season (250-300 cal/m 2 daily). While radiation levels are stable throughout eastern India's wet season, minimum temperatures begin to drop during the late months, and crops that mature during this cooler period have higher yields. Many researchers found that rainfed lowland rice in eastern India, harvested in September had a mean yield of 3.3 t ha^{1}, but those harvested in late October had a mean yield of 4.5 t ha^{1}. While the productivity of rainfed lowland rice may be constrained by high temperatures at low latitudes, it may be limited by low temperatures at high latitudes of NE states. At latitudes greater than 17° N, temperatures are optimum for growing rainfed lowland rice only for a limited period; as minimum temperatures drop below 20°C, immature rice crops experience poor panicle emergence and high spikelet sterility. Thus farmers must use shorter dration varieties which mature before the temperature drops. At the same time, monsoon, which is ever variable in terms of amount and pattern of precipitation, is the only source of water for rainfed lowland rice. So, varieties should mature within the normal span of monsoon whcih lasts in NE India during June to October. While there is a clear association between environmental factors and disease and insect incidence, the complexity and diversity of rainfed environments makes it difficult to provide detailed information on the occurrence of biological stresses. Currently, little or no pesticide is used in many rainfed areas. Integrated pest management can be developed for and applied in these areas before the use of pesticides becomes rampant. These rainfed areas then would avoid the problems associated with dependence on and overuse of pesticides. Host-plant resistance is an essential component of integrated pest management strategies which is being exploited for development of pest tolerant varities

There are several challenges for rainfed lowland rice farming system in Assam. More than 70% rice area in eastern India is rainfed. Threats of climate change being more prominent in rainfed ecology, it directly and adversely affects production and productivity of rainfed lowland rice. The rainfall pattern for last 10 years shows that there is a drop in rainfall amount during the month of July which affects the crop area coverage. It has been observed that there is raise in minimum temperature by 3.5ºC-4.5ºC from the mean of minimum temperature for last 10 years. In most rainfed lowlands, a single crop of rice is grown each year. This cropping pattern is typical for the less favourable sub-ecosystems, where long-duration, photoperiod-sensitive cultivars are generally grown. As population density increases, farm size decreases, marketing systems change and new technologies are adopted. Farmers are pressured to use the land more intensively, even in less favourable areas. So, the farmers need to introduce other upland crops after rice as per availability of moisture and change the rice varieties to photoperiod-insensitive HYVs beside modern cultural practices.

Regional Rainfed Lowland Rice Research Station (RRLRRS) was established in an area of 12.5 ha in village Gerua under Hajo circle of Kamrup district of Assam on Monday, the 15th September, 1997 as a regional station of ICAR-National Rice Research Institute, Cuttack with the following objectives:

- To explore, evaluate, conserve and exchange rice germplasm
- To develop high yielding rice varieties resistant/tolerant to different biotic and abiotic stresses for rainfed lowland ecosystem
- To generate appropriate agronomic and protection technologies for sustaining as well as increasing the productivity of rice-based farming system in rainfed lowlands
- To impart training to rice farmers, field functionaries, extension specialists and research workers on improved rice production technology and rice-based farming system

2. ACHIEVEMENTS

2.1. Rice germplasm

North East India being one of the centres of origin has got wide range of variation of rice cultivars. It has been estimated that at least 10,000 indigenous cultivars are prevailing in this region. Farmers have played a major role in conserving some of the traditional as well as improved varieties. The farmers of this region still grow their traditional cultivars which not only suit to their taste but also provide crop security, being highly adopted to the ecology. The NE India is also the home to many locally adapted aromatic *joha* and quality rice land races. Despite their low-yield potential, these cultivars are grown for their high market and social values. There are prominent cultivar groups within the aromatic rice gene pool of NE India.

Indian Agricultural Research Institute (IARI), New Delhi has collected 6630 accessions of rice from Assam during 1965-72 in cooperation with the International Rice Research Institute (IRRI), Philippines. That collection was known as the Assam Rice Collection (ARC), which is still in use for improvement of rice cultivars. RRLRRS has collected 803 accessions of rice germplasm from different places of Assam and NE Regions since inception and observations on days to 50% flowering, plant height and grain yield were recorded. These accessions were maintained at the station for development of new rice varieties and seed of 250 accessions were deposited in the gene bank of the ICAR-NRRI, Cuttack for conservation.

2.2. Rice variety developed

Central Variety Release Committee has released the rice variety Chandrama for the state of Assam in 2011. It was evolved at RRLRRS, Gerua, Assam from the cross between ARC 6650 and CR 94-721-3. Chandrama is a photo-insensitive variety which matures in 130-135 days during *kharif* season and 165-170 days during *boro* season. It has semi-dwarf plant type (105 to 115 cm) with 12-15 bearing tillers and long and compact panicle (22-25 cm). It is tolerant to leaf and neck blast, bacterial leaf blast (BLB), rice tungro disease (RTD) and sheath blight diseases. It is also having cold tolerance during vegetative stage. It has medium bold grain size with 67% head rice recovery. The variety has the potential yield of 5 t ha^{-1} during *kharif* and 6 t ha^{-1} during *boro* season.

Breeder Seed Production of Chandrama variety at RRLRRS Gerua

2.3. CR Dhan 601

CR Dhan 601 (CRG 1190-1; IET 18558) derived from cross Jaya/IR 64 is a highly promising rice variety under irrigated *boro* in the states of Assam, Odisha and West Bengal. It has semi-dwarf (90-95 cm) plant height with non-lodging, non-shattering and fertilizer responsiveness, produces 9-13 number of effective tillers.

It also has medium slender type grain, good cooking quality with cold tolerance at early vegetative stage. It is also having tolerant to leaf blast and RTV; moderately tolerant to brown spot and sheath rot; tolerant to yellow stem borer, green leaf hopper and leaf folder under natural conditions. It matures in 160 days during *boro* season with yield potential 5.6 t ha^{-1}.

2.3. CR Dhan 909

CR Dhan 909 (IET 23193; CRL 74-89-2-4-1) derived from cross Pankaj/Padumoni is a highly promising rice variety under aromatic short grain category developed at RRLRRS, NRRI, Gerua (Assam). The culture was approved by the Varietal Identification Committee, in the 50th Annual Rice Group Meeting, for release in the states of Uttar Pradesh, Bihar, Assam and Maharashtra. It has semi-dwarf (105-100 cm) plant height, produces 9-12 number of effective tillers, 24-28 cm long panicles. It also has medium slender type grain, strong aroma, and good cooking quality with up to 70% head rice recovery. It is also having tolerant to leaf blast, neck blast, sheath rot and RTD diseases; tolerant to stem borer, leaf folder and whorl maggot under natural conditions. It matures in 140-145 days during *Sali* season with yield potential 4.5-5.0 t ha^{-1}. CR Dhan 909 yielded 5.01 t ha^{-1} as against 4.31 t ha^{-1} of local check "Ketekijoha" at village -2 No. Mazgaon under Darrang district of Assam during sali/kharif 2017. This variety was also tested at ICAR-NEH Tripura centre and its performance was better than the local check.

2.4. Rice cultures developed

Rice culture 'IET 23496' (CRL 2-12-7-2-3-2) yielding 5.3 t ha^{-1} in 163 days was developed for *boro* season. Another culture IET 24172 (CRL 193) has been developed which yields 5.5 t ha^{-1} and takes 165 days to mature in *boro* season.

2.5. Advance breeding lines developed

Advance breeding lines for the improvement of (i) *boro* rice, (ii) semi-glutinous and soft rice and (iii) short duration *ahu* rice have been developed. The range of yield performance of 124 breeding lines were 1008.33 kg ha^{-1} to 7441.67 kg ha^{-1} and few lines performed better than check Swarna-Sub1 (6635.33 kg ha^{-1}) and CR Dhan 909 (6366.67 kg ha^{-1}).

2.6. Breeder Seed production

Breeder seeds of Chandrama, CR Dhan 601, CR Dhan 909, Naveen and CR Dhan 310 varieties of rice have produced at RRLRRS, Gerua based on annual indent received from Department of Agriculture and Cooperation (DAC), New

Delhi. Nucleus seeds of Chandrama, CR Dhan 601 and CR Dhan 909 are maintained at the station and of Naveen and CR Dhan 310 are obtained from ICAR-NRRI, Cuttack for the production of Breeder category of seeds at Gerua, Assam.

2.7. Knowledge generation

2.7.1. Rice varieties suitable for agro-ecology of Assam

Rice varieties 'Naveen' and 'Abhishek' have been identified to be highly promising for growing as summer rice in Assam. Rice varieties 'Abhishek', 'Naveen' and 'Sahbhagi Dhan' have been identified suitable for growing as pre-flood *ahu* crop. Rice variety 'Abhishek' and 'Naveen' have been identified suitable for growing as post-flood late *sali* rice crop. Rice hybrid 'Rajalaxmi' (CRHR 5) and 'Ajay' (CRHR 7) have been identified promising for cultivation as *boro* rice in Assam. Rajalaxmi (CRHR 5) has also been identified suitable for cultivation as *sali* rice in rainfed shallow lowlands.

Optimum time of sowing of seeds for *boro* rice has been ascertained. Transplanting of Chandrama and Naveen on 25th January recorded the highest grain yield (6.45 t ha^{-1}).

The maximum grain yields of Chandrama and Naveen (6.23 t ha^{-1} and 4.73 t ha^{-1}) were observed with transplanting of 50 days old seedlings in *boro* season. Increase in the age of seedlings from 60 to 90 days showed progressive reduction in yield.

2.7.2. Plant spacing in rainfed lowlands

Transplanting of Naveen at 15 cm x 15 cm spacing recorded grain yield of 4.27 t ha^{-1} which was on a par with double transplanting at 15 cm x 15 cm spacing (4.36 t ha^{-1}) under post-flood situation in rainfed lowland ecosystem.

Normal transplanting of *sali* rice under post-flood situation in rainfed lowland ecosystem recorded higher grain yield than double transplanting and wet direct sown. Normal transplanting of Abhishek at 15 cm x 15 cm spacing recorded higher grain yield (5.60 t ha^{-1}), as compared to wider spacing and double transplanting or direct wet seeding.

2.7.3. Nutrient management in rainfed lowland ecosystem

Application of 60 kg N ha^{-1} based on LCC along with PK @ 30:30 kg ha^{-1} in late planted *sali* rice (under post-flood situation in rainfed lowland ecosystem) recorded highest grain yield of 4590 to 4650 kg ha^{-1} which is *on a par* with the treatment 50 kg N based on LCC along with PK @ 25:25 kg ha^{-1} yielded 4360 to 4480 kg ha^{-1}.

2.7.4. Ratoon crop

RRLRRS, Gerua has identified Naveen variety as suitable for ratoon, which can produce more than 50% grain yield of main rice crop in *sali* season. Results revealed that 15th February planting was optimum time for transplanting to obtain the maximum ratoon crop yield with the highest production efficiency. However, both 25% and 50% recommended doses of nitrogen provided significantly higher grain yield over control but it remained statistically at par with each other. Application of 25% recommended doses of nitrogen in ratoon crop provided higher grain yield (2.25 t ha^{-1}) of ratoon crop.

2.7.5. Cropping system

Rice (*Sali*) - rapeseed system yielded higher net return (Rs. 59396 ha^{-1}), production efficiency (35.04 kg ha^{-1} day^{-1}) and B:C ratio (2.29) as followed by rice-lentil/linseed systems. Rice-linseed cropping system in rainfed lowlands recorded maximum REGY (6.98 t ha^{-1}), net return (Rs. 56934 ha^{-1}) and B:C ratio (2.17) while production efficiency (35.04 kg day^{-1} ha^{-1}) was the maximum with rice-rapeseed cropping system which was due to shorter duration and higher productivity.

Application P_2O_5 @ 60 kg ha^{-1} in *kharif* rice of rice-rape seed system resulted the maximum grain yield of rice (4.58 t ha^{-1}), which was significantly higher over control but at par with 20 and 40 kg ha^{-1} of P_2O_5. Sulphur (S) application of 20 and 40 kg ha^{-1} S significantly increased rice yield over control but remained at par with each other while rape seed yield increased significantly up to 40 kg ha^{-1} S.

Incorporation of green manure in *sali* rice can reduce inorganic fertilizer requirement by 50%. Green manuring in rice based cropping system recorded the maximum rice equivalent grain yield (7.1 t ha^{-1}), production efficiency (32.69 kg day^{-1} ha^{-1}), net return (Rs. 60989 ha^{-1}) and B:C ratio (2.29) as compared to rice residue incorporation.

2.7.6. Integrated Farming System

An integrated rice-fish-horticulture farming system has been developed for flood-prone lowland ecosystem of Assam . The components of the integrated farming system were rice in main field, fish in refuge, trenches and rice field (at appropriate water level) and vegetables, fruits, ornamental crops and agro-forestry on pond dyke. A crop sequence of rice-*utera* linseed/ khesari-rice was followed in the main field. Rice variety Ranjit and Anjali were grown during *sali* and *ahu* season respectively. Fingerlings of catla (*Catla catla*), rohu (*Labeo rohita*), mrigal (*Cirrhinus mrigala*) and common carp (*Cyprinuscarpio communis*) were released in the pond @ 6000 fingerling/ha 7 days after transplanting of *sali* rice. Ducks were introduced inthe pond.

Integrated rice-fish-horticulture farming system

Vegetable crops were cultivated on pond dyke throughout the year . Interventions made were lady's finger (var. F_1 Durga), yard bean (var., Reenu) during pre-wet season and wet season, green chilli (var., Tejswini) during wet and post-wet season. French bean, cauliflower, cabbage broccoli, radish, spinach and merrygold during dry season. Interventions made on the hanging platforms were of Pumpkin (var., Arjun), Ridge gourd (var., Malika), bitter gourd (var., Vivek), spine gourd (local) during wet season, bottle gourd and country bean during dry season. Fruit trees, *viz*. coconut, arecanut, Assam lemon, guava, mango and banana and 20 timber (teak) trees have been established on pond dyke.

Interventions of integrated rice-fish-horticulture farming system

Gross income generated from half a hectare of integrated rice-fish-horti farming system in rainfed, shallow lowlands of north eastern region can sustain an average small farm family. The integrated rice-fish-horti farming system can produce 19.68 t ha1 of rice equivalent yield per annum with employment generation of 408 man days per ha. Major contribution in terms of production and income comes from horticultural component (45.7%) followed by rice (25.2%) and fish (20.6%).

2.7.7. Insect-pests of rice in lowland situations

A survey was conducted for recording the incidence of insect-pests on *kharif* rice in flood prone areas of the state. Rice leaf folder (*Cnaphalocrosis medinalis*), stem borers (*Scirpophaga incertulas* and *S. innotata*), gundhi bug (*Leptocorisa acuta*) were found to be the major insect pests of winter paddy. Mealy bug (*Brevennia rehi* (Lindinger), an uncommon pest of rice in NE India was recorded causing mild to severe damage to rice in Baksa (27 ± 11.57 bugs/tiller), Hailakandi, Kamrup (3.8±2.21 per tiller), Nalbari, Udalguri and Goalpara districts of Assam. Number of white stem borer moth on deep water paddy (1.7 nos hill^{-1}) was more as compared to yellow stem borer moth (0.5 nos hill^{-1}) at Lakhimpur. Severe incidence of rice hispa (*Dicladispa armigera*) (1-4 adults plant^{-1}) was noticed at Gogamukh in Dhemaji district and Gohpur in Sonitpur district during 2016.

Severe infestation of swarming caterpillar in Assam

Swarming caterpillar (*Spodoptera mauritia*) and ear head cutting caterpillar (*Mythimna separata*) invaded winter rice crop in Assam and affected altogether 56,768 ha of winter rice crop in 27 of the state's 35 districts during 2016. The swarming caterpillar worst-affected districts are Sivasagar and Charaideo – where the worms affected 6,747 ha of winter rice. Altogether 3.1% of the acreage (18,82,756 ha) under winter rice was devastated by swarming caterpillar and armyworm. Invasion of winter rice by the swarming caterpillar was noticed during the 1st week of September.

Rice stem borers: Four species of rice stem borer, *viz*., yellow stem borer *(Scirpophaga incertulas)* (Lepidoptera: Pyralidae), Striped stem borer *(Chilo supressalis)* (Lepidoptera: Pyralidae), White stem borer *(Scirpophaga innotata)* (Lepidoptera: Pyralidae) and Pink stem borer *(Sesamia inferens)* (Lepidoptera: Noctuidae) were found to infest rice at RRLRRS, Gerua, Assam

Rice leaf folder: Catches of leaf folder moth in light traps installed in winter paddy field started at the first week of October in the year 2016 and moth population found to gradually increase in subsequent days and reached its peak of 11 moths/trap in the first week of November. Thereafter leaf folder moth population gradually declined till the third week of November. Grain yield loss of paddy for each per cent infestation of rice leaf folder on rice variety CR Dhan 909 was 45.67 kg ha^{-1}.

2.8. Diseases of rice in lowland situations

Commonly occurring fungal diseases in *kharif* rice (*sali*) were found to be sheath blight and brown spot followed by bacterial leaf blight, leaf blast and sheath rot, whereas neck blast and *bakanae* are important in *rabi* rice (*boro* and early *ahu*). False smut was found to be an emerging disease. *Tungro* disease sporadically occurs in different rice varieties across the seasons.

2.8.1. Rice tungro disease

Geographical distribution of rice *tungro* disease has been mapped in parts of Assam and Tripura. Incidence of rice *tungro* disease (RTD) was recorded in twenty-two districts of Assam.

Resistance screening revealed that IR 71606-2-1-1-3-3-1-2, Pankhari 203, PTB 18, PTB 21 showed resistant reaction against rice tungro disease and CR 2482-10, CR 2643-1, CR 2644-2, CR2647-5, CR 2649-7, CR2652-14, CR 2654-17, CR 2656-11, IC 516579, IR 68068-99-1-3-3-3, IR 71606-1-5-3-4-3-3-3, Jaymati, Matiyaburushu, Swarna, Swarna*sub1*, Purnendu, Anjali, Jaya, Jaymati, Kalong, Swarna,Lalbadal and Rangabao showed moderately resistant reaction. NRRI breeding lines, *viz*., CR 2656-11, CR 2652-14, CR 2916-8 and CR 2916-10 showed field resistance against *tungro*, under artificially inoculation using viruliferous green leaf hoppers. CR 2652-14 and CR 2916-10 showed moderate resistance against the disease. Cultivars IR 20, PTB 8, PTB 18, PTB 21, Shuli 2 and Utrirajapan showed resistant reaction against Gerua isolate of *tungro* disease whereas, Balimau Putih, Habigunj DW8, Utrimerah, and Pankhari 203 showed moderate resistance

2.8.2. Sheath blight *(Rhizoctonia solani)*

1035 entries were screened for their resistance against sheath blight disease (*Rhizoctonia solani* Kuhn). None of entry was found to be resistant against sheath blight and 232 entries showed moderate resistance reaction. Genotypes IET 17886 and IET 20443 were found to be moderately resistant to sheath blight disease while IET 20755, ADT 39 and Mansarovar tolerant to sheath blight.

2.9. Insect-pest management

- IPM module comprising of seed treatment with carbendazim @ 2 g kg^{-1} seed, application of pretilachlor at 5-7 DAT, cartap hydrochloride @ 25 kg ha^{-1} at 30 DAT and need-based application of insecticide

- Seed treated with Carbenzadim @ 2 g L^{-1} of water and seedling root dip in carbendazim @ 2 g L^{-1} of water recorded the lowest incidence of bakanae disease as compared seed treatment and root dip treatment with *Pseudomonas fluorescens* @ 3 x 10^6 cfu/ml.

- Use of scirpo-lure in funnel trap @ 20 ha ^{1} for YSB, application of Flubendiamide @ 50 ml/ha at 30 DAT for lef folder.

- Azoxystrobin 25 SC (Amistar) @ 1.0 ml L^{-1} of water recorded the highest (52.50-53.98%) reduction in sheath blight disease incidence.

- *Trichoderma viridae* (pest Control India) reduced sheath blight incidence 49.50 to 53.82% as compared to 42.70 to 43.66% for the treatment Validamycine 3% L.

2.10. Weed management

Broad spectrum herbicides, *viz*., Pyrazosulfuron ethyl and Chlorimuron+Metsulfuron methyl and Bensulfuron methyl, have been identified suitable for controlling the weed menace in *boro* rice.

Two hand weedings at 25 and 50 days after transplanting of *boro* rice recorded the highest grain yield (7.2 t ha^{-1}) as compared to recommended chemical control measures

Hand weeding in *boro* rice highest grain yield (4.77 t ha^{-1}) but remained statistically *on a par* with the low volume pre-emergence herbicides. Pyrazosulfuron ethyl recorded higher grain yield (4.58 t ha^{-1}) followed by ready mix Chlorimuron+Metsulfuron methyl (4.54 t ha^{-1}).

3. PUBLICATIONS

Scientist of RRLRRS, ICAR-National Rice Research Institute, Gerua has published 42 research papers in the journals of national and inter national repute. Other publications of the station were 17 popular articles, 23 Technical bulletins, 2 books, 7 book chapters, 4 Technology bulletin and 14 paperwere presented in seminar/symposium/conference.

4. EXTENSION ACTIVITIES

RRLRRS has been popularising NRRI developed HYV rice varieties for different ecologies through conduction of FLDs in Assam (Table 1) and farmers have well adopted these varieties.

State Seed Sub-Committee of Assam recently included nine rice varieties developed from NRRI based on their performance at RRLRRS, Gerua *viz.*, CR Dhan 909, Swarna Sub-1, CR Dhan 310, CR Dhan 500, CR Dhan 501, CR Dhan 505, CR Dhan 506, CR Dhan 508 and CR Dhan 601 in state seed chain of Assam in 2018. Assam Seed Co-operation Ltd, Khanapara, Guwahati, Assam Seed Certification Agency, Ulubari, Guwahati, Duarbagori Cooperative Society limited, Kuthari, Nagaon and a few progressive farmers are the regular buyer of breeder seeds from RRLRRS, Gerua to meet the demand of Foundation and Certified seed for the state Assam (Table 2).

Table 1. FLD on HYV conducted by RRLRRS in Assam.

Variety	Total FLD area (ha)				
	2014-15	2015-16	2016-17	2017-18	2018-19
Naveen	10	17.5	24	2	5
Chandrama	10		10		
CR Dhan 909				5	
CR Dhan 310			4	2	7.5
Total area (ha)	20	17.5	38	9	12.5

Table 2. Breeder seed programme at RRLRRS, Gerua, Assam

Variety	Quantity of breeder seed lifted (qtl.)				
	2014	2015	2016	2017	2018
Chandrama	0.50	25	21	4	30
Naveen		35	25	12	
CR Dhan 909		2		1	
CR Dhan 310				5	20
Total	0.50	62	46	22	50

RRLRRS has screened thousands of rice lines in AICRIP programme and contributed in developmental process of new varieties. The yield of the RRLRRS developed entry IET 23193 (CRL 74-89-2-4-1) ranked first (4908 kg ha^{-1}) and showed yield gain of 37% over the best check (LC) and Varietal Identification Committee has approved it for release.

Assam had witnessed severe incidence of swarming caterpillar and army worm on rice in 2016, which drew the attention of Directorate of Plant Protection, Quarantine and Storage, Faridabadand ICAR, New Delhi for the management of these pest menace. RRLRRS, Gerua actively participate in separate joint field visits with officials and scientists from DPPQ, NCIPM and NRRI, HQ in the affected areas and chock out strategies and advisories for the control the swarming caterpillar and armyworm on rice.

5. MAJOR PROJECTS

The following institute multi-disciplinary research programmes have been in operation at RRLRRS, Gerua to develop production and protection technologies for increasing productivity of rice in rainfed lowland,

- Development of rice genotypes for rainfed, flood prone lowlands (Completed)
- Soil and crop management for productivity enhancement in rainfed flood prone lowland ecosystem (Completed)
- Management of major rice-pests and diseases in rainfed, flood prone lowlands (Completed)
- Genetic improvement and management of rice for rainfed lowlands (on going)

6. LINKAGES

- Local Institutions: The research station has close collaboration with the Department of Agriculture, Government of Assam and Krishi Vigyan Kendras under ICAR & Assam Agricultural University for development and evaluation of varieties and farming system research.
- National Institutes and Agricultural Universities: Besides NRRI, Cuttack and the Indian Institute of Rice Research, Hyderabad, the station is collaborated with Assam Agricultural University, Jorhat (Assam) and ICAR Research Complex for NEH Region, Barapani (Meghalaya) for network research.
- International Institutes: The station is associated with the International Rice Research Institute, Manila, Philippines for evaluation and utilisation of germplasm of INGER nurseries.

- Extension & Development Agencies: The Station maintains close cooperation with Field Functionaries of the Department of Agriculture, Government of Assam and farmers of the region for transfer of technology.

7. ASPIRATIONS

Aspiration of RRLRRS, Gerua is to improve livelihood of the farming community who practices rainfed agriculture for cultivation of rice in lowlands of Assam. Low temperature at early vegetative stage in *boro* season prolonged the crop harvest and recurrent pre-monsoon flood cause heavy crop loss to *boro* and early *ahu* paddy cultivated in lowlands of Assam. Development of *boro* rice varieties of 145-160 days duration having low temperature tolerance at early vegetative stage and early *ahu* varieties of 100-120 day duration having drought tolerance with quick vegetative growth will escape pre-monsoon flood. Similarly, winter rice varieties of 130-140 days duration having medium slender grains and submergence tolerance will perform better in rainfed lowlands of Assam. Periodic soil amelioration and adoption of proper agronomic practices will definitely increase the productivity of rice in rainfed lowland of the state. Insect-pests, diseases and weeds are important constraints to rice production in rainfed lowland ecosystem and therefore development of integrated pest management strategies is equally important for enhancing rice production and productivity in Assam. The future activities of the station will focus on the following.

- Development of short duration rice varieties for pre-flood *ahu* season, medium duration, submergence tolerant varieties for *sali* season and varieties having low temperature tolerance at the early vegetative stage for *boro* season.
- Formulation of soil and crop management practices for rainfed lowlands
- Management of major and emerging biotic stresses of rice in rainfed lowland
- Dissemination of rice production technologies, inputs and capacity building of extension functionary and progressive farmers.

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Human Resource Development: Activities, Achievements and Aspirations

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SUMMARY

ICAR-National Rice Research Institute (NRRI) is a research and development institute, which is considered as knowledge repository in rice sciences. There are ample expertise and experiences available with NRRI scientists in science-led approach, which is to be disseminated to the future generations by providing training to post graduate and doctoral degree students and other stakeholders. As the training needs concerted and focused initiatives to enhance efficiency and effectiveness of each one through various training programmes, a HRD Cell was created at NRRI for strengthening and facilitating training and capacity building of the students/other stakeholders. The Institute offers research and training opportunities in various disciplines of agricultural sciences and also other subjects of life sciences. The programme of HRD in NRRI includes MSc/MTech/equivalent degree, PhD degree, training etc. Besides, there is an excellent opportunity for PG and PhD students to avail the fellowships from NRRI as IRRI is providing 25 scholarships to NRRI in a collaborative project mode. The regional station at Hazaribag also caters to such regional needs of guiding PhD and MSc students. During last 5 years it has trained 5000 persons on rice-based technologies and agri-entrepreneurship and guided 120 MSc and 30 PhD students. Additionally, NRRI attracted rice researchers from developing countries like, Nigeria, Tanzania and Niger to undertake training as post doc or visiting fellows. Finally, after completion of research from NRRI, the students are well placed in different national and international organizations. Overall, NRRI HRD is creating the next generation leaders in rice sciences to overcome the new challenges for agriculture in India.

1. INTRODUCTION

ICAR-National Rice Research Institute (NRRI) is a research and development institute involved in scientific innovations and technology development in rice sciences. There is ample expertise and experiences available with NRRI scientists in rice sciences, which should be disseminated by providing training and guidance to post graduate and doctoral degree students and also other stakeholders. As the training needs concerted and focused initiatives to enhance efficiency and effectiveness of each one through various training programmes, a HRD Cell was created at NRRI for strengthening and facilitating training and capacity building of the students/scientists to work in the emerging areas of rice research guided by leading rice scientists.The objective of HRD programme is to develop a new generation of rice researchers for India and abroad. The program provides an excellent opportunity for students to work in the emerging areas of rice research in their post graduate and doctoral programme, guided by leading rice scientists. Besides, scientists interested to upgrade their knowledge in any specialized area are also given the opportunity to undertake training at NRRI.

The HRD Cell was created at this institute for strengthening and facilitating training and capacity building of the students in early 1950s. Further, the cell was strengthened with necessary staff required for effective functioning of this cell. The work related to human resource development at NRRI is administered by a HRD Cell. There is a Human Resource Development Committee consisting of all Heads of Divisions as members, one of them being nominated as Chairman by the Director, and an HRD Coordinator (a scientist of the Institute nominated by the Director), who acts as Member Secretary of the Committee. Besides, a Co-coordinator was also nominated by Director to help the Coordinator in HRD related works.

The HRD guideline was formulated in 2018 by the HRD Committee of the Institute is in full conformity with that of the ICAR. This guideline was approved by the competent authority for implementation in training and development of students in rice research which is available at NRRI website (http://icar-nrri.in/).

2. DISCIPLINES FOR HRD

The Institute offers research and training opportunities in the disciplines of Agricultural Chemistry, Agricultural Chemicals, Agricultural Economics Agricultural Engineering, Agricultural Statistics, Agricultural Extension, Agronomy, Biochemistry, Biotechnology, Bioinformatics, Botany, Economic Botany, Entomology, Environmental Sciences, Fisheries, Food technology, Genetics, Genomics, Microbiology, Life Sciences, Molecular Breeding, Nematology, Plant Breeding, Plant Pathology, Plant Physiology, Seed Technology, Soil Microbiology, Soil Science, Zoology; and related disciplines covering various aspects of rice research. The Institute can include other disciplines, if deemed appropriate.

3. PROGRAMMES OF HRD

The important programmes implemented at NRRI are listed below.

3.1. MSc/MTech/equivalent degree

The students registered for MSc/MTech/equivalent degree in recognized educational organizations were allowed to undertake research in two sessions i.e., during July-December (Session I) and January-June (Session II) every year. For every student an Advisory Committee consisting of the guide (Chairman of the Committee), one scientist from the same discipline and another from a related discipline (as deemed fit for the research work) is formed to guide and supervise the progress of research work.

3.2. PhD degree

The candidates working as Senior Research Fellows (SRFs) in the on-going externally aided research projects at NRRI pursued their PhD after completing course work from the university where he/she is registered as per provisions of ICAR-HRD Guidelines. Besides, the students awarded with fellowship from DBT/DST (eg. INSPIRE/CSIR or any other equivalent organization) are also eligible to carry out their PhD with due approval of the Director and endorsement of NRRI scientist as guide/supervisor. Since, there is a provision for the students to carry out their PhD who do not have any fellowship but have already qualified the entrance test (conducted by the universities) and completed six months course work, they were permitted to pursue for PhD research as honorary fellow. There is an Advisory Committee comprising the Guide (Chairman of the Advisory Committee), two scientists from the same discipline and another scientist from a discipline deemed fit for the research work. In case of co-guide system (as prevalent in some Universities), the Co-guide is included in the advisory committee.

3.3. Training on rice sciences

The Institute imparts training in various areas related to rice sciences. These trainings are categorized as summer training, foreign training, etc.

For summer internship students, they spend the summer, working at NRRI research laboratory to gain an understanding of rice research and experiences. This experience helps students in improving the most essential skills missing in their regular college curriculum and gives a great experience of a summer internship. The certification provided in the Summer Training Programs helps students to showcase their skills in their resume for their prospective recruiters in these fields. This also helps in improving their chances of getting admission in good colleges for higher studies.

Achievements of NRRI in emerging areas of rice sciences attracted a number of rice researchers from foreign countries to undertake training in some specialized areas to upgrade their knowledge and skills.

The Institute has Post Doctoral Fellow Programme and Training in some specialized areas. There is also a scope for rice researchers to upgrade their skills and expertise in any specialized subjects by undertaking training at NRRI. For example, NRRI showed its significant achievements in developing androgenic protocol in *indica* rice for production of Doubled Haploids having a good expertise in this technology. This technology was capitalized by imparting training to the researchers from public/private sectors through available expertise.

3.4. NRRI-IRRI Students' Programme

ICAR-NRRI and IRRI as leading global rice research organizations, provide an excellent opportunity for the students to carry out the post graduate and doctoral work under the guidance of leading scientists from NRRI and IRRI in world-class scientific environment. The overall objective of the India-IRRI collaborative capacity development program is to develop a new generation rice scientists and research leaders for India that addresses challenges and opportunities in rice agri-food systems development in Odisha. Therefore, IRRI provided an NRRI-IRRI scholars' programme for students to work on rice based systems research in Odisha, under the supervision of NRRI and IRRI scientists during 2018-2021. The scholars registered at an accredited university, with course work completed, and are ready to join to conduct research for completing their research at NRRI in India.

A total of 25 scholarships were planned in a project mode out of which 15 scholarships (5 scholarships per year for 3 years) are meant for Masters and 10 scholarships for PhD programmes. The amount of fellowship is INR 15,000/ month and INR 20,000/ month for MSc and PhD students, respectively. The duration of scholarship for MSc is maximum 9 months whereas maximum 2 years is restricted to the PhD student for completion of the research work. The research areas identified for MSc and PhD students are nutrient management, climate change adaptation and mitigation, agronomy, seed systems, plant breeding and varietal evaluation, geospatial analysis and yield modeling, land use-land cover mapping, extrapolation domains, crop insurance, impact assessment, knowledge management, innovations in extension, gender and youth research, entrepreneurship in agri-food systems. A joint committee was set up by the Director, NRRI comprising of NRRI and IRRI scientists to develop the guidelines and process of selection of the students and implementation of the programme. The fellowship programme has been implemented and currently 5 PhD students are availing fellowships for pursuing their research work in first batch. Subsequently, 3 PhD and 3 MSc students were selected in second batch for this fellowship program.

4. ACHIEVEMENTS OF THE HRD PROGRAMMES

The achievements of HRD of NRRI were visible from the students' skill development in terms of PhD, MSc, summer training, etc. Besides, the resource generation over 5 years is also well focused.

4.1. PhD

The PhD students who have registered in universities conducted their dissertation work at NRRI, Cuttack. A total of 82 students registered for PhD

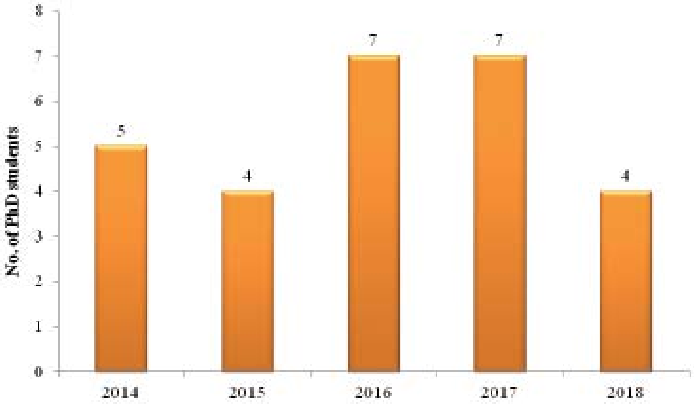

Fig.1. Number of students awarded PhD over the years.

from 2006 onwards out of which 27 students obtained PhD degree after successful completion of their dissertation at NRRI, Cuttack in last 5 years (Fig. 1); only 1 student was awarded PhD in 2019. Additionally, 54 students are continuing their dissertation program under the guidance of scientists, NRRI. The students' number for 5 years (2014-18) is taken in to consideration in division wise which showed maximum number of students (10) were awarded PhD under the guidance of scientists from Crop Improvement Division. Similarly, 8, 5 and 4 students completed their dissertation under the guidance of scientists from Crop Protection, Crop Production and Crop Physiology & Biochemistry, respectively (Fig. 2). The data showed that maximum number of students completed their PhD in Biotechnology since it is considered as an emerging area in recent past (Fig. 3).

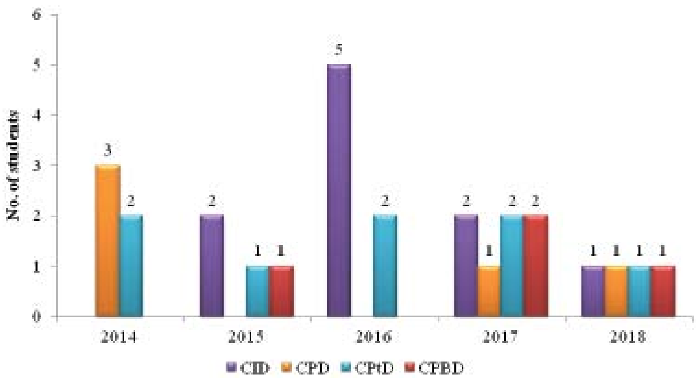

Fig. 2. Number of students obtained PhD degree in different Divisions of NRRI over the years.

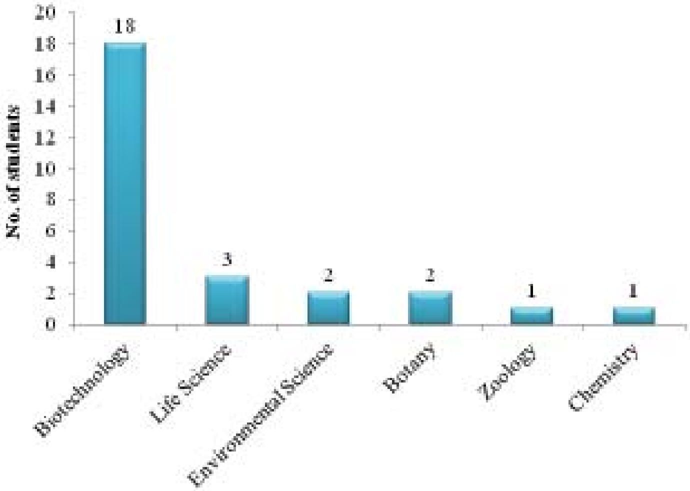

Fig. 3. Subject-wise list of students awarded PhD over last 5 years.

So far, five students obtained their PhD degree under registration with Vinoba Bhave University, Hazaribag after completing their research woks under the guidance of Scientists at CRURRS, Hazaribag.

4.2. MSc

The MSc students as part of fulfillment of their degree programme pursued research and thesis work for 6 months at NRRI, Cuttack. A total number of 118 students completed their MSc dissertation from 2014-2018 (Fig. 3). The maximum number of students carried out dissertation works in 2017 as there were a number MOUs signed between SAUs and NRRI. However, the student numbers were found to be low (19) in 2018 because the students of SAUs joined in mid-2017 and completed the dissertation in 2018.

The students number for 5 years (2014-18) is considered in division wise (Fig. 4). The number of students completed their MSc dissertation at NRRI from 2014 onwards were 118. In the last 5 years, 46 students performed their dissertation work under the guidance of scientists from Crop Improvement Division followed by 45 from Crop Production, 12 from Crop Protection, 9 from Crop Physiology and Biochemistry, 6 from Social Science Division (Fig. 5).

The data of the students in gender-wise showed the number of female students is significantly high over 5 years as compared to the male students. Highest number of female students (90.9%) performed their dissertation as against of male students (9.1%) in 2014. This indicates the interest of female students towards higher studies (Fig. 6).

During 2016-2018, eight MSc students of ICAR-IARI-Jharkhand completed their dissertation works under the guidance of Scientists at CRURRS, Hazaribag.

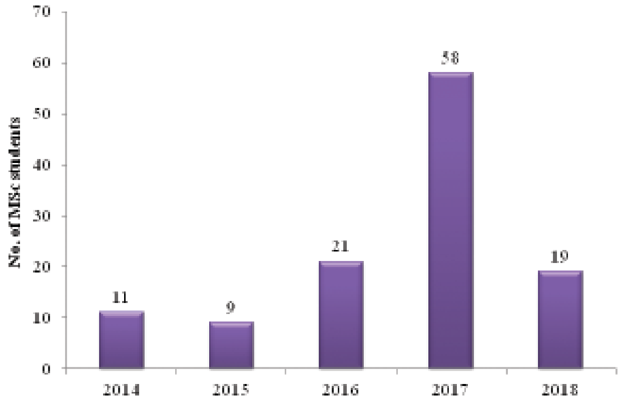

Fig. 4. Number of students completed MSc at NRRI over 5 years.

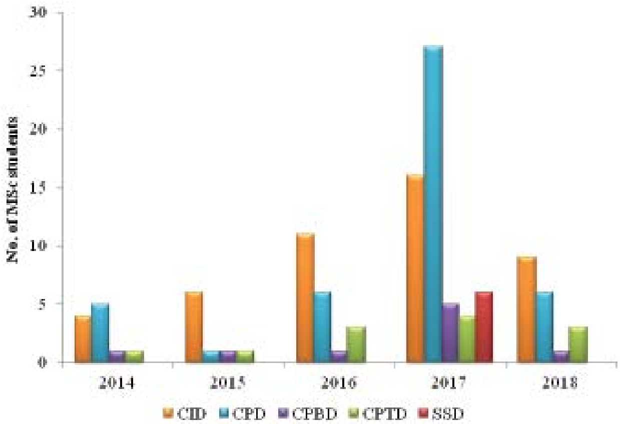

Fig. 5. Number of students obtained MSc degree in different Divisions of NRRI over 5 years.

Fig. 6. Number of male and female MSc students completed dissertation over 5 years.

4.3. Summer training

A total number of 16 students were imparted training in different subjects at NRRI. It was also observed that maximum numbers of students are interested to undertake summer training in Biotechnology (Fig. 7).

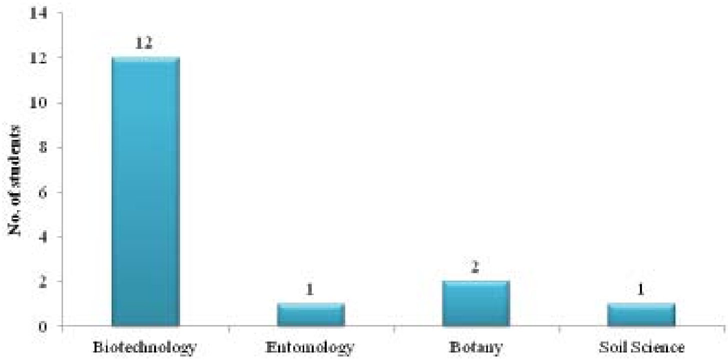

Fig. 7. Number of students undergone summer training at NRRI during 2018.

4.4. Foreign training

Five fellows from developing countries undertook training at NRRI during 2011-16. The details are depicted in Table1.

Table 1. Foreign researchers pursued training/PDF at ICAR-NRRI during 2011-2016.

Country	Training / Fellow	Fellowship
Nigeria	Post Doctorate	DBT-TWAS fellowship
Tanzania	Visiting Fellow	DST- C.V. Raman International Fellowship for African researchers for visiting fellowship
Niger	Post Doc	DST- C.V. Raman International Fellowship for African researchers
Tanzania	Training	International Atomic Energy Agency (IAEA)
Tanzania	Training	International Atomic Energy Agency (IAEA)

4.5. Specialized training

The Doubled Haploid technology developed by NRRI attracted a number of researchers from public and private sectors to undertake training in this specialized area from 2014-18 by charging the fees fixed by NRRI. The details are given in Table 2.

Table 2. Training imparted on specialized area (DH technology).

Trainee	Institute	Year
Research associate	TIERRA Seed Science Pvt. Ltd., Hyderabad	2014
Associate Professor	IGKV, Raipur	2014
Senior breeder	PAU, Ludhiana	2015
Research Associate	IRRI, Hyderabad	2016
Scientist	M/S Bayer Seed Pvt. Ltd., Hyderabad	2017
Senior Scientist	ICAR-SBI, Coimbatore	2018

4.6. Resource generation

As per HRD guidelines, the students were imparted training in various subjects by charging fees from which an amount of Rs. 20.05 lakh was generated which is considered in financial year wise (March-February). The highest amount (Rs. 6.2 lakh) was generated during 2016-17 followed by 2015-16 and 2017-18 (Fig. 8).

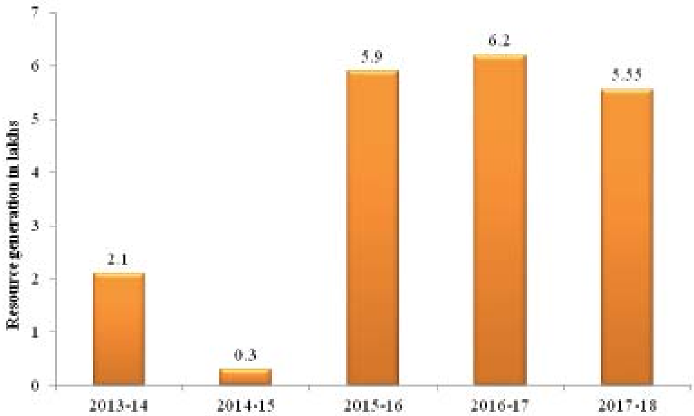

Fig. 8. Resource generation from students' training through HRD-NRRI over last 5 years.

5. IMPACTS

The students have been selected to work as Assistant Professors in various Universities after completion of their PhD from NRRI. Further, students are also working in different projects as Young Professionals, Senior Research Fellows and Research Associates in various ICAR and other institutes. Besides, some of the students were also awarded PDF in foreign countries. Similarly, the students who have completed their dissertation work in MSc have joined the PhD programme in various reputed institutes/universities. With regard to summer training, the certification provided in the Summer Training Programs

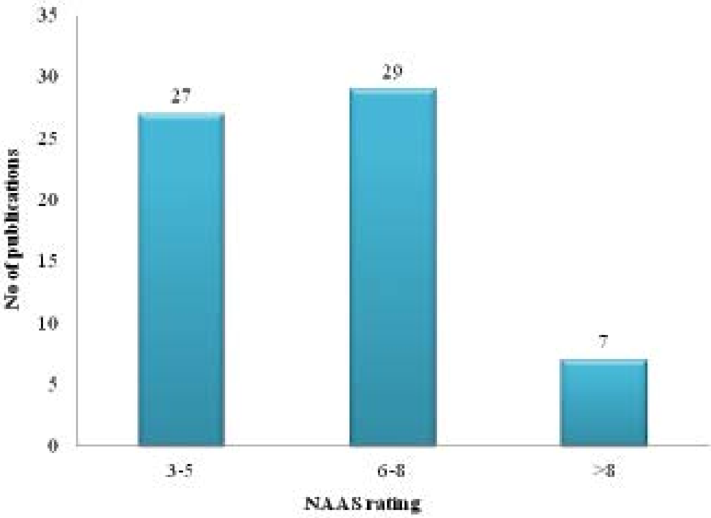

Fig. 9. Publications of PhD students with NAAS score

helped students to showcase their skills in their resume for their prospective recruiters in these fields. This also helped in getting admission in good colleges/ universities for higher studies.

The research work conducted at NRRI by the MSc and PhD students has resulted in good number of publications in national and international journal of repute. Sixty three articles were published out of which 7 articles showed >8 NAAS rating. Also, 29 articles have been published with NAAS score of 6-8 (Fig. 9). The average NASS score of the publications for 5 years was found to be 5.08.

6. ASPIRATIONS

The developments of linkages between institutes contribute to effective cooperation of research and development in different areas of rice research. Accordingly, MOUs signed between NRRI and other reputed institutes will be increased not only for students' admission but also for effective coordination in the research activities. Moreover, challenges of next few decades in terms of increasing rice production in India requires enhancement of skills particularly in data analysis, simulation models, bioinformatics analysis, genome editing, precision breeding, pest forecasting and modeling etc. Thus, HRD of NRRI will encourage in developing a platform for the interested students and rice researchers to undergo training in these areas for addressing the research problems pertinent to India particularly, the eastern India.

7. CONCLUSION

The Human Resource Development is one of the major components of skill enhancement for rice researchers and students to enrich their knowledge in rice sciences. HRD at NRRI has been active in signing MOUs with different public and private institutes/universities for taking students to pursue their MSc and PhD programmes. The number of summer trainings undergone by the students is also increasing over the years as well. Since, there are immense challenges ahead for agriculture in India, it is required to make the next generation ready to overcome these problems through science-led technologies. Therefore, HRD activities of NRRI is always proactive to acquaint the rice researchers and students with emerging technologies particularly in rice sciences to empower and equip them to ably address the ever growing food requirements of the country.❄

ICAR-National Rice Research Institute: Nostalgic Anecdotes

Sangram Keshari Nayak

1. INTRODUCTION

The Central Rice Research Institute was established on 23rd April 1946 and started functioning in a state farm premises with a scenic landscape of 60 hectares. It is endowed with a rich heritage, holding unbelievable stretch of landscape beauty to its eastern side until river Mahanadi where the Sun rise in the morning to reverberate ecstatic assurance of faith and strength, orchards embracing varieties of fruit trees, two large ponds capable of sustaining irrigation to crops round the year, the intertwining red soil roads reaching every corner and a band of committed souls dedicated to explore rice science to sustain food security of the nation. This might sound like rapture but truly and yet enigmatically, this holy premise is considered the seventh heaven on earth. The Institute is surrounded by villages like Bhadimul, Kanheipur, Bidyadharpur and the inhabitants have displayed rare harmony for peaceful coexistence and integrated support. The beauty of nature can have a profound effect upon our senses, those gateways from the outer world to the inner feelings such as awe, wonder, or amazement. The staff irrespective of cadre (scientific, administrative, technical, supporting and casual) exhibit deep emotional involvement to manifold rice research activities to make everybody proud of its status as beacon of hope in the country. It is indeed a rare opportunity for all those who were and are privileged to serve this Institute. Due to paucity of residential accommodation, many staff members out of compulsion stay outside but the lucky ones are those who stay inside the campus. No need to say that staff staying in the campus are soon captivated and intoxicated to stay for their life in this paradise. It also helps scientists to out stretch their work in the lab beyond routine hours. The inmates of the campus live in empathy and fellow feeling. The author out of his 40 years of service lived in this serene campus for more than 25 years and at the end of the day still laments for another lease of life to stay here. In the process of growing in the campus, we unknowingly get sensitized to delicate ambiance of its air, water, wind, trees, animals, glimmering stars, sounds of frogs and many more astounding integrities. We also get indentified with every square inch of the campus like its gulguli, water drainage culverts near cigarette house, sluice gate for inlet of canal water, the drain passing through campus, Bhogamaba bodhi, the Taldanda canal, river Mahanandi and its embankments. We shall continue to admire the nature prevailing in the Institute and elsewhere but also remain grounded to our duties and responsibilities. Having remained glued to such unique experience, we have certainly become more and more valiant to fight for the environment, which have been strengthened over the years through several projects on crop resilience to climate change – an undeniable testimony to understand better the interaction between crop and environment.

Soaked in memory, the author attempts in this write up to unravel a few of the nostalgic anecdotes to make the memory spicy and pleasant. There is a child in each of us and it is urged to read these anecdotes with the child's sense of inquisitive innocence. Of all the emotions, nostalgia, or longing for the past, is perhaps the most potent and crippling. Almost all of us, for some reason or the other, always leave a familiar place. We may not regret leaving it, but we always end up longing for it. The times we lived through, the people we shared those times with a cocktail of experience but each mix tells a story. Put them together, and they can add up to the story of a life. It is an inexplicable feeling, one that we can seldom put into words. The author only recapitulates some events for readers.

2. PT. NEHRU'S VISITS TO CRRI

Odisha's capital city Bhubaneswar celebrated its 70thFoundation Day on April 13, 1948 on which the first Prime Minister Pandit Jawaharlal Nehru had laid the foundation stone of the city. World renowned German architect and urban planner Otto Koenigsberger prepared the city's first master plan in 1948 for a population of 40 thousand. This day was also the Utkal Dibasa. Pt. Nehru visited Central Rice Research Institute for a while and scripted his message on the Visitor's book which was later ornamented for display on the front entrance lounge "*All good wishes to the Rice Institute*……". Dr. K. Ramiah was the Director (1946-51).

His next visit was on January 3, 1962, en route to Paradip Port for the port inauguration. He preferred to take rest in the newly constructed Director's residential bungalow (present) for a while. He took a brief stroll in the colony, which was named as Nehru Colony and also visited the Childrens' Park that carried his name as Nehru Childrens' Park later. It was a hectic day for Pt. Nehru as he had to inaugurate and address the 49th session of Indian Science Congress at Ravenshaw College (now Ravenshaw University), Cuttack. However, there was a problem!

Dr. Richharia, the then Director (1958-66), got upset to know from the police escort party that Prime Minister's vehicle was prohibited to move back in reverse gear. But, the approach road from gate to the portico of Director's bungalow was too narrow that virtually prevented any 'U' turn compliance. Mr. C.N. Relwani, the then Farm Superintendent was summoned and on his call, surprisingly so many labourers instantaneously started working to build the road. The barbed wire fencing (not the present concrete compound wall) was cut to accommodate a gate and masonry work was completed to make two pillars urgently. PM's vehicle plied through this gate to Paradip via Kandarpur as the Paradip Express Highway did not exist then. The eastern side gate of the bungalow that we see today had its genesis to January 3,1962.

The Institute mourned the death of Hon'ble Prime Minister in 1964 with heavy heart and great dignity in the front lawn of the INS Hostel where all staff with their families came to pay their homage in front of his photo. This continued for about a week.

3. LABOUR STRIKE AND DR. I.C. MOHAPATRA

During late fifties, there were series of labour strikes at CRRI that resulted in frequent disruption in farm operations and cultural practices. Rice is a labour intensive crop and often these strikes target to disturb land preparation, transplanting, etc. Dr. Iswar Chandra Mohapatra, was the Head of Agronomy Division and was In-charge of all farm schedules who wanted to dispense with the problem. He was from an influential landlord (jamindar) family in Baudpur, Mayurbhanj who motivated some handful members of adivasi community and succeeded to bring a hoard of them. This community was not only a suitable alternative to overcome labour strike but also was comparatively much more resilient to undertake any hardship. They settled in huts around the embankment of Ratna (earlier Patnaika) tank. The labourers comprising of males and females settled down happily under the ambiance of orchads full of mango, guava, sapeta and litchi trees encircling the tank. They used to observe their holy rituals and amongst them *Makar-Sankranti* observed in January dedicated to Sun God was most prominent. Adivasis cook rice with sugarcane juice or otherwise and ferment it to make *handia*, a local liquor and get intoxicated more particularly on this day. Soon, their intoxication used to get translated in form of dance tuned to the drum bits. Many staff go and participate in the ecstatic wilderness of the ceremony. Noteworthy participation of Dr. S.Y. Padmanabhan, the then Director and Sri C.N. Relwani, Farm Superintendent used to be most spectacular who also danced with the adivasis (tribals) on the rhythm of drum.

The family of these labourers slowly grew and every year the number was found to be many fold of the original size making the space a problem. Additionally, open air defecation and some other vulnerable activities became a nuance. However, in course of time, the services of many of them were regularized while many more were absorbed in various supporting staff categories. That entitled them for quarters and thus they were evacuated to enable reclaim the land into productive experimental purposes.

4. ANTIQUE TRANSPORT SYSTEM

Once upon a time, bullock cart was the only option of transport in CRRI. The memory is still fresh to recapitulate that 2-3 carts fitted with automobile tyre-tube were engaged for various farm operations but more importantly bringing fertilizer, cattle feed, etc. from Malgodown. There was no electricity then. The street lights were provided with kerosene lamps from OMP square to Chauliaganj and later extended up to Naya Bazar square. It was pitch dark from Nayabazar until CRRI and beyond. One won't find a single house by the side of the road from CRRI until college square. All these roads were covered with huge trees and their canopies making the environment more mystique. There were hardly any motor cycle or four wheeler plying in this route. Only bicycles were plenty but by traffic law they all had to fit kerosene lamps burning in the front hanging from the handle bar during evening hours. Our bullock carts used to hang lanterns while moving during evening hours. Under emergencies, these carts worked like ambulance and rescued patients saving lives.

During Dusherra festivals however, the carts along with its passengers projected a funny scenario. Special 2 numbers of long benches used to be fitted facing each other. It would carry 5-10 persons in a festive mood for site seeing all the way from CRRI to Chowdhury Bazar and back. But the Mother deity at Chowdhury bazaar was yet to be decorated with silver (Chandi) ornaments.

During the 1950's and early 1960's, the children of the campus used to go the school i.e., Stewart School and St. Joseph's Convent situated about 10 km from the Institute by Bullock Cart. During the later part of 1960's, the Bedford bus (popularly known as blue bus) was acquired by the Institute for the school going children. In 1972, the institute procured a full body Ashok Leyland Bus for the school going children and subsequently one more was added.

5. DIRECTOR'S OFFICE IN THOSE DAYS

Dr. R.H. Richharia, the then Director (1958-66) had his office inside the farm quadrangle (1954-55). Few buildings were only available while taking over the campus from the state government. The summer season was never as hot as these days. But, one of our labourers, Sri Kanhu Panda used to operate the overhead fan. The mechanism dates back to British regime where a huge long mat supported with wooden structures on top use to hang and strong ropes were tied at both ends for its swinging. Sri Kanhu Panda sitting outside the office used to operate the fan but often found to nap and snore. The Director never disturbed him whatsoever.

Dr. Richharia was one of the leading experts on rice in India. He documented and collected an amazing 19,000 rice varieties during his career. As per his estimation, India was home to 200,000 varieties of rice cultures. During his tenure, many societal segments such as Consumers Cooperative Society, CRRI Milk Society, Dairy Farm and CRRI Recreation Club were founded. He entrusted the Cooperative Association to take care of two tanks, Puja (earlier Kanhori) and Ratna tanks for pisci-culture. The revenue so generated could be spent on approved social work and functions.

6. DR. S.Y. PADMANABHAN, EX DIRECTOR AND HIS PHOTOGRAPHY

Shri S.Y. Padmanabhan, Mycologist of the Institute, was awarded merit promotion to the post of the Director of the Institute during the year 1966 for his outstanding work in the field of Mycology and Plant Pathology. There were number of milestone achievements during his tenure. CRRI was projected as the beacon of hope for rice consumers. Among many visits abroad, his earliest were to Russia and China. He ensured to take the most advanced Kodak camera with him to Russia and snapped various important activities. On his return, he asked Mr. Gowalikar, the then Photographer of the Institute to develop the film. The film was developed only to find the entire film blacked out with no sign of any photo. Mr. Gowalikar was afraid of the situation and requested Mr.P.J. Jachuk, Breeder to resolve the issue. Mr. Jachuk asked the Director, if he had removed the lens cover before shooting to which innocent response was that he was not aware of this protocol.

7. BONHOMIE AT CRRI

The bonhomie amongst the staff members dates back to its very inception. There was a time during the 60′s, 70′s and 80′s when in the absence of any other medical hospital, only option for any treatment was the SCB Medical College and hospital. Any staff suffering from minor to major ailments, had to take treatment from there. The Doctors and Nurses by seeing the number of attendants accompanying a patient could tell that the patient was from CRRI only. A Bedford school bus of the Institute used to take the attendants in batches of 10 to 12 and all day and night. Casual to serious patients were voluntarily supported and that too round the clock.

Dr. S.Y. Padmnabhan once in early 70′s fell seriously ill with incessant blood stool. He was taken in an ambulance and was admitted in SCB Medical College. He was in dire need of blood for survival. Guided by Dr. S.N. Pattnaik, next to Director, Shri S.K. Nayak loudly informed all scientists and staff working in field. Magically soon after, it was a sight to be seen at Central Red Cross Blood Bank where there was a never ending line of CRRI staff mainly comprising of labourers ready to donate blood. More particularly the labourers shouted to Red Cross bank staff in a frenzy that let them take the last drop of their blood but save Padmanabhan, their *Bhagwan*. The staff of Blood Bank were not only surprised by this rare spirit but also found difficult to control the donors. Only 10 bottles were taken in the first installment while the queue was holding more than 100 persons. Despite the appraisal by Shri S.K. Nayak, the eager donors were waiting day and night to donate blood in case the 2nd installment was necessary. It was a phenomenal love and respect for Dr. Padmanabhan who recovered well in a fortnight time. Most delighting episode followed that was never revealed by Shri Nayak who was at least invited twice a week by Madam Padmanabhan to the residence and was fed with fruits an dry nuts with the belief that Shri Nayak was instrumental in systematically organizing blood that primarily saved her husband's life. Otherwise also, she was an epitome of motherly persona to one and all.

All the pujas were observed/held jointly by all the staff members in the staff recreation club followed by dinner for everyone at the backside of the club. The scientific fraternity used to hold a 'Moonlight Dinner' in the threshing floor of the Farm Division. Five/six families used to be entrusted with the responsibility of preparing one particular dish. Similarly, other groups of five/six families used to be asked to prepare different dishes each. All used to bring the prepared dishes to the Farm Section where the 'Moonlight Dinner' used to be held with great fanfare with songs/poems by groups/individuals.

8. WHO RESCUED DR. M.J.B.K. RAO, THE BREEDER?

Dr. M.J. Bala Krishna Rao (called as BK) was married to conventional rice breeding rather than to Dr. Mrs. Suprava Mohanty who was also a scientist but preferred to be a homemaker after marriage. Dr. Rao was a gifted breeder who believed in conventional breeding. Some of his reigning varieties were Bala, Krishna and Padma. Most of the time, he was absent-minded for which he became quite familiar with all. He had a motorcycle (Rajdoot) and the couple often went to college square for marketing. Normally, madam used to shop while BK would wait outside. All on a sudden, he would assume that his wife was already seated on the pillion and he would drive home (CRRI) only to realize the misfortune. However, he would hurriedly recover madam from where he left. This happened for number of times after which madam preferred some other alternative for marketing.

One day while visiting field, he fell down into the irrigation concrete channel and sustained injury. It was midday and nobody was around (lunch break) except his faithful dog. The dog ran to his house and dragged the saree of Madam who realized the message and followed the dog. The irrigation water was flowing and BK was lying flat in the channel. Madam shouted for help and he was rescued with prompt support. So many of his colleagues desired to know how he fell down, did he slip or anything else? He ascertained that he was taking a morning walk in his garden and he did not know how landed in irrigation channel. A very versatile breeder but …..

9. INITIAL SPORTS ACTIVITY (1966-67) AND ITS STATUS QUO

Sports and other welfare activities among the staff of all central government offices were held annually under the banner of 'Central Government Employees' Welfare Co-ordination Committee (CGEWCC). It was statutory that the highest salaried Director among all the Directors became the Chairman of the CGEWCC. Accordingly Dr. S.Y. Padmanabhan was the Chairman who in 1967 asked Sri S.K. Nayak, the then Sr. Res. Assistant to coordinate and take the team in capacity of Manager. Only Volley Ball competition was approved and only the CRRI team represented the CGEWCC in Lal Bahadur Sastri Stadium, Hyderabad, where the meet was conducted. Soon after, the ICAR became autonomous (1966) and CRRI was no more considered under CGEWCC but since then in annual sports meet of ICAR, several times till date CRRI has been dominating in Zonal as well as Final meets and have bagged a plethora of laurels. Kabbadi championship is almost a monopoly of NRRI. The number of awards exceeded the space in Director' office chamber and only recently (2019) Dr. H. Pathak, present Director arranged the display in the corridor to auditorium. Other than victory insignia in sports, the array of decorations also includes several other prizes on significant and distinguished achievements. It emanates a spring of joy to all staff members and visitors. Now, one can feel them.

10. RICHHARIA FOOTBALL CUP & OTHERS

During the middle 1960's, CRRI started organising a prestigious Richharia Football Cup wherein the top club/official teams of Cuttack used to participate. This tournament was held in the CRRI playground once every four years. A large number of staff of this Institute have been very good sportsmen during their heydays. Some of the prominent names includes: Sangram Keshari Nayak (Orissa State Badminton Team & National Umpire), Sharad Kumar Mathur (Junior State CK Nayadu Cricket Trophy), Basant Kumar Sahoo (Coach, Orissa Kabadi Team), Sanatan Baral (All India IFA Cup, Junior National Camp for Asian Youth Football Championship), Narayan Panda (All India IFA Cup), Narayan Das (All India IFA Cup), Sunil Kumar Sahoo (Junior State Football Championship), Pradeep Parida(Orissa State Kabadi Team) and Prasant Kumar Jena (Orissa State Kabadi Team).

11. JAPANESE SCIENTIST IN TROUBLE

Many scientists, students and visitors from abroad such as USA, The Netherlands, South Korea, Japan and China regularly visited CRRI with a specific objective of learning. International Training Course for rice technicians was also organized (July to December, 1966) as a part of India's contribution towards the International Rice Year. Research workers from Burma, Thailand, Guatemala, Hungary and Ghana, in addition to those from India, participated in the six-month training course.

A Japanese scientist came to CRRI on deputation to collect wild rice germplasm and acquire relevant literature. He stayed in Inter-National Students' Hostel (INS). One fine morning he took a brisk walk in his adventure on wild rice hunting. He visited banks of Taldanda canal and every other place *en route* for exploring a new vista of wild rice treasure. He reached All India Radio Transmission Center at Fakirpada, which was about 5-7 km from CRRI gate. Out of his quest to explore wild rice, he entered the prohibited premises inadvertently only to find a guard chasing him. The guard caught hold of him and physically forced him to meet the officer. Soon there was a crowd to see the funny looking man shouting in a funny language. Both the parties had hot exchange of words without understanding each other because there was a mismatch in Japanese, Oriya, Hindi or English. The authority finally decided to hand him over to police when the matter reached CRRI. Dr. P.J. Jachuk's brother Sri I.J. Tachuk was an IPS officer who was in Cuttack intervened and rescued him. The Japanese scientist could not however assimilate his wild rice hunting had such wild consequences.

12. FOUNDATION DAY CELEBRATION OF CRRI

Dr. K.C. Mathur, the then Director (1995-99) started the Foundation Day Celebration in 1999. Initially it was celebrated on April 9 coinciding with the first visit of Dr. Ramiah to CRRI to establish the Institute. Later, the date was shifted to April 23. This was the date when first circular was issued by ICAR to establish the Institute and thus the Central Rice Research Institute (CRRI) was setup on 23 April 1946 at Bidhyadharpur, Cuttack, Odisha. There was also a suggestion to observe the Day on April 22, coinciding with the 'Earth Day'. However, for last several years, Foundation Day of NRRI is celebrated on April 23 with a few exceptions due to unavoidable circumstances.

13. SUPER CYCLONE DISASTER (1999)

On October 29, 1999 a super cyclone with a wind speed of 300 mph or more had struck Odisha, making it probably the greatest cyclonic disaster ever recorded in the last century. Coastal districts of Balasore, Bhadrak, Kendrapara, Jagatsinghpur, Puri and Ganjam were badly affected. Eye of the storm was Paradip while Ersama and Balikuda in Jagatsinghpur district (southwest of Paradip) experienced the worst hit. The India Meteorological Department anemometer at Paradip failed to record the force of wind that gushed for 36 hours at 300 km per hour or more. The storm witnessed a surge of 7-10 meters of ocean water level resulting in ingression of 12-20 km in coastal areas. Life at CRRI campus was miserable due to unprecedented water inundation not only due to high rainfall but the campus accumulated heavy amount of drain water as it was the terminal end of the city and all the accumulated water get evacuated to the river Mahanadi through antique Gulguli sluice system. The river Mahanadi was in full spate and its higher water level compared to the campus level refused any water exit compounding the misery. Entire campus including the Nehru colony was submerged. The deep bore wells those were engaged for irrigation of experimental fields were overflowing like water fountains aggravating the inundation.

Dr. K.C. Mathur, Director and Dr. S.B. Lodh mustered courage to restore the awkward situation. Many young volunteers were lined up to provide drinking water by using mobile tankers pulled by tractors and pump houses were run by diesel generators to enable lift water. Sri S.K. Nayak, on priority basis arranged distribution of drinking water at every doorstep of campus residents. Temporary shelters were given at International Students Hostel and the CRRI Welfare Association prepared one time food for destitutes. In collaboration with State Relief Department rice was distributed to families whose houses were damaged. Sri Chandrababu Naidu, the then Chief Minister of Andhra Pradesh urgently deployed a team of experts with materials like electric poles and arranged restoration of electricity by dragging electric lines. Electric poles were bent like hairpins but the team came with special machines to set right the damaged poles wherever was possible. It was a herculean task to normalize the plots, which were contaminated with drain water, as well as other plots under various treatments were also badly affected. The courage and forceful will power of staff enabled resumption of normalcy in appreciable time period.

14. FLOOD OF 1982 IN RIVER MAHANADI AND THE AFTERMATH ORDEAL

Orissa experienced yet another tragic and devastating flood in 1982 and hardest hit was Cuttack district. Incessant rain beyond the holding capacity of Hirakud dam jerked the opening of all gates that compounded the terrifying torment downstream affecting 10 million people. CRRI was no exception. There was heavy inundation in the campus which was aggravated not due to rain water alone but the heavy gush of city drain water. The water through gulguli could not be evacuated as the Mahanadi flood water level on the other side was higher and almost touching the brim of the embankment bund prohibiting any relief. The bund was under vigilance by police as it was vulnerable for collapse at any point. It became essential to raise the bund height by putting sand bags along the 1.0 km long bund (Kanheipur to Chhota dokan via Bhogamaba). Huge dunes of sand stocked by Mr. Sadhu Nayak, the then contractor helped to arrange hundreds of sand bags. The time for entire operation of stacking the sand bags on the bund was brisk, our tractor drivers were only two Mr. Bata and Mr. Yudhistira that was supplemented by Mr. Sanatan Baral, Foreman. It was panicking to see that in fact water level was higher than the bund at many places but water could not ingress due to timely piling of sand bags. It actually saved the Institute as well as the city in time and the ordeal continued until the water receded. The breakage of Dalei Ghai affected thousands of families and lakhs of hectares of cultivable land but incidentally drained out lot of water giving some solace. The people of in and around villages were given shelter in half constructed buildings of Library and upper floors etc. Despite the imminent tragedy, people in large number were gathering on the risky bund, which was soon controlled by police and CRRI volunteers. It was panicking to feel the thunderous vibration of the bund threatening to collapse any moment. A siren was arranged to blow enabling the villagers to run to the high places immediately in case of any eventuality. Many families residing in INS Hostel lead by Miss Omna prepared cooked food and distributed in shelters. Pumps were engaged day and night to evacuate water stagnation but appeared to be in dismal against the vast water of ocean inside the campus.

15. THE PLIGHT OF PH.D. STUDENTS & CANTEEN

Central Rice Research Institute besides its continuing glorious service dedicated to nation's food security is also a centre par excellence for dissertation work. Many Ph.D. students register under able guides (scientists) of different disciplines and successfully complete their work. Starting from a few numbers in the long past, now the size of Ph.D. students has grown into a school. Now the facilities are befitting but Dr. Mayabini Jena recollects good old days of 1979 and earlier to be comparatively difficult as a canteen was not available then for lunch. She daily joined with 4 or 5 of her classmates who would eagerly wait for Mr. Indramani Mohanty, a mobile vender on cycle to serve them Dahi bara, bara, piagi, alu-dum under the shade of a tree to appease their hunger. Soon a contractual canteen was available in a thatched house inside the quadrangle that appeared like a floating boathouse during rainy season. The canteen owner Mr. Bishnu Behera used to put some bricks as stepping stones for the customers. It continued until we had our canteen in the new building.

16. REHABILITATION OF COASTAL FARMING AFTER SUPER CYCLONE DISASTER

The NRRI campus soon after the super cyclone (October 29, 1999) recovered from ravages to full life. The submergence due to incessant raining during the cyclone coupled with gush of wind at 300 km per hour upset the field infrastructure but with motivated zeal and zest, the recovery was also astounding. Dr. Baij Nath Singh, joined as the Director, CRRI who was full of innovative ideas and spirit to give a new dimension to the ongoing and many new research projects. He visited the coastal belt of Paradip and focused on Astaranga and Ersama blocks those were the eye of storm and were damaged beyond assessment. The people were bereaved of their belongings, houses and were like refugees despite the support extended by the State Government and others for quick rehabilitation. He convened a preparatory meeting that was participated by staff of CRRI, Orissa University of Agriculture and Technology (OUAT), Department of Water Resources, all KVKs, Orissa State Disaster Mitigation Authority (OSDAM) and others. The contingent plan was consolidated into a 100 crore holistic project format that was approved by the

ICAR urgently. All the scientists, technical staff of CRRI and resource persons of OUAT and State Departments were deployed to lend their expertise and strengthen the farmers to resume their trade with more productive knowledge, output and income. The rice-fish farming of CRRI was adopted by farmers community, rice varieties (Lunishree, Sonamani) suitable for saline track were introduced, vegetable growing was one of the most enthusiastic ventures, goatery, poultry, etc. were lavishly inducted. It was a dream come true episode. Such a team spirit proved our effort and potential to recover from tragedy so soon and rehabilitate to lead a decent life with true entrepreneurship.

17. EXTREMELY SEVERE CYCLONE 'FANI' STRUCK NRRI (2019).. CRUSHED BUT NOT DEFEATED

On May 3, 2019, 20 years after the super cyclone (1999), another Extremely Severe Cyclone 'FANI' struck Odisha and other parts of Eastern India. It made landfall near the city of Puri. Bhubaneswar, Puri and Cuttack experienced wind speed up to 250 km per hour. It caused extensive damage in the NRRI campus with uprooting of large number of decades old trees; damaging rainout shelters, poly-houses, glass houses, climate change installations and other research facilities; crops, properties and disrupting the telecommunication and power infrastructure. Many parts of the campus were waterlogged. The entire ground floor housing the main office, Director's office and several laboratories could be saved by timely and valiant efforts of Mr. Abhishek Meena (T-3), Dr. M.J. Baig (Principal Scientist), Mr. Manas Kumar Behera (Security staff) and Dr. H. Pathak (Director), who defiantly came out in the open facing the cyclone at its peak to clear the blockage of drains with spade and shovel. Large volume of water, accumulated in the quadrangle, drained out so that the offices and laboratories were rescued from inundation. Once the cyclone ceased in the evening, main roads were cleared in few hours with voluntary support of the staff and students. Water supply was restored in next few hours with generators. Electric supply and other activities, however took a few days to come to normalcy.

18. EPILOGUE

One can go various other places in the journey of life, one may live on the other side of the world but you can't escape the memories of the place where you worked so dearly for so many years of your life. The past is like a candle at great distance; too close to let you quit, too far to comfort you. These bunch of fond memories are exclusive rights of senior staff members who are now 70 years or more. They are very special editions who conserve these delicate and passionate memoirs for dissemination in appropriate time like this. The author took care to contact such reservoirs but not all and therefore feel some chunks might be missing. However, it offers readers some nostalgic events for interesting reading and imagine the scenarios narrated. As observed very rightly by Kris Kristofferson "I'd trade all my tomorrows for one single yesterday".

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ACRONYMS

4S4R	Self-sufficient Sustainable Seed System for Rice
ABC	Atmospheric Brown Cloud
ABTS	Antioxidant Activity
ADB	Asian Development Bank
AFLP	Amplified Fragment Length Polymorphism
AG	Anaerobic Germination
AGP	Anaerobic Germination Potential
AICRIP	All India Coordinated Rice Improvement Project
AISPA	All India Seed Producer's Association
ALEXI	Atmosphere-Land Exchange Inverse Model
ALS	Acetolactate Synthase
AMF	Arbuscular Mycorrhizal Fungi
AOSCA	Association of Seed Certification Agencies
ARC	Assam Rice Collection
AWD	Alternate Wetting and Drying
BADH	Betaine Aldehyde Dehydrogenase
BB	Bacterial Blight
BCA	Biocontrol Agent
BCM	Billion Cubic Meters
BGREI	Bringing Green Revolution to Eastern India
BHA	Butylated Hydroxyanisole
BPH	Brown Planthopper
BSP	Breeder Seed Production
CA	Conservation Agriculture
CAGR	Compound Annual Growth Rate
CAM	Crassulacean Acid Metabolism
Cas9	CRISPR associated protein-9 nuclease
CAT	Catalase

CCM	Carbon-dioxide Concentrating Mechanisms
CGR	Crop Growth Rate
CIPK	Calcineurin-Interacting Protein Kinase
CKM	Cubic Kilometers
CLCC	Customized LeafColour Chart
CLP	Cyclic Lipopeptides
CM	Cubic Meters
CMS	Cytoplasmic Male Sterile
CR	Crop Residues
CRCT	Climate-Smart Resource Conservation Technology
CRISPR	Clustered Regularly Interspaced Short Palindromic Repeats
CSP	Common Symbiosis Pathway
CT	Conventional Tillage
CVRC	Central Variety Release Committee
DAC	Department of Agriculture Cooperation
DAF	Days After Flowering
DAP	Days After Planting
DAS	Days After Sowing
DFR	Dihydro Flavonol Reductase
DH	Doubled Haploid
DisALEXI	Disaggregated ALEXI
DNA	Deoxyribonucleic Acid
DSI	Drought Susceptibility Index
DSN	Disease Screening Nursery
DSR	Direct Seeded Rice
DSSAT	Decision Support System for Agrotechnology Transfer
DUS	Distinctness, Uniformity and Stability
EBBR	Energy Balance Bowen Ratio
EBC	Energy Balance Closure
EEFs	Enhanced Efficiency Fertilizers

EGMS	Environment Sensitive Genetic Male Sterility
EI	Ecological Intensification
EPA	Environment Protection Agency
EPS	Exopolysaccharide
ER	Endoplasmic Reticulum
ERF	Ethylene Response Factors
ES	Ecosystem Services
ESV	Early Seedling Vigor
ET	Evapotranspiration
ETC	Electron Transport Chain
ETR	Electron Transport Rate
EUE	Energy Use Efficiency
FAO	Food and Agriculture Organization
FIG	Farmer Interest Group
FIRBS	Furrow Irrigated Ridge-till Bed-planting System
FLD	Front Line Demonstration
FPO	Farmer Producers' Organization
FSS	Formal Seed System
FYM	Farm Yard Manure
GA	Gibberellic Acid
GABA	Gamma-Aminobutyric Acid
GBSS I	Granule Bound Starch Synthase I
GCDT	Global Crop Diversity Trust
GCL	Glyoxylate Carboxyligase
GDC	Glycine Decarboxylase
GDH	Glycolate Gehydrogenase
GHG	Greenhouse Gas
GHGE	Greenhouse Gas Emissions
GI	Geographical Indication
GI	Glycemic Index

GIAHS	Globally Important Agriculture Heritage System
GIS	Geographic Information System
GLH	Green Leafhopper
GM	Green Manuring
GM	GeneticallyModified
GMO	GeneticallyModified Organism
GMS	Genetic Male Sterile
GOT	Grow-Out-Trail
GPC	Grain Protein Content
GPS	Global Positioning System
GSOD	Germination Stage Oxygen Deficiency
GSR	Green Super Rice
GST	Glutathione s-Transferases
GV	Granulosis Virus
GWAS	Genome-Wide Association Study
GWP	Global Warming Potential
HAR	Hypernodulation and Aberrant Root Formation
HI	Harvest Index
HLH	Helix-Loop-Helix
Ho	Heterozygosity
HPR	Host Plant Resistance
HR	Homologous Recombination
HRR	Head Rice Recovery
HT	Herbicide Tolerant
HYV	High Yielding Variety
IARC	International Agricultural Research Center
IC	Internal Combustion Engine
ICAR	Indian Council of Agricultural Research
ICIA	International Crop Improvement Association
ICM	Integrated Crop Management

ICT	Information and Communication Technology
IFS	Integrated Farming System
IGP	Indo-Gangetic Plains
InDels	Insertions and Deletions
INM	Integrated Nutrient Management
IPCC	Intergovernmental Panel on Climate Change
IPM	Integrated Pest Management
IPR	Intellectual Property Right
IRAC	Insecticide Resistance Action Committee
IRC	International Rice Commission
IRDF	Integrated Rice–Duck Farming
IRRI	International Rice Research Institute
ISR	Induced Systemic Resistance
ISS	Informal Seed System
ITPGRFA	International Treaty on Plant Genetic Resources for Food and Agriculture
KRIBHCO	Krishak Bharati Cooperative
KSB	Potassium Solubilizing Bacteria
KVK	Krishi Vigyan Kendra
LAI	Leaf Area Index
LAMP	Loop-Mediated Isothermal Amplification
LB	Long Bold
LCC	Leaf Colour Chart
LD	Linkage Disequilibrium
LE	Latent Heat Flux
LR	Lime Requirement
LS	Long Slender
LTS	Long Term Storage
LUE	Light Use Efficiency
LULC	Land Use and Land Cover

LV	Low Volume
LWP	Leaf Water Potential
MAAL	Monosomic Alien Addition Lines
MAB	Marker-Assisted Backcross
MABB	Marker-Assisted Backcross Breeding
MAS	Marker Assisted Selection
MB	Medium Bold
MB	Mould Board Plough
MDH	Malate Dehydrogenase
ME	Malic Enzyme
METRIC	Mapping Evapo Transpiration at high Resolution with Internalized Calibration
MGMG	Mera Gaon Mera Gaurav
MGPT	Marker Based Genetic Purity Testing
MMT	Million Metric Tons
MoA	Ministry of Agriculture
MOU	Memorandum of Understanding
MS	Medium Slender
MSI	Membrane Stability Index
MSP	Minimum Support Price
MTA	Material Transfer Agreement
MTS	Medium Term Storage
NAS	Nicotianamine Synthase
NATCOM	National Communication
NATP	National Agricultural Technology Project
NBPGR	National Bureau of Plant Genetic Resources
NCS	National Collection from States
NCU	Neem Coated Urea
NDVI	Normalized Difference Vegetation Index
NERICA	New Rice for Africa
NGB	National Gene Bank

NGO	Non-Governmental Organization
NGR	New Generation Rice
NGS	Next Generation Sequencing
NHEJ	Non-Homologous End Joining
NIL	Near-Isogenic Line
NIR	Near Infrared Spectroscopy
NNI	Nitrogen Nutrition Index
NPT	New Plant Type
NPV	Nuclear Polyhedrosis Virus
NPV	Net Present Value
NRRI	National Rice Research Institute
NSC	National Seeds Corporation
NSP	National Seed Project
NuDSS	Nutrient Decision Support System
NUE	Nutrient Use Efficiency
ONM	Organic Nutrient Management
OSSC	Odisha State Seed Corporation
OSSOPCA	Organic Product Certification Agency
PA	Phytic Acid
PAC	Proanthcyanidins
PAH	Polycyclic Aromatic Hydrocarbons
PAM	Protospacer Adjacent Motif
PAP	Purple Acid Phosphatase
PAR	Photosynthetically Active Radiation
PCR	Polymerase Chain Reaction
PEPC	Phosphoenolpyruvate Carboxylase
PGA	Phosphoglycerate
PGMS	Photo-Sensitive Genetic Male Sterility
PGPM	Plant Growth Promoting Microbes
PGPR	Plant Growth Promoting Rhizobacteria

PGR	Plant Genetic Resources
PPDK	Pyruvate Orthophosphate Di-Kinase
PPP	Public-Private-Partnership
PSB	Phosphate Solubilizing Bacteria
PSM	Phosphate Solubilizing Microbes
PSP	Participatory Seed Production
PSTOL	Phosphorus Starvation Tolerance
PUE	Phosphorus Use Efficiency
PUL	Pullulanase
Pup1	Phosphorus Uptake 1
qPCR	Quantitative PCR
QTL	Quantitative Trait Loci
QuEFTS	Quantitative Evaluation of the Fertility of Tropical Soil
RAPD	Randomly Amplified Polymorphic DNA
RBCS	Rice Based Cropping System
RCM	Rice Crop Manger
RCT	Resource Conservation Technology
RDF	Recommended Dose of Fertilizer
RDN	Recommended Dose of Nitrogen
REY	Rice Equivalent Yield
RFLP	Restriction Fragment Length Polymorphism
RH	Relative Humidity
RIL	Recombinant Inbred Line
RKVY	Rashtriya Krishi Vikas Yojana
RM	Rice Microsatellite
RMP	Resistance Management Plan
ROS	Reactive Oxygen Species
rPGMS	Reverse Photo-Sensitive Genetic Male Sterility
RTNM	Real Time Nitrogen Management
RTV	Rice Tungro Virus

RuBisCO	Ribulose 1,5-Bisphosphate Carboxylase-Oxygenase
RuBP	Ribulose 1,5-Bisphosphate
RVC	Rice Value Chain
RWC	Relative Water Content
RWS	Rice and Wheat System
RZF	Root Zone Fertilization
SAU	State Agricultural University
SB	Short Bold
SBE	Starch Branching Enzyme
SCMR	SPAD Chlorophyll Meter Reading
SDA	State Departments of Agriculture
SDSM	Statistical Downscaling Model
SES	Standard Evaluation System
SFCI	State Farms Corporation of India
SGSV	Svalbard Global Seed Vault
ShB	Sheath Blight
SHG	Self Help Group
SMR	Seed Multiplication Ratio
SNP	Single Nucleotide Polymorphism
SOC	Soil Organic Carbon
SOD	Superoxide Dismutase
SOM	Soil Organic Matter
SQI	Soil Quality Index
SRI	System of Rice Intensification
SRR	Seed Replacement Rate
SSC	State Seed Corporation
SSD	Sub-Surface Drip
SSDC	State Seeds Development Corporations
SSFN	Site Specific Fertilizer Nitrogen
SSNM	Site Specific Nutrient Management

SSR	Simple Sequence Repeat
STARFM	Spatial and Temporal Adaptive Reflectance Fusion Model
STCR	Soil Test Crop Response
STMS	Sequence Tagged Microsatellite
Sub1	Submergence1
SVRC	State Variety Release Committee
SWAT	Soil and Water Assessment Tool
TAC	Total Anthocyanin Content
TFC	Total Flavonoid Content
TGMS	Thermo-Sensitive Genetic Male Sterility
TIL	TeQing-into-Lemont Backcross Introgression Line
TN1	Taichung Native1
TPC	Total Phenolic Content
TPR	Puddled Transplanted Rice
TSR	Tartronic Semialdehyde Reductase
ULV	Ultra Low Volume
UNDP	United Nations Development Programme
USG	Urea Super Granule
VAP	Value Added Product
VIC	Variable Infiltration Capacity
VOC	Volatile Organic Compounds
VRR	Varietal Replacement Rate
WBPH	White Backed Plant Hopper
WCE	Weed Control Efficiency
WF	Water Footprint
WOFOST	World Food Studies
WUE	Water Use Efficiency
Wx	Waxy
YSB	Yellow Stem Borer
ZT	Zero Tillage

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