

# Annual Report 2019



भाकृअनुप-राष्ट्रीय चावल अनुसंधान संस्थान  
ICAR-National Rice Research Institute





# ANNUAL REPORT 2019



# NRRI



## वार्षिक प्रतिवेदन Annual Report 2019

भाकृअनुप - राष्ट्रीय चावल अनुसंधान संस्थान

कटक (ओडिशा) 753 006, भारत

ICAR - National Rice Research Institute

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**Dr. Himanshu Pathak**

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**Editorial Committee**

Dr. GAK Kumar

Dr. BC Patra

Dr. MJ Baig

Dr. AK Mukherjee

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Shri JP Bisen

**Editorial Assistance**

Mrs. Sandhya Rani Dalal

**Photography**

Shri Prakash Kar

Shri Bhagaban Behera

**Inner Page Design**

Shri JP Bisen

**Cover Page Design**

Shri SK Sinha

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**Contacts**

**ICAR-National Rice Research Institute**

Cuttack - 753 006

Odisha

Phone : +91-671-2367768-83

Fax : +91671-2367663

E-mail : crriect@nic.in |

director.crri@icar.gov.in

directorcrri@cuttack@gmail.com

**NRRI Research Station**

Hazaribag - 825 301

Jharkhand

Phone : +91-6546-222263

Fax : +91-6546-223697

E-mail : crurrs.hzb@gmail.com

**NRRI Research Station**

Gerua, District Kamrup - 781 102

Assam

Phone : +91-361-2820370

Fax : +91-361-2820370

E-mail : oicrrlrrsgerua@rediffmail.com

**NRRI Research Station**

Naira, District Srikakulam - 532 185

Andhra Pradesh

Phone : +8895585994

Fax : 91-671-2367777/2367663

E-mail : rccrs.naira@gmail.com

Visit us at: <http://icar-nrri.in/home/>





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NRRI

# Preface



Since its establishment in 1946, the ICAR-National Rice Research Institute (NRRI) has complied with the contemporary national and global objectives, programmes and goals like Millennium Development Goals (MDGs) and Sustainable Development Goals (SDGs) for the people. The institute is working with different rice stakeholders in India and abroad. Currently, its research programmes and activities are aimed at contributing towards many of the SDGs through enhanced productivity, profitability, input use efficiency and climate resilience. In its 74 year of journey, the institute has released 136 high yielding rice varieties and three rice hybrids.

The year 2019 was the year of significant achievement for NRRI. In this year, despite the occurrence of super cyclone “Fani” the institute has developed 14 high yielding varieties, out of which 11 varieties have been released for cultivation in farmers field and three were identified for the release by VIC. The institute has registered eight rice germplasm with ICAR-NBPGR, New Delhi and one rice variety with PPV & FRA, New Delhi. The Institute has commercialized six new rice technologies during the year. The institute conducted about 700 field demonstrations for 21 high yielding rice varieties and technologies in diverse ecosystems of eight states. During the year, the institute provided 24 agro-advisory services for the farmers. The institute served the interest of more than 9000 visitors including 2400 students in 2019. Also more than 1000 participants have been trained on different aspects of rice through 56 training programmes. The Institute has published

about 80 research papers (more than 70% above NAAS score of 6) in the scientific journals of national and international repute; three books; four research bulletins, 14 technology bulletins; two training manuals and 20 popular articles.

During the year, the Institute worked on 31 research projects under seven research programmes, 137 externally-aided projects and four flagship projects. The salient outputs of the projects are presented in the executive summary and details are presented under various programmes in the report.

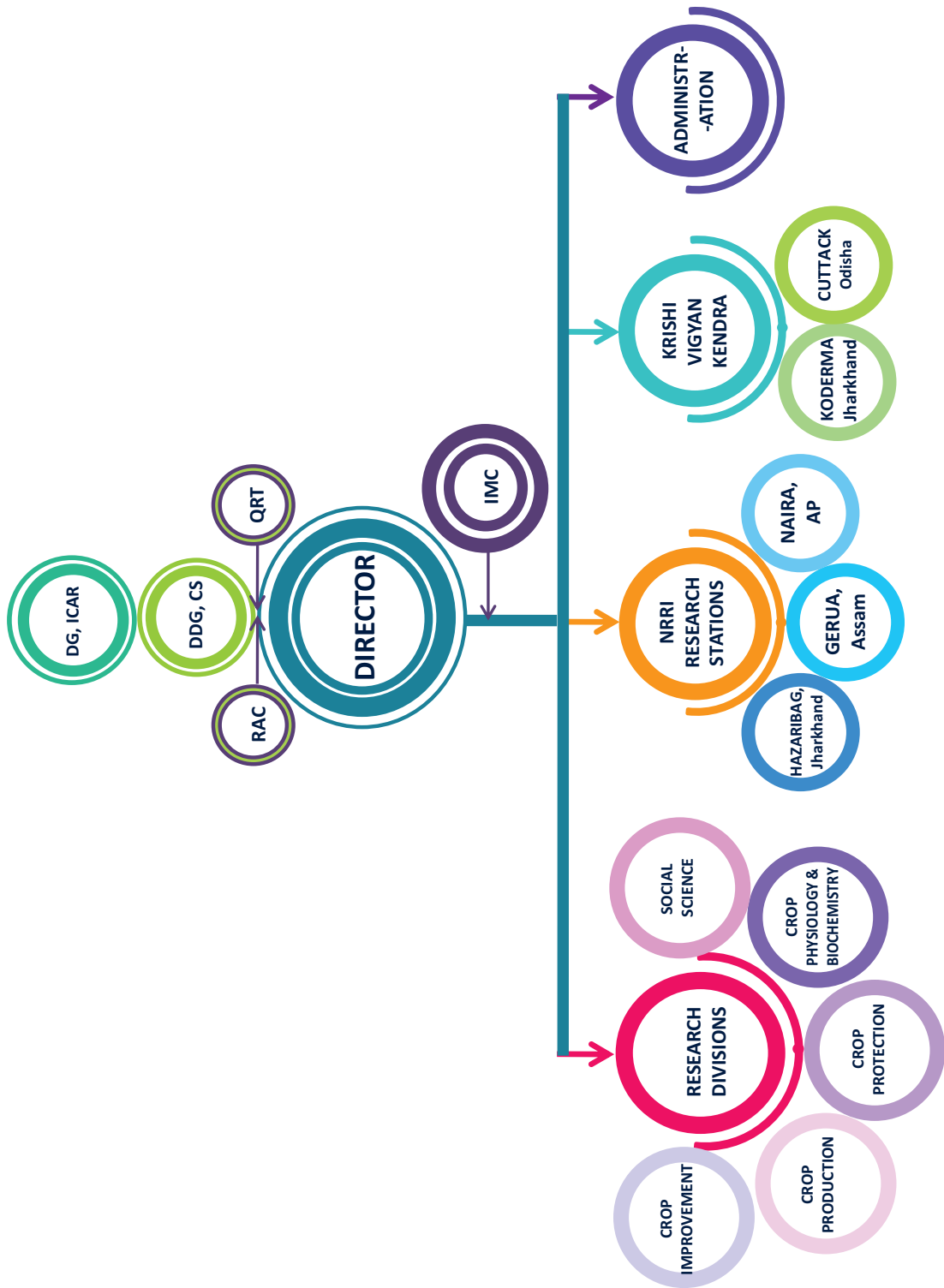
The Institute sincerely acknowledges the guidance and encouragements received from Dr. T. Mohapatra, Director General, ICAR and Secretary, DARE in guiding various research and development programmes. Our sincere thanks are due to Shri C. Roul, Special Secretary, DARE and Secretary, ICAR; Shri B.N. Tripathi and Shri B. Pradhan, Additional Secretaries, DARE and Financial Advisors, ICAR for their continuous support and guidance. Valuable guidance, encouragement and support received from Prof. R.B. Singh, Chairman QRT, Dr. S.K. Datta, Chairman and other esteemed members of Quinquennial Review Team (QRT), Research Advisory Committee; Dr. A.K. Singh, DDG (Crop Sciences), ICAR; esteemed members of Institute Management Committee and Institute Research Council (IRC) are sincerely acknowledged. Thanks are due to Dr. I.S. Solanki and Dr. R.K. Singh, ADGs (FFC), ICAR; Dr. Dinesh Kumar, Principal Scientist and other officials of the Council for their constant support and guidance. I sincerely thank the Heads of the Divisions, Officer In-Charges of Regional Stations, and Administration and Finance sections of the Institute for their whole-hearted efforts and dedication in carrying out the activities of the Institute. My sincere thanks are due to the Publication Committee and Publication Unit for compiling and editing the Annual Report. I appreciate the efforts and commitment of all the staff to serve this premier Institute.

I hope that the Annual Report will be useful for the researchers, policy makers, development functionaries, farmers, farmwomen and students and help in promoting rice research and development.



**(Himanshu Pathak)**  
Director

# ORGANOGRAM



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. It is the staple food for about 800 million population of India playing a major role in diet, economy, employment, culture and history. The country grows rice in about 43 million ha with production of about 115 million tons of milled rice and average productivity of 2.7 t ha<sup>-1</sup>. Rice farmers face serious challenges of low income, degradation of natural resource base, climate change related amplification of both biotic and abiotic stresses, which require all the ingenuity of sciences to deal with. ICAR-National Rice Research Institute, Cuttack accordingly has reoriented its research agenda to address these challenges. Salient achievements of various research programmers of the institute during 2019 are briefly presented below.

The Crop Improvement Division of the Institute with 11 institute research projects and 36 externally aided projects works for developing new varieties and hybrids to enhance yield and nutritional quality of rice. It has 23 scientists from various disciplines like PGR, Plant Breeding, Genetics and Biotechnology with 23 technical staff. Eleven rice varieties were released & Three varieties have been identified for release. 700 new rice germplasm accessions were collected, and 2729 accessions of rice germplasm / elite lines / donors/ varieties were supplied to researchers during the year. About 13.22 q nucleus seed of 57 varieties, 460.10 q of breeder seed of 44 varieties were produced. Five QTLs were mapped, several donors were identified for nitrogen use efficiency, higher root biomass and phosphorus uptake. Using DHs technology, 12 rice lines were derived and tested in farmers' field. Besides, classical and applied genetics and breeding, latest genome editing technology, CRISPR/ Cas9 technology was also used for editing yield related gene *IPA1*.

The Crop Production Division aims at development of improved agro-technologies for enhanced productivity, profitability, input use efficiency and climate resilience. The Division has 24 scientists, 10 technical staffs and three supporting staffs. The sustainability of rice production depends upon resource use efficiency, which is based on three major components such as technical, allocative and environmental efficiencies. The agronomic N-use efficiency ( $AE_N$ ) of rice in India is 18 kg kg<sup>-1</sup>. Average  $AE_N$  in Himachal Pradesh, Tamil Nadu, Punjab and Haryana are higher than the national average. Meghalaya, Andhra Pradesh, Chhattisgarh, Madhya Pradesh, Jharkhand, Bihar and Odisha are the states where  $AE_N$  is lower than the national average. Estimation of energy balance components over Mahanadi Delta region indicated latent heat flux varied from 127.4 to 594.4 Wm<sup>-2</sup> and its higher values were recorded in the south western, northern and north-eastern side of delta region. Microbial-mediated (*Azotobacter chroococcum* AVi2) ascorbic acid (1ppm) formulation was found to regulate defense enzymes of drought stress in rice. Inoculation of *arbuscular mycorrhizal* fungus increased rice yield by 8.0-12.0% under drought conditions compared to without inoculated plants.

The Crop Protection Division is engaged in applied, strategic and basic research on integrated management of rice pests to improve rice productivity and profitability. Major thrust areas are multiple pest resistance, pest modelling and forecasting, tri-trophic interaction of rice, pests and predators/parasites under climate change, novel molecules and formulations for eco-friendly rice pest and stored grain pest management. The Division is also involved in designing, validating and popularizing pest and ecology based integrated pest management (IPM) modules for the farmers to ensure profitability. The Division has 21 scientists, 10 technical staffs and 3 supporting staffs. There are four in-house research projects and 13 externally aided projects. More than 2000 germplasm accessions were screened to find out novel resistance sources against different pests/diseases of rice. Genetic diversity and population analysis of



yellow stem borer, bakane, bacterial blight, sheath blight and false smut were carried out. Bioagents like *Trichoderma* sp., *Arthrobotry* spp. and potassium silicate are recommended to manage rice pests. New techniques like natural stain, Loop-Mediated Isothermal Amplification (LAMP) assay will be helpful for early detection of rice pests. Bio- mixtures can degrade pesticide at faster rate.

The Crop Physiology and Biochemistry Division with eight scientists and six technical staff has three major thrust areas; rice grain and nutritional quality, abiotic stress physiology with tolerance mechanism and improvement of productivity through enhancing photosynthetic efficiency by introduction of  $C_4$  pathway and minimizing photorespiration. In long-term storage test, level of malondialdehyde and free fatty acid observed to increase till 12 months and 9 months of aging, respectively. Four black rice accessions viz. Baraun Goda Dhan, Kaniglass, Mumi Hunger and Petre observed to be consistently tolerant in two consecutive years for vegetative stage drought and for reproductive stage drought, C822-44 and C822-74 were identified tolerant with higher grain yield ( $1.5 \text{ t ha}^{-1}$ ) compared to tolerant parent BVD-109. Varieties N-22 and Annapurna observed to have better non-structural carbohydrates translocation under high temperature stress. In combined stress tolerance of flooding and salinity RBOH (ROS generator) and MT (ROS quencher) genes observed to play major role in aerenchyma formation in rice. AC42088, AC42087 and AC1303 were identified having submergence tolerance ability of up to three weeks with high survival rate of > 52% compared to FR13A (35% survival rate). In developing new rice plant towards  $C_4$ ness, cloning and transformation of *Setaria italica* PPDK (*SiPPDK*) enzyme in rice was confirmed through Southern blot analysis and higher expression pattern of the same gene (PPDK3, PPDK5, PPDK8, PPDK26 and PPDK27) was observed in transgenics than control plants. To minimize the photorespiratory activity, gene constructs encoding *glycolate dehydrogenase (glc)* tagged with RuBisCO smaller subunit transit peptide for chloroplastic transformation was developed successfully.

The Social Science Division aims at development and testing of new extension models, approaches and strategies for technology transfer and conducts socioeconomic research in rice sector. It also undertakes outreach activities for rapid dissemination of recent technologies to the end users and provides feedback to the technologists. The Division with its cadre strength of six scientists and 12 technical staff operates two institute research projects and six externally aided projects. During the year 2019, 21 newly released rice varieties have been demonstrated through 798 field demonstrations in 26 districts of eight states. Also, 423 participants have been trained on different aspects of rice technologies through 18 training programs. Apart from technology transfer and capacity building, attempt has been made to utilize the available database on rice to provide new insights for decision making.

The NRRI Regional Research Station, Hazaribag, Jharkhand works on developing upland rice varieties and their management practices. Drought is one of the major constraints besides weeds, diseases (blast, brown spot), insects and poor P nutrition in rainfed upland rice system. Hence, there is an urgent need to develop more resilient (multi-stress tolerant) varieties as major component of rice cultivation technology under rainfed ecology, along with improved management of the stresses. The research, thus, focuses on following activities: (i) breeding resilient HYVs, (ii) strategize management options for sustainable productivity under DSR, (iii) develop biotic stress management strategies for rainfed drought-prone ecologies and (iv) evolve rice based farming systems.

The NRRI Regional Research Station, Gerua, Assam caters the research needs and requirements of rice farmers of lowland areas. With the present cadre strength of five scientists and four technical staff the Station conducts one institute project, AICRIP trials, FLDs and implemented Tribal Sub-Plan (TSP) activities in Assam. Local genetic resources of rice were utilized to develop suitable medium duration, photo and thermo insensitive, vegetative stage cold tolerant rice varieties for *Boro* and *Ahu* seasons.

The rice production system in the country is encountering a plethora of challenges. The Institute is working to develop and popularize super-yielding varieties and agro-technologies for higher productivity, profitability, climate resilience and sustainability of rice farming.

चावल संसार की सबसे महत्वपूर्ण खाद्य फसल है तथा लगभग चार अरब लोगों का मुख्य भोजन है। भारत में चावल लगभग 80 करोड़ आबादी का मुख्य भोजन है, जो आहार, अर्थव्यवस्था, रोजगार, संस्कृति और इतिहास में प्रमुख भूमिका निभा रहा है। देश में लगभग 430 लाख हेक्टेयर भूमि में चावल उत्पादन होता है, जो लगभग 1150 लाख टन है और औसत उत्पादकता 2.7 टन प्रति हेक्टेयर है। चावल उगाने वाले किसानों को कम आय, प्राकृतिक संसाधन के क्षरण, जलवायु परिवर्तन से संबंधित जैविक और अजैविक चुनौतियों का सामना करना पड़ता है, जिससे निपटने के लिए विज्ञान के सभी तरह के कौशल की आवश्यकता होती है। भाकूअनुप-राष्ट्रीय चावल अनुसंधान संस्थान, कटक ने तदनुसार इन चुनौतियों का समाधान करने के लिए अपने अनुसंधान कार्य योजना को तैयार किया है। 2019 के दौरान संस्थान के विभिन्न अनुसंधान कार्यक्रमों की प्रमुख उपलब्धियां संक्षेप में नीचे प्रस्तुत की गई हैं।

संस्थान के फसल उन्नयन प्रभाग अपने 11 संस्थान अनुसंधान परियोजनाओं और 36 बाहरी सहायता प्राप्त परियोजनाओं के द्वारा चावल की नई किस्में और संकर चावल विकसित करने तथा चावल की उपज और पोषण गुणवत्ता बढ़ाने के लिए प्रयासरत है। इस प्रभाग में पौध एवं आनुवंशिक संसाधन, पौध प्रजनन, आनुवंशिकी और जैवप्रौद्योगिकी जैसे विभिन्न अध्ययन शाखाओं के 23 वैज्ञानिक तथा 23 तकनीकी कर्मचारियां कार्यरत हैं। इस वर्ष के दौरान चावल की 11 किस्में विमोचित की गईं तथा तीन किस्में विमोचन के लिए पहचानी गईं हैं, 700 नए चावल जननद्रव्य प्रविष्टियां संग्रहित किए गए तथा शोधकर्ताओं को चावल जननद्रव्य/श्रेष्ठ वंशों/दाताओं/किस्मों की 2729 प्रविष्टियों की आपूर्ति की गई। चावल के 57 किस्मों के लगभग 13.22 क्विंटल न्यूक्लियस बीज, 44 किस्मों के 460.10 क्विंटल प्रजनक बीज का उत्पादन किया गया। पांच क्यूटीएलों का मैपिंग किया गया तथा कई दाताओं को नाइट्रोजन उपयोग दक्षता, उच्च रूट बायोमास और फास्फोरस अडिग्रहण के लिए पहचाना गया। डबल हॉप्लाएड तकनीक का उपयोग करते हुए 12 चावल वंश विकसित किए गए एवं किसानों के खेत में परीक्षण किया गया। इसके अलावा, सैद्धांतिक और प्रायोगिक आनुवंशिकी एवं प्रजनन, नवीनतम जीनोम संपादन तकनीक, सीआरआईएसपीआर/सीएसएस9 प्रौद्योगिकी का उपयोग उपज से संबंधित जीन आईपीआई1 के संपादन के लिए भी किया गया।

एनआरआई के फसल उत्पादन प्रभाग का उद्देश्य चावल उत्पादकता एवं लाभप्रदता में वृद्धि, इनपुट उपयोग दक्षता बढ़ाना और जलवायु अनुकूलन के लिए उन्नत कृषि-प्रौद्योगिकियों का विकास करना है। प्रभाग में 24 वैज्ञानिक, 10 तकनीकी कर्मचारी और तीन सहायक कर्मचारी हैं। चावल के उत्पादन की स्थिरता संसाधन उपयोग दक्षता पर निर्भर करती है, जो तकनीकी, आबंटनात्मक और पर्यावरणीय क्षमता जैसे तीन प्रमुख घटकों पर आधारित है। भारत में चावल की शस्यात्मक नाइट्रोजन उपयोग दक्षता 18 किलोग्राम प्रति किलोग्राम है। हिमाचल प्रदेश, तमिलनाडु, पंजाब और हरियाणा में औसत शस्यात्मक नाइट्रोजन का उपयोग राष्ट्रीय औसत से अधिक है। मेघालय, आंध्र प्रदेश, छत्तीसगढ़, मध्यप्रदेश, झारखंड, बिहार और ओडिशा में शस्यात्मक नाइट्रोजन उपयोग राष्ट्रीय औसत से कम है। महानदी डेल्टा क्षेत्र पर ऊर्जा संतुलन घटकों के अनुमान ने अव्यक्त गर्मी प्रवाह को 127.4 से 594.4 Wm<sup>-2</sup> से भिन्न दर्शाया और डेल्टा क्षेत्र के दक्षिण पश्चिमी, उत्तरी और उत्तर-पूर्वी हिस्से में इसके उच्च मूल्य दर्ज किए गए। चावल में सूखे तनाव के रक्षा एंजाइमों को नियमित करने के लिए माइक्रोबियल-मध्यस्थता (एजोटोबैक्टीरोकोकम एवीआई 2) एस्कॉर्बिक एसिड (1 पीपीएम) सूत्रण किया गया। बिना संरोपण पौधों की तुलना में सूखे की स्थिति में आर्बूस्कुलार माइकोरिजा कवक के संरोपण से चावल की उपज में 8.0-12.0 प्रतिशत वृद्धि हुई।

चावल की उत्पादकता और लाभप्रदता में सुधार के लिए फसल सुरक्षा प्रभाग चावल के समन्वित नाशककीट प्रबंधन पर प्रायोगिक, रणनीतिक और बुनियादी अनुसंधान में कार्यरत है। प्रभाग ने महत्वपूर्ण क्षेत्र जैसे विविध कीट प्रतिरोधिता, कीट मॉडलिंग और पूर्वानुमान, चावल की त्रि-ट्रॉफिक पारस्परिक क्रिया, जलवायु परिवर्तन के तहत चावल में कीट और परजीवियों, पर्यावरण के अनुकूल चावल कीट और संग्रहीत अनाज कीट प्रबंधन के लिए नई मॉलिक्यूलस् और सूत्रण आदि पर अनुसंधान किया। प्रभाग किसानों को लाभप्रदता सुनिश्चित करने के लिए कीट और पारिस्थितिकी आधारित आईपीएम मॉड्यूलों की परिकल्पना करने, मान्य करने और लोकप्रिय बनाने में भी शामिल है। प्रभाग में 21 वैज्ञानिक, 10 तकनीकी कर्मचारी और तीन सहायक कर्मचारी हैं। प्रभाग में चार संस्थान अनुसंधान परियोजनाएं, 13 बाहरी सहायता प्राप्त परियोजनाएं संचालित की जा रही हैं। चावल के विभिन्न कीटों/रोगों के विरुद्ध नई प्रतिरोध स्रोतों का पता लगाने के लिए 2000 से अधिक जननद्रव्य प्रविष्टियों की परीक्षण की गईं। प्रभाग द्वारा पीला तना छेदक, बकाने, जीवाणुज अंगमारी, आच्छद अंगमारी और आभासी कंड की आनुवंशिक विविधता और कीटों की संख्या का विश्लेषण किया। चावल कीटों का प्रबंधन करने के लिए ट्राइकोडर्मा एसपी,

आण्डीबोद्री एसपीपी और पोटेशियम सिलिकेट जैसे जैवकारक की सिफारिश भी की गई। प्राकृतिक तकनीक, लूप-मेडिटेड आइसोर्थमल एम्लीफिकेशन (एलएएमपी) ऐसे जैसी नई तकनीकें चावल कीटों की शुरुआती पहचान के लिए मददगार होंगी। जैव मिश्रण के प्रयोग से कीटनाशकों का तेजी से न्यूनीकरण हो सकता है।

संस्थान का शरीरक्रिया विज्ञान जैव रसायन प्रभाग 8 वैज्ञानिकों और 6 तकनीकी कर्मचारियों सहित चावल के तीन प्रमुख क्षेत्रों—चावल के दाने और पोषण की गुणवत्ता, सहिष्णुता तंत्र के साथ अजैविक तनाव शरीरक्रिया विज्ञान और 4 मार्ग की शुरुआत तथा फोटोरेसपिरेशन को कम करके प्रकाश संश्लेषण दक्षता बढ़ाने के माध्यम से उत्पादकता में सुधार पर कार्य कर रहा है। दीर्घकालिक चावल भंडारण परीक्षण में, मालोनडिएल्डीहाइड और मुक्त फैटी एसिड का स्तर क्रमशः 12 महीने और 9 महीने तक बढ़ता पाया गया। चार काले भूमिजाति चावल किस्मों जैसे बरौन गोड़ाधान, कनीग्लास, ममीहंगर और पेट्रे में लगातार दो वर्षों तक फसल की वृद्धि अवस्था में सूखे के लिए तथा प्रजनन चरण सूखे के लिए सहिष्णुता पाई गई, सहिष्णु जनक बीपीडी-109 की तुलना में सी 822-44 और सी 822-74 सहिष्णु के रूप में पहचान की गई एवं इससे उच्च अनाज उपज (1.5 टन/हेक्टेयर) मिली। एन-22 और अन्नपूर्णा में उच्च तापमान तनाव के तहत बेहतर गैर-संरचनात्मक कार्बोहाइड्रेट की मात्रा पाई गई। शोध में पाया गया कि बाढ़ और लवणता के संयुक्त तनाव सहिष्णुता में आरबीओएच (आरओएस जनरेटर) और एमटी (आरओएस क्वेन्चर) जीनों ने चावल में एरेनकाइमा गठन में प्रमुख भूमिका निभाते हैं। एसी42088, एसी42087 और एसी1303 में तीन सप्ताह तक जलमग्नता सहने की क्षमता के साथ पहचान की गई जिसमें 52 प्रतिशत से अधिक जीवित रहने की दर है जबकि एफआर13ए की तुलना में यह उत्तरजीविता दर 35 प्रतिशत पाई गई। C<sub>4</sub> वाली चावल के नए पौधे को विकसित करने में, चावल में सेटरिया इटालिका पीपीडीके (एसआईपीपीडीके) एंजाइम के क्लोनिंग और परिवर्तन की पुष्टि नियंत्रण पौधों की तुलना में दक्षिणी धब्बा विश्लेषण और एक ही जीन (पीपीडीके3, पीपीडीके5, पीपीडीके8, पीपीडीके26 और पीपीडीके27) के उच्च अभिव्यक्ति पैटर्न के माध्यम से ट्रांसजेनिक में की गई। इसी वर्ष प्रकाश श्वसन की गतिविधि को कम करने के लिए, जीन क्लोरोप्लास्टिक परिवर्तन हेतु ल्ठपेब के छोटे सबयूनिट ट्रांजिट पेप्टाइड के साथ चिह्नित ग्लाइकोलेट डिहाइड्रोजेन (जीएलसी) को सफलतापूर्वक विकसित किया गया है।

संस्थान का समाजविज्ञान प्रभाग प्रौद्योगिकी हस्तांतरण के लिए नए विस्तार मॉडल, दृष्टिकोण और रणनीतियों के विकास और परीक्षण के उद्देश्य से चावल क्षेत्र में सामाजिक आर्थिक अनुसंधान कार्य करता है। यह अंतिम उपयोगकर्ताओं के लिए हाल में विकसित प्रौद्योगिकियों के तेजी से प्रसार के लिए आउटरीच गतिविधियां भी करता है और प्रौद्योगिकीविदों को विभिन्न भागीदारों की प्रतिक्रिया प्रदान करता है। छह वैज्ञानिकों और 12 तकनीकी कर्मचारियों सहित यह प्रभाग संस्थान स्तर पर दो अनुसंधान परियोजनाओं और छह सहायता प्राप्त परियोजनाओं का संचालन कर रहा है। वर्ष 2019 के दौरान, आठ राज्यों के 26 जिलों में 798 क्षेत्र प्रदर्शनों के माध्यम से 21 नई विमोचित चावल किस्मों का प्रदर्शन किया गया है। इसके अलावा, लगभग 423 प्रतिभागियों को 18 प्रशिक्षण कार्यक्रमों के माध्यम से चावल प्रौद्योगिकियों के विभिन्न पहलुओं पर प्रशिक्षित किया गया है। प्रौद्योगिकी हस्तांतरण और क्षमता निर्माण के अलावा, निर्णय लेने के लिए नई अंतर्दृष्टि प्रदान करने हेतु चावल पर उपलब्ध डेटाबेस का उपयोग करने का प्रयास भी समाजविज्ञान प्रभाग द्वारा किया गया है।

एनआरआरआई के क्षेत्रीय अनुसंधान केंद्र, हजारीबाग बड़े पैमाने पर चावल की किस्मों और उनके प्रबंधन प्रथाओं को विकसित करने पर काम करता है। वर्षाश्रित उपरीभूमि में चावल की फसल प्रणाली में खरपतवार, रोग (प्रध्वंस, भूरा धब्बा), कीड़े और खराब फास्फोरस पोषण के अलावा सूखा एक बड़ी बाधा है। इसलिए, वर्षाश्रित उपरीभूमि के तहत चावल की खेती तकनीक के प्रमुख घटक के रूप में अधिक अनुकूलित (बहु-तनाव सहिष्णु) एवं तनाव के बेहतर प्रबंधन वाली किस्में विकसित करने की तत्काल आवश्यकता है। क्षेत्रीय अनुसंधान केंद्र इस प्रकार, निम्नलिखित गतिविधियों पर ध्यान केंद्रित करता है: (प) उच्च उपज वाली अनुकूल किस्मों को प्रजनन करना, (पप) सीधी बुआई चावल के तहत स्थिर उत्पादकता के लिए प्रबंधन विकल्पों का रणनीति बनाना, (पपप) वर्षा आधारित सूखाग्रस्त पारिस्थितिकी के लिए जैविक तनाव प्रबंधन रणनीतियों का विकास करना और (पअ) चावल आधारित कृषि प्रणाली विकसित करना।

एनआरआरआई क्षेत्रीय अनुसंधान केंद्र, गेरुआ निचलीभूमि क्षेत्रों के चावल किसानों के अनुसंधान की आवश्यकताओं को पूरा करता है। पांच वैज्ञानिकों और चार तकनीकी कर्मचारियों की वर्तमान कैंडर सहित यह केंद्र असम में एक परियोजना और एआरसीआईआरपी परीक्षण, एफएलडी एवं जनजातीय उप-योजना गतिविधियों का संचालन कर रहा है। चावल के स्थानीय आनुवंशिक संसाधनों का उपयोग बोरो और आहु मौसमों के लिए उपयुक्त मध्यम अवधि, फोटो और थर्मो असंवेदनशील, वृद्धि चरण टंड सहिष्णु चावल किस्मों को विकसित करने के लिए किया गया।

देश में चावल उत्पादन प्रणाली अनेक चुनौतियों का सामना कर रहा है। संस्थान उच्च उत्पादकता, लाभप्रदता, जलवायु अनुकूलनीयता और चावल की खेती की स्थिरता के लिए अत्यधिक उपज देने वाली किस्मों और कृषि प्रौद्योगिकियों को विकसित करने और लोकप्रिय बनाने के लिए काम कर रहा है।

# NATIONAL RICE RESEARCH INSTITUTE

## MAJOR RESEARCH AREAS



# AT A GLANCE : YEAR 2019

## NRRI IN NUMBERS



8 DECENT WORK AND ECONOMIC GROWTH



10 REDUCED INEQUALITIES



11 SUSTAINABLE CITIES AND COMMUNITIES



12 RESPONSIBLE CONSUMPTION AND PRODUCTION



13 CLIMATE ACTION



15 LIFE ON LAND



16 PEACE, JUSTICE AND STRONG INSTITUTIONS



17 PARTNERSHIPS FOR THE GOALS





ICAR-National Rice Research Institute (ICAR-NRRI), formerly known as Central Rice Research Institute (CRRI), was established by the Government of India in 1946 at Cuttack, as an aftermath of the great Bengal famine in 1943, to initiate a consolidated approach to rice research in India. The administrative control of the Institute was subsequently transferred to the Indian Council of Agricultural Research (ICAR) in 1966. The institute has three research stations, at Hazaribag, in Jharkhand, at Gerua in Assam, and at Naira in Andhra Pradesh. The NRRI regional station, Hazaribag was established to tackle the problems of rainfed uplands, and the NRRI regional substation, Gerua for problems in rainfed lowlands and flood-prone ecologies. Two Krishi Vigyan Kendras (KVKs) also function under NRRI, one at Santhpur in Cuttack district of Odisha and the other at Jainagar in Koderma district of Jharkhand. The research policies are guided by the recommendations of the Research Advisory Committee (RAC), Quinquennial Review Team (QRT) and the Institute Research Council (IRC). The NRRI also has an Institute Management Committee (IMC) to support implementation of its plans and programmes.

#### **Vision**

To ensure sustainable food and nutritional security and equitable prosperity of our Nation through rice science.

#### **Goal**

To ensure food and nutritional security of the present and future generations of the rice producers and consumers.

#### **Mission**

To develop and disseminate eco-friendly technologies to enhance productivity, profitability and sustainability of rice cultivation.

#### **Mandate**

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.

#### **Linkages**

The NRRI has linkages with several national and international organizations such as the Council for Scientific and Industrial Research (CSIR), Indian Space Research Organization (ISRO), SAUs, State Departments of Agriculture, NGOs, Banking (NABARD) and the institutes of the Consultative Group for International Agricultural Research (CGIAR), such as the International Rice Research Institute (IRRI), Philippines and International Crops Research Institute for the Semi-Arid Tropics (ICRISAT), India.

#### **Location**

The institute 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°55'48" E to 85°56'48" longitudes and 20°26'35" N to 20°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).

## PROGRAMME-1

# Genetic Improvement of Rice for Enhancing Yield, Quality and Climate Resilience

Crop Improvement Division of the Institute aims at developing novel rice varieties, hybrids and technologies to increase yield and improve nutritional quality of rice in order to enhance socio-economic condition of the rice stakeholders. The division with its cadre strength of 23 scientists and 23 technical staff operates 11 institute research projects and 36 externally aided projects. During the year, 11 rice varieties were released and three varieties have been identified for release, 700 new rice germplasm accessions were collected, and 2729 accessions of rice germplasm / elite lines / donors/ varieties were supplied to researchers. As a part of seed production, 13.22 q nucleus seed of 57 varieties, and 460.10 q of breeder seed of 44 varieties were produced. Besides, five QTLs were mapped on the rice chromosomes, identifying several donor lines for nitrogen use efficiency, higher root biomass for P uptake. Using DHs technology, 12 rice lines were derived and their yield performance was analysed under farmers field conditions. Besides classical and applied genetics and breeding, latest genome editing technology, CRISPR/ Cas9 technology was also used for editing yield related gene *IPA1*. The subsequent section discusses the salient achievements of the programme for the year 2019.



## Exploration, Characterization and Conservation of Rice Genetic Resources

The aim of this project is collecting and conserving the seed of cultivated and wild germplasm for long or medium term storage, generating database of rice genetic resources and cataloguing for future breeding. True identity of any donor is the primary necessity of any research program for crop improvement. Identified germplasm are to be supplied to the indenters as per the requirement. Requests for identified donors and other germplasm accessions suitable for specific conditions are made by the scientists and they are supplied with the seed materials for research purpose.

### Exploration & Collection of wild rice

One exploration programme was undertaken in collaboration with ICAR - National Bureau of Plant Genetic Resources (NBPGR), Cuttack, and ICAR - Indian Grassland and Fodder Research Institute (IGFRI), Jhansi during 30<sup>th</sup> October to 9<sup>th</sup> November 2019. During the exploration mission, a total of 49 accessions including 10 accessions of wild rice were collected, processed and deposited for conservation in NGB, New Delhi and MTS at ICAR-NRRI, Cuttack, Odisha.



### Rejuvenation of the conserved germplasm and the new collections

Under this objective, periodic monitoring of seed viability is done for the stored gene bank accessions. A set of 6024 accessions were rejuvenated in the field for periodical maintenance of seed viability, seed increase for conservation and seed supply to different researchers all over the country.

## Characterization of the germplasm for agro-morphological traits & molecular aspects

### i. Agro-morphological characterization

A total of 6024 accessions of rice germplasm were grown which include 700 new collections made from Odisha for characterization on agro-morphological traits of 30 characters. All the thirty morphological observation data on nineteen qualitative characters and eleven quantitative characters were recorded at appropriate stages of crop growth and maturity as per the descriptors. These materials were harvested, processed, packed and stored back in the gene bank for future use.

### ii. Molecular Characterization

#### Molecular Diversity analysis of landraces collected from different regions of India

A total of 48 landraces collected from Assam, Odisha, Kerala, Manipur, Chhattisgarh, UP and WB were assessed using 60STMS markers which are distributed through the genome (5 markers from each chromosome). Overall, 136 alleles were generated from the 60 STMS markers. RM237, RM13666 and RM257 produced maximum four alleles. The maximum PIC value (0.499) was observed with the marker RM171 while RM 27015 showed the minimum value of 0.041. The phylogenetic tree was constructed using UPGMA analysis, and the dendrogram is divided into two major groups. The land race, Saathi collected from UP is found to be more diversified (0.688) from other 47 landraces.

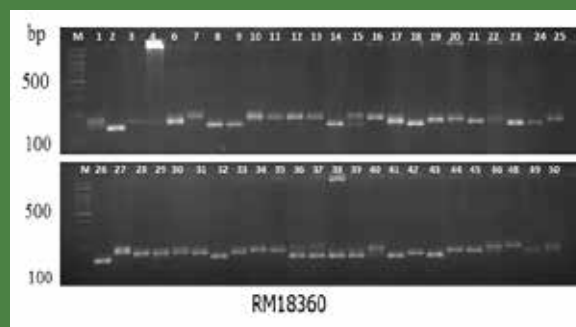


Fig 1.1: Representative STMS profiling of RM18360 in landraces collected from different regions of India.

### Rice germplasm conservation and seed supply to researchers

Different sets of rice germplasm accessions were conserved in gene bank. These materials include

3971 accessions rice germplasm received from ICAR-NBPGR, New Delhi, DUS testing materials, newly collected cultivated and wild rice germplasm. Those were conserved in Medium Term Storage (MTS). Besides, 2729 accessions of rice germplasm / elite lines / donors/ varieties were supplied to researchers for their utilization. Out of 2729 accessions, 431 were shared with different institutes/ organizations throughout the country under proper of MTA.

### Maintenance Breeding, Quality Seed Production and Seed Technology Research for enhancing Rice Yield

#### Nucleus seed and breeder seed production

Panicle progeny rows of 57 varieties were grown for maintenance breeding. In 2018-19, a total of 13.22 q nucleus seed of 57 varieties were produced (Table 1.1). The bulk nucleus seeds are used to produce Breeder Seed of the same variety. Breeder seed was produced as per DAC indent. A total of 460.10 q of breeder seed, consisting of 44 varieties were produced (Table 1.2).

#### Participatory Seed Production

Farmer's Participatory Seed Production was undertaken at farmer's field under agreement (MoU) with Mahanga Krushak Vikash Manch (Goudagop), Mahatma Gandhi Farmer's Club (Kendrapada) and Achyutananda Farmer's Producer Company Ltd (Kendrapada). The seeds of four popular varieties (Pooja, Sarala, Gayatri and Swarna *Sub1*) were produced in three villages namely (i) Goudagop, Mahanga, Cuttack, (ii) Bhandilo, Kendrapada and (iii) Nischintakoili, Cuttack. A total of 905 q seed qualified as per TL seed standard.

#### Identification of QTLs/Candidate genes associated with seed vigour

A set of 216 lines were selected for identification of candidate gene / QTLs for seed vigour. The loci were LOC\_Os12g34380.1 (glutathione synthetase) on chromosome number 12, LOC\_Os08g05570.3 (monodehydro-ascorbate reductase) on chromosome number 8, LOC\_Os03g43400.1 (OsIAA12 - auxin-responsive Aux/IAA gene family member) on chromosome number 3, LOC\_Os01g11054.1 and LOC\_Os01g11054.3 (phosphoenol-pyruvate carboxylase) on chromosome number 1 were significantly (-log10 [0.0000001]) associated with phenotypic variations.

#### Development of cgSSR marker for seed quality

**Table 1.1: Nucleus Seed Production during 2018-19**

Sl. No.	varieties	Total Production (in kg)
1	Annada	30
2	Ciherang <i>Sub1</i>	6
3	CR 1009 <i>Sub1</i>	25
4	CR 1014	4
5	CR Boro Dhan 2	3
6	CR Dhan 100	4
7	CR Dhan 201	4
8	CR Dhan 203	52
9	CR Dhan 204	7
10	CR Dhan 205	8
11	CR Dhan 206	7
12	CR Dhan 209	3
13	CR Dhan 300	8
14	CR Dhan 301	5
15	CR Dhan 303	45
16	CR Dhan 304	12
17	CR Dhan 305	8
18	CR Dhan 307	35
19	CR Dhan 310	98
20	CR Dhan 311	3
21	CR Dhan 409	35
22	CR Dhan 501	34
23	CR Dhan 505	42
24	CR Dhan 601	55
25	CR Dhan 800	52
26	CR Dhan 801	13
27	CR Dhan 907	5
28	CR Dhan 909	5
29	CR Dhan 910	6
30	CR Dhan 10	1
31	CR Sugandhdhan 3	5
32	Dharitri	12
33	Gayatri	14
34	Geetanjali	10
35	Improved Lalat	32
36	Ketekijoha	4
37	Khitish	21
38	Luna Sampad	6
39	Luna Sankhi	4
40	Luna Suvarna	7

41	Moti	3
42	Naveen	25
43	NuaChinikamini	3
44	NuaKalajeera	4
45	Padmini	4
46	Phalguni	3
47	Pooja	118
48	PoornaBhog	3
49	Ranjit	7
50	Ratna	7
51	Samba <i>Sub 1</i>	41
52	Sarala	14
53	Satyabhama	6
54	Savitri	13
55	Shatabdi	110
56	Swarna <i>Sub1</i>	217
57	Varshadhan	14
	<b>Total</b>	<b>1322</b>

**Table 1.2: Breeder Seed Production during the year 2018-19**

Sl. No.	Variety	Total
1	Annada	11.75
2	CR 1009 <i>Sub1</i>	9.90
3	CR 1014	0.40
4	CR Dhan 201	16.05
5	CR Dhan 203	7.45
6	CR Dhan 204	0.30
7	CR Dhan 300	0.45
8	CR Dhan 303	0.50
9	CR Dhan 304	1.80
10	CR Dhan 307	9.05
11	CR Dhan 310	6.60
12	CR Dhan 407	1.35
13	CR Dhan 500	35.40
14	CR Dhan 501	3.30
15	CR Dhan 70	0.30
16	CR Dhan 800	1.20
17	CR Dhan 801	3.00
18	CR Dhan 907	0.75
19	CR Dhan 909	0.90
20	Ciherang <i>Sub1</i>	4.55
21	CR Sugandh Dhan 3	1.50

22	Dharitri	2.85
23	Durga	0.45
24	Gayatri	11.40
25	Geetanjali	1.45
26	Improved Lalat	1.50
27	Ketakijoha	2.10
28	Khitish	14.00
29	Luna Sampad	1.50
30	Luna Suvarna	1.95
31	Moti	0.45
32	Naveen	17.90
33	Nua Chinikamini	0.60
34	Nua Kalajeera	1.20
35	Padmini	0.45
36	Pooja	75.60
37	Ranjit	6.60
38	Sambha <i>Sub1</i>	7.50
39	Sahbhagidhan	0.40
40	Sarala	19.50
41	Savitri	10.20
42	Shatabdi	26.50
43	Swarna <i>Sub1</i>	128.40
44	Varshadhan	11.10
	<b>Total</b>	<b>460.10</b>

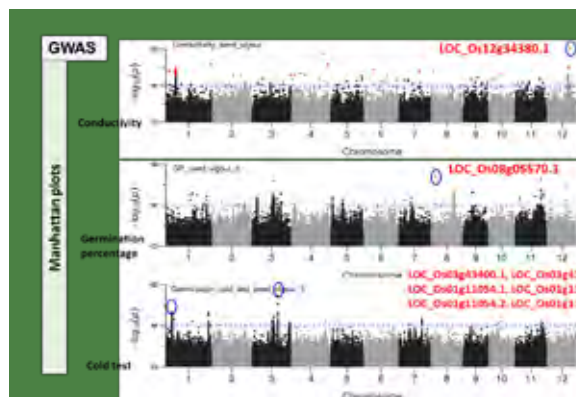


Fig 1.2. Manhattan plots from GWAS mapping of seed vigour

**traits**

A set of 120 markers for seed quality traits (*viz.*, seed dimension, seed weight, germination, seed dormancy etc.) were designed from rice database. These are under screening for polymorphism level for respective traits.

### Marker Trait association for seed vigour in rice

Forty eight rice germplasm lines were phenotyped for 16 biochemical traits along with seed vigour index (SVI). Among all the traits, total phenolic content (139.2568 and 139.1209) followed by total anthocyanin content (105.16 and 105.10) were observed with highest PCV and GCV, respectively. All the traits have high heritability ranging from 78.16 (Peroxidase) to 99.99 (Super oxide dismutase), respectively and are effective for selection in further breeding programmes. The population was found diverse with mean gene diversity of 0.72 and the mean PIC value of 0.68 was observed in the population. Significant positive correlation of SVI-II, Total phenolic content (TPC) and total flavonoids was observed with SVI-I. Again, Chl a, Chl b and total chlorophyll content were found significant and positively correlated with SVI- II. Genetic population structure analysis grouped the whole population into three sub populations based on SVI-I. But these sub groups are not clearly differentiated into high, moderate and low vigour indices. The relatedness among the three subpopulations was observed to be very high. The marker-trait association analysis showed association of seed vigour traits using Generalized Linear Model (GLM) and Mixed Linear Model (MLM/ K+Q model) deploying TASSEL 5 software. Traits like Chlorophyll a, Chlorophyll b, total chlorophyll, carotenoids, starch, amylose, total anthocyanin, gamma-oryzanols and TPC showed higher  $R^2$  value and strongly associated with the markers using the markers by MLM analysis. A stronger association was obtained for TPC, total flavonoids, SOD and catalase with the markers showing  $>0.10 R^2$  value by GLM model.

### Utilization of Wild and Cultivated Gene Pool of Rice for Resistance to Biotic Stresses

#### CR Dhan 312 (CR 3808-13, IET 25997) released and notified by CVRC

CR Dhan 312 was notified by CVRC for irrigated areas of Chhattisgarh and Maharashtra under medium duration in the 83<sup>rd</sup> meeting of Central sub-committee on Crop standards, Notification and Release of varieties for Agricultural Crops (Fig.1.3). It produces 280-300 panicles per m<sup>2</sup>, shows moderate tillering (8-10), compact panicles with test weight of 21.8 g and takes 105-110 days for 50% flowering. This line is moderately resistant to leaf blast, neck blast and rice tungro virus and highly responsive to fertilizer application. The genotype possesses good hulling and

milling quality with white kernels, medium slender grains, no grain chalkiness and desirable alkali spreading value.



Fig.1.3. Field view of CR Dhan 312 (CR 3808-13, IET 25997)

### Identification of source for nematode resistance

Ten accessions of African cultivated rice *Oryza glaberrima* were screened for rice root knot nematode (*Meloidogyne graminicola*) resistance under standard artificial screening conditions. Based on the root gall index (Bhatti and Jain, 1994) and number of nematode females inside the root, the genotypes were categorized in 1-5 scale where '1' (no galls) is considered as highly resistant and '5' (>100 galls) as highly susceptible. Among the 10 accessions, eight were found to be resistant with average number of galls ranging from 5.7-9.8.

### Wide hybridization for developing pre-breeding lines and mapping populations

Twelve different populations involving five varieties of *O. sativa* and five accessions of *O. rufipogon* and *O. glaberrima* are at advanced backcross generations (Table 1.3).

Table 1.3. List of wide crosses for developing pre-breeding lines and mapping populations

Sl. No	CROSS	GENERATION
1	Swarna / <i>O. rufipogon</i> (AC 100015)	BC <sub>3</sub> F <sub>1</sub>
2	Swarna/ <i>O. rufipogon</i> (AC 100444)	BC <sub>3</sub> F <sub>1</sub>
3	Annapurna/ <i>O. rufipogon</i> (AC 100005)	BC <sub>3</sub> F <sub>1</sub>
4	Annapurna / <i>O. rufipogon</i> (AC 100444)	BC <sub>3</sub> F <sub>1</sub>
5	Naveen / <i>O. glaberrima</i> (IR 102336)	BC <sub>2</sub> F <sub>1</sub>
6	Naveen / <i>O. rufipogon</i> (AC 100444)	BC <sub>2</sub> F <sub>1</sub>
7	Naveen / <i>O. glaberrima</i> (IR 102489)	BC <sub>1</sub> F <sub>1</sub>
8	Maudamani/ <i>O. rufipogon</i> (AC 100444)	BC <sub>3</sub> F <sub>1</sub>

9	Maudamani/ <i>O. rufipogon</i> (AC 100015)	BC <sub>2</sub> F <sub>1</sub>
10	Swarna/ <i>O. rufipogon</i> (AC 100005)	BC <sub>2</sub> F <sub>1</sub>
11	Maudamani/ <i>O. rufipogon</i> (AC 100005)	BC <sub>2</sub> F <sub>1</sub>
12	TN 1 / <i>O. rufipogon</i> (AC 100005)	BC <sub>2</sub> F <sub>1</sub>

**Unique set of molecular markers for wild *Oryza* species**

*Os11g0109000* (also identified as protein phosphatase 2C-like domain containing protein located in chromosome 11) was identified as an evolutionary landmark in genus *Oryza* where a single marker (RGNMS3515) can differentiate the different species in evolutionary time scale based on number of bands (Fig.1.4). Another marker RM11508 showed a unique length variation between *O. sativa* complex and *O. coarctata* (Fig.1.5). The length variation of the predicted amplicons in eight species of *O. sativa* species complex occur due to difference in the number of repeats of SSR motif (ct)n and small InDels. The large variation in amplicon length between *O. sativa* species complex and *O. coarctata* arise due to complete absence of (ct)n SSR motif in *O. coarctata* and a 51 bp deletion of unique sequence after the microsatellite motif.

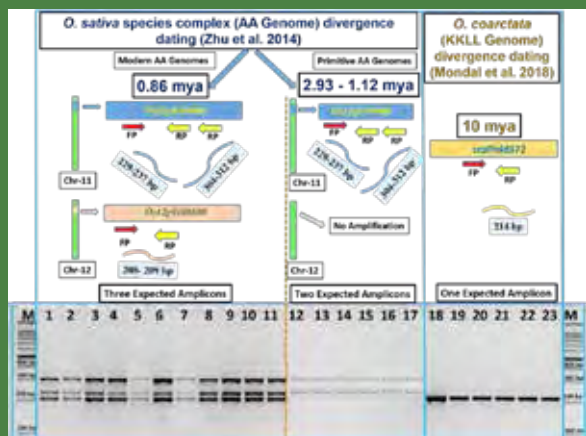


Fig.1.4. The unique amplification pattern of *Os11g0109000* and *Os12g0108600* loci in different *Oryza* species from RGNMS3515.

**Genetic Improvement of rice for enhancing input use efficiency**

All modern high yielding rice varieties are demanding more nutrient and they are nutrient-hungry varieties. Once the semi-dwarf rice varieties with intensive agriculture were considered as boon to the farmer is now turning to be bane for the mankind and environment by depleting the natural resources and unsuitable being nature for the resource poor farmers



Fig.1.5. Multiple sequence alignment of the amplicons of RM11508 in nine species. IND: *O. sativa* var. indica, GLA: *O. glaberrima*, MER: *O. meridionalis*, JAP: *O. sativa* var. japonica, GLU: *O. glumaepatula*, NIV: *O. nivara*, RUF: *O. rufipogon*, LON: *O. longistaminata*, COARC: *O. coarctata*.

of marginal land. Therefore, rice varieties need to be developed suitable for dry direct condition in conjunction with low nutrient tolerance.

**Screening of a mapping panel and identification of suitable donor under low N condition**

A mapping panel consist of 173 rice cultivars of landraces and improved lines suitable for direct



Fig. 1.6. Genotypes identified having more biomass under low nitrogen condition

seeded condition were evaluated over two seasons during *Rabi* 2019 and *Kharif* 2019 under hydroponic condition in modified protocol of Yosidha with one fourth of the recommended nitrogen. The identified tolerant genotypes were analyzed with *TOND1* functional markers to confirm their tolerance. Among the 173 lines, IRGC 78395-1, IRGC 28964-1 and IRGC 36826-1 were identified as low N tolerant genotypes with high biomass (Fig 1.6) and substantiated the presence of *TOND1* gene.

### Identification of new donors and candidates with high root biomass under phosphorus deficiency condition

Sixty five rice genotypes comprising of landraces and improved rice varieties with different duration categories were evaluated under hydroponics in 0.5 ppm of phosphorus during *Rabi* 2019 and *Kharif* 2019. Among them, a landrace IC459373 (SDW 0.112 g, RDW 0.0208 g) from Assam and a short duration variety Shankar (SDW 0.132 g, RDW 0.0306 g) were found to be at par with positive checks Kasalath (SDW 0.115 g, RDW 0.019 g) and Dular (SDW 0.120 g, RDW 0.033 g) for root and shoot biomass. In addition, both genotypes were tested positive for the presence of



Fig. 1.7. Roots scanned in flat bed system grown under low P

*PSTOL1* gene., also mapping panel consisting of 220 genotypes were tested under low P (11.5 kg/ha) in acidic pH of 5.2 during *Rabi* 2019 and *Kharif* 2019. Among them genotypes, Jhona 349 and CN2-175-5-31 were found to have better root system (Fig 1.7) with strong association ( $r = > 0.85$ ) between root dry weight and shoot dry weight under P deficient condition.

### Identification of genotypes with deep root traits under limited moisture condition

Water use efficiency and survival rate of plants could be improved by having deep root system in rice. A mapping panel consisting of 260 genotypes was tested under artificial tank during dry season of 2018 and 2019. One month after sowing, watering was

withheld to increase the moisture deficient condition and to induce root elongation. Leaf rolling was observed in regular interval, at maximum stress (-65 kpa) leaf rolling was observed in the highest number of genotypes. At -65 kpa, plants were uprooted and traits related to deep root were observed. A strong relationship ( $r = > 0.85$ ) was found between root dry weight, shoot length and number of roots at base. Genotypes DZ78 and Dular registered RDR of 0.26 with 68.9 cm and 64.4 cm of root length, respectively.

### Development of mapping population for anaerobic germination tolerance

During dry season 2019, 43 reported anaerobic tolerant lines were tested to validate the level of tolerance under low oxygen condition. Among them, genotypes ARC 10424, ARC 5848 and ARC 12172 exhibited more than 95 per cent of germination with 90% survivability. The tolerant lines ARC 10424 and ARC 5848 were crossed with CR Dhan 801 to identify QTLs responsible for AG tolerance and to develop multiple stress tolerant genotypes. The  $BC_1F_1$  was generated between CR Dhan 801 and ARC 5848, while  $F_1$  was developed between CR Dhan 801 and ARC 10424.

### Genetic Improvement of Rice for Aroma, Nutrition and Grain Quality

**Breeding for aroma:** Ninety two aromatic germplasm accessions were characterized based on their agro morphological trait expression. Twenty one biparental breeding populations at different generations of segregation were evaluated for selection of superior single plants.  $F_3$  seeds of crosses designed for altering the plant type of *Gobindabhog* have been harvested for further improvement through recombination breeding. *Gobindabhog* type2 and type3 sorts, earlier purified from the landrace at the institute were treated with three different doses of the chemical mutagen, EMS (Ethyl methane sulphonate) for development of  $M_0$  populations.

### Breeding for pigmented rice

**Germplasm characterization:** Thirty five accessions of rice genotypes collected from Tamil Nadu, Odisha, Andaman, Manipur, Assam and Nagaland which include 26 pigmented (black and variegated) and nine white rice genotypes were characterized based on their agro morphological trait expression.

**Purification of *Chakhao* landrace:** Selection for

pigmentation and grain type has been done for two seasons for the seven populations collected from farmer's field in collaboration with Green Foundation, Imphal, Manipur. The selected individuals were advanced following panicle progeny row method to maintain genetic purity among the selected lines.

**Semi-dwarf black rice:** Semi-dwarf, dark black grained derivatives of Manipuri Black (Chakhao) have been developed. The progeny lines are in F<sub>6</sub> generation, with plant height ranging from 85 to 105 cm as compared to 130-145 cm of the original landrace Manipuri Black (Chakhao). The recombinants are non-lodging types as compared to the landrace.

**Breeding for superior grain quality with improved biotic and abiotic stress tolerance**

Artificial screening for bacterial blight resistance was carried out in 308 genotypes already characterized for functional SNPs for bacterial blight resistance, chalkiness and aroma. Several lines with superior resistance were identified. Thirty-one genotypes were screened for tolerance to gall midge (*Orseolia oryzae*) under glass house conditions. Among the tested material, Indira was identified as highly resistant whereas Mahsuri was categorized as moderately resistant. More than 250 single plants have been harvested to introgress bacterial blight (*Xa 21*, *xa5* and *xa13*) and *Sub1* genes /QTLs in high protein Swarna lines (CR 2830-PLS-17, CR 2830-PLS-156). Advanced progenies have been generated from

crossing of Geetanjali / Improved Pusa Sugandh-5 carrying two genes *xa13* and *Xa21*. More than 500 slender grained single plants carrying different combinations of *Xa21*, *xa5* and *xa13* genes have been identified and selected for further generation advancement from 32 crosses.

**Value addition in rice**

Effect of different parboiling methods (hot soaking method, cold soaking method and pressure parboiling) on textural properties of popped and puffed rice were studied in three varieties namely Naveen, CR Dhan 310 and Swarna. Treatments were replicated thrice. Among the three methods used, pressure parboiling was found to give better textural properties to the processed products compared to the hot and cold soaking method in all the genotypes.

**Breeding towards Climate Resilient Genotypes for Rainfed Shallow Lowland**

Rainfed shallow lowlands variety 'Mahamani' is released for Odisha state. It produces premium type long slender grain locally known as 'balami' grain type. The variety is strongly photosensitive with average maturity duration of 160-165 days. It produces long heavy panicle with a moderate test weight (22-23.5g). It produces 7 t ha<sup>-1</sup> under favorable environment. The variety has good hulling, milling and head rice recovery compared to the check varieties. It possesses intermediate amylose content and other desirable

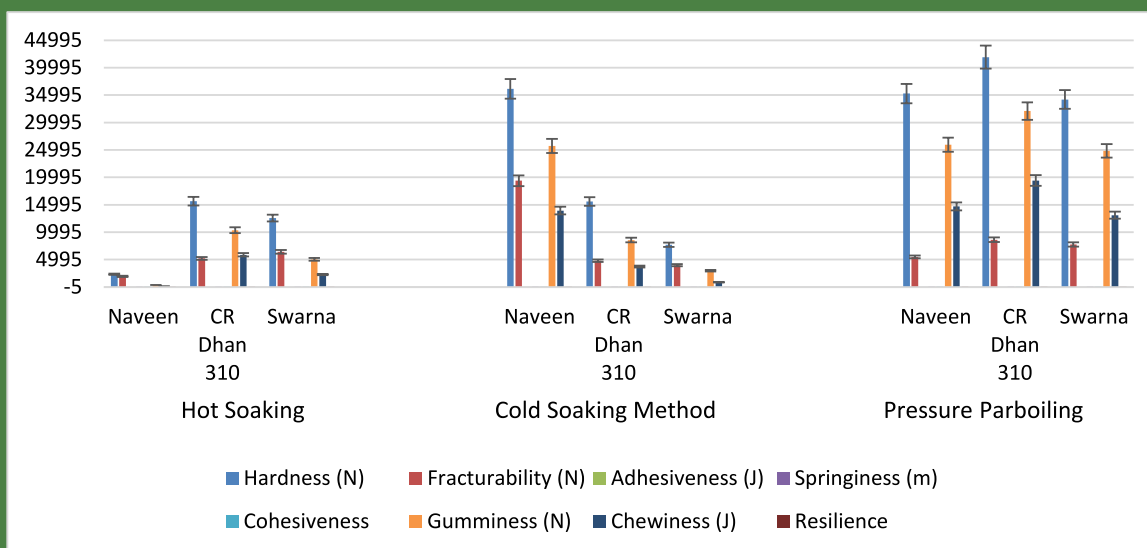


Fig. 1.8. Textural Properties of Puffed rice in three genotypes



Fig. 1.9. Mahamani variety in dough stage of the crop



Fig. 1.10. Panicles of Mahamani

grain quality parameters. It is resistant to stem borer (both dead heart and white ear heads) and leaf folder while moderately resistant to neck blast, bacterial blight, sheath rot and brown spot diseases.

### Genetic Improvement of Rice for Multiple stress tolerance in Unfavourable Rainfed Ecology

#### Generation and selection of breeding lines for coastal saline areas

Twenty new crosses were made using donors (AC39417, Bhurarati, CST7-1, Binadhan 10, FL 478) for salinity tolerance at seedling and reproductive stages and  $F_1$  seeds were harvested in *kharif* 2019.

Around 12000 tolerant and moderately tolerant (SES score= 3, 5) seedlings at seedling stage from 108 breeding lines ( $F_5$ ) derived from eight different cross combinations were rescued from salinity microplot (EC= 12 dSm<sup>-1</sup>) and planted in field. Finally 800 individual plants were selected on the basis of plant type and yielding ability and harvested in *kharif* 2019.

To breed multiple stress tolerant lines for coastal saline areas, around 400 single plants ( $F_5$ ) derived from Swarna/ Kamini//Gangasiuli (CR 3477) and IR64/Pokkali (AC41585)// Gangasiuli (CR 3483) were selected on the basis of submergence tolerance and desired plant type and yield ability. Gangasiuli was tolerant to submergence and water logging and Kamini and Pokkali (AC41585) were salinity tolerant. Six  $BC_1F_2$  populations using donors (AC39416a, Rahspunjar, Patnai, etc) for multiple stress tolerance have been developed.

#### Evaluation of elite lines in simulation tank and at target site

A set of 96 advanced genotypes along with tolerant

checks (Pokkali, FL 478) and susceptible checks (IR 29 and Pusa 44) were evaluated for salinity tolerance under simulated condition during the dry season. EC 10-12.78 dSm<sup>-1</sup> during seedling stage and 6-8 dSm<sup>-1</sup> at reproductive stage were maintained. Many genotypes were found tolerant at seedling stage and few showed tolerance at reproductive stage with higher grain yield as compared to tolerant checks. However, susceptible checks completely died and could not produce a single grain. CR 4307-298-10-1-1 gave the highest yield (10.89 gm/hill) followed by CR 4309-300-13-2-2 (10.34 gm/hill). Among checks Pokkali (AC41585) and FL 478 gave 8.24 gm/hill and 7.89 gm/hill, respectively.

At Ersama block in Jagatsinghpur district, 30 elite breeding lines were tested under coastal saline areas with EC ranging from 1.7 to 6.1. IET 27852 (CR 2851-S-1-6-2B-4-1) yielded highest with 4.3 t/ha estimated grain yield in 147 days while check variety Luna Suvarna yielded 3.9 t ha<sup>-1</sup> in 150 days.

At Naira farm in Andhra Pradesh, seven salinity tolerant elite lines and varieties were evaluated under normal condition in *kharif* 2019. IET 27865 (CR 2859-S-B-2-1-B-7-1) yielded highest with estimated grain yield of 7.5 t ha<sup>-1</sup> in 150 days followed by IET 27852 (CR 2851-S-1-6-2B-4-1) with 7.3 t ha<sup>-1</sup> yield in 140 days. Medium duration inland saline tolerant variety CSR 36 yielded 5.7 t ha<sup>-1</sup>.

### Harnessing heterosis for enhancing yield and quality of rice

Over decades of rigorous efforts, institute could develop more than 50 CMS lines, more than 100 restorers and three popular hybrids viz., Ajay, Rajalaxmi and CR Dhan 701 for irrigated-shallow-lowland ecosystem of Odisha, Bihar, Assam, Gujarat and West Bengal. In order to make this technology



Fig. 1.11. Field view of elite multiple stress tolerant line IET 27852 (CR 2851-S-1-6-2B-4-1) suitable for coastal saline areas

more sustainable and amenable to the stakeholders, this institute is working on hybrid breeding with various specific product goals.

#### Maintenance of source nursery

A source nursery with 1136 diverse parental genotypes were constituted, maintained and characterized; out of these 226 lines harbour Rf (*Rf3* and *Rf4*) genes, which are utilized in crossing programme.

#### Development of CMS, restorer and hybrid combinations

Total 968 test crosses involving 11 CMS were evaluated and could identify 17 pollen promising maintainers and 41 good restorers (> 85% fertility restoration). Besides, 104 mid-early to medium duration hybrids with >15% yield superiority over respective duration checks, US 314 and Rajalaxmi were re-evaluated. In addition, 02 CMS, CRMS 56A (140 days) and CRMS 57A (130 days) with enhanced out-crossing (32-45%) were developed and 71 other sterile crosses ( $BC_2$ - $BC_{10}$ ) with enhanced seed producibility and sustainability were advanced.

#### Anther culture of RxR, BxB crosses to obtain improved B&R lines

Through doubled haploid (DH) breeding approach, total of 45 restorers (RP5599-312-63-5-1/IR 42266-29-3R; IR42266-29-3R/MTU1071) and 93 maintainers (CRMS 32B/RTN 12B) were developed and utilized.

#### Trait development/genetic diversification of parents and hybrids

Pyramiding of 4 BB resistant genes (*Xa4*, *xa5*, *xa13* and *Xa21*) in CRL 22R and Pusa 33-30-3R

were advanced to  $BC_2F_2$ ; salinity and submergence tolerance in IR42266-29-3R (restorer line) was advanced to  $BC_3F_1$ . Besides, lines for introgression of *Wx* gene in CRMS 32B and IR 42266-29-3R were advanced to  $BC_2F_1$ . Introgression of BPH resistant/tolerant in improved-IR42266-29-3R and Imp-CRMS 32A were advanced to  $BC_2F_1$ . Stacking of yield attributing traits (Gn1a, SCM2 from TR-128) in the parents of Rajalaxmi has been advanced to  $BC_1F_1$ . Pyramiding of long stigma trait in CRMS 31A and CRMS 32A from wild donor *O. longistaminata* is advanced to  $BC_3F_3$ . Partial restorers (PR), Gayatri and Mahalaxmi were stacked with *Rf3* and *Rf4* and BC population of Akshaydhan, Azucena ( $BC_3F_4$ ), INH 10001 and NP 801 ( $BC_2F_4$ ) were advanced.

#### Restorer and maintainer breeding

Total 3840 single plant progenies ( $F_3$  to  $F_{11}$ ) of 118 crosses (AxR, RxR and BxB) were evaluated and 16 of those were utilized. Six random mating populations (RMP) of parents (4 maintainers, 2 restorers) were advanced to 8<sup>th</sup> RMP and 2 *inter-subspecific* MAGIC (B and R; each with 10 parental genotypes) were advanced to IC3F1.

#### Development of Iso-cyrestorer

Total 24  $F_1$ s of six iso-cyrestorer of 27P63 were evaluated under TCN (Kh-2019), where 7  $F_1$ s were out yielded (5.68-11.24%) over parental check.

#### Seed production of parents/hybrids

Total 636.0 kg truthfully labeled (TL) seeds of 42 hybrids including three released, Rajalaxmi (112.0 kg), Ajay (144.0 kg) and CR Dhan 701 (88.0 kg) were produced. Besides, 214.0 kg breeder seeds of 13 CMS, CRMS 31A (90.0 kg) and CRMS 32A (48.0 kg); and nucleus seeds of released hybrids were produced. Agro-practices for seed production of 14 new combinations were refined.

#### DNA fingerprinting of parent/hybrid

DNA fingerprints of two CMS, CRMS 56A and CRMS 57A were developed. Besides, 2 RILs of hybrids, CRMS31B/CRL 22R and CRMS31B/CRL 23R were phenotyped, data to be utilized for excavating genomic region responding heterosis in rice.

#### Registration of hybrids/parental lines

CRMS 8A (Annada A), an early duration WA-CMS found to be useful for development of early duration hybrids is submitted for registration with PPV&FR Authority.

Above findings/development will improve rice farm productivity and livelihood of all stakeholders involved in this venture. Parental lines identified/developed with specific traits like breeding values, quality parameters, out-crossing, sustainability will certainly make this technology a paradigm for enhancement of substantial and sustainable genetic gain in rice. Heterotic hybrids identified/developed will help in hybridization of favourable rice area in the country with good remuneration. Molecular profile of parents/hybrids will protect interest of all stakeholders.

### Biotechnological Strategies for Genetic Improvement of Rice

The aim of this project is to utilize novel biotechnological approaches for genetic improvement of rice. Doubled haploid is one of the technologies which can be utilized to develop inbred lines from the rice hybrids achieving the grain yield at par with donor hybrid in terms of yield and better grain quality. Since *in vitro* mutation shows its potentiality in development of mutants, utilization of this method aims at generation of glyphosate tolerance in elite rice varieties. Alternatively, heat stress tolerance is targeted through over expression of heat stress responsive genes through transgenic approach. Moreover, the potentiality of genome editing could be studied by targeting yield related traits via CRISPR/Cas9 to increase the productivity of indica rice.

**Development of mapping population through doubled haploid approach:** A mapping population was developed from the  $F_1$  of IR20 (Susceptible) x Mahulata (Tolerant) for the identification of drought tolerant QTL (s) employing the doubled haploid approach through androgenesis. A total of 141 regenerants were generated which will be further assessed for allelic distribution of used parents.

**Improvement of regeneration protocol in indica rice for *in vitro* culture:** A total of 10 indica rice varieties (Swarna, Savitri, Sambhamahsuri, Ranjeet, Bahadur, Swarna *Sub1*, Savitri *Sub1*, Sambhamahsuri *Sub1*, Ranjeet *Sub1* and Bahadur *Sub1*) were used to establish an improved regeneration method. The frequency of callus response was found to be 100% for Swarna and Swarna *Sub1* which was closely followed by both Savitri *Sub1* and Sambhamahsuri *Sub1* (96%). Similarly, green shoot regeneration was observed to be 100% in Savitri and Savitri *Sub1* in the modified regeneration media which was closely followed by Savitri and Savitri *Sub1* showing 96% green shoot regeneration.

**Mutation *in vitro*:** A protocol was established for *in vitro* mutation in *indica* rice varieties (Shaktiman and CR203) using EMS mutagen. A total of 167 mutants were developed which will be further advanced to check the homozygosity.

**Table 1.4:** Agronomic performances of 12 selected DHs under field trial.

DHs	Days to Flowering	Plant Height(cm)	Fertile Seeds	Spikelet Fertility (%)	Grain Yield	Grain Type
M-104	91	115	555	85	7120	MS
27P63	99	112	477	77	7100	MS
M-41-2	103	94	525	85	5790	MS
M-104-2	99	122	330	78	5680	MS
M-114-1	98	83	541	89	4950	MS
M-78-1	102	81	369	76	4670	MS
M-153-2	104	87	511	89	4620	MS
M-128-1	98	87	473	77	4430	MS
M-81-2	106	115	470	92	4410	MS
M-31-1	105	113	494	70	4320	MS
M-111-1	103	90	467	86	4320	MS
M-102-1	101	111	430	76	4180	MS
M-124-1	98	90	409	88	4080	MS

**Field performance of doubled haploids:** A total of 12 selected DHs derived from rice hybrids were evaluated for grain yield in the field out of which 2 DHs viz., M104 and M104-2 derived from 27P63 showed 7.1 ha<sup>-1</sup> and 5.6 ha<sup>-1</sup> respectively which are at par with the parent hybrid (Table 1.4).

**CRISPR-Cas9** approach was utilized to edit the *microRNA (miR156)* binding site in the coding sequence of *Ideal Plant Architecture 1 (IPA1)* in Swarna and HKR127. The T<sub>0</sub> plants of both Swarna and HKR127 showed 40-50% increase in the number of spikelets per panicle, 10-15cm increase in plant height and a reduction of 2-3 productive tillers. All the developed plants will be analyzed in T<sub>1</sub>/T<sub>2</sub> generation for stability of edited traits.

### Development of Genomic Resources for Rice Improvement

Mummy Hunger and IR64 were sequenced, and several SNPs and INDELS were identified. Genotyping and phenotyping of 450 F<sub>2,3</sub> lines of the cross from Salkathi (tolerant) and TN1 (susceptible) confirm the presence of QTLs BPH tolerant in Salkathi. Insilco analysis identified 25 candidate genes associated with BPH resistance in Salkathi. A core collection consisting of 96 genotypes was evaluated for phenotypic traits related to seedling vigour and also for biochemical traits. The study indicated that the core collection has ample of variation both for seedling vigour and biochemical traits. The three best genotypes were identified based on the seedling vigour traits. The highest activities for biochemical traits like  $\alpha$ -amylase and total amylase were found in 75 genotypes. Marker-trait association for spikelet sterility identified two markers, RM205 and RM242 significantly associated with heat stress tolerance with the phenotypic variance of 7.7% and 6.0%, respectively. The favourable alleles of both the markers reduced spikelet sterility by 11.73% as compared to mean spikelet sterility (33.81%). Both favourable alleles are present in N22, Dular, IR36 and Wita9 and are located on the lower arm of chromosome 9 (18.64-22.41Mb). Therefore, the introgression of this genomic region between RM205 and RM242 into susceptible high yielding varieties could increase heat stress tolerance in rice.

### Whole genome sequencing of donors and elite rice cultivars

Mummy Hunger (rich in pigments, antioxidants and proteins) and IR64 were sequenced with about 40X depth coverage. 92.84% and 91.01% of sequence

were aligned to *japonica* (Nipponbare) genome while 94.44% and 93.86% to *indica*(93-11) genome, respectively. A total of 740573 SNPs and 53176 INDELS were identified.

### Fine mapping of QTLs associated with BPH resistance Salkathi

Mapping population consisting 150 F<sub>3</sub> lines from the cross TN1 (Susceptible) and Salkathi (BPH tolerant) were screened for reaction against BPH and corresponding F<sub>2</sub> lines were genotyped with flanking SNP markers for QTLs associated with BPH resistance in Salkathi. Linkage analysis using phenotype and genotype data on 450 F<sub>2,3</sub> lines confirmed the presence of QTLs for BPH resistance in Salkathi. Insilco analysis led to the identification of a total of 25 candidate genes associated with BPH resistance in Salkathi. Further, transcriptome sequencing and expression analysis is being undertaken to confirm the candidate genes.

### Association mapping to identify genes/ QTLs associated with seedling vigour

A mini core diversity panel consisting of 96 genotypes were evaluated for seedling vigour traits during wet seasons of 2017 and 2018 and dry season of 2018 while biochemical traits like total amylase and alpha amylase activities during dry season 2019. Three genotypes, ARC6101, IR 93341:13-B-2-21-21-1RGA-2RGA-1-B-B and IR 93351:9-B-6-5-10-1RGA-2RGA-1-B-B were identified as best genotypes with high seedling vigour. Wide variations were found in seedling vigour traits and activities of  $\alpha$ -amylase (0.19-0.59 U/10 grains) and total amylase (0.10-0.33 mg /10 min)(Fig. 1.12). Sixteen genotypes showed lowest  $\alpha$ -amylase (0.19) and total amylase (0.10) activities while the highest activities were found in 75 genotypes (0.59 and 0.33). These 96 genotypes were genotyped with 48 early seedling vigour linked SSR markers and 200 SNP markers to identify the marker-trait association for early seedling vigour.

### Gene Prospecting and Allele Mining for Tolerance to Heat Stress

#### a) Allelic phenotypic effect for heat stress tolerance in rice

Marker-trait association for spikelet sterility under heat stress condition identified two markers significantly associated with heat stress tolerance. The phenotypic variance (R<sup>2</sup>) of RM205, and RM242 was found to be 7.7% (p: 0.022) and 6.0% (p: 0.044),

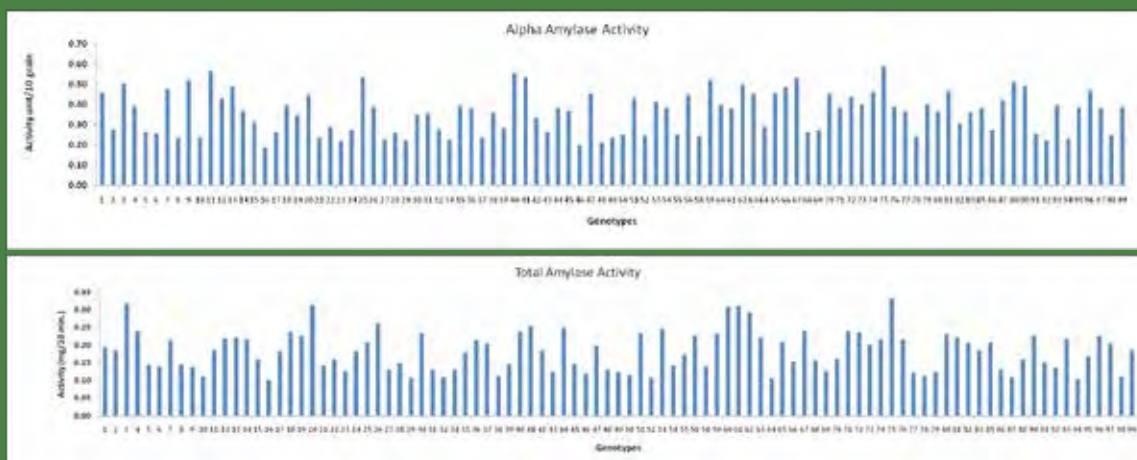


Fig.1.12. Total amylase and alpha amylase activities in 96 genotypes

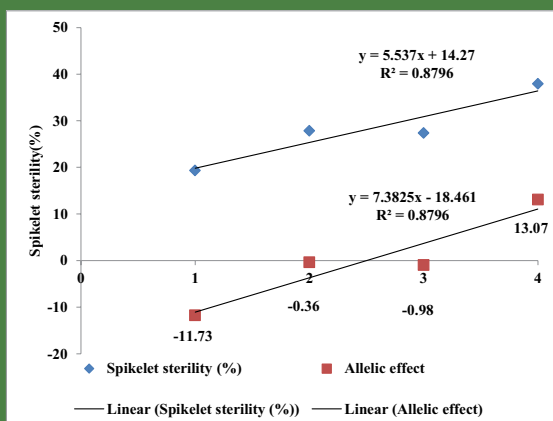


Fig. 1.13. Allelic phenotypic effect of the markers RM242 and RM205

1-Favourable allele for both the markers, 2-Favorable allele only for RM242, 3-Favorable allele only for RM205, and 4- unfavourable allele for both the markers

respectively. The allelic effect of both the markers was analysed for their combined effect on spikelet sterility. The favourable alleles for both the markers are present in N22, Dular, IR36 and Wita9. Further, favourable alleles of both the markers reduced spikelet sterility by 11.73% (Z-test, p value: 0.0009) as compared to mean spikelet sterility (33.81%). In contrast, unfavourable alleles increased spikelet sterility by 13.07% (Z-test, p value: 0.092) (Fig. 1.13). Both the markers are located in the lower arm of chromosome 9 (18.64-22.41Mb). Thus, introgression

of these genomic regions between RM205 and RM242 into high yielding varieties could increase heat stress tolerance in rice.

**Implications of the findings for the body of knowledge :** An androgenic method was established for development of DHs in *indica* rice which is no more found to be recalcitrant to anther culture in vitro.

The *in vitro* mutation approach could be followed for achieving a relatively high frequency of mutants within a short period of time.

The phenotypic effect of the *IPA1* was validated earlier in *japonica* cultivars. The present findings in *indica* cultivars showed functional conservation of *IPA1* gene in rice.

**Implications of the findings/product/technology for farmers:** The DH lines showing high yield could be used by the farmers.

The genome edited lines of *IPA1* could significantly increase the yield by 10-15%.

**Implications of the findings/product/technology for other stakeholders**

**Implications of the findings/product/technology for policy makers :** *IPA1* gene edited lines requires regulatory approval (RCGM, GoI) for its commercialization. Importantly, the developer has to negotiate with the inventor of technology (CRISPR-Cas9) for sharing of benefits.

The different activities under 11 projects undertaken through this programme are vital for keeping the pace of the rice development in the context of the changing climatic conditions and the emerging socio-economic ambitions of the rice stakeholders. The technologies developed including the varieties and the hybrids would enable the rural farmers to be self-sufficient in rice production, besides having nutritionally enhanced food grain. The quality seed produced and supplied through the division is enabling different stakeholders to cultivate modern rice varieties and helping the farmers to harvest the bounty of yield. The results of these studies may also enable the policy makers to make necessary changes in future agricultural policies to address the emerging concerns.





## PROGRAMME-2

# Enhancing Productivity, Sustainability and Resilience of Rice Based Production System

Development of improved agro-technologies for enhanced productivity, profitability, input use efficiency and climate resilience is crucial for enhancing sustainability of rice farming. It depends upon resource use efficiency which is based on three major components such as technical, allocative and environmental efficiencies. In order to deal with the above mentioned issues, a planned programme was made with the aim to develop, validate and disseminate environment friendly technologies to enhance productivity, profitability and sustainability of rice production system.

The main objectives of the programme are to (i) enhance nutrient and water use efficiency in rice by technological intervention, (ii) increase productivity and profitability of rice based cropping and farming system including the site specific weed management, (iii) economic and environmental friendly utilization of soil, water, nutrient, and rice residues by resource conservation technologies and microbial intervention, (iv) develop, refine and validate small scale farm implements for small, marginal farmers and (v) harness microbial resources for alleviating abiotic and biotic stresses for improving soil health particularly in rice.

## Nutrient Management for enhancing productivity and nutrient use efficiency in rice

### Analyzing nitrogen use efficiency of rice across different rice growing states of India

The database of rice grain, straw yield and grain and straw N uptake under varying N application rate was compiled using the data obtained from scientific journals published and dissertations submitted to different state agricultural universities between 1972 and 2018 to calculate state wise agronomic N use efficiency.

Across the states average agronomic N use efficiency ( $AE_N$ ) of rice production ranges from the lowest value of 11.1 kg kg<sup>-1</sup> in Meghalaya to the highest value of 31.0 kg kg<sup>-1</sup> in Himachal Pradesh. The mean  $AE_N$  for rice in India was 18 kg kg<sup>-1</sup>. Average  $AE_N$  in Himachal Pradesh, Tamilnadu, Punjab and Haryana were higher than the national average. Meghalaya, Andhra Pradesh, Chhattisgarh, Madhya Pradesh, Jharkhand, Bihar and Odisha were the states where  $AE_N$  was lower than the national average. In almost all states  $AE_N$  decreases with increasing N rate. At lower N rate of <60 kg ha<sup>-1</sup> Punjab shows the highest  $AE_N$  among all the states, however with increasing N rate it reduced significantly.

### Carbon footprint of rice in India

The Carbon footprint (CFs) of rice in India was calculated as 2.31 t CO<sub>2</sub>e ha<sup>-1</sup>. Among the five regions CF was found highest in northern India (NI) for rice (4.12 t CO<sub>2</sub>e ha<sup>-1</sup>) lowest in North East India for rice (0.46 t CO<sub>2</sub>e ha<sup>-1</sup>). Among the different states in NI, Punjab had the highest TCF for rice (4.91 t CO<sub>2</sub>e ha<sup>-1</sup>).

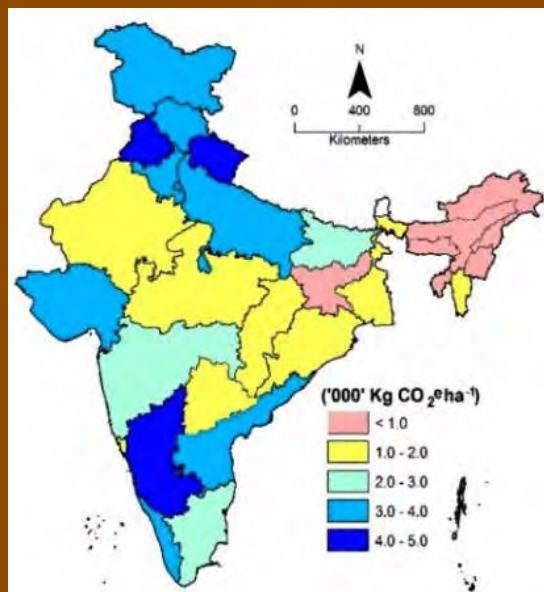


Fig. 2.2. Carbon footprint of rice in India

### Evaluation of rice varieties for phosphorus use efficiency under diversified ecology

The experiment was conducted in *Rabi* (dry season) of 2019 in NRRI farm with four graded doses of P applied (P0: control; P1: 20 kg P ha<sup>-1</sup>; P2: 40 kg P ha<sup>-1</sup> and P3: 60 kg P ha<sup>-1</sup>) and eight varieties, namely Kasalath (P tolerant check- perform well even in low concentration of P), IR-36 (P susceptible check *i.e* responsive var. prefer high concentration of P), CR Dhan 205 (aerobic, 120 days), CR Dhan 304 (125d), Heera, Shatabdi (120d, irrigated), Ajay (125d, hybrid, irrigated) and CR Dhan 801/Phalguni (115-120d, irrigated). Application of phosphorous increased the yield of rice. The highest grain yield was recorded at 60 kg P ha<sup>-1</sup> (P3). Among the varieties the highest

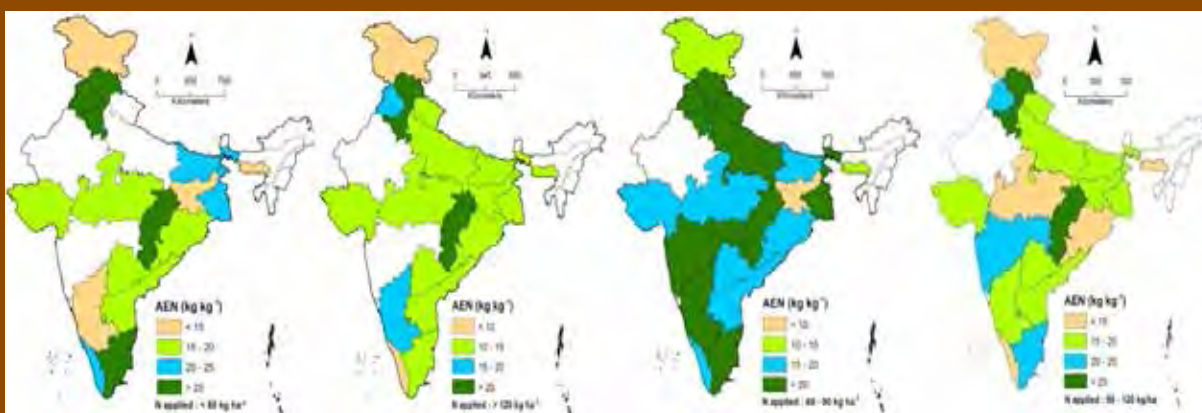


Fig. 2.1. State wise agronomic N use efficiency ( $AE_N$ ) of rice at different N rates

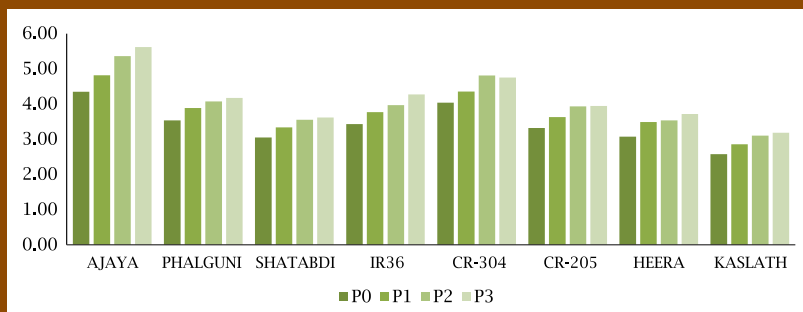


Fig. 2.3. Yield of rice varieties under graded doses of phosphorus

average yield was recorded in Ajay followed by CR Dhan 304. Agronomic efficiency (AE) and recovery efficiency (RE) were found higher in Ajay. The range of AE was 9.4-25.3 kg kg<sup>-1</sup>, while RE was recorded in the range of 8.6-23.5%.

### Population dynamics of fungi under influence of 50 years old long-term fertilizer experiment

The present study was aimed to assess the fungal population in three different media (Potato dextrose, Rose Bengal and CzapekDox) under influence of long-term nutrient managed paddy soil. Maximum counts of fungal population were obtained in the treatment NK with and without FYM (3.5 x 10<sup>4</sup> CFU/g soil), whereas minimum counts were recorded in N-alone (1 x 10<sup>4</sup> CFU/g soil). Thus, the present study revealed that continuous application of N-alone and NK over 50 years suppressed and encouraged the fungal population, respectively.

### Assessing energy and water footprints and increasing water productivity in rice based systems

#### Estimation of energy balance components over Mahanadi delta region

MODIS (Moderate Resolution Imaging Spectroradiometer) calibrated L1B swath product (MOD021) and its corresponding geolocation L1A product were used for estimation of latent heat flux, soil heat flux, sensible heat flux, net radiation, land surface temperature, water vapor over Mahanadi delta. SEBS (Surface Energy Balance System) algorithm was used along with the Soil Moisture Atmospheric correction (SMAC) using aerosol optical thickness. Land surface temperature for the Mahanadi delta region reached upto to 308°K. Higher value of LST estimated in western, north eastern and southern part of the Mahanadi delta region, which

may be attributed to increase in manmade structures for habitation and industry (Fig. 2.4). Latent heat flux (Wm<sup>-2</sup>), representing the loss of energy from the surface due to evaporation, varied from 127.4 to 594.4 Wm<sup>-2</sup> and its higher values were recorded in the south western, northern and north-eastern side of delta region.

#### Relationship of water vapour flux and carbon dioxide flux at different stage of rice growth

A field experiment was carried out to study the relationship of water vapour flux (FH<sub>2</sub>O) and carbon dioxide flux (FCO<sub>2</sub>) in tropical lowland rice-rice system at ICAR-NRRI using eddy covariance (EC) system. Water vapour flux and carbon dioxide flux were measured using open-path infrared gas analyzer (LI-7500A, M/s LICOR Inc., Canada). The relationship between absolute value (ignoring the direction) of carbon dioxide flux (FCO<sub>2</sub>) and the absolute value of FH<sub>2</sub>O in paddy showed that carbon dioxide flux increased proportionately with the increase in FH<sub>2</sub>O, and positive correlations (r<sup>2</sup> = 0.61 to 0.44) between FCO<sub>2</sub> and FH<sub>2</sub>O were observed when data were grouped by growing stage (Fig. 2.5). The significant

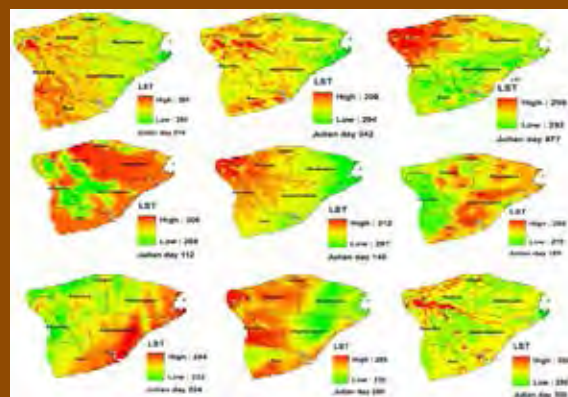


Fig. 2.4 Spatial variation in Land Surface Temperature (°K) over Mahanadi Delta during 2017

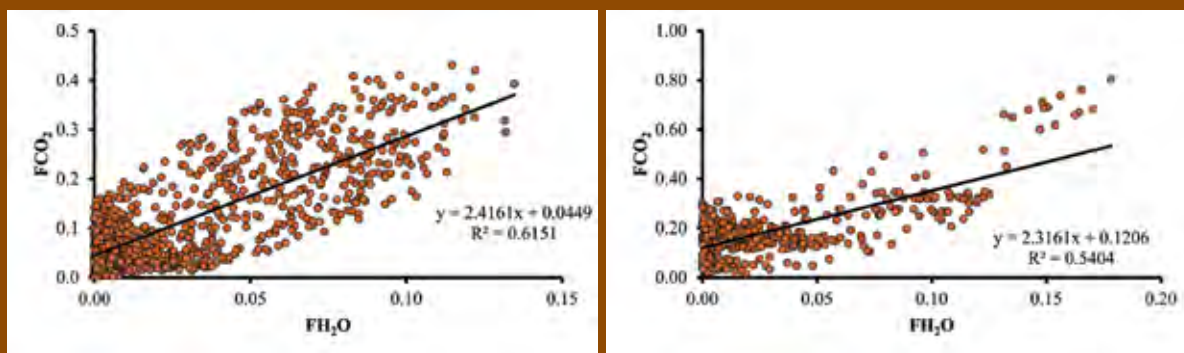


Fig. 2.5. Correlation between  $FCO_2$  and  $FH_2O$  in paddy fields at vegetative and flowering stage.

positive correlation between  $FCO_2$  and  $FH_2O$  in all the stages. Positive correlation between  $FCO_2$  and  $FH_2O$  might be due to their relation in the diffusion of  $CO_2$  from the air to stomata and diffusion of vapour from the leaf stomata to the air. The slope of each regression line at every stage was significantly different ( $p < 0.01$ ).

#### Responses of four different rice cultivars to soil water potential based deficit irrigation management strategies

A field experiment with four rice varieties (Satyabhama, Annada, Ankit and Naveen) and five irrigation schedules based on tensiometric measurement of soil water potential (SWP) was conducted. The irrigation treatments were (a) Continuous flooded (Control); (b) Alternate Wet and Drying (Field capacity); (c) Water Deficit Stress (WDS) at active tillering stage; (d) WDS at heading stage; (e) WDS at grain filling stage. Split plot design was followed with water treatment as main plot and varieties as sub plot. There was a significant decrease in total water input as compared to flooded condition (control). When WDS was imposed at active tillering stage the yield reduction for varieties like Satyabhama, Ankit and Annada was significantly lower as compared to Naveen. WDS during the reproductive stages of rice causes significant lowering of yield as compared to WDS at vegetative stage for all the varieties; however, the yield decline was more for variety Naveen. WDS at reproductive stage is not recoverable and care must be taken to avoid such a situation.

#### Agroecology-based Intensification of Rice based Cropping System for enhancing productivity and profitability

##### Intensification of rice based cropping systems for higher land productivity and profitability

Effect of crop diversification and intensification in rice-rice cropping system was studied. The experiment was laid in randomized block design and replicated thrice. The treatments consist of Rice - Rice, Rice - Groundnut, Rice - Blackgram, Rice - Blackgram + Toria, Rice - Maize, Rice - Maize + Blackgram, Rice - Maize + Cowpea. Results of the experiment reveal that rice-maize cropping sequence recorded higher rice equivalent yield, net return, B: C ratio and land productivity than rice-rice and rice-blackgram. Intensification of rice-maize cropping sequence with inclusion of blackgram or cowpea as an inter crop in maize registered 10.9 and 20.5% increase in rice equivalent yield, respectively, compared to rice-maize system. Among the cropping systems tested rice - maize + cowpea recorded highest rice equivalent yield ( $13.16 \text{ t ha}^{-1}$ ), net return (Rs. 132480), B: C ratio (2.27) and land productivity ( $57.2 \text{ kg REY/day/ha}$ ).

##### Effect of conservation agriculture practices on yield and weed dynamics in rice - maize cropping system

Effect of conservation agriculture practices on the yield and weed dynamics of rice-maize cropping system was studied. The experiment was laid out in a split - split plot design with two tillage systems i.e. conventional and zero tillage in main plots and three residue management system i.e. RDF + No Residue, RDF + Residue Mulching ( $3 \text{ t ha}^{-1}$ ) and RDF + Residue Mulching ( $6 \text{ t ha}^{-1}$ ) to maize in subplots and two N levels to rice i.e. LCC based (75 % RDN) and LCC based (100 % RDN) replicated thrice. The variety Pooja (Rice) and Super 36 (Maize) were used in the experiment. The results indicated that yield achieved in zero tillage was at par with that of conventional tillage both in rice as well as maize in rice - maize cropping system. Mulching with rice straw in maize significantly increased the maize yield

**Table 2.1. System yield, land productivity and economics as influence by different rice-based cropping systems**

Cropping System	Kharif Rice Grain Yield (t ha <sup>-1</sup> )	Rabi REY (t/ha)	System yield (REY t ha <sup>-1</sup> )	Gross return (Rs.)	Net return (Rs.)	B:C	Productivity (kg of REY/day/ha)
Rice-Rice	5.12	5.46	10.58	190800	81180	1.74	44.1
Rice-Groundnut	5.08	5.74	10.82	198760	103190	2.08	47.0
Rice-Blackgram	5.30	2.39	7.69	140430	65400	1.87	38.5
Rice-Blackgram +Toria	5.35	2.79	8.14	177050	93250	2.04	40.7
Rice-Maize	5.08	5.84	10.92	196770	103410	2.11	47.1
Rice-Maize + Blackgram	5.37	6.79	12.12	218970	116100	2.18	52.7
Rice-Maize+Cowpea	5.24	7.92	13.16	236430	132480	2.27	57.2
CD (p=0.05)	0.35	-	0.43	-	-	-	-

and the residual effect increased grain yield of rice. Maize and rice grain yield was increased by 21.5 and 7.66%, respectively, with application of rice residue @ 6 t ha<sup>-1</sup> as mulch in maize. System productivity in terms of rice equivalent yield of conservation tillage system was on par with that of conventional tillage in rice – maize cropping system but significantly higher (14.5%) with application of rice residue @ 6 t ha<sup>-1</sup> as mulch to maize. Conventional tillage (CT) registered significantly lower species wise weed density, total weed density and dry weight of weeds compared to zero tillage(ZT) in both rice and maize crop. The residual effect of residues in maize and nitrogen levels in rice did not have significant impact on density and dry weight of different weed species. Among the residue management in maize, significantly lower total weed density, species wise weed density and dry weight of weeds were recorded under RDF + residue mulching (6 t ha<sup>-1</sup>) as compared to other treatments. Hence rice residue should be mulched in zero tillage maize to manage the weeds and reduce the cost of cultivation.

### **Integrated rice based farming systems for enhancing climate resilience and profitability in eastern India**

#### **Evaluation of different sources of nutrient for growth of fish in the rice field**

A field experiment was conducted with the objective to evaluate different sources of locally available organic source of nutrients as feed supplement to fish for growth and development in the rice-fish system. The

treatments were T1- Rice alone; T2- Rice + Fish, T3 – Rice + Fish + Cow dung; T4 – Rice + Fish goat dung; T5- Rice + Fish + Poultry dropping; T6- rice + Fish + Duck dropping; T7- Rice + Fish + Azolla compost; T8 – Rice + Fish + Plant compost; T9 – Rice + Fish + Pig dung; T10 – Rice + Fish + Pigeon dropping. Polyculture of fish was reared for 120 days. Results revealed that maximum grain yield (8.94 t ha<sup>-1</sup>) was observed with the treatment (T7) with rice + fish + *Azolla* compost which closely followed by treatment (T6) with Rice + fish + duck dropping. Treatment with sole rice crop exhibited lowest grain yield of 6.23 t ha<sup>-1</sup> among all the other treatments. The net body weight of fish was 344, 378 and 381 kg/ha/120 days for rohu, catla and mrigal, respectively with the treatment (T6) with Rice + Fish + Duck dropping.

#### **Capacity building of farmers on rice based integrated farming system**

Six training programmes of 3-4 days duration were conducted on Rice based integrated farming System for Farmers. Lectures were delivered by the experts on various aspects related to management of rice crop under rice-fish system, fish rearing and its management, Production technology of horticultural crops/ agro-forestry, Poultry/duckery, mushroom cultivation on the dykes, livestock management and economics of farming system and supporting schemes. The total number of farmers who participated in the training was 167 from Jagatsinghpur, Puri, Kendrapada, Bhadrak, Jajpur and Cuttack districts of Odisha.

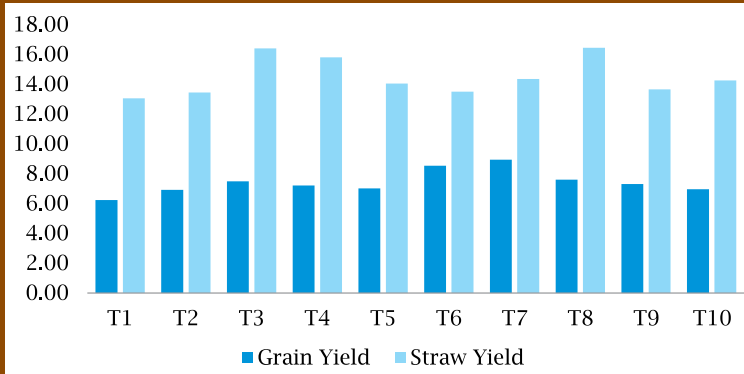


Fig. 2.6. Treatments: T1- Rice alone; T2- Rice + Fish, T3 – Rice + Fish + Cowdung; T4 – Rice + Fish goat dung; T5- Rice + Fish + Poultry dropping; T6- rice + Fish + Duck dropping; T7- Rice + Fish + Azolla compost; T8 – Rice + Fish + Plant compost; T9 – Rice + Fish + Pig dung; T10 – Rice + Fish + Pigeon dropping.

## Increasing productivity and input-use efficiency in rice-based production systems with resource conserving technologies

### Effect of resource conservation technologies on soil aggregates under direct seeded and transplanted condition

The effect of resource conservation technologies was studied on soil aggregates and it was observed that in direct seeded rice, aggregate stability represented in terms of mean weight diameter (MWD) varied from 0.48-0.74 and total percent water stable aggregates (%WSA) ranged from 75.3-88.5% in the upper 0-15 cm surface soil layer. The treatment ZT+100% RDF-N increased significantly the MWD (0.74) and total %WSA (88.5) over other practices and the lowest MWD and total %WSA was found in control plot with no N. Similarly, in transplanted rice, MWD ranged from 0.46-0.76 and total %WSA varied from 75.1-89.2 in upper 0-15 cm layer of soil and was found highest in ZT+100% RDF-N while the lowest was found in control plot with no N, followed by McT+100% RDF-N. The higher organic matter content and no disturbance in soil could have acted as a cementing agent in ZT plots and hence might have contributed to higher aggregate stability.

### Carbon and nitrogen mineralization under resource conservation technology

A field experiment was conducted to study the impact of different components of conservation [minimum soil disturbance/reduce tillage (T), permanent soil cover through crop residues or cover crops (R), and crop rotations (D)] alone and in combination on C and N mineralization. The treatments were control, R, T, D, RT, TD, RD and RTD replicated thrice in randomized

block design (RBD). Result revealed that higher  $\text{CO}_2\text{-C}$  was found in residue added and diversification (R, RT, RD and RTD) treatments. The carbon mineralization in terms of mean cumulative  $\text{CO}_2\text{-C}$  ( $\text{mg CO}_2\text{-C kg}^{-1}$ ) fitted well in first order kinetics ( $R^2=0.94\text{--}0.99$ ) which signifies that the degradation is dependent on the initial concentration of the substrate (Fig. 2.7). Potentially mineralizable nitrogen (N0) content ranged from 185.75 - 226.81  $\text{kg ha}^{-1}$  (Fig. 2.8). The lowest potentially mineralizable nitrogen content was recorded in control, while the highest was recorded in crop rotation. From this experiment it was concluded that among the different components of conservation agriculture, the effect of diversification was more prominent during the initial year (2 years). The residue incorporation was also showing positive impact on carbon and nitrogen mineralization; and when combined with diversification its effect was found more effective.

### Soil organic carbon fractions in rice-groundnut cropping system under organic nutrient management

At the end of three years of field experimentation with different organic nutrient sources (sole and in combination) under rice-groundnut rotation, post analysis of *Kharif* rice season showed that total organic C content (%) varied from 7.42-10.45 under variety Padmini, while it was in the range of 3.98-5.45 under variety Ketakijoha. Very labile, labile, less labile and non-labile C-fractions also were analyzed, and was found to be distributed under eight existing ONM-treatments at two cultivated varieties. These fractions actually define the ratio of soil C presents in active and passive pools. From C-sequestration point of view, it is always preferable that more amount of soil-C to be

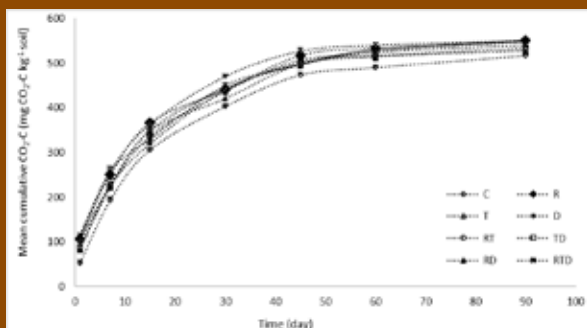


Fig. 2.7. Cumulative release of CO<sub>2</sub>-C as influenced by various treatments of conservation agriculture

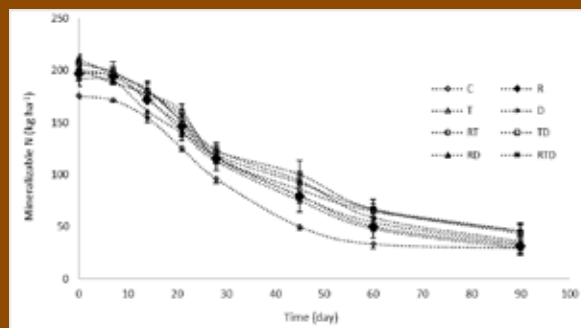


Fig. 2.8. Cumulative degradation of mineralizable nitrogen as influenced by various treatments of conservation agriculture

stored in passive pools i.e. non-labile C fraction. Both the treatments T5 (vermicompost) and T8 (FYM+vermicompost) were found to have a good impact on soil C-sequestration, hence contribute a major share of non-labile soil-C viz. ~91% under variety ‘Padmini’ and ~82% under variety ‘Ketakijoha’.

### Assessing weed dynamics, management for improving productivity and production of rice

#### Development of species wise map showing weed distribution pattern in coastal Odisha

Field survey was conducted in three districts of Odisha viz., Cuttack, Jajpur and Puri during the wet season, 2019 to detect the dominance of prevalent weeds in transplanted rice field by following quantitative survey method using 0.5m x 0.5m size quadrat with 20 samples from each field. The weed samples were collected at 30-45 days after transplanting and counted species wise for computing relative frequency (RF), relative density (RD), relative abundance (RA) and importance value index (IVI). Dominance of

broadleaved weeds and sedges were recorded in all the sampling plots under rainfed shallow lowland transplanted rice fields. Survey data revealed that the broadleaved weeds (47.9%) and sedges (36.3%) occupied 84% of the total weed population. The dominance of sedges and broadleaved weeds might be due to delayed planting during August and the presence of continuous standing water in the crop fields since transplanting. So far the individual weed species concerned, *Ludwigia octovalvis* was the most dominant having highest RF, RD, RA and IVI in all the three districts. Among the sedges, *Cyperus iria* was the dominant species and *Echinochloa crus-galli* was dominant grassy weed (Table 2.2).

#### Development of weed control technology in direct-sown rice

Two field experiments were conducted to study the efficacy of herbicides and suitable weed control technology by integrating chemical and mechanical methods in wet direct-sown rice (W-DSR) during dry season, 2019 with cv. CR Dhan 203 and dry direct-

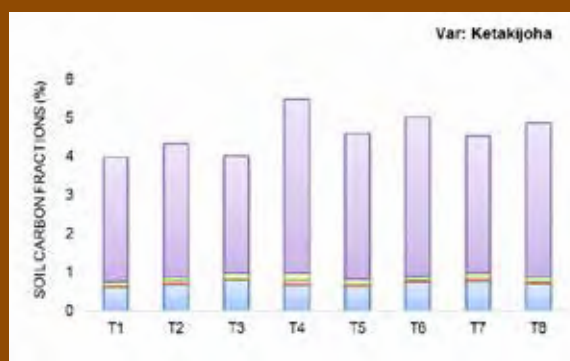


Fig. 2.9. Distribution of soil C-fractions in rice cultivation under different organic nutrient management

**Table 2.2. The relative density, relative abundance and importance value index of different weed species in transplanted rice field in Cuttack, Jajpur and Puri**

Species	Relative density (%)			Relative abundance (%)			Importance Value Index (IVI)		
	Cuttack	Jajpur	Puri	Cuttack	Jajpur	Puri	Cuttack	Jajpur	Puri
Broad leaved weeds	<b>50.70</b>	<b>46.23</b>	<b>46.84</b>	<b>39.48</b>	<b>41.57</b>	<b>40.32</b>			
<i>Ludwigia octovalvis</i>	26.05	20.17	22.57	9.78	8.11	9.51	47.24	40.73	44.84
<i>Sphenoclea zeylanica</i>	3.57	4.60	3.40	3.54	3.70	3.40	11.42	14.53	12.17
<i>Marsilia quadrifolia</i>	3.72	5.19	4.37	2.35	5.37	3.50	12.86	15.40	14.58
<i>Monochoria vaginalis</i>	3.26	3.07	1.94	3.77	3.70	2.59	10.73	10.92	8.56
<i>Alternanthera sessilis</i>	1.86	2.48	3.76	2.58	4.48	4.30	7.53	9.73	12.76
<i>Ludwigia adscendens</i>	2.17	1.89	3.88	3.01	3.41	5.18	8.27	8.07	13.09
<i>Portulaca oleracea</i>	2.17	2.48	1.58	3.01	3.58	3.16	8.27	9.52	7.42
<b>Other</b>	7.90	6.35	5.34	11.44	9.22	8.68	31.69	24.93	23.42
Sedges	<b>30.70</b>	<b>36.91</b>	<b>41.14</b>	<b>29.45</b>	<b>32.16</b>	<b>38.68</b>			
<i>Cyperus iria</i>	9.15	15.09	19.42	4.54	9.10	11.96	22.33	32.50	40.10
<i>Cyperus difformis</i>	5.58	4.01	7.65	4.84	4.84	8.74	15.36	13.0	21.09
<i>Cyperus haspan</i>	2.79	1.65	2.06	3.88	4.84	5.02	9.75	9.95	11.78
<i>Fimbristylis miliacea</i>	5.74	13.68	10.07	3.98	9.00	6.72	15.89	30.29	24.85
<i>Scirpus juncooides</i>	1.86	1.65	1.21	4.31	2.39	3.33	8.02	7.50	6.42
<b>Other</b>	5.58	0.83	0.73	7.90	1.99	2.91	19.65	4.89	4.99
Grasses	<b>18.60</b>	<b>16.86</b>	<b>12.02</b>	<b>31.07</b>	<b>26.27</b>	<b>21.00</b>			
<i>Echinochloa crus-galli</i>	5.28	3.78	4.49	6.96	5.37	6.51	19.02	16.75	18.39
<i>Echinochloa glabrescens</i>	1.86	0.83	0.61	4.31	1.99	2.43	8.02	4.89	4.38
<i>Panicum repens</i>	2.79	4.60	1.94	4.84	5.55	3.89	10.10	14.30	8.51
<i>Leptochloa chinensis</i>	2.33	2.0	1.46	3.23	3.63	2.91	8.64	8.40	7.06
<i>Cynodon dactylon</i>	3.26	3.66	2.91	3.77	5.29	2.91	10.73	12.41	11.20
<b>Other</b>	3.08	1.99	0.61	7.96	4.44	2.35	14.47	11.29	4.38

sown rice (D-DSR) during wet season, 2019 with cv. CR Dhan 310. The treatments included mechanical weed control twice by two row motorized weeder at 20 and 40 days after emergence (DAE), chemical weed control by pendimethalin fb bispyribac sodium (750 and 30 g ha<sup>-1</sup> applied at 3 and 25 DAE), pendimethalin at 3 DAE fb mechanical weed control at 30 DAE, bispyribac sodium at 10 DAE fb mechanical weed control at 30 DAE, manual weeding (once at 30 DAE) at 25 cm row spacing, manual weeding (once at 30 DAE) at 20 cm row spacing, weed free at 25 cm row spacing, weed free at 20 cm row spacing, weedy at 25 cm row spacing and weedy at 20 cm row spacing. Altogether ten treatments were evaluated in randomized complete block design with three replications.

Experimental results revealed that the highest grain yield (4.43 and 5.15 t ha<sup>-1</sup>, during dry and wet season, respectively) was recorded with weed free check at 20 cm row spacing but it was at par with weed free check at 25 cm spacing indicating that increasing row spacing up to 25 cm could not show any significant reduction in grain yield of rice. Among the weed control treatments, it was found that early post emergence application of bispyribac sodium 30 g ha<sup>-1</sup> (10 DAE) fb mechanical weeding with two row motorized weeder (30 DAE) at 25 cm row spacing registered significantly higher grain yield (4.15 t ha<sup>-1</sup>), net return (Rs 37950 ha<sup>-1</sup>) and B:C ratio (2.31) but it was at par with sequential application of pendimethalin (750 g ha<sup>-1</sup>) as pre-emergence fb post emergence application of bispyribac sodium (25 g ha<sup>-1</sup>) at 3 and 25 DAE) at 25 cm row spacing during dry

season, 2019. The same treatment combinations i.e., application of bispyribac sodium  $30 \text{ g ha}^{-1}$  (10 DAE) *fb* mechanical weeding by two row motorized weeder (30 DAE) at 25 cm row spacing performed better than other treatments during wet season, 2019. The highest grain yield ( $4.92 \text{ t ha}^{-1}$ ), net return (Rs 47,840  $\text{ha}^{-1}$ ) and B:C ratio (2.28) was recorded in this treatment combination during succeeding wet season indicating that integration of chemical weed control at early stage in combination with mechanical weed control at vegetative stage (25-30 DAE) controlled the weeds effectively with most economic return from direct-sown rice.

#### **Evaluation of herbicide-based weed control with safest molecule in direct-sown rice**

A field experiment was conducted during the wet season, 2019 to study the weed spectrum and efficacy of sequential herbicide application and herbicide mixtures for broad spectrum weed control in wet direct-sown rice (W-DSR) with cv. CR Dhan 311. The treatments included bispyribac sodium *fb* ethoxysulfuron ( $25 \text{ \& } 15 \text{ g ha}^{-1}$  at 7 and 21 DAS), cyhalofop butyl *fb* ethoxysulfuron ( $100 \text{ \& } 15 \text{ g ha}^{-1}$  at 10 and 21 DAS), flucetosulfuron *fb* ethoxysulfuron ( $25 \text{ \& } 15 \text{ g ha}^{-1}$  at 7 and 21 DAS), XR 848 benzyl ester + cyhalofop butyl ( $150 \text{ g ha}^{-1}$  at 15 DAS), penoxsulam + cyhalofop butyl ( $130 \text{ g ha}^{-1}$  at 15 DAS) and bispyribac sodium + ethoxysulfuron ( $25 + 15 \text{ g ha}^{-1}$  at 15 DAS) with recommended herbicide of bispyribac sodium ( $30 \text{ g ha}^{-1}$  at 10 DAS) and herbicide mixture of bensulfuron methyl + pretilachlor ( $60+600 \text{ g ha}^{-1}$  at 7 DAS) along with weed free and weedy check. Altogether ten treatments were evaluated in randomized complete block design with three replications. Experimental results revealed that there was excellent control of complex weed flora in bispyribac sodium *fb* ethoxysulfuron treated plots with WCE of 90.2% followed by XR 848 benzyl ester + cyhalofop butyl treated plots with WCE 88.3%. The highest yield ( $4.86 \text{ t ha}^{-1}$ ) was recorded in weed free check. The treatment *viz.*, sequential application of bispyribac sodium *fb* ethoxysulfuron showed 15% and 11% yield advantage over the recommended herbicide of bispyribac sodium and recommended herbicide mixture of bensulfuron methyl + pretilachlor, respectively. The yield reduction due to weed competition in weedy plots was more than 48%.

#### **Economic and environment friendly use of rice straw**

#### **Grouping of rice straw for alternate uses**

Rice straw is a useful bio-resource, nevertheless this valuable biomass is unfortunately burnt on field as waste that causes air pollution, global warming, plant nutrient losses and environment menace. As for the basic requirement to predict their suitability for best alternative industrial uses, biochemical characterization was done on the basis of cellulose, hemicellulose, lignin and silica content (Fig. 2.10). The surface morphology of straws was observed through Scanning Electron Microscopy (SEM), while, presence of functional groups were analyzed through Fourier Transform Infrared (FTIR) spectroscopy. Characterization of straws of 18 most widely grown rice cultivars from eastern region of India was carried out. Primarily, quantified biochemical profiles were used to group cultivars for best alternate uses of straw like bio-ethanol, biochar, compost and mushroom production. Morphological feature (from SEM) of straw and functional group (through FTIR) were used to support the grouping (Table 2.3).

Considering all the three characterization methods (chemical composition, morphological features, presence or absence of functional groups), it was found that straws of rice cultivars, Tapaswini and IR 64 were best suited for bio-ethanol and biochar production, respectively. There are overlapping as well as contradictory observations found during grouping, when the three approaches were followed together. This indicates that the grouping of straw for better alternative uses could be done by biochemical and morphological characterization but this should be validated in small scale at farm or factory level for final recommendation.

#### **Preparation of straw biochar from different rice cultivars**

Biochar from straw of nineteen popular rice cultivars was attempted at two different durations (2 hours and 4 hours) at a fixed pyrolysis temperature ( $300^\circ\text{C}$ ) in an  $\text{O}_2$ -free environment and pre-fixing all other preparatory criteria. It was observed that weight loss after heating varied from 25% (Varshadhan) to 91% (CR Dhan 310) and for major number of cultivars, yield of biochar ranged between 50-70% while the pyrolysis was undergone at 2 hours pyrolysis duration. At 4 hours pyrolysis duration the situation was vice-versa i.e. per cent weight loss of the biomass was more while the biochar yield was less. The biochar yield obtained was as low as 10% (Swarna *sub-1*)

**Table 2.3. The desirable features of rice straw for production of valuable products like bioethanol, biochar, compost and mushroom-substrates**

Products	Desirable features of Straw
Bioethanol	<ol style="list-style-type: none"> <li>1. High Hemicellulose or High Hemicellulose and Cellulose</li> <li>2. Low to medium lignin and Si</li> <li>3. C=O, FTIR (hemicelluloses Group)</li> </ol>
Biochar	<ol style="list-style-type: none"> <li>1. High Lignin</li> <li>2. Low to Medium Cellulose and Hemicellulose.</li> <li>3. High Aromaticity (aromatic group in FTIR; more Syngil moiety)</li> <li>4. High silica grooves and low surface area</li> </ol>
Compost	<ol style="list-style-type: none"> <li>1. High to Medium Cellulose</li> <li>2. Low to medium Lignin and Silica</li> <li>3. Low silica grooves and High surface area</li> <li>4. Broad -OH bond (FTIR)</li> </ol>
Mushroom	<ol style="list-style-type: none"> <li>1. High to Medium Cellulose</li> <li>2. Low Silica</li> <li>3. Low silica grooves and High surface area</li> <li>4. Broad -OH bond (FTIR)</li> </ol>

to as high as 52% (Ratna) after 4-hours pyrolysis. Further characterization as well as laboratory and field evaluations using these biochar from different feedstock is undergoing.

**Mechanization of rice-based cropping systems for higher productivity and energy use efficiency**

**Evaluation of urea briquette applicator attachment with mechanical rice transplanter**

The urea briquette applicator attached with eight row mechanical transplanter (Fig. 2.12) was evaluated to apply urea briquettes between the rows. It was found that the operating speed of developed machine was 1.66 km h<sup>-1</sup>. The field capacity and field efficiency of the

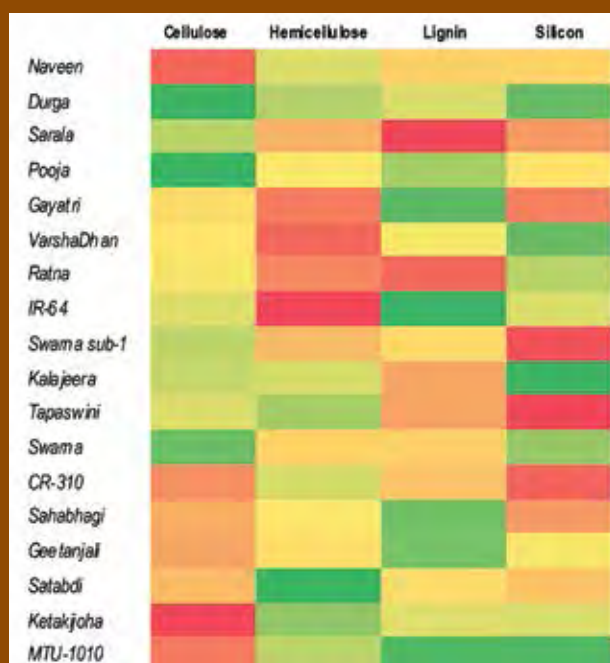


Fig. 2.10. Heat map of values for biochemical properties of straw collected from 18 rice cultivars

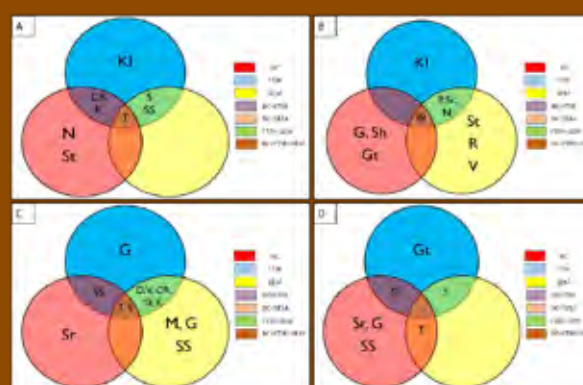


Fig. 2.11. Grouping of 18 rice cultivars for (a) Bioethanol, (b) Biochar, (c) Compost and (d) Mushroom production based on Biochemical, FTIR and SEM analysis

[Here, N=Naveen, SS=Swarna Sub-1, Kl=Kalajeera, T=Tapaswini, S=Swarna, CR=CR Dhan 310, St=Satabdi, K=Ketakijoha, Sr= Sarala, V=VarshaDhan, R=Ratna, IR= IR-64, Sh =Sahabhagi, Gt= Geetanjali, D=Durga, G=Gayatri, M=MTU-1010: BC=Biochemical analysis, FTIR=Fourier Transform Infra-Red spectroscopy, SEM=Scanning Electron Microscope]

machine were  $0.191 \text{ ha h}^{-1}$  and 67.82%, respectively. The cost of operation with the applicator was 85% to 90% less compared to manual placement methods.

### Development of battery powered weeder

A battery powered single row weeder was developed for rice crop (Fig. 2.13). Sixteen cutting blade with 12 cm of width and 5 cm depth of cut attached on cutting unit, which was operated in greater than 20 cm row spacing. The developed weeder consists of 24 volt DC motor with 22 NM torque which gives 0.33 HP power output at speed of 250 RPM to cutting unit. This weeder is light weight and eliminates engine vibration leading to drudgery reduction during field operation.

### Harnessing microbial resources for alleviating abiotic and biotic stresses for improving soil health

#### Role of nitrate as antioxidant to alleviate salt stress in *Azolla*

*Azolla* is an aquatic fern and known biofertilizer for rice crop, but its growth is drastically decreased under salt stress. In order to assess the role of potassium nitrate ( $\text{KNO}_3$ ) as antioxidant against salt stress, an experiment was conducted in *Azolla* subjected to different NaCl treatments (0 mM, 50 mM, 100 mM conc.) in a nitrogen-free liquid IRR medium for 15 days in the presence or absence of  $\text{KNO}_3$  (4 mM). Results indicated that electrolytic leakage was increased by 13.36% and 35.76% in 50 mM and 100 mM NaCl treatments, respectively without addition of  $\text{KNO}_3$ . Result also showed that addition of  $\text{KNO}_3$  in 0, 50 and 100 mM NaCl increased the relative frond

number and relative growth rate by 57.05%, 52.38%, 33% and 78%, 50%, 14%, respectively as compared to control (without addition of  $\text{KNO}_3$ ). Moreover, fluorescence chlorophyll imaging-based minimal fluorescence ( $F_0$ ), maximal fluorescence ( $F_m$ ), maximal PSII quantum yield ( $F_v/F_m$ ) and quantum yield of non-regulated energy dissipation in PSII ( $Y(\text{NO})$ ) were increased by 16.66%, 88.88%, 52.23% and 29.33%, respectively after addition of  $\text{KNO}_3$  in 50 mM NaCl. Overall, the present study suggested that 4 mM  $\text{KNO}_3$  acts as antioxidant in *Azolla rubra* under salt stress.

### Physiological variations of sporocarp-producing *Azolla* strains under sub-humid tropical condition

The aim of the present study was to observe the variation of physiological parameters (growth, photosynthetic pigments estimation, chlorophyll fluorescence imaging through ImageWin software) in sporocarp-producing *Azolla* strains. Results showed that only 23 *Azolla* strains (out of 102) including two known *Azolla* species viz., *A. microphylla* and *A. pinnata* were sporulated during December to February at sub-humid tropical climatic condition of Cuttack, India. *Azolla* strain NRRI 4 and *A. rubra* showed maximum and minimum value of  $F_v/F_m$  as compared to other strains of *Azolla*. Relative growth rate (RGR) was observed highest in *Azolla* strain NRRI 1, whereas *A. mexicana* and R-94 showed the least RGR. Among all strains, IEPI 4 showed the highest concentration of Chlorophyll a and carotenoids. The present study concludes that the less physiological variations were obtained in sporocarp-producing *Azolla* strains grown under sub-humid tropical climatic condition of Cuttack.



Fig. 2.12. Urea briquette applicator attachment for mechanical rice transplanter



Fig. 2.13. Battery powered weeder for rice crop

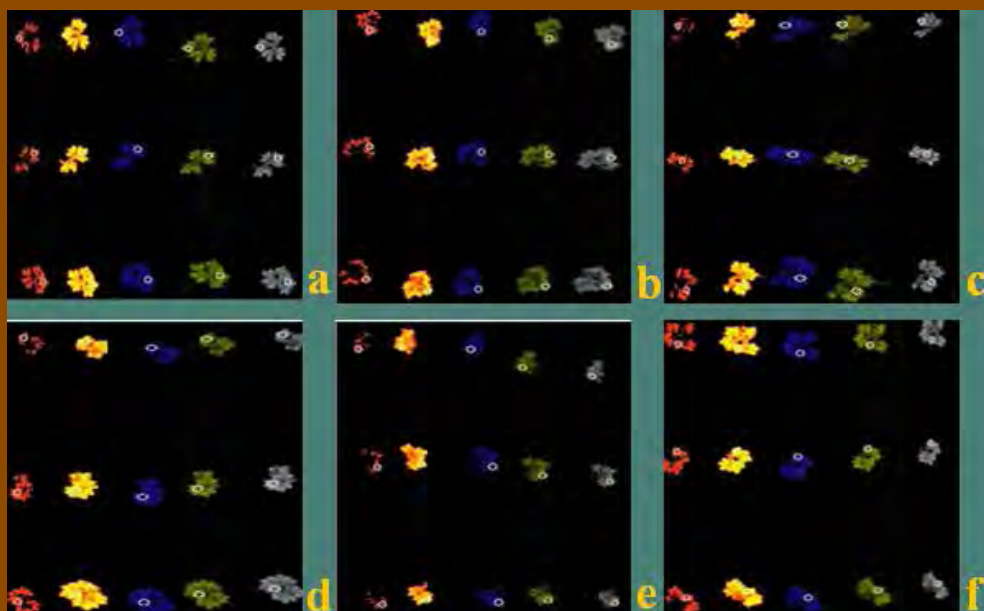


Fig. 2.14. Fluorescence chlorophyll imaging data of *Azolla rubra* under salt (NaCl) stress condition treatment imposed with a) Control: no addition of salt (NaCl) and nitrate ( $\text{KNO}_3$ ); b) Only nitrate (4 mM  $\text{KNO}_3$ ); c) 50 mM NaCl; d) 50 mM NaCl +  $\text{NO}_3$ ; e) 100 mM NaCl; f) 100 mM NaCl +  $\text{KNO}_3$ . Red, yellow, blue, green and gray color depicted the photosynthesis parameter viz., minimal fluorescence ( $F_0$ ), minimal fluorescence ( $F_m$ ), maximal PSII quantum yield ( $F_v/F_m$ ), quantum yield of non-regulated energy dissipation in PSII ( $Y(\text{NO})$ ) and proportion of open PSII (qP), respectively

### Microbial-mediated drought stress alleviation in rice

Two drought susceptible (IR 64 & Naveen) and tolerant (Satyabhama & Ankit) rice cultivars were used to assess the efficacy of microbial-mediated (*Azotobacter chroococcum* AVi2) ascorbic acid (1ppm) formulation. Result depicted that copy no. of ascorbic acid-mediated Avi2-specific *nifH* gene was increased by 80.39%, 79.72%, 84% and 77.41% compared to the moisture control in IR 64, Naveen, Satyabhama and Ankit, respectively. Result also showed that defense enzyme such as superoxide dismutase, catalase and proline were also regulated by addition of ascorbic acid in both drought susceptible and tolerant cultivars used in this study.

### Evaluation of arbuscular mycorrhizal fungus on drought management in rice plants

The response of rice genotypes IR 20, N22 and Naveen inoculation with *arbuscular mycorrhizal* fungus (AMF), was evaluated under well-watered and drought stress conditions. This experiment was conducted in potted (10 kg soil) plants inoculated with 100 g AMF inoculum per pot and drought condition was imposed during vegetative and reproductive stages. In general, AMF inoculation in

well-watered plants recorded higher yields (9.3-13.0 g per plants) in all the rice genotypes as compared to uninoculated control. Similar trend was noticed under drought conditions, however there was 16.8-22.7, 33.9-41.7 and 44-50.5% yield reduction in AMF inoculated N22, Naveen and IR 20, respectively compared to well-watered plants. The uninoculated AMF plants registered 24.7-30.6, 46.0-51.0 and 53.0-59.0% in N22, Naveen and IR 20, respectively under drought conditions than control. Overall, the AMF inoculation increased the yield by 8-12 % under drought conditions compared to uninoculated plants.

### Evaluation of liquid formulations of entomopathogens against rice leaf folder

In this experiment, the liquid formulation of *Skermanella* sp. and *B. thuringiensis* were evaluated ( $2.8-3.9 \times 10^{10}$  CFU/ml) against rice leaf folder in susceptible rice variety TN 1 under glass house condition. The leaf folder incidence was significantly lower (6.0 -7.5%) in inoculated plants compared to control (28.0-33.0%). The inoculated plants recorded significantly higher larval mortality 75.0-90.0% than uninoculated plants.

### Effect of arbuscular mycorrhizal fungi in rice under elevated carbon dioxide conditions

In this experiment, the native the mixed soil-based AMF inoculum (*Funneliformis mosseae*, *Rhizophagus fasciculatus* and *Rhizophagus intraradices*) were evaluated in rice plants (cv. Naveen) under elevated CO<sub>2</sub> concentrations (400 ± 10 ppm, 550 ± 20 ppm and 700 ± 20 ppm) in open top chambers (OTCs). Three different modes of application of AMF inoculum were evaluated, i.e. AMF inoculum applied at the time of transplanting (50 g inoculum per pot) as basal dose, ii) AMF inoculum applied during seedling production i.e. mycorrhized seedlings production (at the rate of 50 g inoculum per plastic trays containing 10 kg soil) iii) combination of mycorrhized seedlings with basal application at the time of transplanting (50 g inoculum per pot). Among the three different modes of application, the combined application of AMF during transplanting of mycorrhized rice seedlings with basal application of AMF had positive influence under elevated CO<sub>2</sub> on soil microbial and enzymatic properties. The same treatment significantly improved grain yield by 25.08 % and also increased

uptake of P by 18.2 % and N by 49.5 %, at 700 ppm CO<sub>2</sub> concentration.

#### **Procurement, collection and conservation of the cyanobacterial strains for rice crop**

A total 42 strains of commercial bio-inoculants of cyanobacteria was procured from culture collection of Conservation and Utilization of Blue Green Algae (CCUBGA), Division of Microbiology, ICAR-Indian Agricultural Research Institute, New Delhi and initiated to maintain at culture room facility of Microbiology in Crop Production Division of ICAR-NRRI.

These have been screened for some growth attributes in terms of cell dry weight, chlorophyll content and nitrogenase activity. Amongst them, 36 showed nitrogenase activity varying from a highest of 941.39 n moles of C<sub>2</sub>H<sub>4</sub> mg chl<sup>-1</sup> h<sup>-1</sup> in *Anabaena* sp. (IR64/ Soil isolate) to lowest of 27.65 n moles of C<sub>2</sub>H<sub>4</sub> mg chl<sup>-1</sup> h<sup>-1</sup> in *Nostoc* sp. (IR64/Leaf isolate).





Nitrogen use efficiency of rice in different states of India was analyzed. There are considerable variations in N use efficiency of rice across the states depending on the agro climatic condition and N application rates. The mean  $AE_N$  for rice in India is  $18 \text{ kg kg}^{-1}$ . Average  $AE_N$  in Himachal Pradesh, Tamilnadu, Punjab and Haryana are higher than the national average. Meghalaya, Andhra Pradesh, Chhattisgarh, Madhya Pradesh, Jharkhand, Bihar and Odisha are the states where  $AE_N$  is lower than the national average. The findings of the study will help assessing the impact of N fertilizer use and devising region specific management practices for enhanced use efficiency.

Assessment of carbon and water footprint for rice production system will help assessing environmental impact of rice based production system and help devising environmental sustainable input management practices. On the basis of biochemical characterization of straw of popular rice cultivars indicated straw of Tapaswini and IR 64 were best suited for bio-ethanol and biochar production, respectively, however this needs to be validated in small scale before final recommendation.

Microbial-mediated (*Azotobacter chroococcum* AVi2) ascorbic acid (1ppm) formulation was found to regulate defense enzymes of drought stress such as superoxide dismutase, catalase and proline in rice. Inoculation of arbuscular mycorrhizal fungus increased rice yield by 8.0-12% under drought conditions compared to uninoculated plants.

## Rice Pests and Diseases – Emerging Problems and their Management

The Crop Protection Division is conducting applied, strategic and basic research on integrated management of rice pests and diseases to improve rice productivity and profitability. Major thrust areas of research are multiple pest resistance genotypes, pest modelling and forecasting, tri-trophic interaction of rice, pests and predators/parasites under climate change, novel molecules and formulations for eco-friendly pest and stored grain pest management. The Division is also involved in designing, validating and popularizing pest and ecology based IPM modules for the farmers to ensure profitability. The Division has 21 scientists, 10 technical staffs and 3 supporting staffs. Besides four in-house research projects, 13 externally aided projects are being operated in the Division. More than 2000 germplasm accessions were screened to find out novel resistance source against different pests of rice. AC 39738 was found as highly resistant against gall midge and IET 27539 was found resistant against brown spot. Genetic diversity and population analysis of Yellow stem borer, bakanae, bacterial blight and false smut were carried out. The division validated IPM modules under semi-deep-water and shallow lowland rice ecosystems and disseminated the technology to different stakeholders. Bioagents like *Trichoderma* spp, *Arthrobotrys* spp and potassium silicate can be used to manage rice pests. New techniques like natural stain, Loop-Mediated Isothermal Amplification (LAMP) Assay will be helpful for early detection of rice pests. Bio-mixtures can degrade pesticide at faster rate.



## Exploration of new sources of resistance for insect-pests and diseases of rice

### Resistant Donor identification against BPH & WBPH

Out of 110 rice varieties screened against BPH and WBPH during 2019, only one variety Gayatri was found to be resistant (score 3) to BPH, while five others viz., CR Dhan 204, Kalyani II, Pradhan Dhan, Gayatri and Kheera were found to be resistant (score 3) to WBPH. AC 39843 was found resistant to BPH, out of 74 rice genotypes, collected from Tripura and Sikkim.

### Studies on mechanism of resistance against BPH in Sikkim and Tripura accessions

Ten accessions were evaluated for different parameters of antixenosis and antibiosis for confirmation of their resistance. Genotypes AC 39843, AC 39842 and AC 39877 showed moderately resistance to BPH. AC 39843 recorded lowest sugar content followed by AC 39842 and AC 39877. Total phenol content in AC 39843 was the highest. Out of 24 microsatellite (SSR) markers used for understanding the polymorphism between the resistant and susceptible genotypes, 14 had shown polymorphism. The neighbor-joining phylogenetic tree for the genotypes showed three major clusters but none of the clusters had bootstrap values of more than 50%.

### Phenotyping and genotyping for gall midge, *Orseolia oryzae* resistance

On phenotyping of 93 NRRI released varieties and 65 Sikkim and Tripura genotypes against Asian rice gall midge, *Orseolia oryzae*, CR Dhan 300 and Samalei were found to be resistant, whereas among Sikkim and Tripura genotypes, AC 39738 was found as highly resistant; while AC 39756, AC 39769 and AC 39777 as resistant.

### Genetic diversity of yellow stem borer (YSB) populations of different locations

The phylogenetic analysis of the *COX1* gene sequence of YSB showed formation of three major clads. The YSB populations from ten locations grouped into two major clades, one comprised of YSB from different countries (India, China, Indonesia, Australia and Canada) and another India specific. Thus, genetic variation in the *COX1* was found within the yellow stem borer population collected in India. Genetic diversity of YSB populations from 10 different locations was

studied using EST-SSR markers. The cumulative genotypic variance of around 62% was observed through factorial analysis. Further, dendrogram analysis showed clustering of 10 YSB populations into three major groups. The comparison of geographical diversity and genetic diversity with SSR dendrogram revealed Chhattisgarh populations were clustered in all the groups showing high diversity, followed by Odisha populations clustering in two groups. Additionally, high genetic similarity was observed between Telangana and Karnataka populations, Chhattisgarh and Odisha populations of YSB. This is the first report on understanding the genetic diversity of YSB using EST-SSR and *COX-1* markers.

### Effect of elicitors and insecticide on the settling behaviour of YSB moths

Impact study of elicitor (potassium silicate, salicylic acid, chitin, methyl salicylate and chitosan) and insecticide spray (chlorantraniliprole and thiamethoxam) on settling behaviour of yellow stem borer adult moths revealed that the mean number of moths settled and also number of eggs laid by the moths on water sprayed plants is more than elicitor and insecticide sprayed plants. This preliminary experiment confirms, spray of elicitor can be employed to disturb the settling of yellow stem borer adult moths on rice plants and by this egg laying by YSB moths can be reduced.

### A novel technique of staining *Tribolium* (stored grain pest) eggs by using natural stains

*Tribolium spp* are the most widespread stored grain pest, lays microscopic and white/colourless eggs in the infested food material. Dyes namely, bromocresol green, acid fuchsin, orange G etc., were used to identify the eggs, may cause skin and eye irritations. Thus, with the aim of identifying the natural coloured materials which could substitute the conventional dyes, turmeric, teak, onion, beetroot and grape extracts were used. It was found that turmeric extracts had highest anthocyanin content (155 mg/100g), whereas, teak extract had highest flavonoid content (12.13mg catechin/g). Total phenols were highest in onion extract (5.033 mg GAE/g). The eggs were white shiny translucent leaving the coloured flour particles in accordance with the colour of the dyes. Beetroot and teak stains could easily colour the flour in red and dark brown, respectively and leave the eggs unstained showing clear distinction between eggs and flour. Grape and onion stains gave

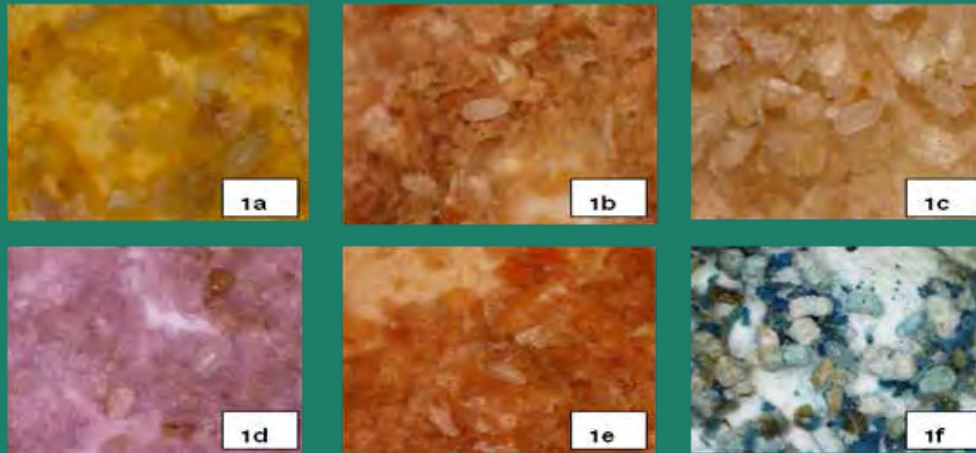


Fig. 3.1. Eggs of *Tribolium* stained with Beetroot (1a), Turmeric(1b), Onion(1c), Grapes(1d), Teak (1e), Bromocresol (1f)

a slight purplish and light pink colour to the eggs while remaining particles were dark violet and dark pink, respectively. (Fig. 3.1) Highest percentage of hatchability was observed in grape stained eggs with 83.33%. Compared to phytochemicals content, colour and pH of the extracts determined the ability of a dye to stain flour and keeping the eggs unstained. No morphological changes in growth and development of the stain specimens were observed. These natural extracts are indeed cheap, easily procurable, innocuous for staining and can be sustainable substitutes of chemical dyes.

### Screening of resistant donor to different pathogen causing rice diseases

#### Bacterial blight

A total of 530 lines have been screened for bacterial blight resistance using artificial inoculation method. Sixty-nine lines were identified to be resistant and 56 lines were moderately resistant. The rest of them were susceptible.

#### Leaf blast

A set of 152 landraces and improved lines were screened for leaf blast disease under natural conditions in the Uniform Blast Nursery (UBN) during *Kharif* 2019 and *Rabi* 2018-19. Among the screened lines, seven lines namely Boro, ARC 10378, Boraya, Kaliboro 26, Kali boro 2-2, Gobir sail, Ziri and Jamir were found to be resistant.

#### Brown spot

A rice genotype IET 27539 was found resistant in the

natural condition. Hence, under greenhouse condition IET 27539 along with the susceptible check of CO 39 was carried out following standard screening technique. IET 27539 was found to be resistant with score 3.

#### Sheath blight

A total of 619 entries, comprising of 189 farmers' varieties, 49 released varieties, 58 Next Generation Rice lines, 298 Assam Rice Collections and 25 doubled haploid lines were evaluated for identifying resistant donor against sheath blight disease caused by *Rhizoctonia solani* during *rabi*, 2019 under artificial inoculation and 6, 5, 4, 8 and 3 entries were observed as moderately resistant, respectively. Some of the promising entries were as follows; Biradia Bankoi, Champeisiali-D, Koraput-Dasmantapur-Assamchudi, Chintamali-K, Bolangir Jhilli, Koraput-Kundra-Haladichudi as farmer's varieties; SBC17, SR 134-1, SR 76-1, C538-13-11-2-1-1-1-1 as Next Generation Rice lines; ARC 5843, 6097, 6173, 6225, 7050, 10061, 10519, 10606 as Assam Rice Collections and CRHR-DH-6, CRHR-DH-8, CRHR-DH-14 and CRHR-DH-21 as doubled haploid lines.

#### False Smut and Sheath rot

Altogether 432 accessions comprising 90 DSN and 342 NSN1 were grown for screening against false smut (*Ustilaginoidea virens*) and sheath rot (*Sarocladium oryzae*) pathogen under natural infection condition. Incidence of false smut was very negligible (LSI<1), thus none of the entries were considered as resistant. Location severity index for sheath rot disease was moderately high (5 to 5.2). Two entries from NSN1 and none of the DSN entries were found resistant.

### Genetic diversity and population structure of false smut pathogens of eastern and north-eastern India

Genetic diversity and population structure analysis of false smut pathogens was carried out using 50 SSR and 50 RAPD markers of which 17 SSR and 14 RAPD markers have shown polymorphic band. SSR markers produced average 2.6 allelic bands of which RM 318 have shown highest (6) number of alleles. Phylogenetic tree (Fig.3.2) based on the markers generated data showed that all the isolates were divided into three clades with a similarity coefficient of 0.706. Cluster-I was the smallest cluster with two isolates. Cluster-II consists of two-sub-clusters having a total of 31 isolates. Cluster-III again has two sub-clusters and consists of 30 isolates. PCoA analysis could not explain the location specific grouping of the *U. virens* isolates. Mantel test was also used to find the relationship between the genetic and geographic distances. The analysis showed increase in geographic distance also increased the genetic distance among the isolates. Further, the linear regression equation was found to be  $y = 0.5803x + 29.174$  ( $R^2 = 0.0912$ )

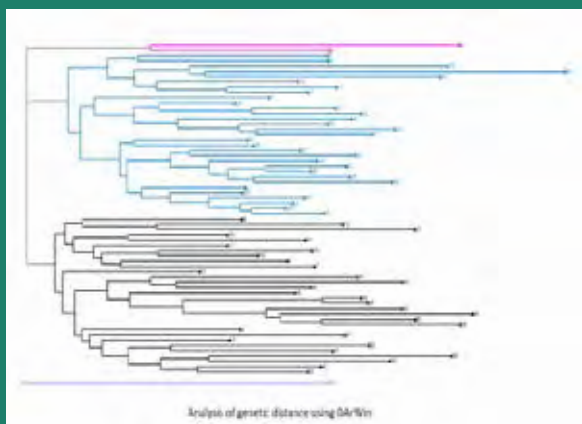


Fig. 3.2. Phylogenetic analysis of *Ustilaginoidea virens* isolates. Cluster I (pink), Cluster II (blue) and Cluster III (black)

### Evaluation of aromatic rice genotypes for bakanae disease resistance, their population structure and genetic diversity analysis

A total of 108 aromatic rice genotypes were screened for bakanae disease resistance. Among them, AC 44208 was found as highly resistant (HR) and AC 44216, AC 44206, AC 44132, AC 44171 and AC 44179 were found as resistant.

Genetic diversity and population structure analysis was carried out using 12 microsatellite (SSR) markers.

The PIC value of markers RM-10153 showed lowest value, whereas for RM-3698 it was highest which represented the informativeness for genetic diversity analysis. All the markers were highly informative ( $pic > 0.5$ , informative markers). The genetic relationships among the aromatic genotypes were determined through AMOVA analysis. The results of this analysis demonstrated maximum percentage of variation present among individuals within groups (95%) while minimum variance existed among populations (5%). The  $F_{IS}$  and  $F_{IT}$  value for four markers loci were observed to be 1.0 and  $F_{ST}$  was found to be 0.033 at  $P > 0.001$ .

### Evaluation for resistance against rice root knot nematode, *Meloidogyne graminicola*

Among the 115 NRRI released varieties screened against rice root knot nematode, twenty varieties were reported to exhibit high susceptibility (gall index - 5) and 27 varieties registered moderately resistant reaction (gall index - 3). Examination of the moderately resistant varieties revealed lesser number of nematode penetration and female development in it with longer period of life cycle compared to susceptible varieties.

### Development of nematodes in moderately resistant and susceptible varieties

Developmental biology of *M. graminicola* in the moderately resistant cv. Abhishek and the susceptible cv. CR Dhan 201 were studied. In both the varieties, nematodes entered into the roots on third day after inoculation. Development of females and deposition of egg mass got delayed by three to five days in resistant variety. This resulted in extended life cycle of nematodes in resistant variety over susceptible variety by five days.

### Bio-ecology of rice insect pests and diseases for climate smart protection strategies

#### Abundance and density of spiders in rice ecosystem

Although rice is infested by a multitude of insect pests, the most destructive of them are the stem borers, brown plant hopper, leaf folder, gundhi bug, green leafhopper. The effective prey searching ability and polyphagy of spiders make them important predators of crop pests. Spider samples were collected from rice fields both in tillering and panicle initiation stages of crop during *Kharif* 2019 from three different pest management regimes *viz.*, ecological engineering-

based pest management fields, integrated pest management fields and farmers practice (mostly pesticidal management) fields of semi-deep and shallow lowland rice ecosystems. Through visual searching methods, 1382 spiders different from quadrats (1m x 1m) were collected from rice fields. Among the collected individuals, eight families of spiders were recorded *viz.*, Tetragnathidae, Clubionidae, Oxyopidae, Araneidae, Theridae, Salticidae, Lycosidae and Thomisidae (Fig. 3.3 & 3.4).

### Racial distribution and genetic variability of *Xanthomonas oryzae* pv *oryzae* causing bacterial blight in rice

Around 85 bacterial blight (BB) infected leaf samples were collected across several districts of Odisha and few Eastern India states *viz.*, West Bengal, Bihar, Assam, Tripura. The pathogen was isolated aseptically and different isolates were confirmed for pathogenicity and maintained in live condition using a susceptible cultivar Taichung Native1 (TN1). Out of all, only 52 *Xoo* isolates were tested for virulence spectrum studies using NILs developed by IRRI along with resistant and susceptible check varieties. From the field studies, 10 pathotypes based on their disease pattern on the differential hosts could be categorised. Also, few virulent isolates were found to be defeating the two gene pyramids. Even, few were able to manifest relatively larger lesions on three gene pyramids.

The aforementioned isolates were also subjected to DNA fingerprinting for genetic diversity studies. Different PCR assays namely ISSRs (9,19,20,21,30,37,38), IS (JEL1 and JEL2) and REP (ERIC, REP) were conducted. Distinct haplotypes were observed with substantial amount of variations among the isolates. The concatenated cluster analysis of the 10 primers used revealed broadly two clusters.

Cluster I comprises of majority of the isolates while cluster II contains 16 isolates. A maximum genetic similarity of 97% was noticed between two isolates from West Bengal. Two isolates from Tripura showed a minimum similarity of 72.5%. Out of Odisha isolates, 75% belong to cluster I while the rest are present in cluster II. All the isolates collected from West Bengal shared same cluster. However, almost every state test isolate sampled for these studies were distributed in different clads as well as cluster. Hence, this throws light on the finding that there is hardly any positive correlation between genetic diversity and geographical isolation (Fig. 3.5).

### Development of Loop-Mediated Isothermal Amplification (LAMP) Assay to detect *Ustilagoidea virens* causing false smut disease of rice

Loop primers were designed for the pathogen *Ustilagoidea virens*, causing false smut disease of rice. These primers were screened for rapid and sensitive detection of the pathogen. In this case of LAMP assays, the specific primers in presence specific polymerase enzyme and other ingredients efficiently amplified target genes in 63°C for 60 min, followed by heating at 80°C for 10 min for termination. On addition of SYBR green, green colour is visualized if targeted genes are present and other than green colour indicate negative result. On validation, this LAMP assay can successfully and rapidly detect false smut infected paddy plant and help in taking management decision.

### Characterization of sheath rot pathogen

A total of 40 isolates were isolated from diseased rice sheath portion. All the isolates were different in their morphological characters and pathogenicity. Isolates were characterized at molecular level by using the universal fungal ITS1 and ITS4 primers. From the molecular characterization results, *Sarocladium*

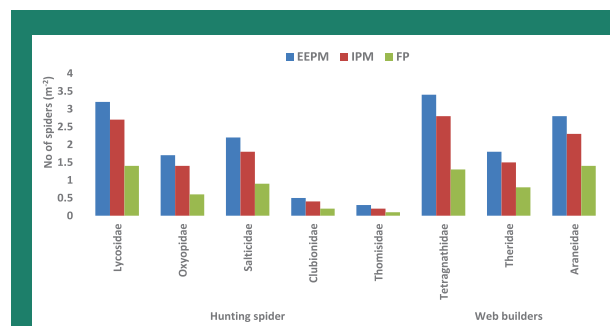


Fig. 3.3. Spider diversity in tillering stage of rice in semi-deep-water ecology under different pest management regimes

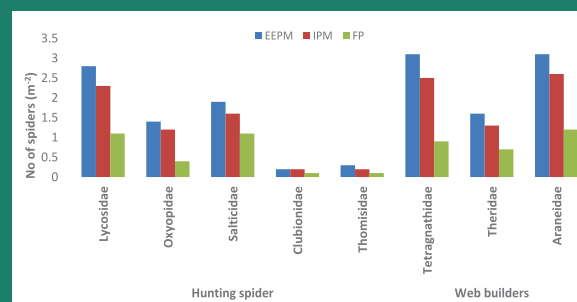


Fig. 3.4. Spider diversity in Panicle Initiation stage of rice in semi-deep rice ecology under different pest management regimes

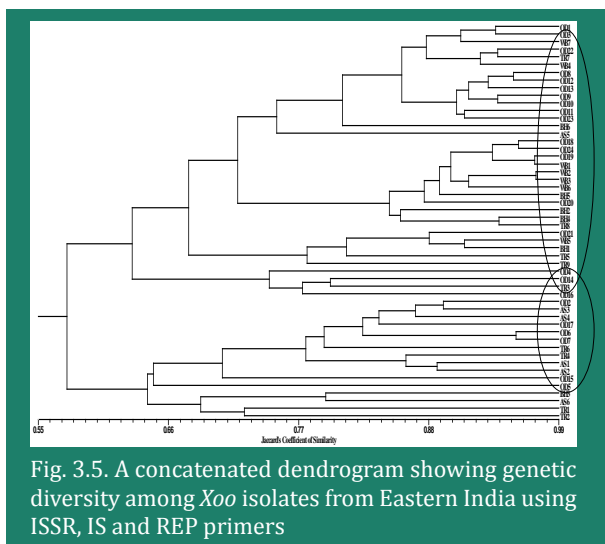


Fig. 3.5. A concatenated dendrogram showing genetic diversity among *Xoo* isolates from Eastern India using ISSR, IS and REP primers

*oryzae* and *Fusarium proliferatum* were found to be the major disease-causing agents for sheath rot disease of rice. Furthermore, the *Fusarium* isolates were confirmed using the *Fusarium*-specific primer pairs targeting translation elongation factor 1 (TEF1).

#### Genetic diversity and population structure analysis of *Fusarium* spp. associated with *bakanae* disease using microsatellite markers

A total of 84 *Fusarium* spp. isolates were obtained from different rice growing areas of Odisha and morphological characterization was made in our previous studies. The isolates were collected from both infected stem and seeds. Following the species-specific PCR-based assay, 84 isolates (60% of the total *Fusarium* spp.) were identified as *F. fujikuroi*. The 19 selected SSRs were used for genotyping analysis of the *Fusarium* spp. collection. The number of detected alleles for each marker across all *Fusarium* spp. strains ranged from 2 to 15 with an average over loci and populations of 3.6. Polymorphism information content (PIC) values varied from 0.19 (SSR8) to 0.83 (TUZ7), with an average of 0.5 across the whole collection, while the minor allele frequency (MAF) ranged from 0.006 (TUZ7) to 0.34 (SSR26) with 0.08 as average. Analysis of molecular variance (AMOVA) showed that 98% of genetic variability occurred within *Fusarium* populations (Fig. 3.6).

#### Bio-intensive approaches for insect pest management in rice

##### Screening of bioagents against bakanae disease

Out of six bioagents [*T. harzianum* (three strains) and *Bacillus* spp. (three strains)], screened against

*Fusarium fujikuroi* *T. harzianum* Th-3 treatment gave highest vigour index. Among all the treatments, *T. harzianum*T-3, *T. harzianum* Th-2 and *Bacillus amyloliquefacience* (20%) showed least bakanae disease incidence and high reduction in incidence (67.8%). During the greenhouse trial, seed germination was found significantly high when cultivar Pooja treated with bio agent. Among all the bio agents low bakanae incidence was recorded with *Bacillus amyloliquefacience* (30%) followed by *T. harzianum* Th-3 (45%).

##### Effect of *Trichoderma* on plant health

##### Estimation of chlorophyll content and expression of stress related enzymes in root and shoot

Significant variation was observed in chlorophyll a, chlorophyll b, total chlorophyll and chlorophyll a/b ratio among the treatments. Total chlorophyll content was ranged from 4.73 -17.18 mg/g. *T. erinaceum* (CRRIT-2) treated plants of variety Naveen exhibited highest total chlorophyll content. Physiological parameters like chlorophyll content and Chla/Chlb were much higher in the treatment of indigenous *Trichoderma* spp. as compared to market formulation. Similar type of result was also found for the expression of stress related enzyme (Fig. 3.7 & 3.8).

##### Use of above ground *Trichoderma* isolate as a plant-growth promoting fungi in rice variety CR-103 in Farmer's Field

*Trichoderma* treatment in the hybrid rice seed enhanced the plant growth and yield parameters. Not only root and shoot length, and fresh and dry weight have significantly improved but also the number of effective tiller/plant varied statistically. Generally, *Trichoderma* treatment performed better than non treated one. The growth promotion of direct seeded rice variety CR-103 under field condition using *Trichoderma* spp. isolated from above ground sources is shown in Fig. 3.9.

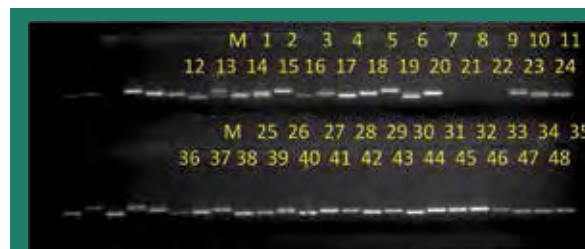


Fig. 3.6. Amplification pattern of microsatellite primer TUZ-7, M: Molecular weight marker (50 bp DNA ladder plus) (Isolates1-48)

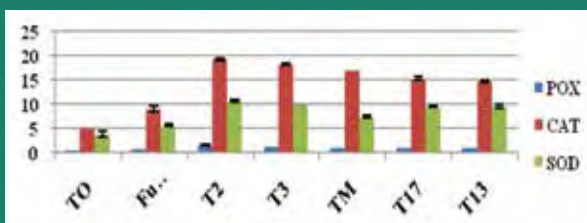


Fig. 3.7. Expression of stress related enzymes in the roots of rice variety Naveen



Fig. 3.8. Expression of stress related enzymes in the shoots of rice variety Naveen

### Interaction of Host-pathogen and Biocontrol agents

The combined application of seed treatment+seedling dip+foliar spray of BS5 liquid formulation significantly reduced the intensity of brown spot disease under glasshouse and field conditions. Furthermore, a 2D-PAGE analysis revealed a total of nine proteins with differential expressions using MALDI-TOF Mass spectrometry (MS). The Mascot algorithm demonstrated homology among proteins such as ribulose 1, 5 bisphosphate carboxylase, 2-cys-peroxiredoxin, ATP synthase, trehalose-phosphate phosphatase, serine/threonine protein kinase and 50s ribosomal protein. The functions of the proteins were mainly related to plant metabolism, defense response and disease resistance.

### Evaluation of identified bacterial cultures against yellow stem borer of rice

Evaluated nine bacterial cultures (BPY, BPW, SCF, BT-171, BT-172, BT-55, BT-5, BT-165, BiYSB) against third instar larvae of yellow stem borer in terms of mortality and larval weight gain. Observed mortality in the range of 40 - 66.7% compared to untreated control (13.3%) and highest mortality (66.7%) was obtained in the SCF culture followed by BPW, BT-171, BT-55 and BiYSB (60.0%). Regarding larval weight gain (LWG), highest LWG was observed in untreated control (0.107 g) and in treatments it was ranged between 0.002-0.047g.

### Biocontrol efficacy of *Arthrobotrys* spp. against rice root knot nematode

The efficacy of nematophagous fungi, *Arthrobotrys* spp. obtained from the Division of Plant Pathology, Banaras Hindu University, Varanasi, India was evaluated against the infective juveniles of rice root knot nematode, *Meloidogyne graminicola*, *in vitro*. Observation on the nematode mortality after 24 h revealed efficacy of the fungus in killing the

nematodes. Formation of trapping structure of the fungus on the nematode juveniles and the sporulation of the fungi inside the nematode body were the primary reason for the immobilization and death of the nematodes (Fig. 3.10).

### GC-MS identification of grain volatiles eliciting behaviour in *Sitotroga cerealella*

Grain volatile from susceptible variety for *Sitotroga cerealella* has been trapped on adsorbent following Poropak Q in customized air entrainment. GC-MS analysis of volatile extract 'with grain' and 'without grain' was carried out. Probable major volatile compounds responsible for behaviour in *Sitotroga cerealella* were Hexanal; Cyclotrisiloxanehexamethyl; Propane, 1,1-diethoxy-2-methyl; Octane, 4-methyl; o-Xylene; 1-Butanol, 3-methyl-, acetate; 1,3,5,7-Cyclooctatetraene; Benzene, 1,3-dimethyl; Nonane; alpha-Pinene; Camphene; Bicyclo [3.1.1] heptane, 6,6-dimethyl-2-methylene-, (1S); o-Cymene; D-Limonene; Eucalyptol; Benzeneethanamine, beta-methyl; Benzeneethanamine, beta-methyl-; 1-Pentadecene; Hexasiloxane, tetradecamethyl-; Heptasiloxane, hexadecamethyl-; 1-Hexadecanol and 1,2-Benzenedicarboxylic acid, bis(2-methylpropyl) ester. Major compounds from this study could be synthesized and exploited in attracting the *Sitotroga cerealella* moth through traps in godowns.

### Optimization of chemical pesticide-use for management of rice pests in different eco-systems

#### Dissipation of Imidacloprid and Carbendazim when applied in combination from a biomixture

The biomixture was prepared by mixing paddy straw, soil and FYM (cow dung compost) in volumetric ratio of 50:25:25 and kept in a plastic tray. Treatments *viz.*, Imidacloprid, Carbendazim and combination of Imidacloprid and Carbendazim were applied at hundred times of the recommended dose. Faster

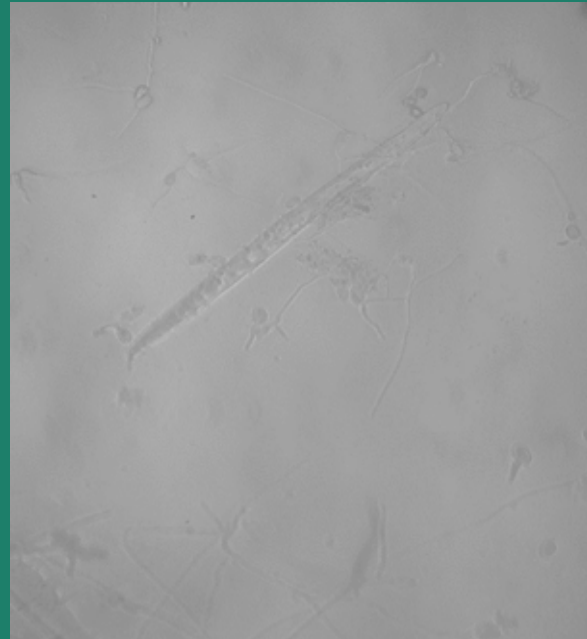

 Fig. 3.9. Control (a) & *Trichoderma* treated (b)


Fig. 3.10. Fungus infested nematode

degradation of Carbendazim was observed compared to Imidacloprid. 7.97 mg Imidacloprid sample recovered two hours after pesticide application. Similarly, 7.55 mg recovered from Imidacloprid+Carbendazim treated sample. On day-0, 181.83 mg of Carbendazim was extracted from Carbendazim only treated sample. Whereas, 180.44 mg Carbendazim was recovered from Imidacloprid+Carbendazim treated sample. On seventh day, 6.70 mg and 6.16 mg of Imidacloprid and Imidacloprid+ Carbendazim combined treated sample, respectively. Carbendazim degradation rate was higher in solely treated sample compared to combination. Sixty days after pesticide application, Carbendazim residue could not be recovered from both the treatments. Fortification of pesticides greatly reduced microbial population in biobed system. Despite the negative effects on microbes, the bio-mixture worked very well against both the pesticides by providing an ample environment for microbes. This bio-mixture may be recommended to prevent point pollution.

#### Effect of long term application of pesticides on yield of rice

In long term pesticide trial (*Rabi and Kharif 2019*), the grain yield of insecticide Cartap were 5.9 and 5.5 t ha<sup>-1</sup> followed by Chlorpyrifos were 5.6 and 5.2 t ha<sup>-1</sup> and Carbendazim 4.8 and 3.9 t ha<sup>-1</sup>, Pretilachlor 4.6 and 3.7 t ha<sup>-1</sup>, whereas in control 4.0 and 3.4 t ha<sup>-1</sup>, respectively.

#### Efficacy of Seed treatment formulation of Chlorantraniliprole for the management of stem borer and leaf folder

Chlorantraniliprole 625 g L<sup>-1</sup> FS (Lumivia), a seed treatment formulation, provided excellent control of stem borer and leaf folder. Amongst all the concentrations Chlorantraniliprole 625 g L<sup>-1</sup> FS, @ 75 g a.i. ha<sup>-1</sup> recorded best result in terms of dead heart reduction and registered highest yield. All the dosage of Chlorantraniliprole 625 g L<sup>-1</sup> FS (Lumivia) recorded *at par* result with the market standard (Cartap Hydrochloride) and the untreated check in terms of natural enemy count (dragonfly, spider and damselfly) and did not record any phytotoxicity symptoms and 100% germination was recorded at 7, 14 and 21 DAS. Thus, Chlorantraniliprole 625 g L<sup>-1</sup> FS (Lumivia) @ 75 g a.i. ha<sup>-1</sup> can be recommended for managing stem borer and leaf folder in paddy.

#### Combined effect of Chlorantraniliprole and potassium silicate seed treatment on rice and YSB infestation

The seed treatment effect of Chlorantraniliprole dissolved in water and Chlorantraniliprole dissolved in one per cent potassium silicate on rice germination, plant shoot and root length, shoot and root weight, productive tillers per cent and dead heart infestation caused by YSB was tested. It was found that in both

water and potassium silicate treated control the mean germination observed was 98.7% and in treatment ranged between 98.7-99.3% and 98.7-100.0%, respectively. Productive tillers per cent was 70 and 85% in water treated control and potassium silicate treated control, respectively and in respective treatments it was ranged between 83-87 and 92-97 per cent, respectively. With respect to dead heart infestation by YSB it was more in untreated control (83%) compared to treatments (6.7-25%) and in potassium silicate seed treatment also it was less compared to water control.

### Optimization of Chemical Pesticide use for management of rice pests in different ecosystems

#### Baseline susceptibility study of insecticides against *Nilaparvata lugens*

Brown Plant Hopper of rice used for bioassay in laboratory were collected from major rice growing areas of India covering six states viz., Karnataka, Andhra Pradesh, Odisha, Uttarakhand, Punjab, Chhattisgarh where high population of the insect prevailed.

##### A. Toxicity of imidacloprid to *N. lugens*

All the field populations of BPH have shown considerable variation in their susceptibility to imidacloprid. The  $LC_{50}$  values of imidacloprid to different populations collected from rice fields of Abohar, Sitarganj, Raipur, Bargarh, Sambalpur, Cuttack, Tadepalligudem and Gangavati were 8.259, 8.626, 8.902, 8.539, 9.030, 7.690, 10.086 and 11.747 ppm, respectively whereas the  $LC_{90}$  values were 40.025, 49.513, 39.733, 40.582, 46.602, 45.969, 48.018 and 61.266 ppm, respectively. The present study clearly indicated that imidacloprid had a higher  $LC_{50}$  values compared to other insecticides used in investigations.

##### B. Toxicity of dinetofuran to *N. lugens*

The  $LC_{50}$  values of dinetofuran to different populations collected from rice fields of Abohar, Sitarganj, Raipur, Bargarh, Sambalpur, Cuttack, Tadepalligudem and Gangavati were 0.246, 0.24, 0.231, 0.203, 0.225, 0.221, 0.310 and 0.272 ppm, respectively whereas the  $LC_{90}$  values were 1.665, 2.425, 2.641, 2.153, 1.713, 1.939, 3.216 and 2.601 ppm, respectively. Though the dinetofuran is a relatively new neonicotinoid compound and it is not commonly used by the farmers of the BPH population collection sites, the observed

$LC_{50}$  values to this could be attributed to the cross resistance from imidacloprid which is extensively used in these areas.

##### C. Toxicity of triflumezopyrim to *N. lugens*

The baseline susceptibility data on the topical  $LC_{50}$  values of triflumezopyrim to different geographic populations of Brown Plant Hopper, *Nilaparvatalugens* are presented below. The  $LC_{50}$  of triflumezopyrim (DPX- RAB55) for the BPH population ranged from 0.134 to 0.224 ppm. The  $LC_{50}$  values of triflumezopyrim (DPX- RAB55) to different brown plant hopper population viz., Abohar, Sitarganj, Raipur, Bargarh, Sambalpur, Cuttack, Tadepalligudem and Gangavati population were 0.139, 0.172, 0.208, 0.224, 0.134, 0.210, 0.197 and 0.204 ppm. The  $LC_{90}$  values were 1.072, 1.232, 1.256, 1.356, 1.04, 1.3, 1.507 and 1.936 ppm, respectively. The Sambalpur population was highly susceptible as indicated from the lowest  $LC_{50}$  (0.134 ppm). However, there was very narrow variation noticed among populations with Bargarh population registered highest  $LC_{50}$  value (0.224 ppm) followed by Cuttack (0.21 ppm).

#### Evaluating the efficacy of new combination fungicides against sheath blight disease in rice, caused by *Rhizoctonia solani* Kuhn under field condition

Among eight treatments, azoxystrobin 11%+ tebuconazole 18.3% w/w SC @1.5 ml l<sup>-1</sup> have shown best performance with 77.6% reduction in disease severity and 68.1% increase in grain yield over control; followed by azoxystrobin 18.2% w/w + difenocoazole 11.4 % w/w SC @ 1.0 ml l<sup>-1</sup> which reduced 76.2% disease severity and 56% increase in grain yield over control.

#### Isolation of YSB larval associated bacterial microbiota

Larva associated bacterial microbiota of YSB from four different locations was carried out and found bacteria belonging to phylum Firmicutes (53%) is major followed by Proteobacteria (40%) and then Actinobacteria (7%). The identified bacterial isolates encompassed seven families, Bacillaceae, Burkholderiaceae, Enterobacteriaceae, Microbacteriaceae, Moraxellaceae, Sphingomonadaceae and Xanthomonadaceae comprising nine genera viz., *Bacillus*, *Stenotrophomonas*, *Acinetobacter*, *Pantoea*, *Burkholderia*, *Sphingomonas*, *Enterobacter*, *Klebsiella* and *Microbacterium*. Among nine genera identified,

*Bacillus* (53%) was the predominant genus being found associated with yellow stem borer larva and also noticed to be present in all the locations used in the study. In addition, phylogenetic analysis of bacterial genotypes identified with 16S rDNA conveyed grouping of bacterial isolates in to two clads where isolates identified grouped in one distinct clade and isolates of previous report clustered in another clade.

#### **Frequency distribution of sensitivity of *U. virens* isolates from eastern and north-eastern India to Tebuconazole**

Sensitivity test of 63 isolates from eastern and north-eastern India at five different concentrations based on the LD<sub>50</sub> value (0.034) of native isolate, viz., 0.02, 0.03, 0.034, 0.04, 0.05 and control revealed that 90.5% isolates are sensitive in the ranges 0.019 to 0.035 µg ml<sup>-1</sup> of Tebuconazole standard of which 34.9% sensitive in 0.021-0.025 followed by 30.2% in 0.019-0.02.

#### **Evaluation of new molecules against false smut pathogen**

Eight new fungicides were tested against false smut pathogen under field condition during *Kharif 2019* following standard evaluation method. Fungicides Prochloraz 45% EC (2 ml l<sup>-1</sup>) followed by Azoxystrobin 18.2 % w/w + difenoconazole 11.4% W/W SC (1 ml l<sup>-1</sup>) was found best based on per cent panicle and per cent spikelet infection for controlling false smut disease.

In another experiment of field evaluation, eight new combination fungicides were tested against false smut pathogen under field condition during *Kharif 2019* for the second season following standard evaluation method. Fungicides Fluxapyroxad 62.5% + Epoxyconazole 62.5% (1.5 ml l<sup>-1</sup>) followed by Trifloxystrobin 25% + Tebuconazole 50% (0.4 g l<sup>-1</sup>) was found best based on per cent panicle and per cent spikelet infection for controlling false smut disease. Fluxapyroxad 62.5% + Epoxyconazole 62.5% (1.5 ml l<sup>-1</sup>) were found best during last year *Kharif 2018* also.

The Division has undertaken research activities on different aspects of rice pest management through its in-house projects. Division identified new resistant donors against pests, underlying the mechanism behind their resistance, population dynamics of pests, novel bio-agents and products to manage the pests and progressed in pesticide efficacy, resistance, residue and decontamination study. The contribution is reflected through the quality publications and human resource development through training. The division will adopt 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.





## PROGRAMME-4

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# Biochemistry and Plant Physiology of Rice for Grain Quality, Abiotic Stress Tolerance and Improving Photosynthetic Efficiency

Crop Physiology and Biochemistry Division of the Institute is presently working on development of food formulations containing rice having low glycemic index values, understanding the process of nitrogen uptake, assimilation and partitioning for high and low protein rice, the mechanism of rice ageing, biochemical changes during storage, evaluation of milling, cooking and eating quality, identifying donors and understand physiological and molecular mechanism of abiotic stress tolerance, improving productivity through enhancement of photosynthetic efficiency. The division with its cadre strength of nine scientists and five technical staff operates three institute research projects and four externally aided projects. During the year 2019, rice grain quality in relation to GI, mineral bioavailability and protein content, texture profile analysis of boiled rice, nitrogen assimilation pattern at different growth stages of plant, biochemical changes and the mechanism of grain aging during long term storage in colored, non-colored and scented rice varieties were studied. For abiotic stress tolerance four black rice germplasm lines as vegetative stage drought tolerant, two varieties having better partitioning efficiency under high temperature stress, three unique germplasm lines having submergence tolerance ability up to three weeks were identified. Also photosynthetic efficiency of rice variety enhanced by introduction of  $C_4$  pathway and minimizing photorespiration.

### Rice grain quality in relation to GI, mineral bioavailability and protein content

Exploitation of the reservoir of genetic variability present in the landraces/germplasms is an effective method for improving grain quality of rice. The fact that rice cannot be altogether removed from the diet necessitates development of food formulations containing rice that have low GI values. Understanding the process of nitrogen uptake, assimilation and partitioning is an effective way for knowing the mechanism behind high and low protein rice. Although the mechanism of rice ageing is not fully understood, biochemical changes during storage are important in the evaluation of milling, cooking and eating quality. Majority of the Indians prefer the rice variety with medium hardness, gumminess and chewiness as well as lower adhesiveness and springiness in case of boiled rice.

### Addition of pulses, cooking oils and vegetables lowers the glycemic index of rice

Effect of the pulses, cooking oils/fats and vegetables on the Glycemic index (GI) of rice was tested in three rice varieties having contrasting GI values. Among the eight pulses tested, addition of pigeon pea to rice lowered maximum GI. Putting *ghee* (clarified butter) to rice during cooking caused more GI lowering effect compared to other five vegetable oils. Addition of vegetables like fenugreek and cauliflower caused more reduction in GI compared to other eight tested vegetables. The findings emphasize the importance of identifying and developing rice with low GI, and the need to formulate combinations of rice with other foods that suit consumption by diabetics.

### Study of Nitrogen assimilation pattern at different growth stages of plant

Nitrate reductase (NR) and Nitrite reductase (NiR) was estimated at different plant growth stages in Naveen, ARC 10075 and CR Dhan 310. NR and NiR activity was found to be higher for ARC 10075 and CR Dhan 310 than that of Naveen which may be due to higher expression level of the genes involved. (Fig. 4.1 A and B).

### Sensory quality of some boiled red rice cultivars of India

Texture profile analysis of boiled red rice was done by Texture analyzer (TA.XT plus, Stable Micro Systems Ltd, Surrey, UK). The textural attributes of boiled rice (Table 4.1) showed that Kolabiroin had the highest hardness. Mami Hunger exhibited highest springiness, cohesiveness and chewiness while Mayurkantha showed highest adhesiveness. Thus, Balam and PB 170 were found to be better than other cultivars with respect to texture of boiled rice.

### Study of biochemical changes in rice grain during long term storage

The level of lipid peroxidation products like Malondialdehyde (MDA) and Free Fatty Acids (FFA) content were estimated in rice stored for long duration at every three months interval till 18 months. Fifteen rice varieties grouped in three categories (six colored, six non colored and three scented) were used for the estimation of MDA and FFA.

Level of MDA and FFA was increased till 12 months and nine months of aging, respectively in all three

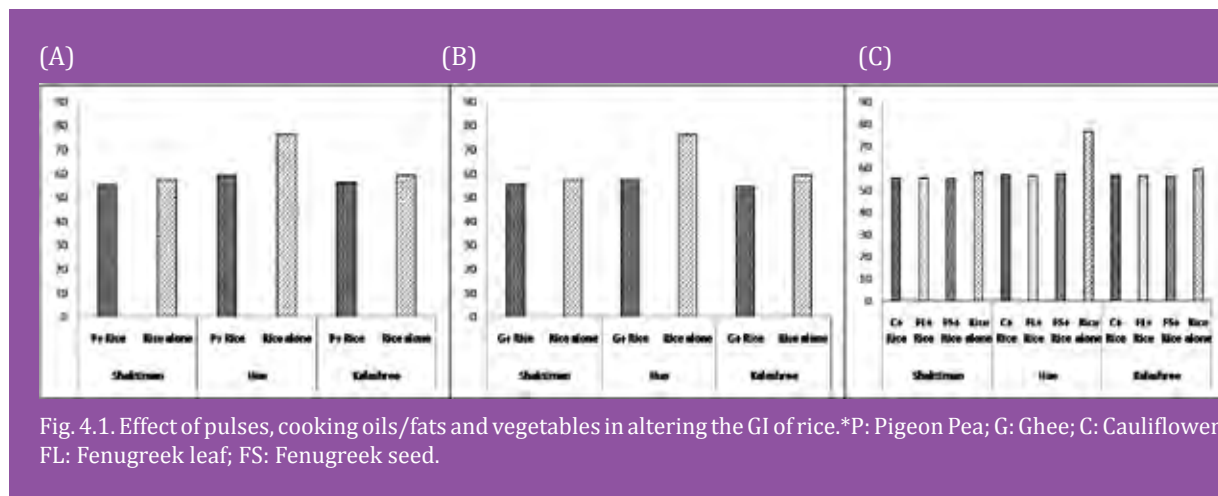


Fig. 4.1. Effect of pulses, cooking oils/fats and vegetables in altering the GI of rice.\*P: Pigeon Pea; G: Ghee; C: Cauliflower; FL: Fenugreek leaf; FS: Fenugreek seed.

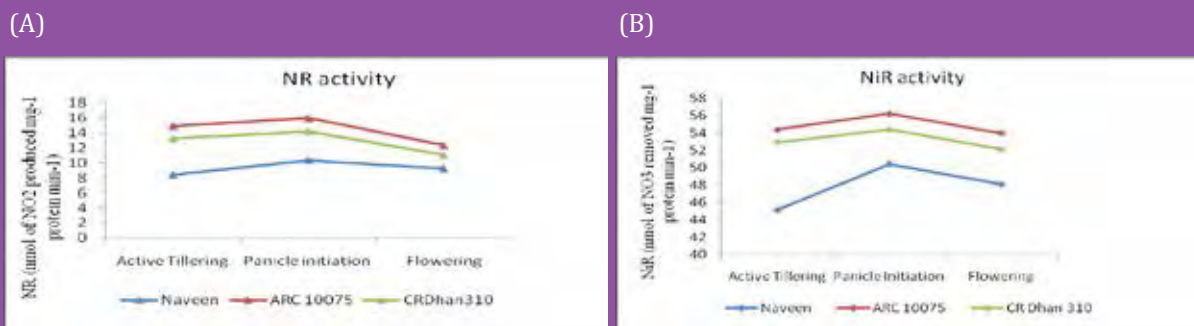


Fig. 4.2. Activity of NR and NiR at different stages in the three varieties.

groups and then the synthesis decreased or remained static in next three to six months till 18 months of storage. The generation of MDA was more prominent in non colored and scented rice varieties as compared to colored varieties to the tune of 32-38%. Similarly, 23-25% more generation of FFA was observed in non colored and scented rice varieties as compared to colored varieties during long term storage. These findings will help in understanding the biochemical changes and the mechanism of grain aging during long term storage in colored, non colored and scented varieties of rice.

#### Evaluation and identification of genotypes for vegetative stage drought tolerance:

Out of 498 germplasm accessions including black rice and doubled haploid genotypes screened for vegetative stage drought tolerance under field condition during dry season 2019, 103 lines were tolerant to vegetative stage drought. However, four black rice accessions viz., Baraun Godadhan, Kaniglass, Mumi Hunger and Petre observed to be consistently tolerant (SES score '1') to vegetative stage drought in two consecutive years (Fig 4.3).

#### Phenotyping of mapping population from BVD109 x IR 20 cross for Reproductive stage drought tolerance

Out of 186 mapping populations developed from BVD109 x IR 20 exposed to reproductive stage drought tolerance, 10 best lines (C822-44, C822-74, C822-63, C822-55, C822-96, C822-41, C822-99, C822-131, C822-94 and C822-70) recorded more than 0.5 grain yield under stress at 10-12% of soil moisture content. C822-44 (2.52 t ha<sup>-1</sup>) and C822-74 (1.32) had higher grain yield under stress with less than 60% of spikelet sterility and more than 70% of leaf relative water content, -2.6 to -2.74 Mpa of leaf water potential and 33-35.2°C of canopy temperature compared to other lines. However, the tolerant parent BVD 109 had lower yield reduction (64.8%), coolest canopy temperature (30.1°C), highest leaf water potential (-1.7 MPa), high RWC (78.7%) with low spikelet sterility (70.4%) as compared to susceptible parent IR 20 with higher yield reduction of 98.2%, high canopy temp 40.5°C, low LWP -4.19MPa, lower RWC 58.9 and high spikelet sterility 92.12% (Table 4.2).

Table 4.1. Textural quality of boiled rice of some red rice cultivars of India

	Hard(N)	Adh(g.s)	Spring(mm)	Cohc	Gum (N)	Chew(N)
PB-140	8.28F	-25.00D	0.02F	0.09E	1.87F	0.18E
Mamihunger	10.37E	-20.71E	6.88A	1.08A	5.08E	7.95A
Mayur kantha	26.93C	-55.39A	2.36B	0.52C	13.61D	7.64A
Kartibiroin	47.96B	-31.25B	2.38B	0.79B	87.87B	7.94A
Amona bao	10.65E	-9.89G	0.17D	0.74B	91.06A	2.06C
Balam	26.59C	-27.86C	0.03F	0.58C	25.11C	2.09C
Kolabiroin	100.15A	-22.00E	0.56C	0.51C	90.43A	3.22B
PB170	30.81D	-11.02F	0.09E	0.43D	14.28D	1.36D
<b>Mean</b>	32.72	-25.39	1.56	0.59	41.16	4.06
<b>P value</b>	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001

\*Hard: Hardness; Adh: Adhesiveness; Spring: Springiness; Cohc: Cohesiveness; Gum: Gumminess; Chew: Chewiness.

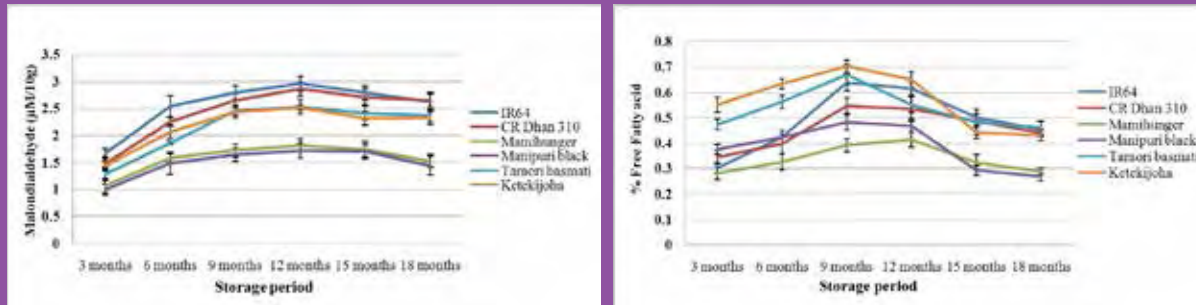


Fig. 4.4. Level of MDA (a) and FFA (b) in two representative varieties of each category for 3, 6, 9, 12, 15 and 18 months aged rice grains.

### Non-structural carbohydrates translocation under high temperature stress

Non-structural carbohydrate (total sugar and starch) content was estimated in seven rice varieties grown under elevated temperature conditions from flowering till maturity in source and sink tissues in four different planting times. Translocation ability decreased as temperatures increased in all the varieties, but N-22 (~60%) and Annapurna (~50%) had better partitioning efficiency between control and extreme heat conditions (Fig. 4.6).

### Understanding the mechanism of tolerance for combined stresses waterlogging and salinity

The mechanism of combined stress tolerance of flooding and salinity was studied in two rice cultivars viz., Varshadhan and Rashpanjor and it was observed that RBOH (ROS generator) and MT (ROS quencher) genes could play major role in aerenchyma formation in rice. Under control condition higher RBOH expression leads to higher ethylene production (>2.1-fold) and well-developed aerenchyma in Rashpanjor as compared to Varshadhan, which make this cultivar better prepared to withstand combined stress (Fig. 4.7).

### Identification of morpho-physiological factors for prolonged (~ 3 weeks) submergence tolerance in rice

Through multiple season evaluation, three unique rice germplasm viz., AC42088, AC42087 and AC1303, are identified having superior submergence tolerance ability of up to 3 weeks. After 21 days of stress high survival rate of 70%, 62% and 52% was observed in AC42088, AC42087 and AC1303, respectively, while FR13A had only 35% survival rate, which might be due to the presence of thicker leaf gas film (LGF) and leaf hydrophobicity (>125°) as compared to FR13A or Swarna *sub-1*.

### Improvement of Photosynthetic Efficiency of Rice

To maintain our present per capita consumption, we will need 44 per cent more rice within 50 years. The area for rice cultivation is continually being reduced by expansion of cities and industries, so we will need rice plants to deliver may be 50 or 55 per cent more to cater the growing population. The average land



Fig. 4.5. Distribution of different group of rice genotypes for drought tolerance

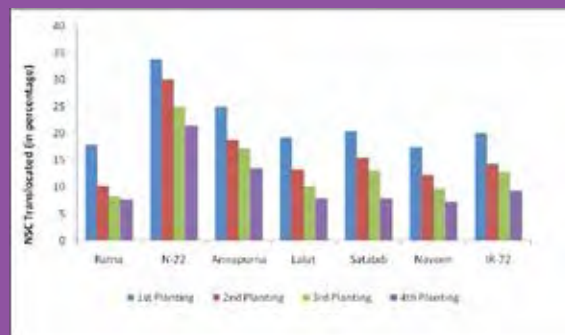


Fig. 4.6. Percentage of NSC translocated in varieties exposed to four different temperature regimes

**Table 4.2. List of best performing lines in terms of grain yield under reproductive stage drought and their respective physiological traits**

Sl No	Genotypes	Grain Yield (t ha <sup>-1</sup> )		% of Yield reduction	Sterility (%) under stress	RWC (%)	LWP (-Mpa)	Canopy Temp.(°C)
		Non-stress	Stress			Stress	Stress	Stress
1	C822-44	3.22	2.52	21.57	54.44	79.57	-2.6	35.2
2	C822-74	3.15	1.32	58.09	56.19	79.70	-2.74	33.5
3	C822-63	2.30	0.77	65.42	57.43	74.13	-2.95	36.5
4	C822-55	1.35	0.64	47.37	64.25	77.97	-3.92	33.5
5	C822-96	2.96	0.60	79.60	68.10	79.61	-2.71	33.6
6	C822-41	2.06	0.55	72.99	69.95	79.83	-3.16	32.4
7	C822-99	3.60	0.52	85.39	59.29	73.98	-3.67	33.3
8	C822-131	1.94	0.52	73.11	72.10	71.45	-1.83	35.8
9	C822-94	1.70	0.52	68.27	75.68	72.31	-3.85	32.4
10	C822-70	1.46	0.52	64.25	70.78	79.94	-1.95	35.6
11	BVD109 (Tol. parent)	3.12	1.10	64.77	70.38	78.70	-1.7	30.1
12	IR 20 (Sus. parent)	3.5155	0.062	98.23638	92.12254	58.89	-4.19	40.5

holding of an Indian farmer is down to 1.1 hectare, and is shrinking further. So, the only way to enhance agricultural production is through vertical expansion or in other words, enhancing productivity from the same area of land. The only way is to increase the unit

area production by increasing the photosynthesis. Improving yields against a background of climate change and increasing competition for resources such as land and water. In this project by using all the tools available to modern biotechnology, attempts were made to create a new rice plant towards C<sub>4</sub> ness that addresses many of these problems.

**Cloning and transformation of *Setaria italica* PPDK (*SiPPDK*) enzyme in rice**

**Molecular and Physiological Characterization of the transgenics**

Southern blot analysis of positive transgenic plants with *hpt* gene probe showed the introduction of *SiPPDK* gene with WT-wild type control plant, 3, 5, 8,

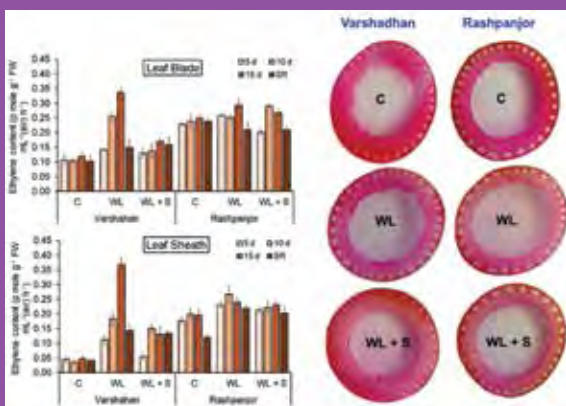


Fig. 4.7. The periodic build-up of ethylene content in leaf blade and leaf sheath and their consequences in aerenchyma formation under control (C), waterlogging (WL) and combined stress of salinity and waterlogging (WL + S).



Fig. 4.8. Confirmation of cloned SiPPDK gene construct in pCambia binary vector

9, 26 and 27- different transgenic plants. Relative gene expression of *SiPPDK* gene (PPDK3, PPDK5, PPDK8, PPDK26 and PPDK27) and control lines showed higher expression pattern in transgenics than control plants. The relative *SiPPDK* enzyme activity ranged recorded a significant increase in enzyme activity in transgenics than control and vector control plants.

Higher photosynthetic rate was observed in transgenic plants compared to control plants. The Plant no-26 carrying *Setaria italica* PPDK gene showed highest photosynthetic rate at flowering stage.

**Development of gene constructs encoding glycolate dehydrogenase (*glc*) tagged with RuBisCO smaller subunit transit peptide for chloroplastic transformation to minimize the photorespiratory activity**

Introduction of bacterial glycolate catabolic pathway into rice is one of the possible ways to minimize the loss of fixed carbon through bypassing photorespiration in the chloroplast. For this strategy, glycolate catabolic enzyme encoded genes (*glycolate dehydrogenase*) from *E. coli* were cloned into pGEMT-Easy vector, confirmed through restriction digestion and sequencing. To design plant transformation vector, gene fragments were restricted with *Bam*HI+*Xba*I and ligated into pCAMBIA binary vector. *A. tumefaciens* was transformed with engineered binary vector and positive clones screened through colony PCR.

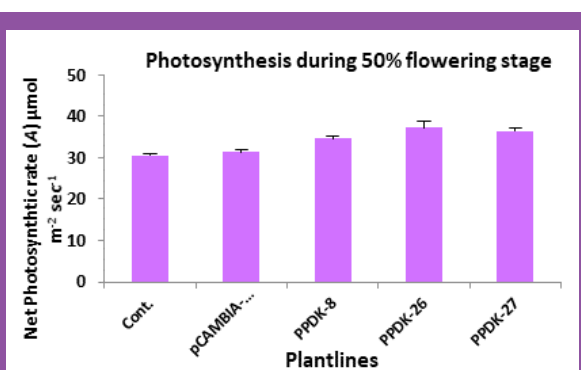


Fig. 4.10. Net photosynthetic rate (A) measured in *SiPPDK* transgenic and control plants at 50% flowering stage



Fig. 4.11. Gene constructs encoding glycolate dehydrogenase (*glc*) tagged with RuBisCO smaller subunit transit peptide for chloroplastic transformation.

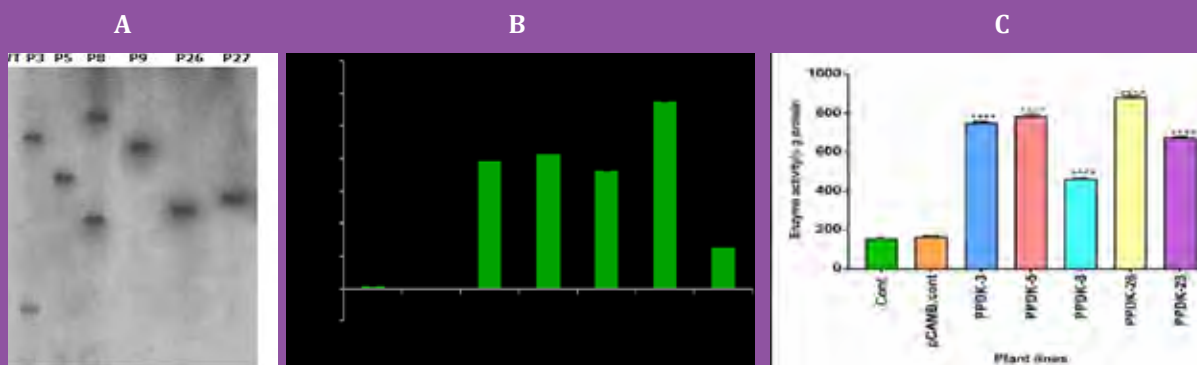
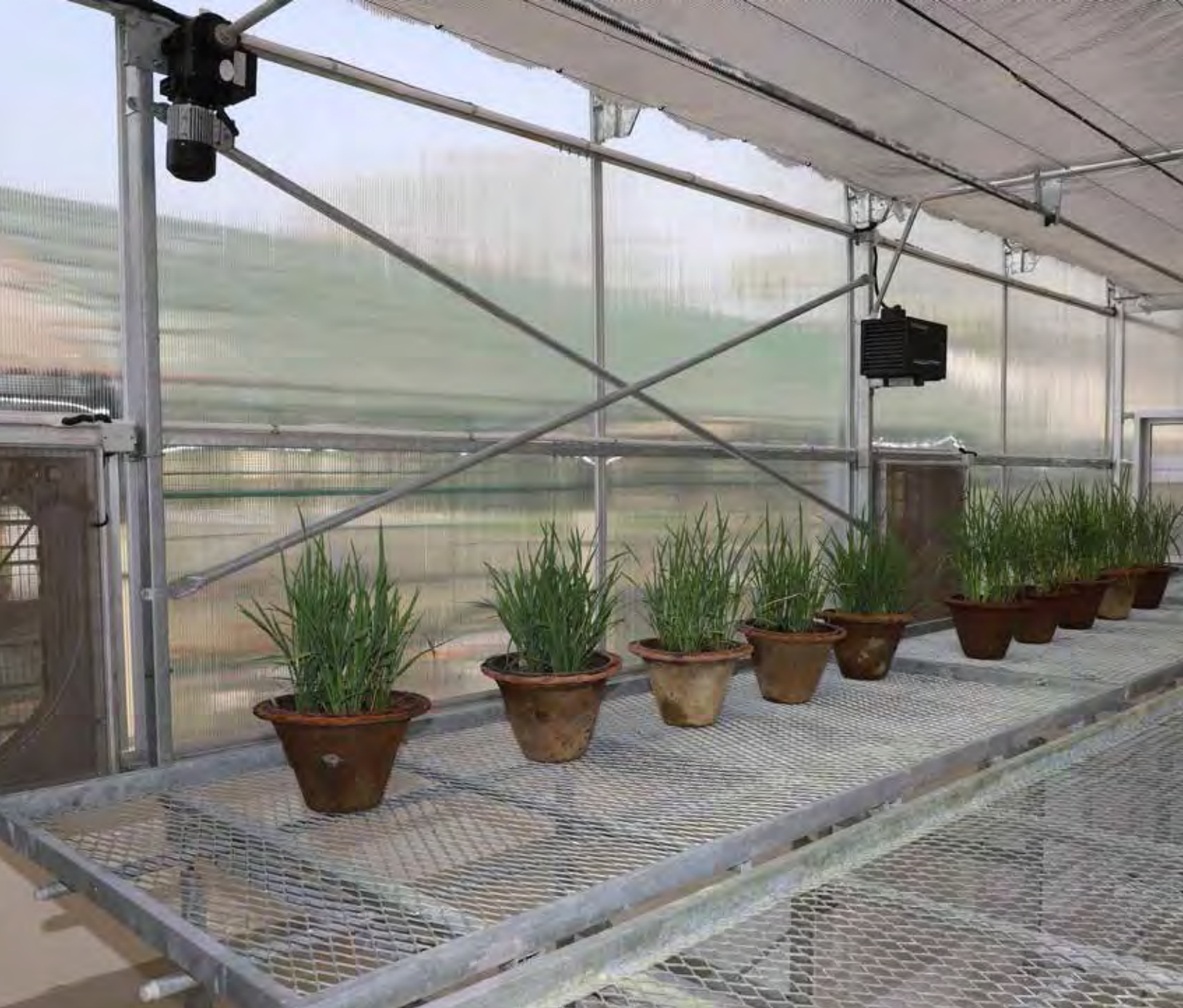


Fig. 4.9. Southern Blot (A), gene expression (B) and Enzyme activity of *SiPPDK* (C)



Different activities undertaken through Crop Physiology and Biochemistry programme could identify dietary combination with rice for diabetics, enzymatic changes in aging process during long term storage, texture profile analysis of boiled rice for eating preferences, nitrogen assimilation pattern in high protein rice varieties. Also identified new sources for different abiotic stress tolerance, mechanism of tolerance for individual and combined stresses. Enhanced photosynthetic efficiency by introduction of  $C_4$  pathway genes and minimizing photorespiration, which provides advanced technological know-how for improving rice productivity.





## PROGRAMME-5

# Socio-Economic Research to Aid Rice Stakeholders in Enhancing Farm Income

Social Science Division of the Institute aims at development and testing of new extension models, approaches and strategies for technology transfer and conducts socioeconomic research in the rice sector. It also undertakes outreach activities for rapid dissemination of recent technologies to the end users and provides feedback to the technologists. The division with its cadre strength of six scientists and 12 technical staff operates two institute research projects and six externally aided projects. During the year 2019, twenty one newly released rice varieties have been demonstrated through 798 field demonstrations in 26 districts of eight states. Also, about 423 participants have been trained on different aspects of rice technologies through 18 training programs. Apart from technology transfer and capacity building, attempt has been made to utilize the available database on rice to provide new insights for decision making. The subsequent section discusses the salient achievements of the programme during the year 2019.

## Developing Extension Approaches to enhance Rice Farmers' Income

### Developing extension approach for faster spread of rice varieties in different states (INSPIRE-1.0 Model)

Innovative extension model for fast SPread of varieties In Rice Ecosystems (INSPIRE 1.0 Model)) was developed and tested since last three years to narrow down the gap between development of rice varieties and their faster spread and adoption. Under this model during *Kharif* 2019, on-farm demonstrations were conducted in farmers' fields with 21 recently released NRRI varieties benefiting over 800 farmers and covering about 190 hectare area in 26 districts of eight states namely Odisha (six districts), West Bengal (three districts), Bihar (four districts), Jharkhand (four districts), Assam (two districts), Madhya Pradesh (two districts), Chhattisgarh (three districts) and Maharashtra (two districts) through close convergence with respective Krishi Vigyan Kendras (KVKs) and state agriculture departments apart from participating farmers. Paddy seed minikits of 5-10 kg each were provided as critical input to all participating farmers followed by subsequent field monitoring and technological backstopping. Just before harvesting of the crops, Crop Cutting Experiments (CCEs) followed by Field Days were organized in all the states. Most of the newly released NRRI varieties outperformed the existing popular check by giving an average grain yield advantage of 10-30 % as evident from the results of CCEs. Highest grain yield of 10.53 t ha<sup>-1</sup> was recorded in case of CR Dhan 307 (Maudamani) against local hybrid check PHB 71 with 5.9 t ha<sup>-1</sup> from farmers' field in Ranchi, Jharkhand.

### Testing and validating the 'Self-sufficient Sustainable Seed System for Rice' (4S4R) model of NRRI

The strengthened and institutionalized local paddy seed system, popularly named as Self-sufficient Sustainable Seed System for Rice (4S4R) Model has been piloted and validated in five blocks (Mahanga, Athagarh, Niali, Badamba and Banki) of Cuttack district through five Farmer Producer Companies (FPCs). During *Kharif* 2018, 922.47 quintals of foundation and certified seeds of four popular rice varieties, viz., Pooja, Sarala, Gayatri and Swarna-Sub1 were produced in 89.7 acres by 77 seed growers. The total cost of production of one kg of quality seed being Rs. 30.00 was sold at Rs. 45.00 per kg with a B:C ratio of 1.5. Under these five FPCs, 190 Farmers Interest Groups (FIGs) have been formed with 3800 participating members. During *Kharif* 2019 also, quality seed of six popular rice varieties, viz., Pooja,



Crop Cutting Experiments in Farmers' Fields



Field Days and experience sharing by Participating Farmers

Maudamani, Sarala, Gayatri, Swarna and Swarna-Sub1 have been grown in 88.5 acres, which are being processed and packaged for sale before forthcoming *Kharif* season.

### Yield Gap Analysis and Impact Assessment to Aid Rice Research and Policies

The continuous development and release of modern rice varieties and their adoption in farmers' fields stood at crossroad. There exist yield gap between the modern and existing popular varieties and factors that advocate this yield gap. Under this project, the yield gaps in Assam, Bihar, Chhattisgarh, Jharkhand, Madhya Pradesh, Maharashtra, Odisha and West Bengal states for rice varieties were calculated. These findings are useful for policy makers as well as programme planners for taking corrective steps to bridge the existing yield gaps by enhancing rice productivity through future agricultural programmes and policies. The project utilized the available database on rice to provide new insights for decision making. The next section briefs the salient achievements of the project during the year 2019.

#### Estimation of yield gap between modern and existing popular rice varieties

Result of the yield gap estimation in eight states namely Assam, Bihar, Chhattisgarh, Jharkhand, Madhya Pradesh, Maharashtra, Odisha and West Bengal indicates yield advantage of -82 to 20 per cent for test varieties (Modern rice varieties released by NRRI) over existing popular varieties. For the purpose of computing the yield gap seed minikits of recently released rice varieties of NRRI were provided to the farmers which were cultivated under farmers' management practices. The gap in yield from the potential yields of respective varieties was ranged between 7-47 per cent. This results advocate for intensive technology targeting in the farmers' field to enhance total factor productivity of land.

#### New insights from database on rice

State wise area under rice cultivation indicates that, 14 states contribute more than 90 per cent towards the rice production while 21 states/UTs contribute only nine per cent of country's rice production (Table 5.1).

Further, the rice growing states have been classified into three categories (High yielding, medium yielding and low yielding states) based on the per hectare yield of paddy. It is interesting to note that the high yielding states (>4.5 t ha<sup>1</sup>) contributes 37 per cent to the total central pool of rice production while the



Fig 5.1 Glimpse of seed production activities under FPCs

**Table 5.1: Production shares of different states (2017-18)**

States	Cumulative area (mha)	Production (mt) and share (%)
<b>Major rice growing states (14):</b> UP, WB, Odisha, CG, Bihar, Punjab, Assam, AP, MP, Telangana, TN, Jharkhand, MH and Haryana	39.85	103.00 (91.35)
<b>Minor rice growing states (21):</b> Karnataka, Gujarat, Tripura, J&K, UK, Manipur, Nagaland, Rajasthan, Kerala, Arunachal Pradesh, Meghalaya, HP, Goa, Mizoram, Puducherry D&NH, Sikkim, Delhi, A&N Island, D&D and Chandigarh	3.92	9.75 (8.65)

**Table 5.2: Yield vis-a-vis Area and Production Share (2017-18)**

States	Yield (t ha <sup>-1</sup> )	Area (mha) and share (%)	Production (mt) and share (%)
<b>High yielding states (7) (&gt; 4.5 t ha<sup>-1</sup>):</b> Punjab, AP, TN, Telangana, Haryana, A & N Island and Karnataka	Max: 6.55 (Punjab) Min: 4.56 (Karnataka) <b>Average: 5.51</b>	11.43 (26.12)	42.00 (37.25)
<b>Medium yielding states (17) (3.0-4.5 t ha<sup>-1</sup>):</b> Tripura, WB, Delhi, Kerala, Meghalaya, Goa, Manipur, UK, Bihar, Puducherry, RAJ, JH, UP, Gujarat, D & NH, Assam and MP	Max: 4.45 (Tripura) Min: 3.04 (MP) <b>Average: 3.66</b>	22.63 (51.69)	55.25 (49.00)
<b>Low yielding states (11) (&lt;3.0 t ha<sup>-1</sup>):</b> MH, J&K, Sikkim, Arunachal Pradesh, Odisha, Mizoram, Nagaland, HP, CG, D & D and Chandigarh	Max: 2.82 (MH) Min: 1.97 (CG) <b>Average: 2.39</b>	9.70 (22.20)	15.50 (13.75)

medium yielding states (3-4.5 t ha<sup>-1</sup>) contribute 49 per cent and the low yielding states (<3 t ha<sup>-1</sup>) contribute 14 per cent to the central pool (Table 5.2). Yield in majority of the high yielding states indicates either the land is more fertile or the inputs are intensively utilized in these states.

#### Futuristic demand and supply of rice

Under the scenarios of 2.46 and 1.87 per cent growth in rice production over the years, the projected demand supply gap for the year 2020, 2030, 2040 and 2050 indicates that India would have surplus of rice to export after meeting its domestic rice requirement. This reinforces the contribution of scientific development in the agricultural sector to elevate the country's stature from being a food deficient state to a food surplus state (Table 5.3). However, these projections call for immediate investment in the storage and processing sector to manage the surplus grains without exposing it to wastage.

Considering the land diversion from farming activities and resource conservation, attempt was also made to compute the required yield enhancement to fulfill the increasing demand of rice. For this, it was considered to eliminate the region with low total factor productivity and compensating the production loss due to the decline in area by increment in the yields from the suitable regions for rice cultivation. Results indicate that if the rice area remains the same as in 2017-18, yield level need to be increased by about 1.5 t ha<sup>-1</sup> to meet the increase in demand during the year 2050. However, under the scenarios of five to 15 per cent decline in rice area, the yields need to be enhanced additionally by 1.59 to 2.25 t ha<sup>-1</sup> (Table 5.4). This result strongly advocates technology targeting in the suitable rice producing regions and crop diversification in the unsuitable regions for rice cultivation.

**Table 5.3: Projected demand-supply gap for rice for the year 2020, 2030, 2040 and 2050**

Year	Population (billion)	Projected demand (mt)			Projected supply (mt) at different growth rates (%)		Demand-supply gap (mt) at different growth rates (%)	
		Direct	Indirect	Total	@ 2.46%	@ 1.87%	@ 2.46%	@ 1.87%
2020	1.38	99.39	10.61	110.00	124.34	122.21	14.34	12.21
2030	1.51	125.39	11.90	137.29	174.74	147.08	37.45	9.79
2040	1.60	153.45	13.20	166.65	202.17	177.02	35.52	10.37
2050	1.65	182.90	14.49	197.40	257.78	213.05	60.38	15.65

**Table 5.4: Required incremental yield to attain future rice demand under different scenarios of area change**

Particular	Values		
Base year (2017-18) area (mha)	43.77		
Base year (2017-18) yield (t ha <sup>-1</sup> )	2.23		
Projected demand in 2050 (mt)	197.40		
FUTURE SCENARIOS	Changed area (mha)	Required yield (t ha <sup>-1</sup> )	Yield improvement required (t ha <sup>-1</sup> )
a) 0% decrease in area	43.77	3.75	1.5
b) 5 % decrease in area	41.58	3.82	1.59
c) 10 % decrease in area	39.39	4.12	1.89
d) 15 % decrease in area	37.20	4.48	2.25



The different activities undertaken through this programme is not only vital for making the rural villages self sufficient in seeds but also opens the localized employment avenues for the rural youth. Also, the technology dissemination in the form of newly released rice varieties help in bridging the yield gap between research station and farm level yield which are key in releasing the unsuitable areas under rice cultivation while maintaining the food security balance in the country. The results of scenarios on demand and supply of rice provide the direction for policy makers to make necessary changes in future agricultural policies to address the emerging concerns.







## PROGRAMME-6

# Development of Resilient Production Technologies for Rainfed Upland Rice Systems

Rice research in the country in general and upland rice in particular is increasingly guided by concerns for environmental protection and sustainability owing to the new challenges in the ecological and climatic fronts. NRRI Research Station of the institute at Hazaribag has strived to address these concerns through development of stress tolerant varieties, suitable crop production and protection systems which measures up to the demands of small farmers cultivating rice in marginal environments. The station has focused on direct seeded rice as part of an enterprise mix wherein the farmers are able to grow shorter duration, drought tolerant varieties with the onset of monsoon so that a second crop of pulses or oilseeds can be grown after early rice harvest to increase the cropping intensity resulting in generating more on-farm employment and farm income. The research station with its cadre strength of seven scientists and eight technical staff operates one institute research project and seven externally aided projects. During the year 2019, the station developed and promoted several new multiple stress tolerant lines. One among them, IET 26337 (CRR747-12-3-B) has been identified as promising for zone III (Jharkhand) and zone VII (TN) based on its performance in All India Coordinated Trials. Identification of new donors / novel alleles of major QTLs/ genes imparting drought tolerance and blast resistance were another research focus. One accession from NBPGR (SKY-67) was found to have high level of tolerance to both vegetative and reproductive stage drought. Two accessions, one from Meghalaya (Kba pnah) and other from Sikkim (Anadi, AC39741) showed presence of three blast R genes. Utilization of vesicular arbuscular mycorrhizae for enhanced phosphorus uptake showed that continuous five years of AMF inoculation (soil) supported maintaining desirable native AMF population for two subsequent years without application. IPM modules for upland rice have been fine tuned and validated; nativo (Trifloxystrobin + Tebuconazole) was found most effective fungicide for management of false smut. The station was also involved in popularizing recently released varieties like IR64*Drt1* and Sahbhagidhan which was taken up in large scale frontline demonstrations (FLDs) in three districts of Jharkhand. Breeder seed demands for indented varieties from different states were also met.

## Breeding resilient HYVs

### Characterization of germplasms and varieties

#### Drought tolerance

A set of upland rice germplasm (251) from NBPGR were evaluated for drought tolerance. Four reproductive stage drought tolerant entries identified were Lal Dhan, SKSS-09, IC 515116 and SKY-67. SKY-67 possesses high level of tolerance at both vegetative and reproductive stages.

With an objective of identifying suitable markers for discriminating varieties for yield under drought, another set of 60 rice germplasm were studied for genetic diversity at molecular level employing 35 randomly chosen SSR markers. Twenty-eight markers were polymorphic among the genotypes with a total of 89 alleles. The number of alleles per locus ranged from 2 to 4 with an average of 3.17 per locus. The PIC value ranged from 0.101 to 0.71 with an average of 0.504. The Nei's expected heterozygosity value was 0.522. Grain yield under drought stress (DTY) linked markers RM3825, RM431, RM11943, RM520 and RM28048 were found to be the most appropriate to discriminate among the rice genotypes owing to the highest PIC value of more than 0.5. The drought QTLs qDTY12.1 was detected in maximum (43.33%) germplasm and qDTY2.2 in least (8.33%) germplasm.

#### Root architectures

Nine popular upland rice varieties along with Swarna were studied for root phenotypic diversity as function of response to moisture stress to get some insight of drought tolerance mechanism. While root dry weight was reduced in all varieties under stress with maximum in Swarna (65.5%), three drought tolerant varieties (Vandana, N22 and Sahbhagidhan) showed increase in root length to the tune of 52.2%, 28.1% and 11.2%, respectively (Fig. 6.1).

Deeper rooting gene (*Dro1*), however, were found to be present in *aus* genotypes such as Black gora, Lalnakanda 41, Bhutmuri, AUS257 and Kalakeri (Fig.6.2). Besides, Vandana, having one *aus* parent (Kalakeri) also possesses *Dro1*.

#### Blast resistance

Presence of six major blast resistance (R) genes such as *Pi2*, *Pi9*, *Pib*, *Pi-z*, *Pita* and *Pizt* were surveyed using linked markers in seventy north-east Indian rice



Fig. 6.1. Root phenotype of ten rice genotypes under drought and control conditions

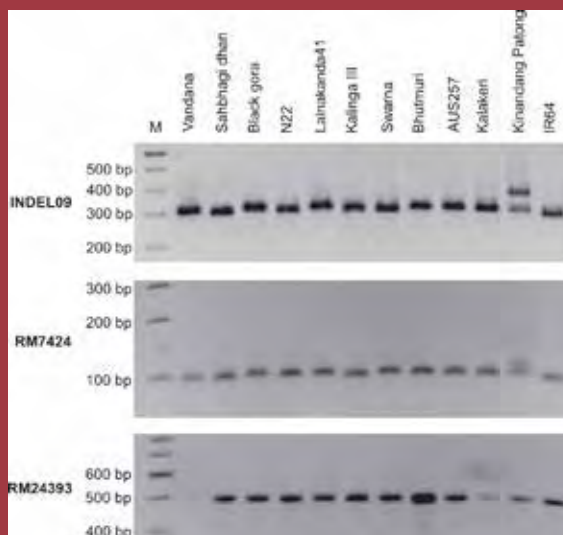


Fig. 6.2. Screening of *Dro1* gene in a set of upland rice varieties

accessions. The PCR assay identified gene frequencies ranging from 0.01% (*Piz*) to 100.0% (*Pib*). Only one accession, Chakhao from Manipur was positive for four blast R genes: *Pi2*, *Pib*, *Pizt* and *Pi9*. Two accessions, one from Meghalaya (Kba pnah) and other from Sikkim (Anadi, AC39741) showed presence of three blast R genes (*Pib*, *Pi9* & *Pi2*).

#### Hybridization, generation advancement and evaluation of breeding lines

Three  $F_2$  populations (DRR Dhan 44/Pratikshya, Sahbhagidhan/ BPT 5204 & Swarna/Naria phula) were grown following field based RGA protocol and single panicle selection (500 each cross) were made which are being generation advanced following SSD



method. The field based RGA method has also been fine tuned for Hazaribagh situation.

Forty advanced breeding lines were evaluated under preliminary yield trial (PYT). Only three entries resulted in significantly higher yield than best check variety Vandana under DSR. The top yielding entry was CRR564-5-1-1-1-B.

Recombinant-inbred-lines (128) from Sahbhagidhan/IR87707-446-B-B population were evaluated under drought stress and non-stress conditions. The lines were also genotyped with the linked SSR markers of three *DTY* QTLs (*DTY2.2*, *DTY4.1* & *DTY12.1*) and blast resistance gene *Pita2*. Many superior lines having higher grain yield, better drought tolerance and blast resistance than the parental genotypes with one or more *DTY* QTLs/ *Pita2* alleles were selected for evaluation as potential stable drought and blast resistant rice genotypes.

### **Strategize management options for sustainable productivity under DSR**

#### **Fine tuning Arbuscular mycorrhiza (AM) based technology component for improvement in P nutrition of DSR**

Application of on-farm produced AM fungal mass inoculums has proved to improve P nutrition in upland rice. Results of long term, fixed plot study was analysed to workout residual effects of inoculation for next season under AM-supportive rice based crop rotation. It was evident that continuous five years of AMF inoculation (soil) supported maintaining desirable native AMF population for two subsequent years without application.

#### **Evaluation of soil management options for sustainable rice production under DSR**

Preliminary results indicated two years of continuous application of FYM (@ 10 t ha<sup>-1</sup>) increased soil organic carbon by 22%.

### **Develop biotic stress management strategies for rainfed drought-prone ecologies**

#### **Integrated management strategy for False smut under shallow rainfed ecology**

False smut management strategy in transplanted rice under the target ecology was fine tuned. Nine potential fungicide formulations were evaluated under field condition, along with established cultural management options of early transplanting (20 July) and moderate fertilizer dose (N : P : K ; 80 : 40 : 40) in susceptible Hybrid variety PHB 71. Nativo (Trifloxystrobin + Tebuconazole) was found most effective under identified false smut cultural management options combinations.

#### **Evaluation of botanical oils against major rainfed direct seeded rice diseases**

Among nine botanical oils evaluated at different doses, clove oil resulted highest significant reduction of leaf blast, brown spot and false smut in direct seeded rice (DSR) variety Sahbhagidhan which was statistically at par with spray of Carbendazim. This was followed by Citronella oil> Eucalyptus oil>Nirgundi oil> Neem oil>Cedar Wood oil>Lemon Grass oil in terms of reduction in diseases incidence.

#### **Non-insecticidal approach for management of leaf folder**

Preliminary investigation revealed that, elicitor potassium silica (K<sub>2</sub>SiO<sub>3</sub>) spray (@0.5% and 1.0%) significantly reduced leaf folder damage over control. Spraying of elicitor, on the other hand, encouraged spider population in field and increased grain weight/panicle and 1000 grain wt. over control and insecticide spray.

Development of improved technologies for upland rice production has been one of the key interventions aimed at improving the productivity and sustainability of rainfed upland systems. NRRI Research Station, Hazaribag has developed and validated several improved upland rice varieties and associated technologies that outyielded traditional varieties or practices. The different activities undertaken through the Program 6 of the Institute has actively promoted these technologies over the years. In addition, several government supported schemes such as BGREI/ NFSM also promoted spread of these technologies. The technology combination consisting of improved rice varieties and integrated crop management (ICM) has not been fully adopted by farmers or in all locations, but farmers who have adopted it were able to obtain higher yield and income from rice. In several cases, potential for positive environmental benefits was also indicated because higher yields have helped reduce the pressure to intensify the use of fragile uplands for food production. However, not much assessment of the patterns of technology adoption and its impacts has yet been conducted. A systematic impact assessment would give a clear idea about the benefit of these technologies in improving livelihood of upland farmers.



# Genetic Improvement and Management of Rice for Rainfed Lowlands

Rice is the major staple food crop of Assam with more than 90% of the population depending on it for the nutritional requirements. Though the dependency on rice is very high in Assam, rice productivity in the state ( $2.2 \text{ t ha}^{-1}$ ) is much lower than the national average ( $2.7 \text{ t ha}^{-1}$ ) and because of these total annual production is just 5.2 MT from the total rice cultivated area of 2.41 Mha. The reason being the fact that a major share of the rice growing areas in Assam are flood prone rainfed lowlands. Depending on the rainfall pattern, there are three distinct rice growing seasons viz., *Ahu* or autumn rice (March/April to June/July), *Sali* or winter rice (June/July to November/December) and *Boro* or summer rice (November/December to May/June). The ideal rice production practices and the requirements vary depending on the seasons. In the Programme 7, utilizing local genetic resources to develop suitable medium duration, photo and thermo insensitive, cold tolerant vegetative stage rice varieties for Boro and Ahu season are the major thrust areas. For Sali/winter season, rice varieties of 130-140 days duration having medium slender grains and submergence tolerance perform better in rainfed lowlands of Assam. Insect-pests and diseases are important constraints to rice production in rainfed lowland ecosystem. Exploration of geographical distribution of these biotic factors and development of pest management strategies are important to schedule pest management activities in rainfed lowlands of Assam.



### Maintenance of rice germplasm

A total of 339 accessions of rice germplasm were maintained during *Kharif* 2019 at the station. Observations on days to 50% flowering, plant height, number of effective tillers, panicle length and grain yield were recorded for all the genotypes.

One cross between Chandrama/BRRI 75 was attempted and F<sub>1</sub> seeds were grown for developing high yielding, early duration rice variety for *Ahu* cultivation.

### Breeder Seed Multiplication of high yielding varieties

A total of 54.65 q of breeder seed was produced for

**Table-1. Breeder Seed produced**

Sl.No.	Name of Rice Variety	Quantity Produced (Qtl)
1	Chandrama	12.89
2	CR Dhan 310	23.93
3	CR Dhan 309	1.23
4	CR Dhan 311	1.69
5	CR Dhan909	3.50
6	CR Dhan 801	2.19
7	CR Dhan 802	2.45
8	CR Dhan 307	0.70
9	CR Dhan 506	0.31
10	CR Dhan601	5.76
	<b>Total</b>	<b>54.65</b>

the varieties Chandrama and CR Dhan 310. Other high yielding varieties like CR Dhan 801, CR Dhan 802, CR Dhan 309, CR Dhan 505, CR Dhan 311, CR Dhan 909, CR Dhan 601, Maudamani and Sahbhagidhan were also grown during *Kharif* 2019. Besides, 8.12 q of TL seed of Swarna *Sub-1* was produced during the period.

### Efficacy of fungicide against Rice Bakanae disease

In an experiment with Abhishek variety it was observed that root dip treatment with carbendazim and propiconazole solution was effective to prevent the spread of disease with 80.58 % and 70 % disease control, respectively over control. Foliar spray treated with carbendazim and propiconazole solution could control the disease by 54.62% and 50.58%, respectively over control. Treatments were found significant at 1% level of significance CD (0.01) = 2.39. Treatments are significantly different from the control but between the fungicides treatments and mode of treatments do not show any significant difference.

### Population dynamics of rice stem borer moths on *Ahu* rice

Moths of rice stem borer were captured through installing pheromone traps in the experimental farm during *Ahu* 2019. Moth activity of rice stem borer started at the second week of May. Daily catches of rice stem borer reached its first peak (3.0 nos. of moth trap<sup>-1</sup>) on 18-05-2019 and then moth population gradually declined up to 0.25 nos. of moth trap<sup>-1</sup> in the fourth week of May before reaching its second peak 3.75 nos. of moth/trap on 27-05-2019 (Fig. 7.1).

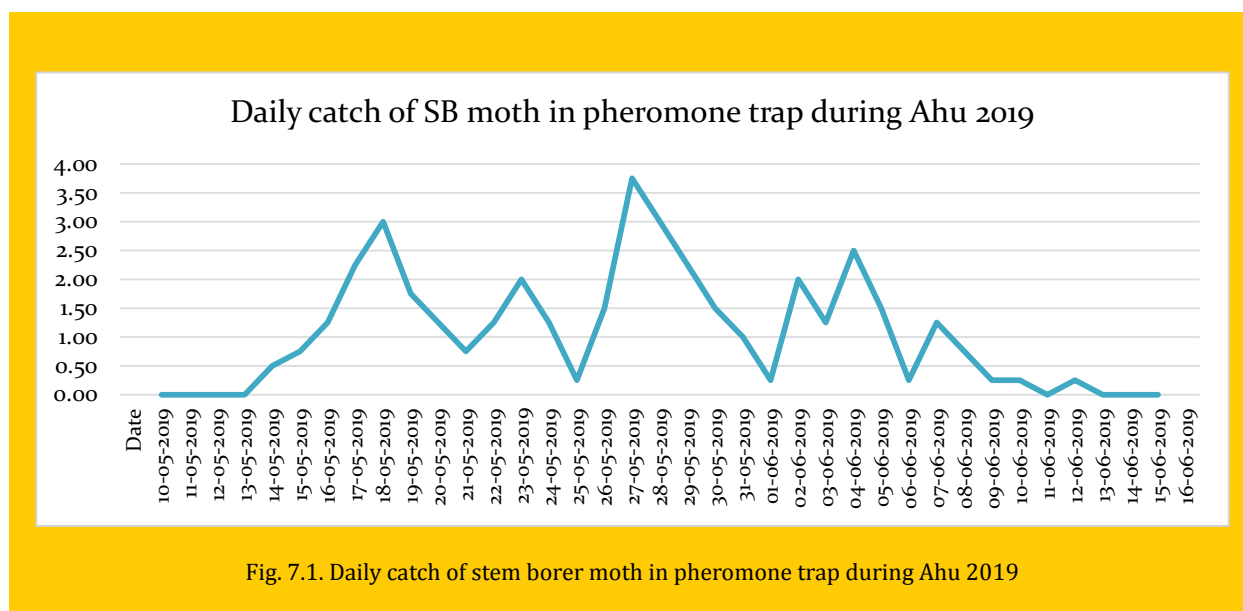


Fig. 7.1. Daily catch of stem borer moth in pheromone trap during Ahu 2019

Rice variety Naveen was transplanted in three different dates at 15 days intervals during *Ahu* 2019. Rice transplanted in the first fortnight of March recorded the lowest 1.64% dead heart in comparison to the crop transplanted in second fortnight of March (1.85%) and first fortnight of April (2.04%). Crop transplanted in first fortnight of March recorded the highest yield of 5.30 t ha<sup>-1</sup> as compared to crop transplanted in second fortnight of March (4.70 t ha<sup>-1</sup>) and first fortnight of April (4.53 t ha<sup>-1</sup>).

#### **Management of rice stem borer, leaf folder and gundhi bug in rainfed lowland**

Spraying of chlorantraniliprole 18.5% @ 150 ml/ha

recorded the lowest dead heart at 45 (1.43%) and 60 (1.73%) days after treatment (DAT), respectively in comparison to 2.41 and 3.45 per cent in control plots. Application of cartap hydrochloride 4% granule @ 20 kg/ha recorded the lowest 0.64 and 0.90 per cent leaf folder at 45 and 60 DAT, respectively in comparison to 1.18 and 1.31 per cent in control plot. Dusting with Malathion @ 20 kg ha<sup>-1</sup> recorded the lowest 0.20 no. of gundhi bug per hill and was followed by spraying of cypermethrin @ 2ml/ha (0.25 nos/hill) and crab trap @ 20 nos./ha (0.25 nos/hill). Spraying of chlorantraniliprole 18.5% @ 150 ml/ha recorded the highest yield 4.48 t ha<sup>-1</sup> as compared to control (3.31 t ha<sup>-1</sup>).



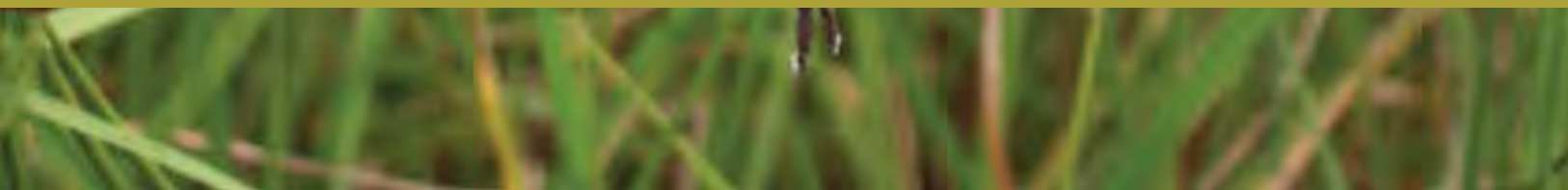
The year round research activities of NRRI Research Station, Gerua, Assam undertaken towards the development of rice varieties, maintenance of germplasm, evaluation of new varieties under AICRIP and breeder seed production for the rainfed lowland ecologies of the country has immense value to the farmers in the target ecology of country. The advisory services and capacity building activities help to develop the capacity of farmers in the eastern hilly regions of the country in terms of decision making in their day to day business. Field demonstrations conducted under Programme 7 are immense value to the nation by spreading the fruits of science for the betterment of the farming community.





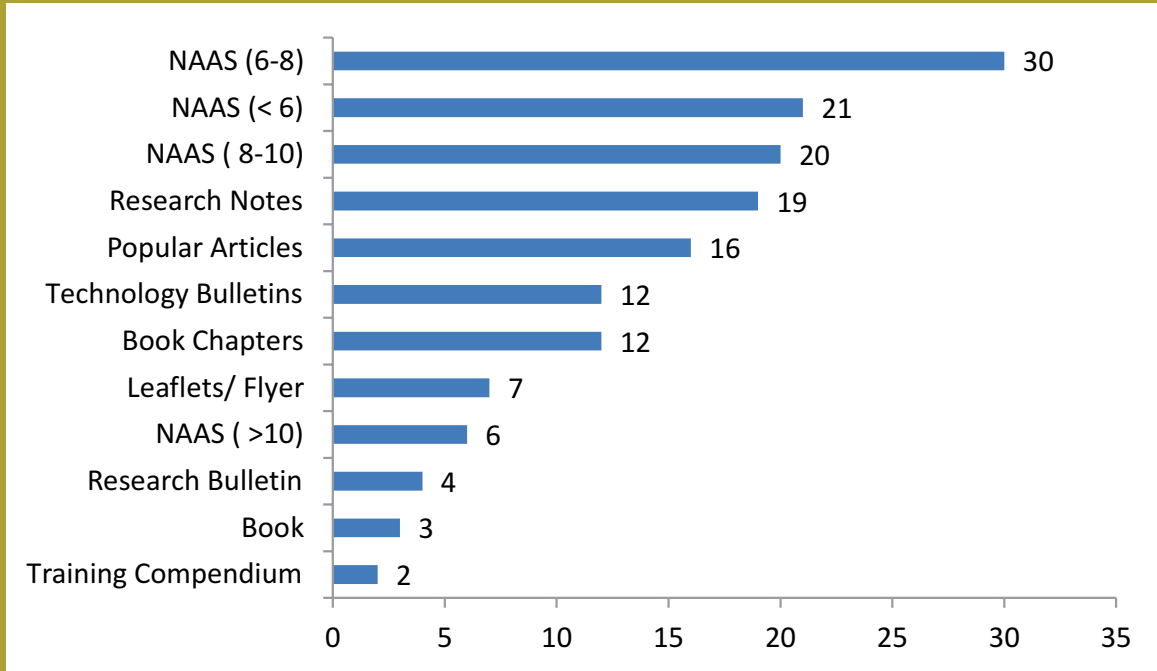
# Addendum

Besides seven research programmes, institute also conducts a number of supporting activities whose account has been provided in ensuing sections which are Publications, Activities and Events, Commercialization of ICAR-NRRI Technologies, Awards and Recognition, HRD-Training and Capacity Building, Extension Activities, In-Charge and Members of Different Cells, Personnel, Financial Statement, Ongoing Externally Aided Projects (EAPs) and Weather.



# Publications

During the year 2019, the institute has published different research, technology and extension materials which is shown by the below given figure.



Please Visit - <http://icar-nrri.in/research-papers/>



## Activities and Events

During the year 2019, ICAR-NRRI organized several events and conducted diverse set of routine and extracurricular activities to comply with the Council's vision and the Government of India programmes. The brief account of the events and activities undertaken are as follow-

### A) Activities:

<b>A.1) Important Meetings</b>			
<b>Activity</b>	<b>Period</b>	<b>Distinguished participants</b>	<b>Remarks</b>
Quinquennial Review Team (QRT) Meeting for the period 2012-2018	15 -16 November 2019	Prof. RB Singh, (C), Dr. Dinesh Kumar (M), Dr. P Anand (M), Dr. TS Thind (M) and Dr. SR Das (M), Dr. H Pathak (Director NRRI), Dr. BC Patra (MS) and Scientists of the Institute	Review of ongoing projects for the period for their achievements and direction for future research work.
25 <sup>th</sup> Research Advisory Committee (RAC)	29- 30 November 2019	Prof. SK Datta (C), Dr. PK Mohapatra (M), Dr. DK Mishra (M), Dr. AR Sharma (M), Shri SK Panigrahi (M) and Shri A Mishra (M), Dr. SN Meera (Representative of Director, IIRR, Hyderabad), Dr. H Pathak (Director NRRI), Dr. BC Patra (MS) and Scientists of the Institute	Review of ongoing projects for the period for their achievements and direction for future research work.
33 <sup>rd</sup> Institute Management Committee (IMC) Meeting	12 July 2019	Dr. H Pathak (C), Dr. KK Rout, Dean of Agriculture, OUAT, Bhubaneswar (M), Deputy Director (Finance) ICAR, New Delhi (M), Shri A Mishra, Bhubaneswar (Non-Official) (M), Shri SK Panigrahi, Nayagarh (Non-Official) (M), Dr. D Sarkar, Principal Scientist, CRIJAF, Barrackpore, Kolkata, (M), ADG (FFC), ICAR, New Delhi, (M), DD (F)-III, ICAR, New Delhi, (M), Shri VK Sahoo, F&AO, IIWM, Bhubaneswar, (M), Dr. JN Reddy (M), Dr. AK Nayak (M), Dr. (Mrs.) P Swain (M), Dr. PC Rath (M), Dr. SK Mishra (M), Shri SK Das, FAO (M), Shri SK Mathur, AO (M) and Shri BK Sahoo, Head of Office, (MS).	Matters related to infrastructure development and budgetary provisions for construction works.
38 <sup>th</sup> Institute Research Council (IRC) Meeting	1, 2 and 13 May 2019	Dr. H Pathak, (Chairman), Dr. (Mrs.) Padmini Swain, (MS), Head of Divisions, Scientists of the Institute and KVKs	Review of ongoing projects for the period for their achievements and suggestion for improving quality of work.
Institute Joint Staff Council (IJSC) Meeting	28 June 2019	Dr. H Pathak, (Chairman), Dr. (Mrs.) Padmini Swain, (M), Dr. M Shahid (M), Dr. NKB Patil (M), Shri BK Sahoo, (M), Shri SK Das, (M), Shri NC Parija, Secretary official side); Shri M Swain, CJS Member; Shri SK Sahoo, (M), Shri P Moharana, (M), Shri AK Moharana, (M), Shri B Pradhan, (M), Shri SK Bhoi, (M), and Shri B Naik, (M),	Various administrative and financial issues were discussed and modalities to solve them were planned.
20 <sup>th</sup> Scientific Advisory Committee (SAC) Meeting of KVK, Cuttack	15 May 2019	Dr. H Pathak (Chairman)	Action Taken Report of last SAC meeting along with brief presentation of report on achievements of KVK, Cuttack
14 <sup>th</sup> Scientific Advisory Committee (SAC) Meeting of KVK, Koderma	13 February 2019	Dr. D Maiti (Chairman)	Action Taken Report of last SAC meeting along with brief presentation of report on achievements of KVK, Koderma

<b>A.2) Distinguished visitors</b>		
<b>Visitor</b>	<b>Designation</b>	<b>Date of Visit</b>
Shri AK Tripathy, IAS	Development Commissioner-cum-Addl. Chief Secretary	10 April 2019
Shri Saurabh Garg, IAS	Principal Secretary (Agriculture), Govt. of Odisha	10 April 2019
Dr. SK Ambast	Director, ICAR-IIWM	3 July 2019
Dr. T Mohapatra	Secretary, DARE and DG, ICAR	26 September 2019
Dr. Manoranjan Kar	Ex-Vice Chancellor, OUAT, Bhubaneswar	2 October 2019
Shri SK Priyadarsi, IPS	Inspector General (Police)	4 November 2019
Dr. SK Srivastava	Director, ICAR-Central Institute for Women in Agriculture (CIWA), Bhubaneswar	18 November 2019

<b>A.3) Foreign Deputation</b>			
<b>Scientist</b>	<b>Country</b>	<b>Purpose</b>	<b>Date</b>
Drs. AK Nayak, BB Panda and R Tripathi	Oslo, Norway	To attend the Indo-Norwegian project meeting	24 May to 2 June 2019
Dr. AK Nayak	Oslo, Norway	To deliver a talk on Biophysical and resource mapping using GIS/Remote sensing under Indo-Norwegian project RESILIENCE meeting	24 May to 2 June 2019
Dr. AK Nayak	Brunei	To participate in a bilateral meeting on rice expert during the 5 <sup>th</sup> ASEAN-India Ministerial Meeting on Agricultural and Forestry (AIMMAF) meeting	14 to 17 October 2019
Dr. H Pathak	Colombo, Srilanka	To attended the launch of the UN Global Campaign on Sustainable Nitrogen Management and the UKRI GCRF South Asian Nitrogen Hub Work package meeting	23 to 26 October 2019
Dr. AK Nayak	Penang, Malaysia	To attend the 4 <sup>th</sup> Crawford Fund Master Class in Agricultural Research Leadership and Management in collaboration with APAARI at World Fish Centre Headquarters	3 to 8 November 2019
Dr. AK Nayak and Dr. SD Mohapatra	Dar-Es Salaam and Mbeya, Tanzania	To participate in the Rice Outreach and Knowledge Exchange Programme under RESILIENCE project	8 to 17 December 2019

C: Chairman; M: Member; MS: Member Secretary

## **B) Programmes and Events**

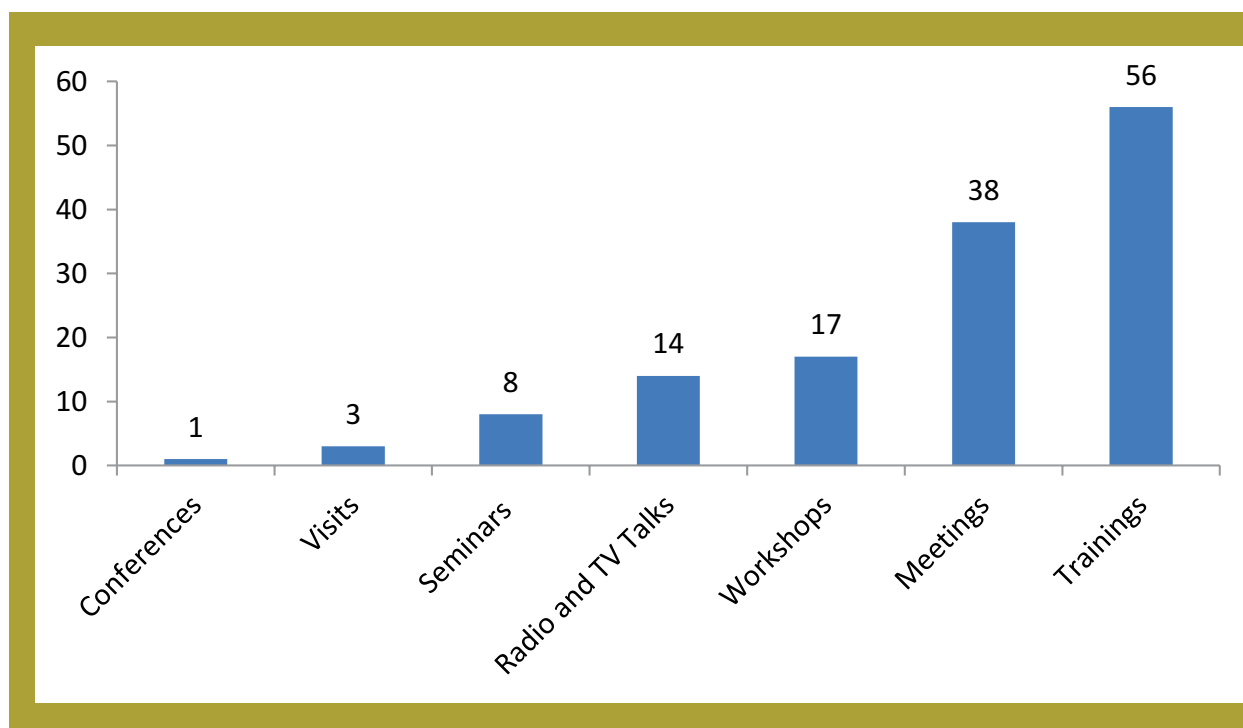
<b>Sl. No.</b>	<b>Events</b>	<b>Period</b>	<b>Venue</b>	<b>Participants</b>
<b>A) Programmes &amp; Events of International Importance</b>				
1.	5 <sup>th</sup> International Yoga Day	21 June 2019	ICAR-NRRI, Cuttack & CRURRS, Hazaribagh	Staff members and their family
2.	World Soil Day	5 December 2019	Maritime Museum, Cuttack	30 delegates and state government officials
3.	World Milk Day	1 June 2019	Mahulasahi village of Tangi-Choudwar block	100 children, farmers, and farmwomen
4.	World Egg Day	11 October 2019	Kankali village of Cuttack district	250 children, farmers, farmwomen and officials
5.	International Women's Day	8 March 2019	ICAR-NRRI, Cuttack	Staff members

<b>B) Programmes &amp; Events of National Importance</b>				
6.	Webcast/telecast of PM-KISAN	24 February 2019	ICAR-NRRI, Cuttack, NRRI-KVK Santhapur, Cuttack and Modi Ground in Bargarh, Odisha	4000 farmers and officials from Agriculture departments
7.	70 <sup>th</sup> Anniversary of Constitution of India	26 November 2019	ICAR-NRRI, Cuttack	Institute staff and 200 members of FPOs
8.	Vigilance Awareness Week	28 October to 2 November 2019	ICAR-NRRI, Cuttack	Invited experts and Institute staff
9.	National Productivity Week	12 to 18 February 2019	ICAR-NRRI, Cuttack	Invited experts and Institute staff
10.	Jal Shakti Abhiyan	31 July 2019	ICAR-NRRI, Cuttack	Invited experts and Institute staff & pensioners
11.	Hindi Fortnight	16 to 28 September 2019	ICAR-NRRI, Cuttack	Institute staff, school & university students and family members of staff
12.	Swachchhata Pakhwada	11 September to 2 October 2019 and 16 to 31 December 2019	ICAR-NRRI, Cuttack and adopted villages	Farmers, Institute staff, school & university students and family members of staff
13.	Swachchhata Pakhwada	3 to 27 October 2019	ICAR-NRRI, Cuttack and adopted villages	Farmers, Institute staff, school & university students and family members of staff
14.	TOLIC Meeting	22 October 2019	ICAR-NRRI, Cuttack	Office heads and staffs of central government offices, banks and undertakings located in Cuttack
<b>C) ICAR Programmes and events</b>				
15.	54 <sup>th</sup> Annual AICRIP Meeting and Rice Workshop	30 May to 2 June 2019	ICAR-NRRI, Cuttack	NARES scientists and delegates of AICRIP, seed industry and other
16.	ICAR Sports Tournament for Eastern Zone 2019	18 to 22 November 2019	ICAR-NRRI, Cuttack	19 ICAR Institutes of Eastern Zone of ICAR
17.	Pension Adalat	23 August 2019	ICAR-NRRI, Cuttack	Pensioners of ICAR Institutes of Eastern Zone
18.	Kisan Mela	26 February 2019	ICAR-NRRI, Cuttack	Union Agriculture & Farmers' Welfare Minister, Union Minister of Petroleum & Natural Gas and Skill Development & Entrepreneurship, DG ICAR, Directors of ICAR Institute, VC of OUAT, Staff and 3000 farmers



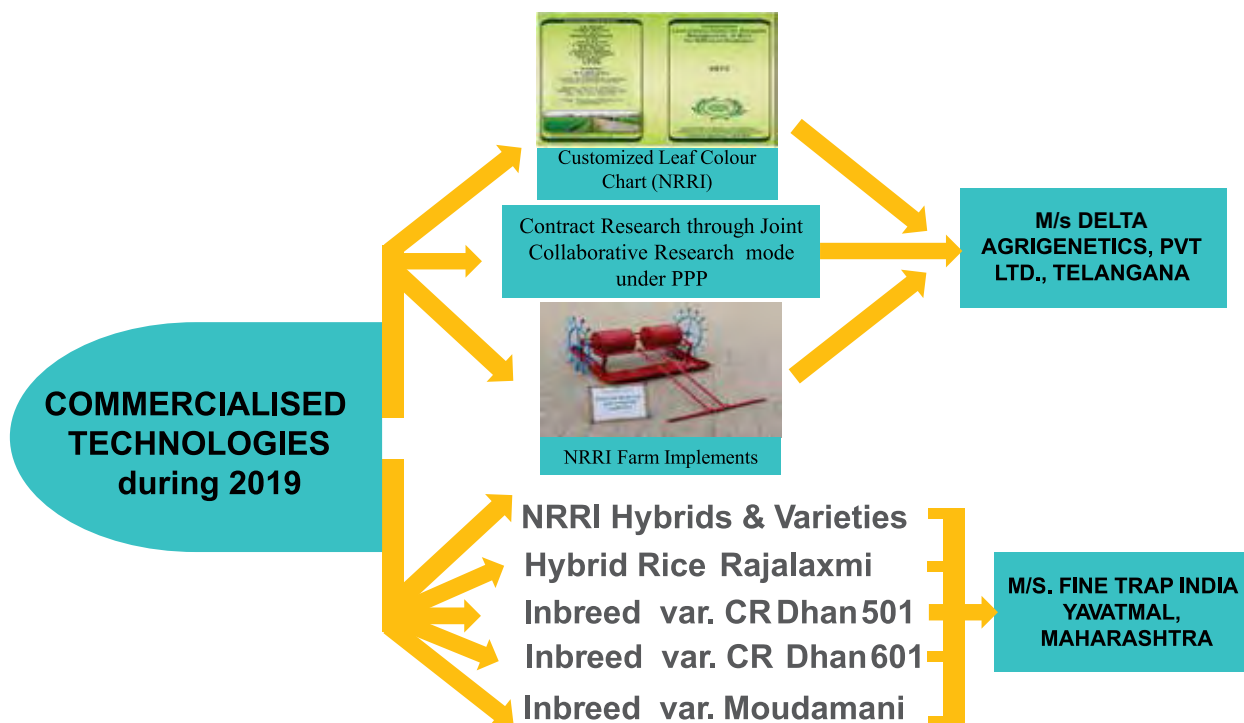
19.	Kisan Mela	19 October 2019	NRRI Research Station, Hazaribag	300 farmers and officers from SAU, State dept, Banks and NABARD
20.	Rice Walk	13 November 2019	ICAR-NRRI, Cuttack	1500 school students and teachers of nearby areas
21.	Institute Advisory Committee meeting	16 January 2019	ICAR-NRRI, Cuttack	Scientists of NRRI, CIWA, CARI, CHES, KVK, HoDs and 20 representative farmers
22.	73 <sup>rd</sup> Foundation Day	29 April 2019	ICAR-NRRI, Cuttack	DG, ICAR and Institute staff and family members
23.	Agribusiness Incubation Programme	26 September 2019	ICAR-NRRI, Cuttack	DG, ICAR, Institute staff and 24 Agro-entrepreneurs
24.	2 <sup>nd</sup> Rice Germplasm Field Day	11 <sup>th</sup> November 2019	ICAR-NRRI, Cuttack	75 participants from different Institutes, SAUs, and Private Sector
25.	Impact Assessment Meeting cum Workshop	1 to 2 March 2019	ICAR-NRRI, Cuttack	Project staff of Farmers FIRST programme from Odisha, Telangana and Andhra Pradesh

**Participation in Symposia/ Seminars/ Conferences/ Trainings/ Visits/ Workshops/ Radio and TV Talks**



## Commercialization of ICAR-NRRI Technologies

During the year 2019, the Institute has signed Memorandum of Understanding with two private companies for seven technologies. One rice variety CR Dhan 304 has also been registered with PPV&FRA during the year. Also, the Institute has registered eight rice germplasm with ICAR-NBPGR during the year. The details of commercialized technologies are depicted below.



Sl. No.	Rice Germplasm/ Variety	Year of Registration	Registration No.	Important Trait
<b>REGISTERED WITH PPVFRA</b>				
1	CR DHAN 304 (IET 22117)	2019	214 of 2019	New Extant Variety
<b>REGISTERED WITH NBPGR</b>				
1	Cherayi Pokkali (AC 39416A; IC0413644)	2019	INGR No.18150	Combined stress of drought and salinity
2	Khora-1(AC 41620; IC0574806)	2019	INGR No.18166	Anaerobic Germination
3	Dhobanumberi (IC 0256804)	2019	INGR No.18164	Resistant to BPH
4	Kamini (AC 44118; IC 599610)	2019	INGR No.18097	Tolerant to salinity stress
5	Talmugur (AC 43228; IC 0596460)	2019	INGR No.19063	Tolerant to salinity stress at vegetative stage
6	Chettivirippu (AC39394; IC 0599610)	2019	INGR No.19064	Tolerant to salinity stress both at vegetative and reproductive stage
7	IC 121865	2019	INGR No.19017	Resistant to blast disease
8	IC 199562	2019	INGR No.19064	Resistant to blast disease

## Awards and Recognition

During the year 2019, ICAR-National Rice Research Institute and its staff members have bagged several prestigious awards. The details of the awards are given below.

Awards and Recognition for the Institute:

Sl. No.	Award Title	Awards for	Award Conferred By
1.	Rafi Ahmed Kidwai Award: Dr. Himanshu Pathak	Outstanding research in the field of climate change, nutrient management and simulation of agricultural processes	ICAR
2.	Nanaji Deshmukh Award for Outstanding Interdisciplinary Team Research in Agricultural and Allied Sciences in the discipline of Crop Science and Horticulture: Dr. K Chattopadhyay, Dr. SG Sharma, Mr. TB Bagchi, Dr. Avijit Das and Mr. BC Marndi	For release and dissemination of the first high protein (10.3%) rice variety of India, CR Dhan 310 and nutrient rich rice variety Mukul (CR Dhan 311) with high protein (10.1%)	ICAR
3.	Fellow of the Indian Society of Soil Science: Dr. AK Nayak	Outstanding contribution in soil carbon sequestration, greenhouse gas emission, nutrient management and stress agronomy in rice	Indian Society of Soil Science
4.	Young Scientist Award-2019: Dr. Divyendu Chatterjee	Outstanding contribution in research	The Clay Minerals Society of India
5.	Fellow of Indian Society of Plant Genetic Resources: Dr BC Patra	Outstanding contributions in the field of plant genetic resources	Indian Society of Plant Genetic Resources
6.	Excellence and Innovation Award-2019: Dr. KR Rao	Contribution to Chemical Ecology	Dr. B Vasantharaj David Foundation, Chennai
7.	Fellow of Crop and Weed Science Society, BCKV, West Bengal: Dr. MK Bag	Outstanding contribution in research	Crop and Weed Science Society, WB
8.	Dr. K Pradhan Young Scientist Award: Dr. RK Mohanta	Outstanding contribution in research	Animal Nutrition Society of India
9.	ARRW Fellow 2019: Dr. SK Pradhan	Crop Improvement	ARRW
10.	Research Peace award of 2019: Dr. Awadhesh Kumar	International innovative research in glycemic index of rice	RULA (Research under Literal Access)
11.	Cash Award Scheme in Administrative category: Mr. SK Das	Efficiency in administrative work	ICAR
12.	Zonal Overall Championship Award	Best performance in TEZ-2019	ICAR
13.	2 <sup>nd</sup> Prize for CRURRS, ICAR-NRRI Hazaribagh	Working in Official Language Hindi	NARAKAS, Hazaribagh
14.	J-Gate@ CeRA Best Usages in the Eastern Region – 2019 Award	Best Usages in the Eastern Region	J-Gate@ CeRA
15.	3 <sup>rd</sup> position in 67 <sup>th</sup> Senior State Kabaddi Championship	Kabaddi	Orissa Kabaddi Association
16.	Champions in the ICAR Inter Zonal Tournament	Kabaddi, Football, Basketball	ICAR
<b>RECOGNITIONS</b>			
17.	Dr. AK Nayak nominated as Member of the Institute Management Committee at NRRI, Cuttack for the period of 5 March 2019 to 4 March 2022		
18.	Dr. AK Nayak acted as member of 43 <sup>rd</sup> Institute Management Committee at CIFA, Bhubaneswar on 15 March 2019		



19.	Dr. AK Nayak nominated as expert committee member for selection of Odisha states awards on 24 February 2019
20.	Dr. Mohammad Shahid was selected as “NAAS Associate 2020
21.	Dr. P. Panneerselvam was invited as one of the “experts in the field of Microbiology” by National Bio-diversity Authority for preparation of “People’s Biodiversity Registers”
22.	Drs. NP Mandal, PK Sinha, M Variar and VD Shukla was honoured for developing Rice variety Sahbhagidhan and contributing towards food and nutrition security of the country during 58 <sup>th</sup> All India Wheat & Barley Research Workers’ Meet, Indore, M.P.

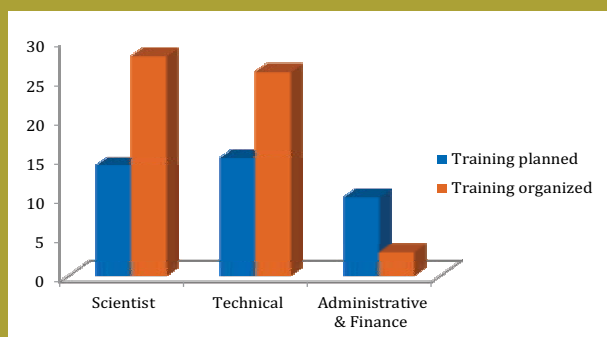




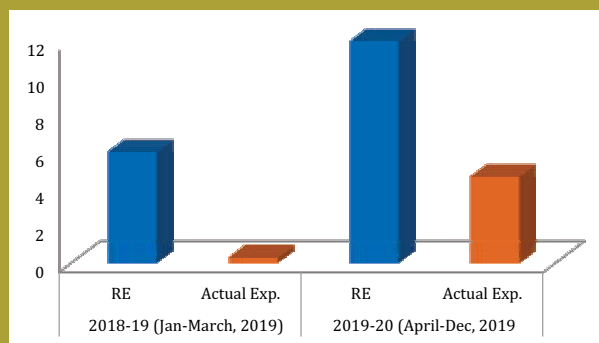
## Human Resource Development and Capacity Building

Human Resource Development (HRD) cell of NRRI has been established to strengthen and facilitate the training and capacity building of the students/scientists/other staffs to work in the emerging areas of rice research and management. The targets and achievements of HRD cell of the institute is presented below.

Physical targets and achievements of HRD cell for the year 2018-19



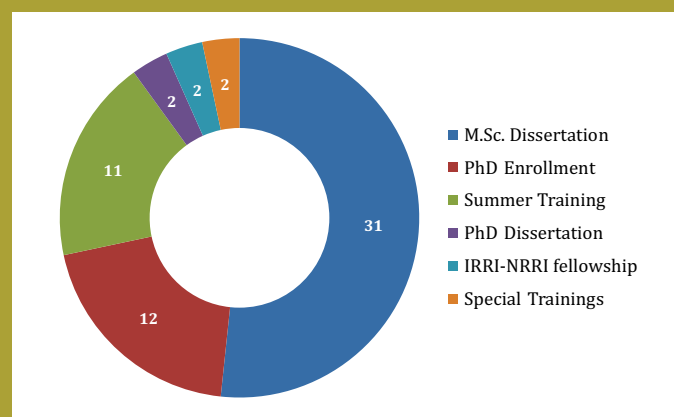
Financial targets and achievements of HRD cell for the year 2018-19



### Capacity building of the students

During the year 2019, 31 MSc students have completed their dissertation; 12 students have enrolled for PhD programme; two PhD students have completed dissertation and two PhD students have availed IRRI-NRRI fellowship among other achievements of the HRD cell.

Achievements of the HRD programmes for the students during 2019



## Extension Activities

With the aim of imparting knowledge to different stakeholders on diverse areas, ICAR-NRRI, Cuttack has undertaken several extension activities in the year 2019. The extension activities undertaken range from field demonstration of new technologies to exhibitions, agro-advisory services, visitors advisory services, training programmes for farmers and extension professionals and ICAR mandated programmes like Mera Gaon Mera Gaurav (MGMG) and Tribal Sub Plan (TSP) etc. The brief report of the extension activities undertaken are as follow:

### Field demonstrations

ICAR-NRRI, Cuttack has conducted about 700 field demonstrations of newly released rice varieties and crop production as well as protection technologies in the farmers' field during the year 2019. About 15 promising rice varieties were demonstrated in the states of Assam, Bihar, Chhattisgarh, Jharkhand, Madhya Pradesh, Maharashtra, Odisha and West Bengal through these activities.

### Exhibitions

The institute participated in 11 exhibitions at different locations in the country and showcased its promising technologies and significant milestones of NRRI to the visitors in the exhibitions.

### Fortnightly agro-advisory services

A total of 24 agro-advisories on rice were issued on fortnightly basis in English as well as Odia language during the year 2019. The advisories were sent by mail to the officials of agriculture and related departments of the state as well as uploaded in Institute website for public awareness and reference.

### Visitor's advisory services

A total of 9062 visitors including 4396 farmers, 1807 farmwomen, 2404 students 455 agriculture officers from Andhra Pradesh, Assam, Chhattisgarh, Gujarat, Haryana, Himachal Pradesh, Jharkhand, Karnataka, Madhya Pradesh, Odisha, Tamil Nadu, Telangana and West Bengal have visited demonstrations and experimental plots, agricultural implement workshop, net houses and *Oryza* museum of the institute during 2019 and they have been provided advisory on different aspects of rice cultivation.

### Training programmes for farmers and extension professionals

More than 1000 participants including farmers, extension officials, administrative personnel and others benefitted through 40 training programmes of different durations (2-8 days) in the area of improved rice production and protection technologies, integrated farming system (IFS), rice seed production technologies, enterprise management, financial management system (FMS), climate change etc.

### Mera Gaon Mera Gaurav (MGMG) Programme

There are 21 multi-disciplinary teams working at 21 clusters of villages (comprising 5 villages each) covering eight districts of Odisha to promote the direct interface of scientists with the farmers through providing requisite information, knowledge and advisories. During the year 2019, about 101 visits have been made by different teams, 81 number of interface meeting/ *gothies* /trainings conducted at the villages. Mobile-based advisories through personalized calls and messages provided to more than 100 farmers, even on multiple occasions. Literature on rice and rice-based farming in local language were distributed to farmers during the visits and different programmes.

### Tribal Sub-Plan (TSP) Programme

Two tribal village, namely Bandhasahi and Pitabari in Kandhamal district of Odisha adopted by the Institute under TSP programme for their all-round development through demonstration of improved rice varieties and production technologies as well as other developmental activities. Seeds of seasonal vegetables, saplings of tuber roots, yams, etc. were distributed to ensure their nutritional security. Animal health camps organized on regular basis and feed supplements distributed for development of livestock. A pre-*kharif* workshop-cum-training on rice-based farming conducted during June 30 – July 01, 2019 in which about 100 tribal farmers participated. Further, a workshop-cum-distribution of saplings & farm-tools programme organized on August 08, 2019, during which saplings of fruit plants and farm tools were also distributed among the beneficiaries besides hands-on training on care of fruits plants and tuber crops, inter-culturing, integrated pest management and paddy straw mushroom cultivation practices, etc.

## In-Charge and Members of Different Committees

### Quinquennial Review Team

**Prof. RB Singh**, Chairman

**Prof. SK Sanyal**, Member

**Prof. TS Thind**, Member

**Prof. SR Das**, Member

**Prof. P Anand Kumar**, Member

**Dr. H Pathak**, Member

**Dr. BC Patra**, Member Secretary

### Research Advisory Committee

**Prof. SK Datta**, Chairman

**Dr. DK Mishra**, Member

**Dr. JS Bentur**, Member

**Dr. PK Mohapatra**, Member

**Dr. AR Sharma**, Member

**Dr. RP Singh 'Ratan'**, Member

**Shri Sukanta Kumar Panigrahi**, Member

**Shri Amareswar Mishra**, Member

**Dr. H Pathak**, Member

**ADG (FFC)**, ICAR, New Delhi, Member

**Dr. SR Voleti**, Special Invitee

**Dr. BC Patra**, Member Secretary

### Institute Management Committee

**Dr. H Pathak**, Chairman

**Director of Agriculture & Food Production**

Govt. of Odisha, Member

**Director of Agriculture**

Govt. of West Bengal, Member

**Dean, College of Agriculture**

OUAT, Bhubaneswar, Member

**Dr. AK Nayak**, Member

**Dr. (Mrs.) Padmini Swain**, Member

**Dr. LV Subba Rao**, Member

**Dr. D Sarkar**, Member

**ADG (FFC)**, ICAR, New Delhi, Member

**DD (F)-III**, ICAR, New Delhi, Member

**Shri VK Sahoo**, Member

**Shri SK Panigrahi**, Member, Non-Official

**Shri Amareswar Mishra**, Member, Non-Official

**Shri BK Sahoo**, Member Secretary



## Personnel (January-December 2019)

**Dr. Himanshu Pathak**, Director

### Crop Improvement Division

<b>Scientist</b>								
BC Patra (HEAD)	JN Reddy	MK Kar	SK Pradhan	LK Bose	K Chatto- padhyay	S Samanta- ray	L Behera	SK Dash
H Subudhi	A Anandan	M Cha- karaborti	RK Sahu	SSC Pattnaik	J Meher	RL Verma	S Sarkar	Md Azha- rudheen TP
RP Sah	BC Marndi	P Sang- hamitra	JL Katara	K Ali Molla	Parame swaran C	Devanna		
<b>Technical Staff</b>								
R Chandra	A Sahoo	B Nayak	P Kumar	JS Anand	PL Dehury	LK Singh	M Soren	N Barik
KC Mallik	B Mishra	D Nayak	D Samal	B Behera	RP Rao	A Parida	D Majhi	B Hembram
M Patra	S Sarkar	AK Dulet	A Choudhary	P Pandit				
<b>Administrative Staff</b>								
M Swain								
<b>Skilled Supporting Staff</b>								
N Das	G Dei	FC Sahu	J Biswal	SK Bhoi	P Dei	R Dei	D Bhoi	

### Crop Production Division

<b>Scientist</b>								
AK Nayak (HEAD)	P Bhat- tacharya	S Saha	BB Panda	A Poonam	PK Nayak	R Tripathi	P Panneer- selvam	S Mohanty
M Shahed	BS Satapathy	S Munda	A Kumar	D Chatterjee	D Bhaduri	Vijaykumar S	U Kumar	K Kumari
PK Guru	BN Totaram	M Debanath	S Chaterjee	H Priya	R Khanam	M Siv- ashankari	S Priyadar- sani	
<b>Technical Staff</b>								
KK Swain	PK Sahoo	KK Suman	AK Mishra	B Das	KC Bhoi	JC Hansda	JP Behura	SK Ojha
KC Palaur	B Ojha	BC Behera	P Behera	S Panda	PK Jena	AK Moharana	R Jamunda	A Pal
SC Sahoo	S Baskey	EV Ramaiah	A Meena	G Mandi	SP Lenka	P Saman- taray	S Mohanty	G Bihari
D Behera	PK Ojha	D Parida	PK Parida	R Beshra	CK Ojha	S Pradhan	JK Sahu	Md Wahid
AK Suman	Md H Alam	KK Meena	S Kumar	SP Sahoo	TK Behera	MK Parida		
<b>Administrative Staff</b>								
S Sur	SK Bhoi							
<b>Skilled Supporting Staff</b>								
K Bhoi	S Bhoi	S Dei	S Biswal	B Marandi	B Khatua	M Dei	K Dei	PK Das
J Marandi	N Singh	D Naik						

## Crop Protection Division

Scientist								
PC Rath (HEAD)	SD Mohapatra	KR Rao	S Lenka	AK Mukherjee	MK Bag	S Mondal	NKB Patil	Basana Gowda G
GP Pandi G	G Prasanthi	M Annamalai	MK Jadav	Aravindan S	Raghu S	Prabhu Karthikeyan SR	MS Baite	Keerthana U
SS Pokhare	Sankari Meena S	T Adak						
Technical Staff								
R Swain	S Pradhan	P Moharana	SK Sethi	SK Rout	MK Nayak	A Panda	C Majhi	H Pradhan
A Mohanty	EK Pradhan	A Malik	M Meena	S Biswal	AK Naik	D Dash	JP Das	KC Barik
S Das	Md Shadab Akhtar	NK Meena						
Administrative Staff								
B Mahana								
Skilled Supporting Staff								
L Murmu	B Bhoi	D Naik						

## Crop Physiology & Biochemistry Division

Scientist								
P Swain (HEAD)	MJ Baig	K Chakra-borty	PS Hanjagi	SM Awaji	TB Bagchi	A Kumar	N Basak	G Kumar
Technical Staff								
C Tudu	J Bhoi	J Senapaty	D Baral	S Banerjee	DB Sahoo	S Haldhar	AR Meena	S Kumar
R Meena								
Administrative Staff								
T Ram	A Kumar							
Skilled Supporting Staff								
GC Sahoo	J Dei	N Naik						

## Social Science Division

Scientist								
GAK Kumar (HEAD)	NC Rath	SK Mishra	B Mondal	NN Jambhulkar	JP Bisen			
Technical Staff								
P Kar	P Jana	B Behera	G Sinha	SR Dalal	DR Sahoo	AK Parida	SK Mohapatra	A Anand
SK Tripathy	AK Panda	HS Sahoo	SK Roul					
Administrative Staff								
L Trivedi								
Skilled Supporting Staff								
Surubal Hembram								

### NRRI Research Station, Hazaribagh

Scientist								
D Maiti (HEAD)	NP Mandal	S Bhagat	SM Prasad	S Roy	BC Verma	A Banerjee		
Technical Staff								
J Kumar	DR Meena	S Oran	AN Singh	R Tirky	U Saw	J Prasad	HR Meena	SC Meena
S Akhtar								
Administrative Staff								
CP Murmu	R Paswan	S Kumar	CR Dangi	AK Das	SK Pandey			
Skilled Supporting Staff								
MN Prasad	R Ram	L Mahato	S Devi	N Devi	B Oran	P Devi	K Devi	D Devi
T Ram	S Gope	G Gope	HC Bando					

### NRRI Research Station, Gerua

Scientist								
R Bhagwati (HEAD)	K Saikia	BR Goud	SKG Lahre					
Technical Staff								
S Baruah	D Khan	H Thakuria	B Kalita					
Administrative Staff								
DK Mohanty	J Das							
Skilled Supporting Staff								
M Das								

### NRRI Research Station, Naira

Technical Staff								
C Kamaraju	KC Munda							

### KVK, Cuttack

Technical Staff								
S Sethy (OIC)	DR Sarangi	M Chourasia	TR Sahoo	RK Mohanta	A Bisoi			
Administrative Staff								
BB Polai								

### KVK, Koderma

Technical Staff								
C Kumari (OIC)	S Shekhar	B Singh	R Ranjan	M Kumar	B Medhi	S Kumar	BK Khuntia	
Skilled Supporting Staff								
M Ram								

### Administrative/ Technical

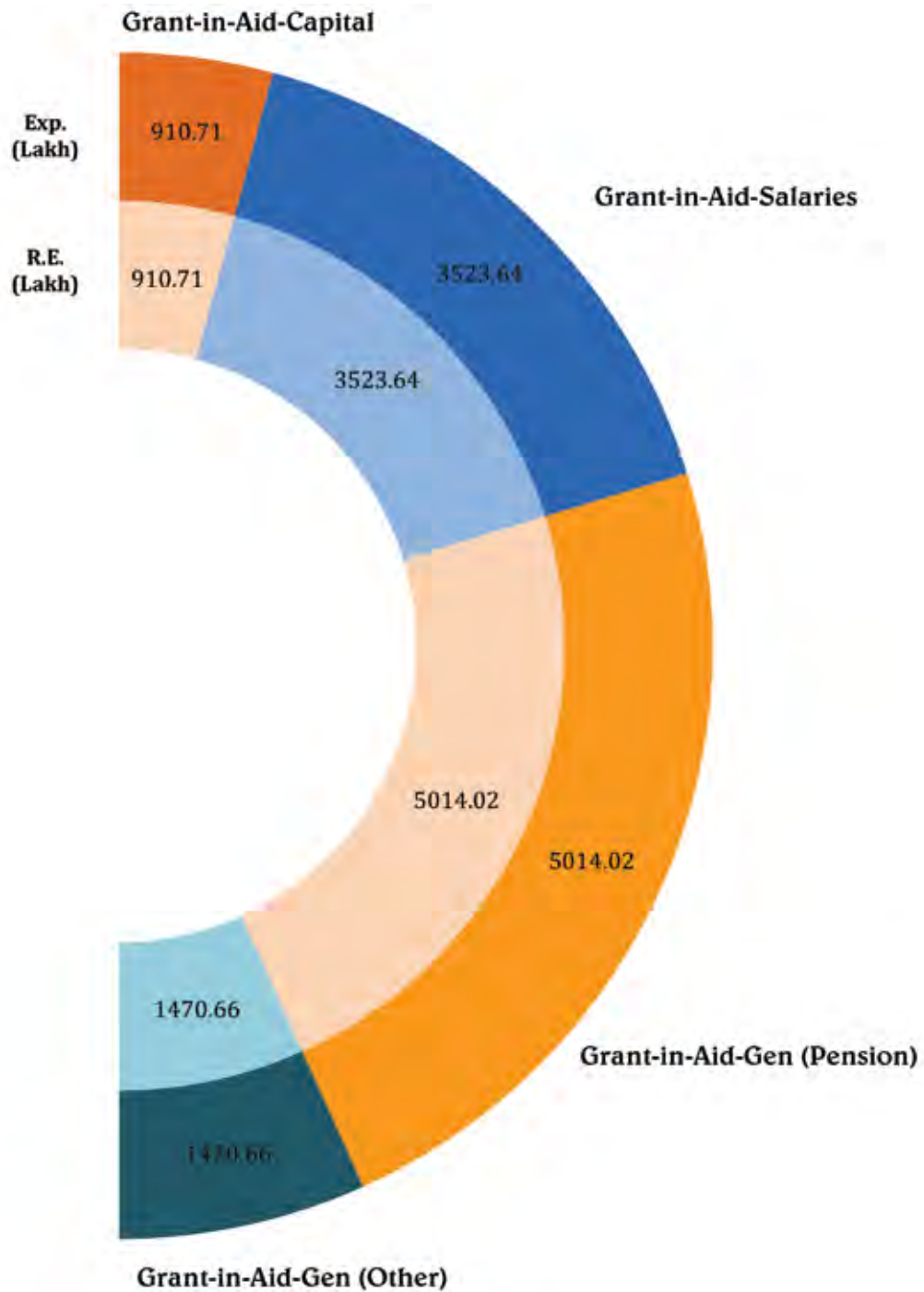
Administrative								
BK Sahoo	SK Das	SK Mathur	AK Tiwari	J Pani	NC Parija	SK Das	NK Swain	SK Jena
NK Das	N Mahavoi	J Nayak	GK Sahoo	N Mohanty	BK Mohanty	SK Sinha	N Biswal	A Kullu
D Khuntia	N Jena	MB Swain	SP Sahoo	S Sahoo	KK Sarangi	SK Behera	S Nayak	SK Sahu
RK Behera	RC Das	R Kido	NP Behura	SK Sahoo	M Mohanty	SK Nayak	DK Parida	SK Satapathy
MK Sethi	KC Behera	PC Das	AK Pradhan	RC Pradhan	V Kumar	G Dei	S Kumar	R Dutta
SK Lenka	SK Sahoo	M Das	PK Sahoo	KC Das	AK Nayak	B Pradhan	RC Nayak	S Pradhan
A Sethi	R Sahoo	CR Dangi	D Muduli	S Mishra	R Behera	S Mahapatra	S Kumar	B Sethi
B Sahoo	AK Sinha	BK Gochhayat	H Marandi	AK Das	SK Pandey	RK Singh	RPS Sabarwal	SK Patra
SK Das								
Skilled Supporting Staff								
K Naik	D Naik	G Majhi	R Naik	P Naik	D Naik	B Naik		

### Canteen Staff

A Jena	M Sahu	M Nayak	M Pradhan			
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# Financial Statement (January-December 2019)



## Ongoing Externally Aided Projects (EAPS)

Sl. No.	Project No.	Title of the Project/PI &Co-PIs	Source of Funding
1.	EAP 27	Revolving fund scheme for seed production of upland rice varieties at NRRI Research Station, Hazaribag-NP Mandal	AP Cess
2.	EAP 36	National Seed Project (Crops)-RK Sahu, RP Sah	NSP
3.	EAP 49	Revolving fund scheme for breeder seed production-RK Sahu, RP Sah, P Sanghamitra	NSP/Mega seed
4.	EAP 60	Front line Demonstration under Macro-Management scheme of Ministry of Agriculture – New High Yielding Varieties-Y Kumar	DAC
5.	EAP 100	Seed Production in Agricultural Crops-RK Sahu, RP Sah, P Sanghamitra	ICAR
6.	EAP 125	Stress tolerant rice for poor farmers of Africa and South Asia (STRASA)- Drought prone rain-fed rice areas of South Asia – Hazaribag Centre-NP Mandal	ICAR - IRRI (BMGF)
7.	EAP 126	Stress tolerant rice for poor farmers of Africa and South Asia (STRASA)- Drought prone areas- NRRI Centre-A Anandan, P Swain	ICAR - IRRI- (B&MGF)
8.	EAP 127	Stress tolerant rice for poor farmers of Africa and South Asia - Submergence and Flood prone areas (STRASA)-JN Reddy, SSC Patnaik, K Chakraborty, K Chattopadhyay	ICAR-IRRI (B&MGF)
9.	EAP 128	Stress tolerant rice for poor farmers of Africa and South Asia – Salt affected areas (STRASA)-B Marandi, A Nayak, A Poonam, K Chattopadhyay, K Chakraborty	ICAR-IRRI (B&MGF)
10.	EAP 130	All India Network Project on Soil Biodiversity –Biofertilizers- D Maiti	ICAR
11.	EAP139	AICRP on energy in agriculture and agro-based industries-PK Guru, NT Borkar	AICRP
12.	EAP 140	Intellectual Property Management and Transfer/ commercialization of agricultural technology under National Agricultural Innovation Fund (NAIF)-BC Patra	ICAR
13.	EAP 141	DUS Testing of Rice and documentation- BC Patra	PPV&FRA
14.	EAP 161	Monitoring of the new initiative of “Bringing Green Revolution to Eastern India (BGREI) under the Rashtriya Krishi Vikas Yojana”-H Pathak, BB Panda	DAC, GOI
15.	EAP 163	Stress tolerant rice for poor farmers of Africa and South Asia – Sub grant, Seed (NRRI, Cuttack)-RK Sahu, RP Sah	IRRI-ICAR (STRASA)
16.	EAP 176	Using wild ancestor plants to make rice more resilient to increasingly unpredictable water availability- SK Dash, P Swain, L Behera	DBT-BBSRC (DFI, UK)
17.	EAP 178	National Initiative on Climate Resilient Agriculture-Sudhansu Sekhar	NICRA (ICAR)

18.	EAP 183	Characterization of toxins of <i>Bacillus thuringiensis</i> isolated from rice genotypes and their virulence assessment against leaf folder ( <i>Cnaphalocrocis medinalis Guenee</i> )-Sonali Acharya (TK Dangar)	DST Inspire
19.	EAP 184	Utilization of fly ash on amelioration and source of nutrients to rice-based cropping system in eastern India-Sanghamitra Maharana (AK Nayak)	DST Inspire
20.	EAP 185	Development of crop and nutrient management practices in rice for Odisha state- S Saha, BC Patra, S Munda	ICAR-IRRI STRASA
21.	EAP 186	Use of microbes for management of abiotic stresses in rice- AK Mukherjee	ICAR-IRRI
22.	EAP 187	Low carbon resource conservation technologies for sustainable rice production in low land ecology- P Bhattacharyya	ICAR
23.	EAP 189	Front Line Demonstrations under NFSM- NC Rath	DAC -IIRR (NFSM)
24.	EAP 191	NRRI-NCIPM collaborative project on development and validation of IPM module for rice- SD Mohapatra, S Lenka, J Berliner, K Saikia, KB Pun, T Singh, T Adak, U Kumar	NRRI/NCIPM
25.	EAP 192	DNA marker based pyramiding and study of interactions among QTLs for higher grain number in rice ( <i>Oryza sativa</i> L.) - Gayatri Gouda (T Mohapatra)	DST Inspire
26.	EAP 193	Future rainfed lowland rice systems in Eastern India 15 (T3) (Development of crop and nutrient management practices in rice)- AK Nayak, P Gautam, B Lal, M Shahid, R Tripathi, D Bhaduri, K Chakraborty	STRASA South Asia
27.	EAP 195	Artificial induction of chlamyospore in <i>Trichoderma</i> sp. and identification of genes expressed during the process-HK Swain, (AK Mukherjee)	DST Inspire
28.	EAP 197	Consortia research platform (CRP) on bifortification- K Chattopadhyay, S Samantaray, M Chakraborty, A Kumar, N Basak, LK Bose, A Poonam	ICAR Plan-CRP
29.	EAP 198	Incentivizing Research in Agriculture: Study of rice yield under low light intensity using genomic approaches- L Behera, MJ Baig, A Kumar, SK Pradhan, S Samantaray	ICAR Plan
30.	EAP 199	Incentivizing Research in Agriculture: Towards understanding the C3-C4 intermediate pathway in Poaceae and functionality of C4 genes in rice- MJ Baig, P Swain, L Behera, S Ray, A Kumar, K Ali Molla	ICAR Plan
31.	EAP 200	Incentivizing Research in Agriculture: Genetic modifications to improve biological nitrogen fixation for augmenting nitrogen needs of cereals- U Kumar, P Panneerselvam	ICAR Plan
32.	EAP 201	Incentivizing Research in Agriculture: Molecular genetic analysis of resistance/tolerance to different stresses in rice, wheat, chickpea and mustard including sheath blight complex genomics- MK Kar, L Behera, A Mukherjee, S Aravindan, NP Mandal, S Samantaray, M Azharudheen	ICAR Plan

33.	EAP202	Associated mapping of genes/QTLs for yield under reproductive stage drought stress in rice ( <i>Oryza sativa</i> L.)- L Behera, P Swain, SK Dash, SK Pradhan, BC Patra	BIRAC
34.	EAP 203	Strategic development of water utilization in rice production system for higher crop and water productivity and profitability- BB Panda, P Swain, SK Pradhan, L Behera, R Tripathi	CRP – Water (ICAR)
35.	EAP 204	CRP on Agro biodiversity: PGR Management and Use of Rice (Component I & II)- BC Patra, GP Pandi, AK Mukherjee, K Chakraborty	CRP –Agro-biodiversity (ICAR)
36.	EAP 205	Nutrient cycle in agricultural system at field and regional scales- AK Nayak, S Mohanty, R Tripathi, M Shahid, A Kumar	ISRO – EOAM
37.	EAP 206	Eliciting soil microbiome responses of rice for enhanced water and nutrient use efficiency under anticipated climate changes- AK Nayak, P Bhattacharyya, MJ Baig, Md. Shahid, S Raj, A Kumar, T Adak, S Roy, U Kumar	NASF - ICAR
38.	EAP 207	Conservation agriculture for enhancing the productivity of rice based cropping system in Eastern India- AK Nayak, R Tripathi, BB Panda, M Shahid, S Munda, S Saha, SK Mishra, SD Mohapatra, P Guru, R Khanam	CAP - ICAR
39.	EAP 208	Evaluation of efficiency of zinc metalosate and boron metalosate foliar supplements for maximizing yield through balanced nutrition of important crops grown in India- M Shahid, AK Nayak, A Kumar	AICRP (Contract)
40.	EAP 209	CRP on hybrid technology- RL Verma, JL Katara	CRP - ICAR
41.	EAP 210	Fine mapping and identification of candidate gene/QTL for brown plant hopper resistance in rice cultivar, Salkathi- P Patnaik, (L Behera)	DST Inspire
42.	EAP 211	CRP on molecular breeding- MK Kar, L Behera, GP Pandi, A Mukherjee, M Chakraborti, S Aravindan, PC Rath	CRP - ICAR
43.	EAP 212	Multilocal monitoring of Rynaxypyr 20SC against <i>Scirpophaga incertulas</i> in rice and rice hopper susceptibility survey in India for DPH-RAB55 106SC against <i>Nilaparvata lugens</i> and <i>Sogatella furcifera</i> - SD Mohapatra, M Jena, B Gowda	Du Pont
44.	EAP 213	Maintenance, characterization and use of EMS of upland variety Nagina 22 for functional genomics in rice-Phase II- MK Kar, P Swain, AK Mukherjee, M Chakraborti, S Saha	DBT
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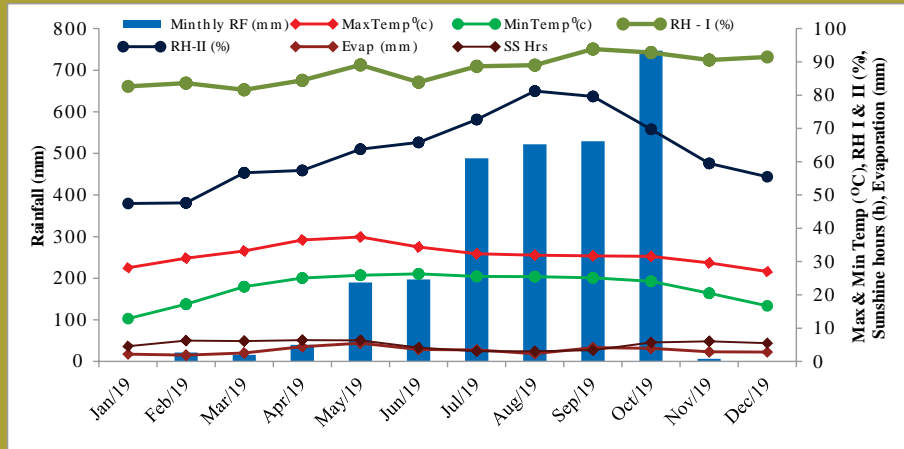
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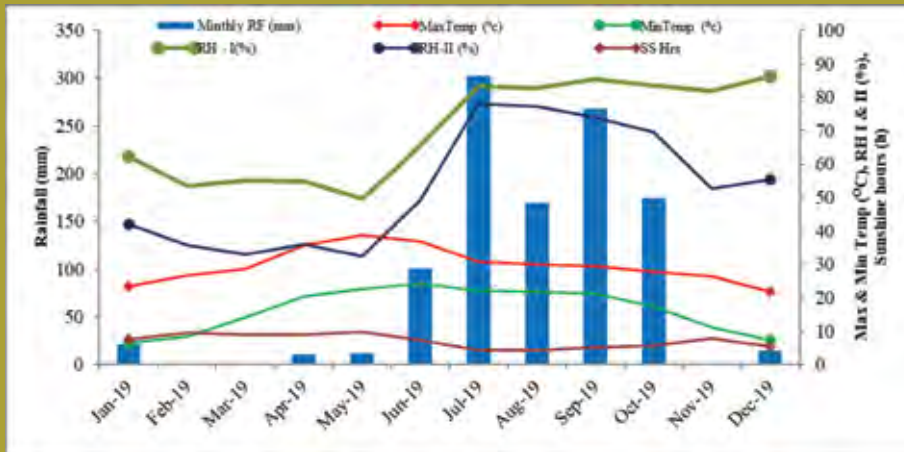
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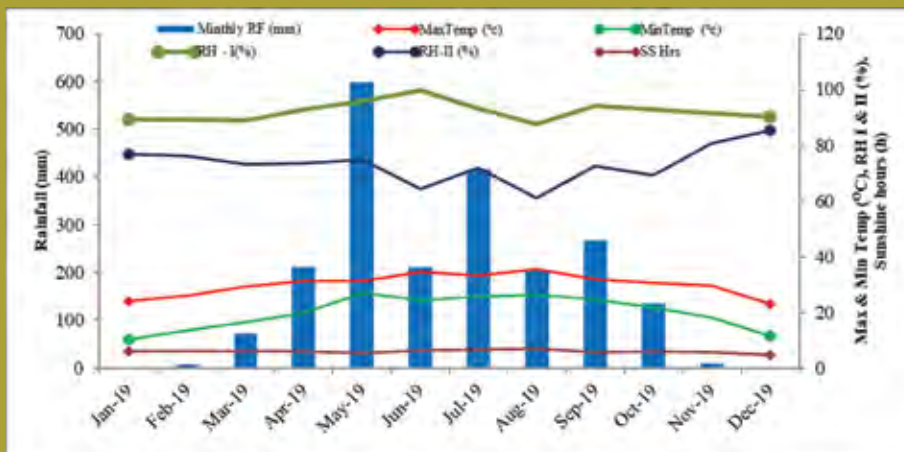
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## ICAR-National Rice Research Institute

(Formerly Central Rice Research Institute)

Cuttack 753006, Odisha, India

Phone: 91-671-2367757, Fax: 91-671-2367663

Email: [director.nrri@icar.gov.in](mailto:director.nrri@icar.gov.in) | [directorccricuttack@gmail.com](mailto:directorccricuttack@gmail.com)

Website: <http://www.icar-nrri.in>



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