Annual Report 2020

भाकृअनुप-राष्ट्रीय चावल अनुसंधान संस्थान

ICAR-National Rice Research Institute

ANNUAL REPORT 2020

NRRI

वार्षिक प्रतिवेदन
Annual Report
2020

भाकृअनुप - राष्ट्रीय चावल अनुसंधान संस्थान
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The morale of farmers, farmwomen and agriculture scientists remained high even during pandemic COVID-19 period. As a result, the agriculture sector only thrived and recorded positive growth rate during the period.

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NRRI

PREFACE

Celebrating 2020-21 as Platinum Jubilee Year of its establishment, the ICAR-National Rice Research Institute (NRRI) has come a long way from facing the challenges of Bengal Famine to achieve record breaking rice production in the country. During its long journey, the institute significantly contributed to famous Green Revolution and helped make India self-sufficient in food grain production. The institute is working with different rice stakeholders in India and abroad. The institute addresses all 17 Sustainable Development Goals (SDGs) through its current research programmes and activities having multi-dimensional approaches benefitting the people of India and scientific community of the world. In its 75 years of journey, the institute has released 143 high yielding rice varieties and three hybrids.

Despite the effect of COVID 19 during major part of 2020, the institute kept thriving and achieving new heights. The institute has developed nine high yielding varieties, out of which seven were released and notified for cultivation in farmers' field and two have been identified by the Variety Identification Committee (VIC). The institute has registered eight unique rice germplasm with National Bureau of Plant Genetic Resources (NBPGR), New Delhi and one rice variety with Protection of Plant Varieties & Farmers' Rights Authority (PPV & FRA), New Delhi. The Institute has also commercialized rice technologies through signing MoUs with 20 entrepreneurs during the year. About 903 field demonstrations for 30 high yielding rice varieties and other technologies in diverse ecosystems of eight states were conducted. During the year, the institute provided 27 agro-advisory services for the farmers, besides serving the interest of more than 1376 visitors including 110 students. Also more than 2292 participants have been trained on different aspects of rice through 102 training programmes. The Institute has published about 146 research papers (more than 70% above NAAS score of 6) in the scientific journals of national and international repute; four books; eight research bulletins, 15 technology bulletins; two training manuals and 30 popular articles.

During the year, the Institute worked on 31 research projects under seven research programmes, 125 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.

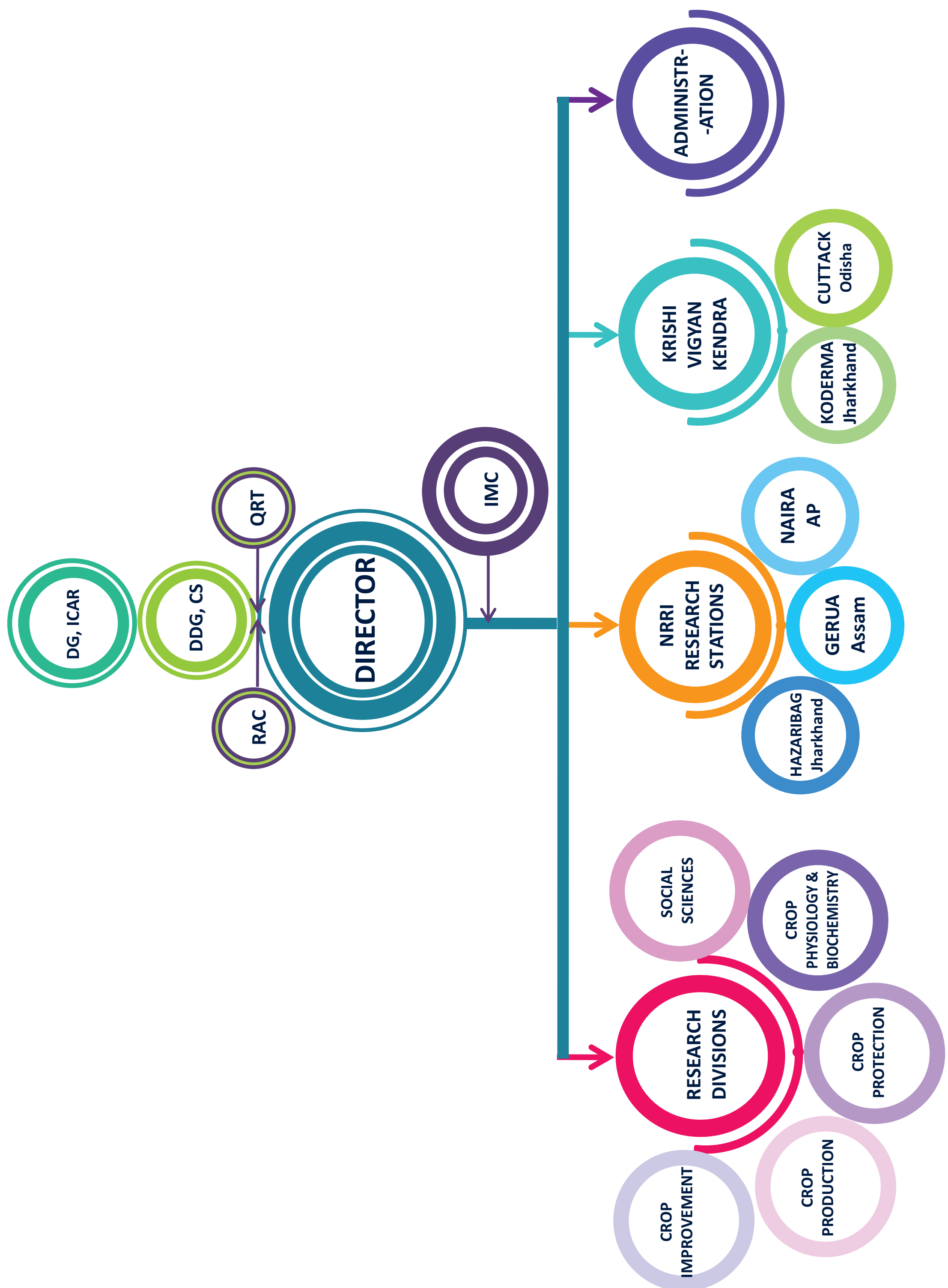
During the year, under the COVID pandemic situation, the institute successfully conducted several institute level (Institute Research Council, Research Advisory Committee, Institute Management Committee) and national level (ICAR- Regional Committee II, Interaction meeting with Agril. Dept. Govt. of WB) meetings, Webinar events, state and national level training programs and hosted 1st Indian Rice Congress (conducted by the Association of Rice Research Workers) on virtual mode.

The Institute sincerely acknowledges the guidance and encouragements received from Dr. T. Mohapatra, Secretary, DARE and Director General, ICAR in guiding various research and development programmes. Sincere thanks are due to Shri Sanjay Singh, Special Secretary, DARE and Secretary, ICAR; Shri B. Pradhan and Shri G. Srinivas, Additional Secretaries, DARE and Financial Advisors, ICAR for their continuous support and guidance. Valuable guidance, encouragement and support received from Dr. SK Datta, Chairman and other esteemed members of Research Advisory Committee (RAC); Dr. TR Sharma, DDG (Crop Sciences), ICAR; esteemed members of Institute Management Committee and Institute Research Council (IRC) are sincerely acknowledged. Thanks are also due to Dr. DK Yadav, ADG (Seeds), Dr. RK Singh, ADG (CC), Dr. Dinesh Kumar, Former ADG (FFC), Dr. YP Singh, ADG (FFC) and other officials of the Council for their constant support and guidance. I sincerely thank the Head of the Divisions, Officer In-Charge of Regional Stations and Administration & 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 members of Publication Committee and Publication Unit for compiling and editing the Annual Report. I sincerely appreciate the efforts and commitment of the staff of Director's Cell and all other staff to serve this premier institute with utmost devotion.

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

(D Maiti)
Director

ORGANOGRAM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SOCIAL
SCIENCES
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PHYSIOLOGY &
BIOCHEMISTRY
CROP
PROTECTION
CROP
PRODUCTION
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IMPROVEMENT

EXECUTIVE SUMMARY

Rice is the primary source of energy for over half of the world's people. It contains decent amounts of fibre, protein, vitamin B, iron and manganese. Accordingly, rice is an important constituent of Food Security Mission of Govt. of India as it plays a vital role against malnutrition in the country. The country grows rice in about 43 million ha area with production of about 118.43 million tons and average productivity of 2.75 t ha^{-1}. However, 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 programms of the institute during 2020 are briefly presented below.

The Crop Improvement Division of the Institute aims at developing novel rice technologies like new varieties and hybrids for different rice ecologies to increase grain yield and improve nutritional quality of rice in order to enhance socio-economic condition of the stakeholders. During the year 2020, seven rice varieties were released and two varieties have been identified. A set of 3000 accessions of rice germplasm/ elite lines/ donors/ varieties/ wild rice were supplied to researchers across the country. As a part of seed production, 38.9 q nucleus seed of 60 varieties, and 333.65 q breeder seed of 49 varieties were produced. Using DHs technology, 12 rice lines were derived and their yield performance was analysed under farmers' field conditions. Besides, 31 QTLs were mapped on the rice chromosomes, identifying several donors for nitrogen use efficiency, higher root biomass for P uptake, narrow (angle) root trait and P uptake.

The Crop Production Division has developed block-wise soil micronutrients maps of Odisha, site specific secondary and micronutrient recommendation, which will enhance the nutrient use efficiency of rice production system. A simplified and farmer friendly colour coded tensiometer has been developed for irrigation management in rice. In conservation agriculture, the higher energy productivity (0.38 kg MJ^{-1}) and energy ratio (8.40) was found in zero tillage plus diversification system. In direct sown rice, application of bispyribac sodium followed by ethoxysulfuron is recommended for efficient weed management. The low-cost *Azolla* pellet making machine has been developed to produce livestock feed. A microbial consortium for *ex situ* decomposition of paddy straw has been developed.

The Crop Protection Division is engaged in basic, strategic and applied research in the field of rice pests and diseases. Keeping sustainability of pest and disease management in focus, the major thrust of research was to search for new sources of resistance and new sources of resistance, which were identified against brown plant hopper (BPH), white backed plant hopper, Asian gall midge, sheath blight, false smut and root knot nematode. A whopping 600 farmers' varieties were phenotyped against BPH and subsequently 104 panel populations were genotyped using 87 molecular markers linked to 34 different BPH resistance genes for marker-trait association and genetic diversity. Distribution of BPH under current and projected climate change scenario was predicted using a species distribution model and genetic analysis of Indian populations of BPH was carried out based on mitochondrial *cox1* and *its1* gene sequences. Seed-priming with *Trichoderma* resulted in higher yield by improving root/shoot length, fresh/dry weight and number of effective tillers per plant in the farmers' field. Integrated Pest Management (IPM) modules have been validated in farmers' field. Novel pesticide mixtures were developed with twin objectives: to combat BPH & yellow stem borer of rice and pesticide resistance.

The crop Physiology and Biochemistry Division is engaged in identifying and developing rice varieties with desirable grain and nutritional quality traits, tolerance to various abiotic streses and iproving photosynthetic efficiency of rice keeping in view the changing climate scenario. Phytic acid (PA) content was estimated in the brown (BR) and milled rice (MR) of 58 NRRI rice varieties where large variation was found in the BR (0.30-2.37 g/100g) and MR (0.20-1.12 g/100g). After milling, the PA content was reduced to 70%. Among the genotypes studied, Khira showed lowest PA (0.30 g/100g), while the highest PA (2.37 g/100g) was found for Phalguni. Reduction of antioxidant capacity along with total phenolic and flavonoid content was observed in parboiled brown rice as compared to raw rice. Amylose content of pigmented rice is generally low as compared to the white rice. In drought tolerance screening, Vandana and Gangavati Ageti were found to be highly tolerant genotype with minimum yield reduction under rainfed condition. One genotype Kamini was identified, which showed similar level of salt-tolerance as Pokkali rice, but with much higher mesophyll Na^+ load, which can potentially reduce the energy cost of salt-tolerance. Presence of *Sub1* QTL in the genetic backgrounds positively influences surface hydrophobicity and thickness of LGF. One important C_4 gene, *pyruvate orthophosphate dikinase* (PPDK) was integrated in rice using transgenic approach. Besides, five chloroplast-targeted bacterial genes were integrated in rice to bypass the photo respiratory mechanism.

The Social Science Division developed an **IN**novative extension model for fast **SP**read of varieties **I**n **R**ice **E**cosystems (INSPIRE 1.0 Model) and validating in farmers field since 2017-18. During 2020, on-farm demonstrations of 30 rice varieties were conducted in 903 farmer's fields covering about 120 ha area in 30 districts of ten states and results average grain yield advantage of 10-20 per cent over local check. Another module, INSPIRE 2.0, was initiated with the collaboration of private institutions, like non-government organizations, farmer producer organizations and corporate social responsibility wings of industries and 20 quintals seed of different varieties were demonstrated and notice about 13% yield advantage. During the 3rd year validation of Self-sufficient Sustainable Seed System for Rice (4S4R) Model, about 1305 quintals of foundation, certified and truthfully labeled seeds of seven popular rice varieties were produced in 35 ha by 79 seed growers in *kharif* 2020. Cost of cultivation of rice were calculated using primary data collected from five states and indicated that farmers used to get moderate remuneration only when imputed value of family labour added to the net returns. Historical data on rice production indicates five-fold increase over 1950s and domestic consumption increased three-fold over 1960s.

NRRI Research Station, Hazaribag developed and promoted 12 multiple stress tolerant lines during 2020. Altogether, 227 diverse germplasm accessions were characterized for multiple stress tolerance. Genetic diversity analysis has been undertaken on a set of 57 drought tolerant lines for selecting parents for crossing programs. Among 49 *gora* rice accessions, 29 were resistant to blast based on first year UBN data. Molecular survey indicated the frequency of *Pi5* (90%) followed by *Pi54/Pi-kh* (35%), *Pib* (6%), and *Pita 2* (2%) in *gora* accessions. Thirty-one new crosses were generated targeting drought tolerance, blast and brown spot resistance and root system architecture. IPM modules for controlling blast, brown spot and false smut disease have been evaluated and demonstrated. The station has been popularizing recently released varieties like IR 64 *Drt1* and Sahbhagidhan, which was taken up in large scale frontline demonstrations (FLDs) in three districts of Jharkhand.

NRRI Research Station, Gerua collected 30 aromatic *Joha* and 97 deep water *Bao* rice from different parts of Assam and evaluated 803 lines during 2020. About 21 q breeder seeds of paddy, 4 kg seeds of summer vegetable and 92 kg seeds of winter vegetables have been distributed amongst 350 beneficiaries of Baksa district under Scheduled Tribe Component. Biotech KISAN Hub was established with three KVKS as partnering institutes in the aspirational district of Baksa, Barpeta and Darrang with 102, 100 and 147 beneficiary farmers, respectively. Demonstration of high value low volume vegetable cultivation in both season and scientific backyard rearing of poultry and duckery and integration of paddy cum fish cultivation were conducted in all three districts.

कार्यकारी सारांश

संसार के आधे से अधिक जनसंख्या को उपलब्ध होने वाली ऊर्जा का प्राथमिक स्रोत चावल है। इसमें रेशा, प्रोटीन, विटामिन बी, लौह और मैंगनीज की अच्छी मात्रा है। इसलिए, सरकार के खाद्य सुरक्षा मिशन का एक महत्वपूर्ण घटक चावल है तथा भारत में यह फसल कुपोषण के विरुद्व एक महत्वपूर्ण भूमिका निभाता है। देश में लगभग 43 मिलियन हेक्टेयर भूमि में चावल की खेती की जाती है जिससे लगभग 118.43 (2019) मिलियन टन चावलका उत्पादन होता है और जिसकी औसत उत्पादकता 2.75 टन (2019–20) प्रति हेक्टेयर है। चावल की खेती करने वाले किसानों को कम आय, प्राकृतिक संसाधनों का क्षरण, जलवायु परिवर्तन से संबंधित जैविक और अजैविक दोनों प्रकार के तनावों का सामना करना पड़ता है, जिससे निपटने के लिए सर्वोत्तम अनुसंधान की आवश्यकता है। भाकृअनुप–राष्ट्रीय चावल अनुसंधान संस्थान, कटक ने इन चुनौतियों को दूर करने के लिए अपने अनुसंधान कार्यसूची का पुनः अवलोकन किया है। वर्ष 2020 के दौरान संस्थान के विभिन्न अनुसंधान कार्यक्रमों की मुख्य उपलब्धियां संक्षेप में नीचे प्रस्तुत की गई हैं।

संस्थान की फसल उन्नयन प्रभाग का उद्देश्य विभिन्न चावल पारिस्थितिकी के लिए चावल की नई और संकर किस्मों और चावल प्रौद्योगिकियों का विकास करके उपज बढ़ाना है तथा विभिन्न हितधारकों की सामाजिक–आर्थिक स्थिति में उन्नति करने के लिए चावल की पोषण गुणवत्ता में सुधार करना है। वर्ष 2020 में चावल की सात किस्में विमोचित हुईं तथा दो किस्में विमोचन के लिए पहचान की गई हैं। धान जननद्रव्य की 3000 प्रविष्टियां/श्रेष्ठ वंश/दाताओं/किस्में देशभर के अनुसंधानकर्ताओं को आपूर्ति की गई। वर्ष 2020 के रबी के दौरान, 60 किस्मों से 38.9 क्विंटल केंद्रक बीज तथा 49 किस्मों से 333.65 क्विंटल प्रजनक बीज का उत्पादन किया गया। डबल हाप्लाएड तकनीक का उपयोग करते हुए 12 चावल वंश विकसित की गई तथा किसानों के खेतों में उनकी उपज क्षमता का मूल्यांकन किया गया। इसके अतिरिक्त, चावल के गुणसूत्रों पर 31 क्यूटीएल का मैपिंग किया गया, नाइट्रोजन प्रयोग दक्षता के लिए कई दाताओं की पहचान की गई तथा फोस्फोरस अधिग्रहण के लिए अधिक जड़ आदि पर कार्य किया गया।

फसल उत्पादन प्रभाग ने ओडिशा के प्रखंड–वार मिट्टी सूक्ष्मपोषकतत्व तथा स्थान विशिष्ट, माध्यमिक और सूक्ष्म पोषक संस्तुतियों के आधार पर मानचित्र विकसित किया है जिससे चावल उत्पादन प्रणाली की पोषक उपयोग क्षमता में वृद्धि होगी। धान फसल में सिंचाई प्रबंधन के लिए एक सरलीकृत और किसान अनुकूल रंग कोडित टेन्सियोमीटर विकसित किया गया है। संरक्षण कृषि में, उच्च ऊर्जा उत्पादकता (0.38 किलोग्राम एमजे$^{-1}$) और ऊर्जा अनुपात (8.40) शून्य जुताई एवं विविधीकरण प्रणाली में पाया गया था। सीधी बुआई चावल में, इथोक्सिसल्फ्यूरोन का प्रयोग एवं उसके बाद बाइस्पिरीब्रैक सोडियम का प्रयोग खरपतवार प्रबंधन के लिए अनुशंसित किया जाता है। पशुओं की खाद्य चारा के उत्पादन करने के लिए कम लागत वाली एजोला टिकिया बनाने की मशीन विकसित की गई है। धान के पुआल को खेत से बाहर अपघटन के लिए एक माइक्रोबियल डीकोस्पोजिंग कंसोर्टियम विकसित किया गया है।

फसल सुरक्षा प्रभाग की कृषि कीटविज्ञान, पादप रोगविज्ञान, सूत्रकृमिविज्ञान एवं कृषि रसायन इकाइयां धान की फसल में लगने वाले कीट एवं बीमारियों पर मूलभूत, रणनीतिक एवं प्रायोगिक अनुसंधान कार्य में प्रयासरत है। कीट और रोग प्रबंधन की स्थिरता को ध्यान में रखते हुए, अनुसंधान का प्रमुख लक्ष्य प्रतिरोधिता के नए स्रोतों की खोज करना था तथा भूरा पौध माहू, सफेद पीठवाला पौध माहू, एशियाई गाल मिज, आच्छद अंगमारी, आभासी कंड तथा जड़ गांठ सूत्रकृमि के विरुद्ध प्रतिरोधिता के नई स्रोतों की पहचान की गई। भूरा पौध माहू प्रतिरोधिता के लिए आनुवंशिक आधार को समझने हेतु भूरा पौध माहू के विरुद्ध किसानों की 600 चावल किस्मों को फेनोटाइप किया गया और बाद में 87 आणविक मार्करों का उपयोग करके 104 पैनल संख्या को जीनोटाइप किया गया जिनका संबंध 34 विभिन्न भूरा पौध माहू प्रतिरोधता जीन और आनुवंशिक विविधता से है। एक प्रजाति वितरण मॉडल का उपयोग करके वर्तमान और अनुमानित जलवायु परिवर्तन परिदृश्य के तहत भूरा पौध माहू का वितरण का पूर्वानुमान किया गया और भारतीय भूरा पौध माहू की संख्या की आनुवंशिक विश्लेषण माइटोकॉन्ड्रियल कॉक्स 1 और आईटीएस1 जीन अनुक्रमों के आधार पर किया गया था। किसानों के खेत में ट्राइकोडर्मा के साथ बीज–प्राइमिंग प्रयोग ने प्रति पौधे जड़/शूट की लंबाई, ताजा/सूखा वजन और अधिक दौजियों की संख्या में सुधार हुआ जिससे उच्च उपज प्राप्त हुई। किसानों के खेत में एकीकृत कीट प्रबंधन मॉड्यूल को मान्य किया गया है। नई कीटनाशक मिश्रण को दोहरे उद्देश्यों, चावल में लगने वाले भूरा पौध माहू तथा पीला तना छेदक का मुकाबला करने एवं कीटनाशक प्रतिरोधिता के लिए विकसित किया गया है।

फसल कार्थिकी एंव जीवरसायन प्रभाग को एनआरआरआई द्वारा विकसित चावल की 58 किस्मों के भूरा चावल और मिल्ड चावल में फाइटिक एसिड की मात्रा का अनुमान लगाया, जिसमें भूरा चावल में (0.30–2.37 ग्राम/100 ग्राम) और मिल्ड चावल (0.20–1.12 ग्राम/100 ग्राम) में बड़ी भिन्नता पाई गई। मिलिंग के बाद, फाइटिक एसिड की मात्रा 70 प्रतिशत तक कम हो गई थी। अध्ययन किए गए जीनप्ररूपों में से क्षीरा ने सबसे कम फाइटिक एसिड (0.30 ग्राम/100 ग्राम) दिखाया, जबकि फाल्गुनी में सबसे ज्यादा फाइटिक एसिड (2.37 ग्राम/100 ग्राम) पाया गया। कुल फेनोलिक और फ्लेवोनोइड सामग्री के साथ एंटीऑक्सिडेंट क्षमता में कमी कच्चे चावल की तुलना में भूरा चावल में देखी गई थी। सफेद चावल की तुलना में रंगीन चावल की एमाइलोज मात्रा आम तौर पर कम होती है।

सूखा सहिष्णुता परीक्षण में, वंदना एवं गंगावती अगेती वर्षाश्रित परिस्थिति के तहत अत्यधिक सहिष्णु जीनप्ररूप पाए गए एवं उपज नुकसान भी बहुत कम हुआ। एक जीनोटाइप कामिनी की पहचान की गई, जिसमें पोकली चावल के समान नमक–सहिष्णुता का स्तर दिखाई दिया लेकिन बहुत अधिक मेसोफिल सोडियम भार के साथ, जो संभवतः नमक–सहिष्णुता की ऊर्जा लागत को कम कर सकता है। आनुवंशिक पृष्ठभूमि में सब 1 (*Sub1*) क्यूटीएल की उपस्थिति एलजीएफ की सतह हाइड्रोफोबिसिटी और मोटाई को सकारात्मक रूप से प्रभावित करती है। एक महत्वपूर्ण सी4 जीन पाइरुवेट ओर्थोफोस्फेट डिकिनेस (पीपीडीके) को ट्रांसजेनिक उपाय से चावल में एकीकृत किया गया। इसके अलावा, पांच क्लोरोप्लास्ट–लक्षित बैक्टीरियल जीन को प्रकाश श्वसन तंत्र को नजरअंदाज करने के लिए चावल में एकीकृत किया गया।

सामाजिक विज्ञान प्रभाग ने चावल पारितंत्र (INSPIRE 1-0) में किस्मों के प्रसार के लिए अभिनव विस्तार मॉडल 2017–18 के दौरान विकसित किया गया तथा किसानों के खेतों में इसे मान्य किया गया था। वर्ष 2020 के दौरान, दस राज्यों के 30 जिलों में 903 किसानों के खेतों में लगभग 120 हैक्टर की भूमि में 30 चावल किस्मों का प्रदर्शन आयोजन किया गया तथा स्थानीय चेक की अपेक्षा 10–20 प्रतिशत अधिक औसत उपज मिली, बेहतर फसल स्थापना, बेहतर दौजियां हुई एवं कीट तथा रोग प्रकोप कम हुआ। INSPIRE 2-0 में भाकृअनुप/राज्य कृषि विश्वविद्यालयों की प्रौद्योगिकियों के प्रसार के लिए नवोन्मेष विस्तार उपाय का आरंभ गैर सरकारी संगठनों, किसान उत्पादक संगठनों तथा उद्योगों के कॉरपोरेट सोशल विंग के सहयोग से किया गया तथा विभिन्न किस्मों के बीस क्विंटल बीजों का प्रदर्शन किया गया। चावल आत्मनिर्भर स्थायी बीज प्रणाली (4S4R) मॉडल के अपने मान्य के तीसरे वर्ष के दौरान 2020 के खरीफ में 79 बीज उत्पादकों द्वारा सात लोकप्रिय चावल किस्मों से लगभग 1305 क्विंटल फांउडेशन, प्रमाणित एवं विश्वसनीय बीज उत्पादित किया गया था। चावल की खेती की लागत की गणना पाँच राज्यों से एकत्र किए गए प्राथमिक आंकड़ों का उपयोग करके की गई थी जिससे यह पता चला कि किसानों को मध्यम पारिश्रमिक तभी मिलता था, जब शुद्ध रिटर्न में पारिवारिक श्रम का मूल्य वर्धित मूल्य जोड़ा जाता था। चावल उत्पादन पर ऐतिहासिक डेटा से पता चलता है कि 1950 के दशक में पांच गुना वृद्धि हुई और 1960 के दशक में घरेलू खपत में तीन गुना वृद्धि हुई है।

केंद्रीय वर्षाश्रित उपरारुंभूमि चावल अनुसंधान केंद्र, हजारीबाग ने वर्ष 2020 के दौरान 12 बहु तनाव सहिष्णु वंशों का विकास किया और बढ़ावा दिया। कुल मिलाकर, 227 विविध जननद्रव्य प्रविष्टियों का बहु तनाव सहिष्णुता के लिए लक्षण वर्णन किया गया। सत्तावन सूखा सहिष्णुता वंशों की एक सेट पर संकर कार्यक्रम हेतु जनकों के चयन के लिए आनुवंशिक विविधता विश्लेषण किया गया। उनचास गोरा चावल प्रविष्टियों में से, यूबीएन डेटा के प्रथम वर्ष के आधार पर 29 प्रध्वंस प्रतिरोधी पाए गए। आण्विक सर्वेक्षण से पता चला कि गोरा चावल प्रविष्टियों में *Pi5* की आवृत्ति 90% है, *Pi54/Pi-kh* की आवृत्ति 35% है, *Pib* की आवृत्ति 6% तथा Pita 2 की आवृत्ति 2% है। सूखा सहिष्णुता, प्रध्वंस एवं भूरा धब्बा प्रतिरोधिता तथा जड़ प्रणाली आकार को लक्षित करते हुए 31 नई संकरें विकसित की गईं। विभिन्न एकीकृत फसल प्रबंधन विकल्पों का मूल्यांकन किया गया। एकीकृत नाशकजीव प्रबंधन माड्यूलों का मूल्यांकन प्रध्वंस, भूरा धब्बा एवं आभासी कंड रोग के लिए किया गया तथा उनका प्रदर्शन किया गया। केंद्र अभी हाल ही में विमोचित चावल किस्में जैसे आईआर 64 डीआरटी1 एवं सहभागीधान को लोकप्रिय कर रहा है जिसे झारखंड के तीन जिलों में बड़े पैमाने पर अग्रिम पंक्ति प्रदर्शन किया गया।

क्षेत्रीय वर्षाश्रित तरारुंभूमि चावल अनुसंधान केंद्र, गेरुआ ने वर्ष 2020 के दौरान असम के विभिन्न भागों से 30 सुगंधित जोहा जाति के वंश तथा 97 गहरा जल बाओ चावल का संग्रह किया गया तथा 803 वंशों का मूल्यांकन किया गया। धान के प्रजनक बीज का 21 क्विंटल बीज, चार किलोग्राम ग्रीष्म सब्जी तथा नौ किलोग्राम शीतकालीन सब्जी के बीज अनुसूचित जनजाति घटक के तहत बक्सा जिले के 350 हितधारकों में वितरित किया गया। बायोटेक किसान हब की स्थापना तीन कृषि विज्ञान केंद्र जिलों बक्पा, बारपेटा और दारंग के आकांक्षी जिलों के रूप में क्रमशः 102, 100 और 147 लाभार्थी किसानों के साथ की गई। तीनों जिलों में दोनों मौसमों में होने वाली उच्च मूल्य किंतु कम लागत वाली सब्जी की खेती का प्रदर्शन, पश्चप्रांगण मुर्गी और बत्तख पालन के वैज्ञानिक तरीके, धान सह मछली की खेती की एकीकरण का प्रदर्शन किया गया। वर्ष 2019–20 में बोरो में 5970 किलोग्राम प्रजनक बीज और 3477 किलोग्राम विश्वसनीय बीज का उत्पादन तथा खरीफ 2020 के दौरान 9864 किलोग्राम प्रजनक बीज और 1793 किलोग्राम विश्वसनीय बीज का उत्पादन किया गया।

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- Germplasm Exploration & Conservation
- Super Rice
- Hybrid Rice
- Bio-fortified Rice
- Climate Smart Varieties

2
- Input Management
- Resource Conservation Technologies
- Harnessing Microbial Potentials
- Climate Resilience
- Farm Mechanization
- Integrated Farming Systems

3
- IPM
- IDM
- Stored Grain Pests
- Pesticide Formulation
- Pesticide Residue Management

4
- Stress Tolerant Rice
- Low Glycemic Rice
- Grain Quality
- C_4 Rice

5
- Development and Testing of New Extension Models
- Socio-economic Studies
- Rice Value Chain
- Technology Dissemination and Feedback Sharing
- Training and Advisory Services

NRRI & SUSTAINABLE DEVELOPMENT GOALS

1 NO POVERTY | 2 ZERO HUNGER | 3 GOOD HEALTH AND WELL-BEING | 4 QUALITY EDUCATION | 5 GENDER EQUALITY | 6 CLEAN WATER AND SANITATION | 7 AFFORDABLE AND CLEAN ENERGY

AT A GLANCE : YEAR 2020

NRRI IN NUMBERS

1. **7** Rice Varieties Released & **2** Varieties Identified for Release
2. **8** Rice Unique Germplasm Registered with ICAR-NBPGR
3. **1** Rice Variety Registered with PPV & FRA
4. **20** Technologies Commercialized
5. **146** Peer Reviewed Publications
6. **10** States Covered through Extension Activities
7. **30** New Rice Varieties Demonstrated in Farmers Field
8. **1376** Visitors Visited the Institute during the Year
9. **102** Trainings Conducted
10. **56** Agromet Advisory Bulletins Released
11. **27** Agro Advisory Services Released
12. **903** Field Demonstrations Conducted

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

INTRODUCTION

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, the NRRI regional station, Gerua for problems in rainfed lowlands and flood prone ecologies and NRRI regional station, Naira for coastal ecology. 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 the 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 seven km from the Cuttack railway station on the Cuttack-Paradeep State Highway. The institute lies approximately between 850 55'48" E to 850 56'48" longitudes and 200 26'35" N to 200 27'35" N latitudes with the general elevation of the farm being 24 m 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

The Crop Improvement Division of the Institute aims at developing novel rice varieties, hybrids and other related 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 staff strength of 24 scientists and 21 technical personnel operates 11 institute research projects and 39 externally aided projects. During the year, seven rice varieties were released by CVRC and two varieties have been identified by VIC for release and eight unique rice germplasm have been identified and registered as donors at ICAR-NBPGR, New Delhi. A total of about 3000 accessions of rice germplasm / elite lines / donors/ varieties/wild rice were supplied to researchers of all over the country for utilisation in their crop improvement programmes. As a part of seed production, 38.9 q nucleus seed of 60 varieties, and 333.65 q of breeder seed of 49 varieties were produced. Besides, few QTLs were mapped on the rice chromosomes, identifying several donor lines for nitrogen use efficiency, higher root biomass for P uptake. Using DHs technology, as many as 12 rice lines were derived and their yield performance was analysed under farmers' field conditions. Besides classical and applied genetics and plant breeding, latest genome editing technology, CRISPR/ Cas9 technology was also used for editing yield related gene *IPA1*.

Exploration, characterisation and documentation of rice germplasm

One exploration programme was undertaken for collection of wild rice (*Oryza nivara* and *O. rufipogon*) in collaboration with ICAR-NBPGR base Centre, Cuttack during 1-6 December, 2020 from Dhenkanal and Jagatsinghpur districts of Odisha. A total of 44 accessions of *O. rufipogon* (22), *O. nivara* (18) and *O. spontanea* (4) were collected.

About 400 germplasm accessions of Jeypore Botanical Survey (JBS) collection were characterised phenotypically based on various qualitative and quantitative characteristics as per DUS descriptors. Wide range of variation among the accessions for the traits fertility percentage (35.85%) followed by effective tillers (22.69 %) was observed (Table 1.1). AC 43316 and AC 21531 were observed with the shortest (85.33 cm) and the tallest plant height (185.33 cm), respectively. Earliest flowering was AC 20839 (53 days) while flowering in AC 43360 took 103 days. Among the yield contributing traits, average number of tillers was 7.0 with the highest value 13.0 was observed in AC 21759. Panicle length ranged from 18.67-38.0 cm with the lowest and highest value observed in AC 44263 and AC 21670, respectively. The 100-grain weight ranged from 1.1-4.12 g with highest recorded was in AC 21166.

Maintenance breeding, quality seed production and seed technology research for enhancing rice yield

Nucleus seed and breeder seed production

Panicle progeny rows of 60 varieties were grown for maintenance breeding. After thorough rouging and rejection of probable variants in progeny lines, true to the type panicles were collected for next generation nucleus seed production. The remaining lines were harvested, threshed separately and after table top examination, pure lines were bulked as nucleus seed. In 2019-20, 38.90 q nucleus seed of 60 varieties were produced (Table 1.2). The bulk nucleus seeds will be used to produce breeder seed of the same variety. About 333.65 q of breeder seed, consisting of 49 varieties were produced as per DAC indent (Table 1.3).

Participatory seed production

Under ICAR seed production in agriculture crops, farmers' participatory seed production was undertaken at farmers' field in-agreement (MoU) with Mahalaxmi Krushak Manch, Mahatma Gandhi Farmer's Club and Achyutananda Farmer's Producer Company Ltd. The seeds of six popular varieties (Pooja, Sarala, Gayatri, Swarna *Sub1*, CR Dhan 307 and CR Dhan 309) were produced in three villages namely, (i) Baripada, Jagatsinghpur, (ii) Bhandilo, Kendrapara and (iii) Nischintakoili, Cuttack. This seed production programme was jointly performed with the involvement of farmers under the supervision of NRRI scientists. Proper monitoring of farmers' field and suggestive measures were followed to fit the seed standard. Seed quality testing was done at NRRI, Cuttack. About 600.90 q seed could qualify as TL seed standard, which was procured by the institute and sold to the farmers.

Table 1.1. Variability observed for quantitative traits.

Sl. No.	Characteristic	Mean	Range	C.V. (%)
1	Plant height (cm)	147.86	85.33-185.33 (AC 43316-AC 21531)	10.32
2	Leaf length (cm)	38.86	25.33– 68.67 (AC 21452-AC 21767)	19.39
4	No. of effective tillers	7.0	3.00-13.00 (AC 21125 – AC 21759)	22.69
5	Panicle length (cm)	25.45	18.67-38.00 (AC 44263 – AC 21670)	9.51
6.	Days to 50% flowering	69.98	53-103 (AC 20839-AC 43360)	10.25
7.	Fertility (%)	60.26	18.26-97.98 (AC 21100-AC 36454)	35.85
8.	Days to maturity	95.79	81-133 (AC 34975-AC 43360)	22.46
9.	100-grain weight (g)	2.43	1.1-4.12 (AC36459-AC 21166)	16.44

Table 1.2. Nucleus seed production during 2019-20.

Sl. No.	Variety	*kharif*, 2019 (q)	*rabi*, 2020 (q)	Total (q)
1	Annada	0.30	2.50	2.80
2	Ciherang *Sub1* (Bina Dhan 11)	0.06	0.20	0.26

3	CR 1009	0.08	0.00	0.08
4	CR 1009 *Sub1*	0.08	0.00	0.08
5	CR Boro Dhan 2	0.03	0.15	0.18
6	CR Dhan 10	0.01	0.00	0.01
7	CR Dhan 100 (Satyabhama)	0.06	0.07	0.13
8	CR Dhan 101 (Ankit)	0.00	0.12	0.12
9	CR Dhan 200	0.00	0.07	0.07
10	CR Dhan 201	0.04	0.08	0.12
11	CR Dhan 202	0.00	0.06	0.06
12	CR Dhan 203	0.52	2.50	3.02
13	CR Dhan 204	0.07	0.08	0.15
14	CR Dhan 205	0.00	0.08	0.08
15	CR Dhan 206 (Gopinath)	0.06	0.00	0.06
16	CR Dhan 207 (Srimati)	0.00	0.05	0.05
17	CR Dhan 209	0.03	0.08	0.11
18	CR Dhan 300	0.14	0.10	0.24
19	CR Dhan 301	0.05	0.00	0.05
20	CR Dhan 303	0.35	2.50	2.85
21	CR Dhan 304	0.06	0.08	0.14
22	CR Dhan 305	0.06	0.08	0.14
23	CR Dhan 306	0.00	0.08	0.08
24	CR Dhan 307 (Maudamani)	2.21	3.00	5.21
25	CR Dhan 309	0.00	0.08	0.08
26	CR Dhan 310	0.98	2.50	3.48
27	CR Dhan 311 (Mukul)	0.03	0.17	0.20
28	CR Dhan 405	0.04	0.08	0.12
29	CR Dhan 407	0.06	0.00	0.06
30	CR Dhan 409	0.09	0.00	0.09
31	CR Dhan 500	0.07	0.00	0.07
32	CR Dhan 505	0.07	0.00	0.07
33	CR Dhan 601	0.57	2.50	3.07
34	CR Dhan 800 (Swarna MAS)	2.50	0.00	2.50
35	CR Dhan 801	0.07	0.00	0.07
36	CR Sugandh Dhan 907	0.06	0.00	0.06
37	CR Sugandh Dhan 908	0.06	0.00	0.06
38	CR Sugandh Dhan 909	0.06	0.00	0.06
39	CR Sugandh Dhan 910	0.06	0.00	0.06
40	Dharitri (CR 1017)	0.08	0.00	0.08
41	Gayatri (CR 1018)	0.08	0.00	0.08
42	Geetanjali	0.05	0.10	0.15
43	Heera	0.00	0.06	0.06
44	Improved Lalat	0.32	2.00	2.32
45	Improved Tapaswani	0.00	0.06	0.06
46	Khitish	0.21	0.00	0.21
47	Luna Sampad	0.06	0.00	0.06
48	Luna Suvarna	0.06	0.00	0.06
49	Naveen	0.25	0.15	0.40
50	Phalguni	0.00	0.10	0.10
51	Pooja	2.50	0.00	2.50
52	Ratna	0.00	0.06	0.06
53	Sahbhagidhan	0.00	0.08	0.08
54	Samba *Sub1*	0.08	0.00	0.08
55	Sarala	0.08	0.00	0.08
56	Shatabdi	1.10	2.60	3.70
57	Swarna *Sub1*	2.50	0.00	2.50
58	Tapaswani	0.00	0.05	0.05
59	Utkalprava (CR 1030)	0.06	0.00	0.06
60	Varshadhan	0.07	0.00	0.07
	Total	16.43	22.47	38.90

Table 1.3. Breeder seed production during 2019-20.

Sl. No.	Variety	*kharif*, 2019 (q)	*rabi*, 2020 (q)	Total (q)
1	CR 1009 *Sub1*	4.05	-	4.05
2	CR 1014	0.10	-	0.10
3	CR Dhan 300	0.90	0.30	1.20
4	CR Dhan 303	2.00	3.80	5.80
5	CR Dhan 304	0.90	0.12	1.02
6	CR Dhan 307	20.40	3.60	24.00
7	CR Dhan 409	6.30	-	6.30
8	CR Dhan 505	11.10	-	11.10
9	CR Dhan 800	27.00	-	27.00
10	CR Dhan 801	3.00	-	3.00
11	CR Dhan 907	0.90	-	0.90
12	CR Dhan 909	1.95	-	1.95
13	CR Sugandh Dhan 3	0.75	-	0.75
14	Dharitri	0.45	-	0.45
15	Gayatri	6.60	-	6.60

16	Geetanjali	0.60	0.10	0.70
17	Ketekijoha	0.45	-	0.45
18	Luna Sampad	0.65	-	0.65
19	Luna Suvarna	0.45	-	0.45
20	Moti	0.60	0.20	0.80
21	Nua Chinikamini	0.20	-	0.20
22	Nua Kalajeera	0.45	-	0.45
23	Pooja	46.50	-	46.50
24	Ranjit	0.45	-	0.45
25	Samba *Sub1*	6.15	-	6.15
26	Sarala	4.95	-	4.95
27	Swarna *Sub1*	129.30	-	129.30
28	Varshadhan	4.95	-	4.95
29	Annada		1.10	1.10
30	Ciherang *Sub1*		0.25	0.25
31	CR Boro Dhan 2		0.70	0.70
32	CR Dhan 100		0.15	0.15
33	CR Dhan 101		0.15	0.15
34	CR Dhan 201		0.35	0.35
35	CR Dhan 203		9.20	9.20
36	CR Dhan 204		1.65	1.65
37	CR Dhan 205		1.05	1.05
38	CR Dhan 206		0.85	0.85
39	CR Dhan 207		0.15	0.15
40	CR Dhan 310		4.18	4.18
41	CR Dhan 311		0.90	0.90
42	CR Dhan 405		0.20	0.20
43	CR Dhan 601		1.00	1.00
44	Improved Lalat		9.80	9.80
45	Khitish		2.60	2.60
46	Naveen		4.30	4.30
47	Ratna		1.70	1.70
48	Sahbhagidhan		0.15	0.15
49	Shatabdi		3.00	3.00
	Total	**282.10**	**51.55**	**333.65**

Identification of QTLs/candidate genes associated with seed vigour

Genome wide association study for seed vigour was carried out in a panel of 216 genotypes comprising landraces and improved lines. Two candidate genes on chromosome 4, *viz., LOC_Os04g24340.1* (encoding for a phytase) and *LOC_Os04g56330.4* (encoding for a putative ABC transporter) were identified to be putatively associated with seed vigour.

Gene diversity studies in the NRRI varieties using gene-based markers

Forty gene-based SSR markers were designed for well characterized cloned genes associated with yield in rice. NRRI varieties were genotyped with the gene-based markers. In addition to the genetic diversity for genes governing yield-attributing traits, the study also resulted in the identification of few variety-specific gene-based markers and also some rare alleles for yield-related traits among NRRI varieties. The study has implications in the DNA fingerprinting of NRRI varieties; and also, in the future breeding programmes once the breeding values of rare alleles are estimated.

Utilization of wild and cultivated gene pool of rice for resistance to biotic stresses

Wide hybridization for developing pre-breeding lines

Populations involving *O. sativa* (cv. Swarna, Annapurna, Naveen and CR Dhan 307) and three accessions of *O. rufipogon* (AC 100005, AC 100015 and AC 100444) have been developed and are at advanced backcross generations. *O. longistaminata* (AC 110404) has been used in hybridization programme and F_1s have been developed for further evaluation. Twenty five fertile disomic wide cross derivatives of Savitri / *O. brachyantha* (AC 100499) / Savitri in BC_3F_6 generation were evaluated under field condition. Out of 25 entries, five genotypes *i.e.* CR 3993-281-11-33-13-2, CR 3993-298-15-41-3-15, CR 3993-98-13-12-5-18, CR 3993-107-25-12-15, CR 3993-55-11-5-9-13-2-1 and CR 3993-13-21-3-17-2 were identified as promising entries. Five disomic fertile lines of wide cross derivatives *i.e.* CR 4156-1-56-2-24, CR 3993-33-58-3-1, CR 3993-514-2-15, (IET 28287) CR 3993-4-1-19-31 of *O. brachyantha* (AC 100499) derivatives and CR 3426-2-25 of *O. nivara* (AC 100476) were nominated for AICRIP trial.

Development of chromosome segment substitution lines (CSSLs)

Chromosome segment substitution lines (CSSLs) are useful genetic stocks where the complete diverse genome of a particular genotype (wild or cultivated) is represented through overlapping segments in the background of a cultivated genotype. These may be used for constructing genetic map, precise mapping of QTLs, genes or study of QTL or gene interactions and functional genomics. Among the several wild species derived pre-breeding lines developed, one cross involving high yielding *indica* rice genotype CR Dhan 307 (Maudamani) and wild rice *O. rufipogon* (AC 100444) was chosen for development of CSSL (Fig. 1.1, Fig. 1.2, and Fig. 1.3). Out of the cross transferable molecular markers identified in the earlier study, polymorphic marker combinations distributed all over the genome of the two species were identified. The markers are now systematically utilized in stepwise manner for identifying the CSSLs through genotyping of BC_1F_1, BC_2F_1 and BC_3F_1 generations to identify the CSSL sets. The population has now been advanced to BC_3F_1.

Mapping of stable QTL for sheath blight resistance

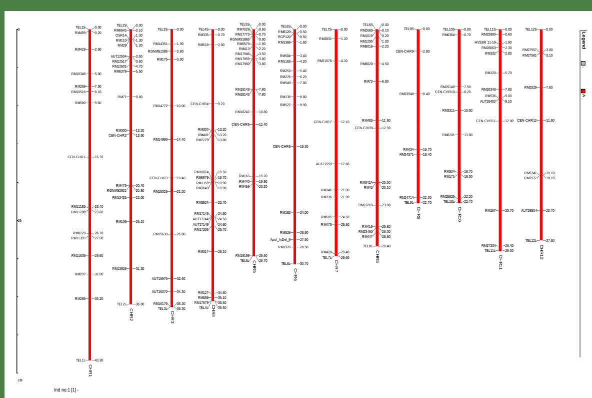


Fig. 1.1. Identification of genome-wide polymorphic markers between Maudamani and O. rufipogon (AC 100444).

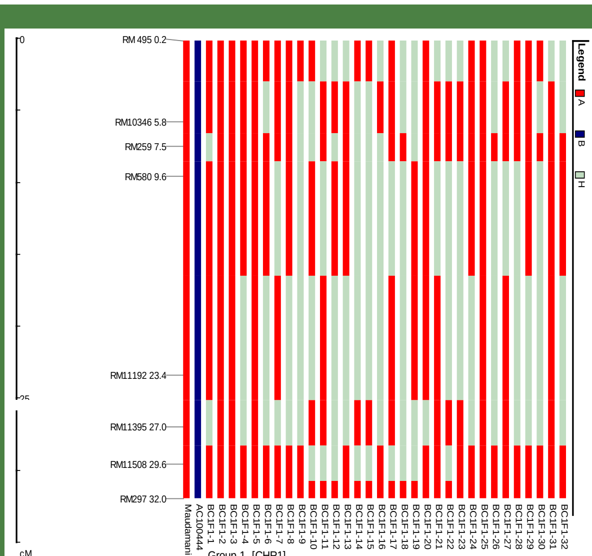


Fig. 1.2. Graphical genotyping of BC_1F_1 generation of Maudamani and *O. rufipogon* (AC 100444).

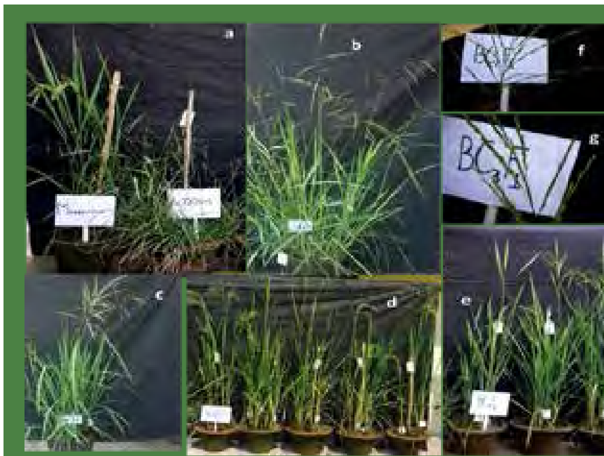


Fig. 1.3. Representative Photographs of different generations of Maudamani and *O. rufipogon* (AC 100444) cross. a. parental lines; b. F_1 plants; c. BC_1F_1 plants; d. BC_2F_1 plants; e. BC_3F_1 plants; f. representative panicle of BC_2F_1 plants and g. representative panicle of BC_3F_1 plants.

Sheath blight disease of rice causes substantial crop losses and resistance sources are rare. A moderately resistant genotype CR 1014 was identified and hybridized with highly susceptible genotype Swarna *Sub1*. In the F_2 and $F_{2:3}$ generations, three QTLs (*qShB-1.1, qShB-1.2* and *qShB-1.3*) were mapped in chromosome-1. In F_5 generation of the same cross and F_4 generation of an alternative mapping population (Tapaswini / CR 1014), only the major QTL *qShB-1.1* was recorded consistently with high LOD score (> 5.0). This stable QTL was co-localized with *qShB1* reported earlier from *Oryza nivara*. A typical leucine rich repeat (LRR) motif containing gene *(LOC_Os01g65650)* and a chitin-inducible gibberellin-responsive protein coding non-LRR gene *(LOC_Os01g65900)* located

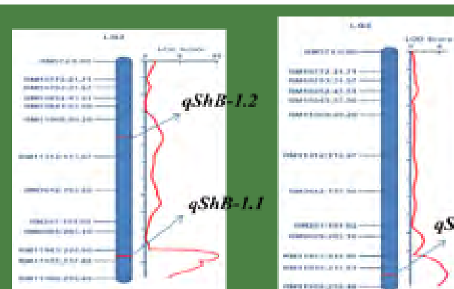


Fig. 1.4. Graphical representation of quantitative trait loci (QTLs) for sheath blight (ShB) resistance mapped in linkage group 2 (LG2) of chromosome 1 from the contrasting cross of Swarna *Sub1* × CR 1014. a: QTLs *qShB-1.1* and *qShB-1.2* mapped in F_2 generation; b: the QTL *qShB-1.1* was again mapped in $F_{2:3}$ generation.

within *qShB-1.1* with high expression levels in leaf and shoot were predicted as putative candidate genes among others (Fig. 1.4). Nearly 27.8% reduction in relative lesion height was recorded among several near isogenic lines of Swarna *Sub1* carrying the QTL region from CR 1014.

Increasing combined N and P use efficiency in the mid-early rice genotype

Looking to improve nitrogen (N) and phosphorus (P) use efficiency in the mid-early group of rice, a cross was initiated between nitrogen use efficient CR Dhan 310 and low P tolerant CR Dhan 801 during *kharif*, 2017 and *rabi*, 2018. In subsequent years, two back crosses were attempted with NUE efficient line CR Dhan 310. During the first and second back cross generations, all lines were screened for the *PSTOL1* gene with markers K46-1 and K29-3. Consequently, the selected first and second-generation back cross genotypes were also tested for drought-tolerant yield QTLs (*DTY1.1, DTY 2.1, DTY 3.1*) and *Sub1* QTL as CR Dhan 801 has harboured all these QTLs. Among the 1600 lines tested with foreground markers in BC_1 and BC_2, 100 lines were selected and advanced to the next generation. Wherein, 17 lines were BC_1F_6 and 83 were of BC_2F_6. Those 100 backcross lines were also tested to confirm the presence of all mentioned QTLs/genes using QTL/gene-specific SNP markers. The SNP has grouped the genotypes into three major clusters and further sub-clustered them into 12 (Fig. 1.5). The *PSTOL1* donor (CR Dhan 801) was found to be clustered with 20 lines (blue coloured cluster). Among them, genotype no. 46 and 51 of BC_1F_6 were found to have *PSTOL1, DTY 1.1, DTY 3.1*, and *Sub1*. While one of the lines of BC_2F_6 was found to have all *DTY* QTLs and *Sub1* similar to the donor CR Dhan 801 (Genotype no. 1) without *PSTOL1*. However, all these 100 advanced breeding lines will be tested for NUE, PUE, drought and submergence tolerance.

Screening of popular rice varieties of Odisha and identification of novel traits in low P condition at the seedling stage

Sixty five rice genotypes were evaluated under hydroponics in 0.5 ppm of phosphorus and P deficient soil (pH 5.3, 3 ppm of P) during *rabi,* 2020 and *kharif,* 2020, respectively. Among them, a landrace IC 459373, Shankar, and Sidhanta registered high root and shoot biomass of par with Dular and Kasalath (Fig. 1.6). Besides, these genotypes were screened based on a non-destructive method to identify novel geometric traits under P deficient conditions. Novel geometric traits such as minimum enclosing circle, convex hull, and calliper length were promising in differentiating tolerant and susceptible genotypes. The shoot length, stem dry weight, 4th and 5th leaf weight, average root diameter, shoot and root dry weight could be utilized as substitute parameters in the absence of a non-destructive phenotyping method. The conglomeration of both non-destructive and essential destructive characters would facilitate in identification of low P tolerant rice cultivars at an earlier stage.

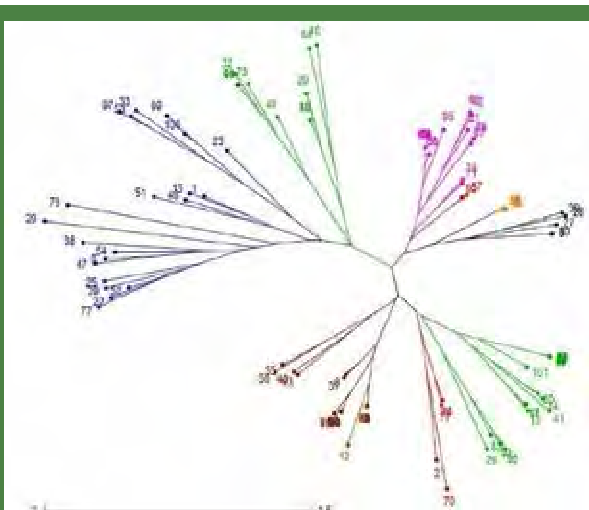


Fig. 1.5. Unrooted tree using the unweighted neighbour-joining method depicting clustering pattern of 100 selected BC_1F_6 and BC_2F_6 lines in response to QTL specific SNP markers.

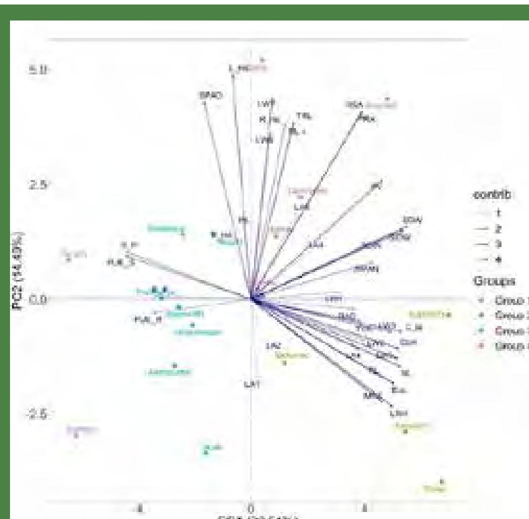


Fig. 1.6. PCA biplot of 18 genotypes based on the variance in 38 morpho-physiological and geometric traitsmeasured under P stress environment, explained in two axes.

Identification of donors for narrow (angle) root trait under moisture stress condition

A mapping panel consisting of 260 rice genotypes was tested under an artificial controlled tank during *rabi,* 2020 to study the root angle under limited water conditions (Fig. 1.7). Irrigation was withheld after a month of sowing to increase the moisture deficient condition. Leaf rolling was observed in regular intervals, at maximum stress (-60 kPa) leaf rolling was observed in the highest number of genotypes. At -60 kPa, plants were uprooted and root traits related to deep roots were observed. Genotypes DZ78 and DA12 registered RDR (ratio of deep rooting) of 0.39 and 0.54 with 81.20 cm and 66.8 cm of root length, respectively.

Fig. 1.7. Rice germplasm evaluated for narrow root in artificial cemented tank.

Developing multiple stress-tolerant Lalat MAS for drought, submergence, low P and bacterial leaf blight with eight QTLs/genes by introgressing DTY 1.1, DTY 2.1, DTY 3.1, Sub1 and PSTOL1 with xa5, xa13, and Xa21

Multiple stress-tolerant genotype of medium duration group is highly required in the present climate-changing scenario that suits to grow in both dry and wet seasons (Table 1.4). Therefore, a region specific rice variety Lalat having three bacterial leaf blight (*xa5, xa13* and *Xa21*) genes has been selected to introgress with multiple QTLs/genes responsible for abiotic stress such as drought, submergence and low phosphorus tolerant donor CR Dhan 801 which is the first multiple abiotic stress tolerant rice variety released from NRRI having tolerance to drought and submergence with inherent low P tolerance. This program was executed under the institute program as well as NICRA. The crossing program was initiated during *kharif,* 2017 and subsequent backcrosses were carried out. In each back-cross population, genotypes were screened with respective foreground markers of *DTY1.1, DTY 2.1, DTY 3.1, Sub1* and *PSTOL1* (K46-1, K29-1 & K29-3). In BC_2F_2, 2205 lines and in BC_3F_2, 3395 lines were genotyped with foreground markers. Among the 2205 lines of BC_2F_2, three lines that carried all desired QTLs were backcrossed with the recurrent parent to generate 3395 BC_3F_2. Besides, 213 lines of BC_2F_4 and BC_3F_2 were selected based on foreground markers as well as genotyped with respective SNP markers of *DTY1.1, DTY 2.1, DTY 3.1, Sub1, xa5, xa13,* and *Xa21*. The SNP markers have classified the 213 genotypes into four major clusters (1 to 4). Cluster 1 was further sub-clustered into two (red and green colour (Fig. 1.8). The recurrent parent (Lalat MAS) (brown circled) and their close resemblance with different gene combinations were grouped under red colour clade. While the donor CR Dhan 801 (red circled) is grouped under red clade. Among all the lines genotyped with SNP, line number 48 (BC_3F_2) and 155 (BC_2F_4) (black circled) had all desired QTLs (7 no.) except *qDTY3.1*. Lines with different combination of genes for drought, submergence, low P and bacterial blight genes were grouped in red clade with donor CR Dhan 801. Similarly, line number 194, 180, 27, 204, and 146 (black circled) were grouped with 6 QTLs such as *DTY 1.1, DTY 2.1, sub1, xa5, xa13,* and *Xa21*. The selected advanced breeding lines will be tested for drought, submergence tolerance, PUE and resistance against bacterial leaf blight in *rabi,* 2021.

Table 1.4. List of top performers of different durations evaluated during *kharif,* 2020.

Breeding lines	Duration (days)	Grain yield (t/ha)
4345850	100-110	4.1
1320-3-2-1-1-4-1-2-1	100-110	4.9
1345-2-3-4-3-1	115-120	8.3
1369-1-3-2-1-1-3	115-120	8.2
14155-4-1-3-1-5-1-1-2	125-135	8.1
1442-4-1-3-1-3-7-1-3	125-135	7.6
1442-4-1-1-2-1-3-1-5	140-145	6.5
1404-9-1-1-3-3-2-1-6	140-145	6.3

Evaluation of CSSLs for drought and submergence

A potential CSSL tolerant to drought (*O. meridionalis* in Curinga background) was crossed with IR 64 *Sub1* and Swarna *Sub1* to introgress drought tolerance from CSSLs into popular rice variety through marker-assisted backcrossing SNP genotyping using Cornell 6-7K Infinium Rice Array. BC_3F_3 introgressed lines

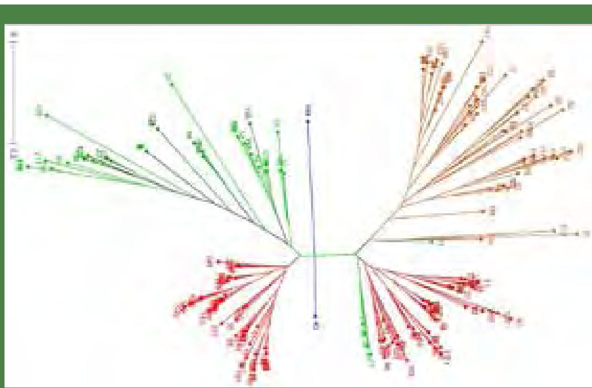


Fig. 1.8. Unrooted tree using the unweighted neighbour-joining method depicting clustering pattern of 213 selected BC_2F_4 and BC_3F_2 lines in response to QTL specific SNP markers.

in the background of IR 64 *Sub1* and Swarna *Sub1* were evaluated for yield under drought. Genotype AC 18844 and AC 18761 in the background of IR 64 *Sub1* registered 1.31 and 1.10 t ha^{-1} grain yield under stress conditions. Similarly, AC 18630 recorded 0.39 t ha^{-1}yield, while IR 64 *Sub1* and Swarna *Sub1* produced a yield of 0.36 and 0 t ha^{-1}, respectively, under drought.

Evaluation of advanced breeding lines of different duration category

During *kharif,* 2020, 322 advanced breeding lines of 19 very early to early, 226 mid-early, 63 medium, and 14 late group genotypes were evaluated for yield in 2.5 m^2 plot under transplanted condition. The grain yield of the early group ranged between 1.1 and 4.30 t ha^{-1} followed by the mid-early group which recorded 0.8 to 8.3 t ha^{-1}, the medium had 1.4 to 8.1 t ha^{-1}, and late group yielded between 2.3 and 6.5 t ha^{-1}. Among them, 197 lines (9 early, 134 mid-early, 45 medium, and 9 late group) were forwarded for further evaluation in *rabi,* 2021.

Rice varieties notified during 2020

CR Dhan 308 {IET 25523 (CR 3505-7-1-1-1-2-1)}, a derivative of the cross IR 36/Vijetha out performed BVC in all three years in the Central zone with 19, 7, and 20 % yield advantage, respectively. Therefore, this entry was recommended for release in the irrigated ecology of the Central Zone.

CR Dhan 313 {(IET 25489 (CR 3511-3-2-2-5-1-1)}, derived from the cross IR 36/Surendra outperformed BVC in the Central Zone with 9, 6, 8% superiority. Therefore, this entry was recommended for release in the irrigated ecology of the Central Zone.

Genetic improvement of rice for aroma, nutrition and grain quality

The goal of the project was to develop genotypes with superior grain quality combined with good plant type and comparable yields. Accordingly, there were four objectives to focus the breeding program on aroma, nutrition, grain type and specialty traits like antioxidant traits in rice.

Development of aromatic, high yielding, disease resistant genotypes with short /long slender grains

Purified sorts of *Gobindabhog* were subjected to sensory analysis after cooking. *Gobindabhog* Type 1 and Type 3 were identified as superior in sensory analysis and have been used for further improvement. EMS treated mutant populations of *Gobindabhog* at M_1 and M_0 stages were grown in *kharif,* 2020 with the aim to identify a dwarf or semi-dwarf mutant of the popular landrace. *Banspatri,* a popular aromatic landrace of Western Odisha was subjected to purification following the panicle progeny method and simultaneous improvement for its disease resistance. Twenty new combinations of crosses were attempted for creation of variation under recombination breeding for aromatic varieties. Seventy five breeding lines developed from earlier crosses were grown and evaluated for their superior yields and aroma. Out of these, 18 aromatic long and short grained rice were evaluated for grain quality characters such as hulling (%), milling (%), head rice recovery (HRR) (%), grain length, grain breadth, water uptake, alkali spreading value, kernel length after cooking. Hulling (%) varied from 67.0 (Pusa Basmati 1121) to 79.5 (Nua Chinikamini), while milling (%) varied from 56.5 (Pusa Basmati 1121) to 72.0 (Nua Chinikamini). HRR (%) ranged from 47.0 (Basmati 370) to 67.0 (Nua Dhusara). The kernel length was highest in Pusa Sugandha 3 (7.59 mm) and lowest in Nua Chinikamini. Similarly, kernel breadth highest in Pant Sugandha Dhan 21 (1.9 mm) and lowest in Pusa Basmati 1121 (1.41 mm). Volume expansion ratio was 3.75 for all the varieties. Similarly, alkali spreading value was 3.0 in all the tested varieties. Kernel length after cooking was lowest in Nua Chinikamini (6.9 mm) and highest in Pusa Basmati 6 (13.0 mm). Water uptake was lowest in T-23 (70) and highest in Poornobhog (208). Demonstration of 10 aromatic varieties released by the institute was undertaken for the visitors like farmers, millers, state officials and other dignitaries.

Development of high yielding genotypes with higher grain zinc and/ or protein content

CR Dhan 315 (IET 27179: CR 2826-1-1-2-4B-2-1) has been identified for CVRC release by VIC in 2020 for the states of Gujarat and Maharashtra as bio-fortified high zinc rice variety (Fig. 1.9). It contains an average 25 ppm zinc in milled rice in Western Zone (zone VI). It has medium duration (125-135 days), semi-dwarf plant type (110 cm), long panicle (28 cm) with medium slender grain and good cooking quality. It is suitable for irrigated and favorable shallow rainfed ecology. National average of grain yield of this variety was 5054 kg ha^{-1}.

Fig. 1.9. Bio-fortified rice variety CR Dhan 315 with high zinc (25 ppm).

Up scaling of bio fortified varieties

Breeders' seed indent received for the bio fortified varieties CR Dhan 310 and CR Dhan 311 were 44.10 q and 3.0 q, respectively, during 2020. The breeders' seed indent for the high protein rice CR Dhan 310 was nearly six times higher than the last year *i.e.* 2019. CR Dhan 311 (Mukul) with 10.1% grain protein, 20 ppm Zn content and with average 4.5 t ha^{-1} yield was notified in 2019. Nearly five quintals of truthfully labelled seeds of both the varieties were sold/ distributed for demonstration to the farmers for promoting the varieties.

Breeding for specialty traits in rice grains with emphasis on pigmentation and end use

Thirty five pigmented (purple, black & variegated) rice genotypes were collected from different states of India for assessing variation for the trait and its utilization in breeding (Fig. 1.10).

The F_6 generation of the dwarf black rice derivative of *Chakhao* were advanced through panicle progeny method for fixation of the breeding lines for their black grain and agro-morphological features. Nearly

Fig. 1.10. Four out of 35 pigmented genotypes collected from different parts of India.

15 different crosses were attempted using the dwarf black grained derivatives for creation of new variation under genetic improvement of the trait. Third cycle of selection for identification of the best aromatic black grained sort of *Chakhao* from seven populations of the landrace was undertaken during *kharif,* 2020. It is under purification in collaboration with the Green Foundation, Imphal, Manipur. Panicle progeny row of the selected plants was followed for the purpose.

Breeding towards climate resilient genotypes for rainfed shallow lowland

CR Dhan 410 (Mahamani; CR 2683-45-1-2-2-1) was notified in the Gazette, Department of Agriculture and Co-operation, Ministry of Agriculture for cultivation in the states of Odisha. The variety was recommended for cultivation in the rainfed shallow lowlands of the state. The variety was developed from the breeding materials of cross CRLC/AC 38700. The mean yield of the variety was 5.052 t ha^{-1} in the state based on farmers' field demonstrations and AICRIP trials. The genotype is strongly photosensitive with average maturity duration of 155 days. It possesses long slender grain with a long and heavy panicle (Fig. 1.11). The seed test weight is 24 g. The variety 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. It has good hulling, milling and head rice recovery as compared to check and qualifying varieties. It possesses intermediate amylose content, long slender grain and other desirable grain quality parameters.

A total of 360 BC_1F_1 seeds carrying *Sub1+Xa21+xa13+xa5+qDTY1.1+qDTY2.1+qDTY3.1* were produced during *kharif*, 2019. CR 2682-7-1-2-1-2, CR 4039-2-1-2-1-1, CR 4039-2-1-1-2-1, CR 4039-1-2-3-1-2-1, CR 3933-39-2-1-2-1, CR 3145-4-1-2-3-3-2, CR 3145-4-1-3-2-1-2 and CR 2582-3-35-2-1-1-2 were promoted to AVT1 SDW based on the performance in the trial IVT SDW during *kharif,* 2019. One shallow lowland elite culture, CR 3987-3-1-1-1-1 was promoted to AVT1 RSL trial.

Fig. 1.11. Rice variety, CR Dhan 410 (A) at maturity stage (B) panicles and (C) kernels.

Breeding for development of near isogenic lines carrying *Sub1* + *Xa21* + *xa13* + *xa5* + *qDTY1.1* + *qDTY2.1* + *qDTY3.1* in the background of Swarna was started during 2017-18. Two promising lines, CR 4050-121-28-13-1 and CR 4050-121-28-13-2 carrying *Sub1* + *Xa21* + *xa13* + *xa5* were hybridized with CR Dhan 801. The F_1 generation seeds were generated containing *Sub1* + *Xa21* + *xa13* + *xa5* + *qDTY1.1* + *qDTY2.1* + *qDTY3.1* genes/QTLs. The presence of the target genes/QTLs were confirmed in the multiple F_1 from the genotyping results of *Sub1* + *Xa21* + *xa13* + *xa5* + *qDTY1.1* + *qDTY2.1* + *qDTY3.1* during *kharif*, 2019. True F_1 plants carrying the gene combination of *Sub1* + *Xa21* + *xa13* + *xa5* + *qDTY1.1* + *qDTY2.1* + *qDTY3.1* was hybridized with variety Swarna to produce BC_1F_1 seeds. A total of 360 BC_1F_1 seeds were produced.

The entries namely CR 2682-7-1-2-1-2, CR 4039-2-1-2-1-1, CR 4039-2-1-1-2-1, CR 4039-1-2-3-1-2-1, CR 3933-39-2-1-2-1, CR 3145-4-1-2-3-3-2, CR 3145-4-1-3-2-1-2, CR 2582-3-35-2-1-1-2 were promoted to AVT1 SDW based on the performance in the trial IVT SDW. Similarly, CR 3987-3-1-1-1-1 nominated to rainfed shallow lowland trial (IVT RSL) has been promoted to AVT1 RSL. Another 18 entries showing more than 6 t ha^{-1} under station trial were nominated to the 1st year AICRIP lowland trials.

Genetic enhancement for multiple stress tolerance in rice for coastal ecosystem

Detection of QTLs for salinity tolerance

QTLs for salinity tolerance at seedling stage were detected using donor AC 41585 from backcross derived population from IR 64/AC 41585. A total 28 QTLs for salinity tolerance at seedling stage in relation to chlorophyll fluorescence and photosynthetic efficiency were detected. Thirteen QTLs for Fv/Fm (maximum quantum yield in PSII), 5 QTLs *for* ΨEo (efficiency with which a PSII trapped electron), 8 QTLs for ΦEo (quantum yield of electron transport flux from Q^{-} to PQ pool), one each for ΦRo (quantum yield of reduction in the end electron acceptors of PSI) and PI (performance index on absorption basis) and two QTLs for SSI-Na-K (stress susceptibility index for Na/K concentration ratio in shoot) were detected. Development of nine backcross derived mapping population for reproductive stage salinity tolerance using donors such as CSR 27, Pokkali (AC 41585), Binadhan 10, Patnai, etc. are in progress.

Detection of QTLs for combined stress tolerance

Rahaspunjar, a landrace tolerant to salinity and waterlogging was used to develop RIL populations from the cross Swarna/Rahaspunjar. This population was phenotyped for combined stress (waterlogging with saline water– $4dSm^{-1}$) tolerance. High-throughput DNA sequencing of 150 RILs and parents was performed on Illumina HiSeq platform. Average 2.8 million SNPs were found in parents and RILs. All Polymorphic SNPs detection between parents was filtered with less than 30% gap and λ^2 testing. Polymorphic high-quality SNPs (around 150) were used in linkage mapping covering 2134.9 cM map distance distributed among 12 rice chromosomes. Seven additive QTLs were detected for Fv/Fm (maximum quantum yield of primary PS II photochemistry), Y-NO (quantum yield of non-regulated energy dissipation) and qL (coefficient of photochemical quenching) with PVE varies from 11.315% to 34.489% in LOD score of 2.9 to 8.42 (Table 1.5). Two pleiotropic QTLs were found on chromosome 1 and 11 for Fv/Fm and Y-NO. Development of eight backcross derived mapping populations for detection of multi-environmental and multi-background robust QTLs for multiple stress tolerance (salinity and waterlogging) using donors such as Rahaspunjar, AC 39416a, Luna Suvarna and Patnai are in progress.

Table 1.5. QTLs for combined stress (water logging with saline water) tolerance detected using RIL population from Swarna/Rahaspunjar.

Sl. No	QTL	Chromo-somes	Position (cM)	Left Marker	Right Marker	LOD	PVE (%)	Add
1	qFv/Fm-S-1-1	1	16	SNP15	SNP2	3.2946	16.260	-0.025
2	qFv/Fm-S-11-1	11	54	SNP426	SNP409	2.9098	11.315	0.018
3	qY-NO-S-1-1	1	16	SNP15	SNP2	4.5429	33.301	0.042
4	qY-NO-S-10-1	10	177	SNP405	SNP389	6.7489	32.856	0.045
5	qY-NO-S-10-2	10	203	SNP389	SNP407	8.4214	34.489	0.044
6	qY-NO-S-11-1	11	56	SNP426	SNP409	3.3855	17.248	-0.026
7	qqL-NS-5-1	5	78	SNP200	SNP193	3.0056	29.929	0.043

Evaluation of elite saline tolerant lines for water logging tolerance

Fifty elite genotypes with tolerance to salinity including tolerant and susceptible checks (Sabita, CR Dhan 508, Swarna, Savitri and Rahaspunjar) were evaluated at normal condition and at water logging (~50cm) condition. Eleven genotypes yielded higher than Sabita and CR Dhan 508 and eight genotypes showed higher yield stability index (YSI) and stress tolerance index (STI) than Sabita and CR Dhan 508 (Table 1.6).

Harnessing heterosis for enhancing yield and quality of rice

Heterosis is a solitary means of exploiting absolute hybrid vigour in crop plants. Given its yield advantage and economic importance, several hybrids have been commercialized in more than 40 countries, which create huge seed industry world wide. So far, India has commercialized 117 (37-public and 80-private sector) *indica* hybrids for different ecologies and duration (110-150 days) which accounted 6.8% of total rice area in the country. ICAR-NRRI has been pioneering to start with the technology, acquired prerequisite parental lines (CMS and restorer lines) from IRRI, Philippines during 1979 and capitalized under interdisciplinary mode to develop parents and hybrids for irrigated and shallow submergence ecosystem. Over decades of rigorous efforts, institute could develop more than 50 CMS lines, above one hundred 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 more sustainable and amenable to the stakeholders, institute is working on hybrid breeding with various specific product goals.

Maintenance of source nursery

A source nursery with 1167 diverse parental genotypes were constituted, maintained and characterized; out of these, 81 lines harbour Rf (*Rf3* and *Rf4*) genes which were utilized in crossing programmes.

Development of CMS, restorer and hybrid combinations

All together 1206 test crosses involving 11 CMS were evaluated and 38 heterotic hybrids (>15% heterosis over respective duration hybrid checks), 17 promising maintainers and 105 good restorers (> 85% fertility restoration) could be identified. Total 82 mid-early to medium duration hybrids with >15% yield superiority over respective duration checks, US 314 and Rajalaxmi were re-evaluated under station trials. Besides, mid–early duration CMS, CRMS 57A (WA) under genetic background of CR-210B (CRMS31B/25B) having dual stigma exsertion and 32% out-crossing was developed and 83 other sterile crosses (BC_1-BC_{10}) with enhanced seed producibility and sustainability were advanced.

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 is advanced to BC_2F_3; salinity and submergence tolerance in IR42266-29-3R (restorer line) were advanced to BC_3F_1. Introgression of BPH resistant/tolerant in improved-IR42266-29-3R and Imp-CRMS 32A were advanced to BC_2F_2. Pyramiding of long stigma trait in CRMS 31A and CRMS 32A from wild species donor *O. longistaminata* was advanced to BC_3F_4. Genetically fixed lines with long stigma were started making conversion into new CMS, the

Table 1.6. Evaluation of saline tolerant genotypes for water logging tolerance.

Genotypes	Parentages	Control (5-10 cm)				Water logging (45-55 cm)				Stress tolerant index (STI)	Yield stability index (YSI)
		Plant height (cm)	Panicle length (cm)	Tiller no.	Yield/ plant (g)	Plant height (cm)	Panicle length (cm)	Tiller no.	Yield/ plant (g)		
RIL-SP-207	Savitri/ AC39416a	139.2	23.0	17.0	32.50	145.2	25.6	16.0	31.60	1.828	0.972
RIL-SP-211	Savitri/ AC39416a	128.2	25.5	13.6	42.98	140.1	23.9	15.3	32.11	2.457	0.747
RIL-SP-164	Savitri/ AC39416a	116.3	21.3	9.6	30.60	102.0	22.8	11.4	29.06	1.583	0.949
RIL-SP-225	Savitri/ AC39416a	79.7	21.8	12.7	29.16	99.6	23.1	15.9	28.14	1.460	0.965
RIL-SP-160	Savitri/ AC39416a	146.5	46.0	8.4	38.03	159.0	25.5	9.0	28.07	1.900	0.738
IET 25101 (CR2459-23-2-1-1-S-B1-2-B-1)	Gayatri/ Rahaspunjar	116.0	21.7	10.9	27.69	150.5	23.7	11.7	26.53	1.307	0.958
RIL-SP-157	Savitri/ AC39416a	123.6	27.8	10.0	26.29	139.7	24.7	7.3	25.12	1.175	0.955
DH-SP-1-9	Savitri/ AC39416a	103.2	22.4	11.4	24.86	117.5	23.7	12.6	23.97	1.060	0.964
RIL-SP-85	Savitri/ AC39416a	137.2	24.3	12.7	37.12	141.3	27.9	9.6	22.31	1.474	0.601
IET 27051 (CR 2851-S-1-B-4-1-1-1-1)	Gayatri/SR 26B	126.5	22.1	9.0	22.64	127.3	24.2	11.9	21.86	0.881	0.965
RIL-SR- 204	Swarna/ Rahaspunjar	135.4	23.1	10.8	26.89	152.3	21.6	9.9	20.98	1.004	0.780
CR Dhan 508		92.2	23.8	11.0	26.95	113.1	23.2	11.6	19.79	0.949	0.734
Sabita		128.5	24.4	10.6	25.19	121.0	23.5	14.0	18.92	0.848	0.751
Mean		118.2	24.0	11.0	24.98	130.1	23.5	10.6	15.69		

population was advanced to BC_1F_1 which recorded ~60% outcrossing. Partial restorers (PR), Gayatri and Mahalaxmi were stacked which could restore >80.0% fertility in derivative three-line hybrids; and BC population of Akshaydhan, Azucena (BC_3F_5), INH 10001 and NP 801(BC_2F_5) were advanced. Introgression of WC genes in partial restorer but good combiner inter-sub specific line SR 11-3-1 (*ixj*) from Khawo Hawm (donor) was advanced to BC_2F_1 generation.

Development of heterotic pool

Altogether 192 good combining and genetically diverse lines (48 maintainers and 144 restorers) were phenotyped over seasons and locations. They will be genotyped with 1K SNP platform (IRRI platform).

Restorer and maintainer breeding

Total 4571 single plant progenies (F_3 to F_{12}) of 127 crosses (AxR, RxR and BxB) were evaluated and 37 of those were utilized. Six random mating populations (RMP) of parents (4 maintainers, 2 restorers) were advanced to 9^{th} RMP and 2 *inter-sub specific* MAGIC (B and R; each with 10 parental genotypes) were advanced to IC3F1.

Speed breeding and breeding modernization strategy adoption

The field rapid generation advance (RGA) facility was used (compact spacing and solitary tillers) for rapid fixation of segregating loci in breeding populations. Altogether, 113 breeding populations (44 maintainers and 69 restorers), BC_2-BC_5 were advanced with reduction of 30-35 days maturity duration. Besides, electronic data collection and their management were also adopted.

Development of Iso-cytorestorer

A total of 21 F_1s of 7 iso-cytorestorer of 27P63 were evaluated under Test Cross Nursery (*rabi,* 2020), where 9 F_1s out yielded (5.29%-15.20%) the parental check.

Seed production of parents/hybrids

A total of 753.0 kg truthfully labeled (TL) seeds of 38 hybrids including three released, Rajalaxmi (162.0 kg), Ajay (184.0 kg) and CR Dhan 701 (115.0 kg) were produced. Besides, 174.0 kg breeder seeds of 13 CMS, CRMS 31A (68.0 kg) and CRMS 32A (51.0 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 4 CMS lines (CRMS 53A, CRMS 54A, CRMS 55A, CRMS 56A) and two hybrids (CRHR 102, CRHR 103) were developed. Besides, 2 RILs of hybrids, CRMS 31B/CRL 22R and CRMS 31B/CRL 23R were phenotyped; data are now being utilized for excavating genomic region responding to heterosis in rice.

Development of new generation rice (NGR) for breaking yield ceiling

CR Dhan 314: This variety has been identified by CVRC for irrigated areas of Odisha and Bihar state in 2020 (Fig. 1.12). Basically, it is a new generation rice (NGR) derived from the cross of CR 3724-1 / TJ 171-1 (CR 2668-6-7). One of the parents is derived from tropical *japonica* (TJ 171-1) and the other is *indica*. It matures in 130-135 days with slightly raised height (111.0 cm), strong culm and long bold grains. It has got very high yield potential of 8.72 t ha^{-1} and shown average yield of 6.63 t ha^{-1} in eastern zone (Zone III) in three-year trials. It is highly resistant to false smut, moderately susceptible to leaf blast and neck blast. Similarly, it is resistant to leaf folder and moderately resistant to stem borer (dead heart).

CR Dhan 602: This variety has an average yield of 5.79 t ha^{-1} and yield potentiality of 9.4 t ha^{-1}. The maturity duration of the variety is 154-163 days with semi-dwarf plant type. The culture is non-lodging type with a special quality of long slender grains, which will be highly beneficial for the farmers. It is moderately resistant to leaf blast, sheath blight and sheath rot; resistant to plant hopper (predominantly WBPH) and moderately resistant to stem borer (DH).

Fig. 1.12. CR Dhan 314 in dough stage.

Evaluation of elite cultures for NGR traits related to grain yields

Four hundred and fifty rice genotypes of different ecologies were evaluated for NGR traits such as tiller number hill^{-1}, panicle length, panicle weight, grain numbers panicle^{-1}, flag leaf area, etc. The varieties like Nua Dhusara, Sonamani, Pusa Sugandh 4, Pravati, Mahanadi, ADT-51, Nua Kalajeera, Rajendra Dhan 2 are having panicle length >30 cm. The tiller number hill^{-1} is more than 15 in varieties like ADT-38, Savitri *Sub 1*, MTU 1075, Dhanalaxmi, Bhagirathi, Gayatri, PR 114, Ranjeet. The panicle weight is >5.0 g in varieties such as R-Mahsuri, Mahalaxmi, Indravati, CR Dhan 501, CR Dhan 508, Maudamani, Golak, Jogen, Purnendu, Upahar, Padmanath etc. The varieties like Kanchan, RTN 24, WGL 32183, ADT 45, Sampad, ADT 39 and Mahendra are having >250 grains panicle^{-1}. The genome estimated breeding values of IR 17A1193 (6.98), IR 16A3884 (6.86), CR Dhan 304 (6.51), IR 17A2164 (6.39) and IR 17A2213 (6.37) were utilised for selection of parents in collaboration with IRRI.

Constitution of core set of tropical japonica germplasm of rice

A set of 590 accessions with control cultivars, were evaluated for 15 quantitative and 2 qualitative traits (17) for three years during *kharif*, 2014-2016 with appropriate management practices for selection of the most appropriate parental genotypes for improving rice productivity and breaking yield ceiling. Robustness of core was confirmed using tests *viz*., Mann Whitney Wilcoxon (MWC) test, Levene's test, Mean difference percentage (MD%), the coincidence rate (CR%) and variable rate (VR%); Shannon-Weaver (1949) was used as a measure of the phenotypic diversity of each trait. A genetically diverse core set of 64 genotypes was developed by employing Power Core software with 594 TJ genotypes. Approximately, 10% of entire 590 TJ genotypes were selected for core collection (Fig 1.13).

Genetic improvement of rice with novel NGR attributes along with acceptable grain quality and biotic stress tolerance

AYT 2: Fifty-four very high yielding advanced generation fixed genotypes were evaluated under station trial with large plot size (15 m^2) with two replications, along with three checks *viz*., established (IR 64, CR Dhan 206, Naveen) and NGR (CR Dhan 307). Among the top five, CR 3856-44-22-2-1-11-4-4-5(6.16 t ha^{-1}) topped the list with 44.4% yield increment over the check followed by CR 3856-44-22-2-1-11-4-1-1(6.04 t ha^{-1})), CR 3856-44-22-2-1-11-4-3-1(5.89 t ha^{-1}), CR 4334-2-1-1(5.7 t ha^{-1}) and CR 3967-51-2-1-1-1(5.67 t ha^{-1}) with 42.9%, 39.6%, 35.2% and 34.6% yield increment over the check, respectively.

Among the best genotypes, CR 3856-44-22-2-1-11-4-4-5 was endowed with the most of the desirable NGR traits (Fig. 1.14) *viz*., little raised plant height (115.7

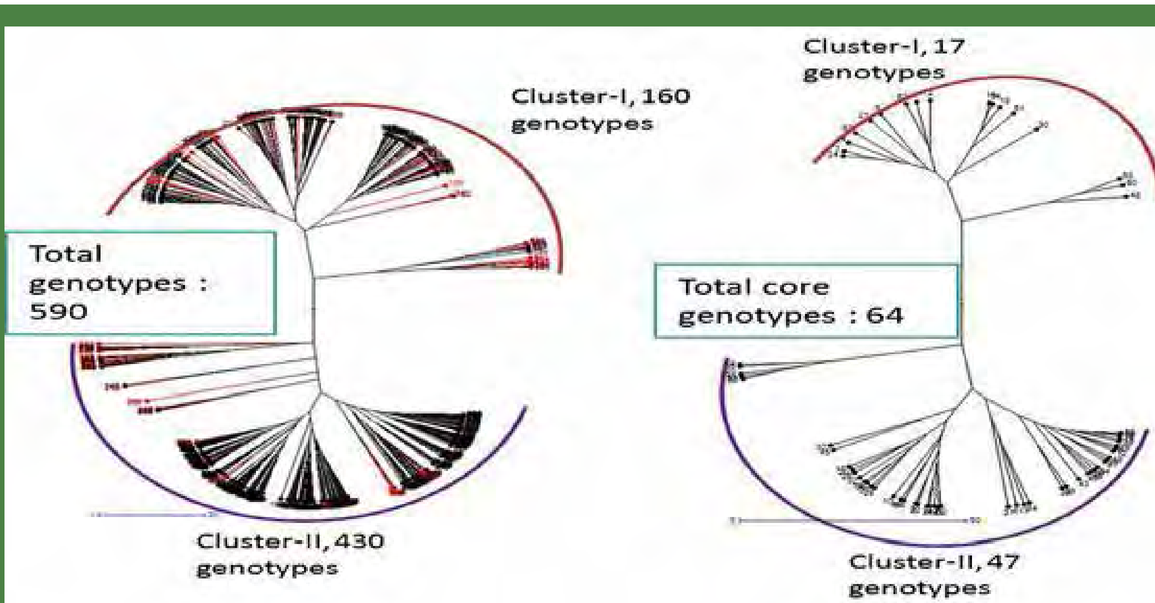


Fig. 1.13. Clustering pattern of 590 TJ genotypes; b. clustering pattern of 64 core set of TJ genotypes. The red lines represents the genotypes of core set.

cm), strong culm (2.74 culm diameter), V shaped, upright, long (33.5 cm) and wide (1.9 cm) leaf, long panicle (26.0 cm), moderately high tiller (8.2), moderately heavy panicle (4.81 g) and moderately high grain number (169.2).

Fig. 1.14. CR 3856-44-22-2-1-11-4-4-5 endowed with the most of the desirable NGR traits.

In PYT, eighty six advance generations fixed NGR materials were evaluated for yield and yield attributing traits. Out of them, at least 37 genotypes out yielded the best check i.e., IR 64 even in not so well managed conditions. C 1418-4-3-1-1-5 (7.35 t ha^{-1}), C 1606-1-1-1-1 (7.25 t ha^{-1}), C 1418-4-3-1-1-2 (6.75 t ha^{-1}), C 1747-4-1-1-1 (6.61 t ha^{-1}) and C 1648-5-2-1 (6.55 t ha^{-1}) performed superior and recorded yield increment of 53.1%, 51.0%, 40.63% 37.7% and 35.6%, respectively over the best check IR 64 (4.80 t ha^{-1}). Some of the promising advanced generation segregants were found to be KP 33 (4.97 t ha^{-1}), SR 3967-21-11-1-2-2-1-1 (4.57 t ha^{-1}), C 946-108-1-2(6.37), CR 3856-44-22-2-1-11-1-4 (4.56 t ha^{-1}).

Targeted trait improvement in available NGR cultures

One of the NGR genotype previously identified as superior, CR 3856-44-22-2-1-11-5 (SR 1-3-1) was tested in multi-locational trial (MLT) in six different districts of Odisha in 2017 and 2018. This culture was introgressed with BLB resistance (*Xa21*, *xa13* and *xa5*) and submergence tolerance (*Sub 1*) genes. The back crosses with different gene combinations were found to be high yielders.

Clustering of NGR cultures for breeding

A total of 314 advanced breeding materials and eight landraces were used for evaluation of yield. On the basis of grain yield, a set of 96 lines (125-145 days of maturity) were chosen for molecular study. These 96 elite rice lines consists of 71 NGR, 14 advance breeding lines (ABL), four high nitrogen responsive lines (NRL) and one landrace. A set of 40 molecular markers consisting of 23 genes based, 16 random markers related to DSR grain yield QTL, and one fertility restore linked marker. The 96 genotypes are grouped in to three major clusters (Fig. 1.15). The cluster 1 includes 51 lines, cluster 2 with 8 lines and cluster 3 with 37 lines.

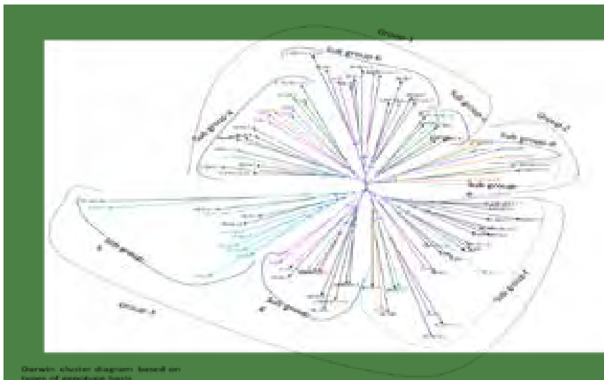


Fig. 1.15. Darwin cluster diagram based on types of genotype.

Molecular dissection of NGR traits

A panel of 60 genotypes comprising New Plant Types (NPTs) along with *indica*, tropical and temperate *japonicas* was phenotypically evaluated. The association analysis using GLM and MLM models led to the identification of 30 novel QTLs linked with 16 SSRs associated with 11 agronomic traits. Some of the SSRs were co-localized with more than two traits. The highest co-localization was identified with RM5709 linked to nine traits, followed by RM297 with five traits. Similarly, RM5575, RM204, RM168, RM112, RM26499 and RM22899 were also recorded to be co-localized with more than one trait. CR 3856-44-22-2-1-11-4-3-2, CR 4121-36-19-1-1 and CR 3856-44-22-2-1-9 along with two checks *viz*., Swarna and MTU 1010 could be rated as important for marker-assisted backcross breeding programs, for pyramiding QTLs to produce new-generation rice for prospective increment in yield potentiality and breaking yield ceiling.

Biotechnological strategies for genetic improvement of rice

An increased androgenic potential in *indica* rice hybrids and biparental cross by manipulating chemical factors was achieved and more than 1000

DHs were developed and evaluated. Morphological indicator for discrimination of haploids from diploids was identified. CRAC-3994-2-5 (DH derivative of CRHR 32) for higher zinc and yield superiority has been promoted to AVT-I. Using *in vitro* mutation, a method was developed. A robust regeneration method in popular *indica* rice varieties which could be utilized in transgenics and CRISPR/Cas9 approach was standardized. Genome edited lines for the genes *IPA1, DEP1, DUF* for yield was developed in different backgrounds. Mapping population for the identification of vegetative drought tolerant QTL was also developed. Besides, a method has been standardized for somatic embryogenesis in *indica* rice varieties. Also, 12 promising DHs of 27P63 based on grain quality and yield were selected. A prototype device for anther culture was designed to facilitate the handling of anthers during harvesting and culturing (Table 1.7).

Improved method for Androgenesis and development of DHs from five indica rice genotypes

An improved method was developed for androgenesis in *indica* rice lines; Arize 8433DT, Arize Bold, TCN, BCN and IR 20 x Mahulata. Among the five lines, Arize 8433DT showed better response than the rest (Table 1.8, Fig. 1.16).

Development of mapping population for the identification of drought tolerant QTL(s)

Developed androgenic protocol efficiency for DHs was tested in generating a mapping population of parents IR20 (susceptible) x Mahulata (tolerant) (Fig. 1.17). F_1s for the identification of drought tolerant QTL; a total of 198 regenerants were developed.

Table 1.8. Androgenesis response in *indica* rice lines.

Genotype	Callus (%)	Regeneration (%)	Number of Doubled haploid plants
Arize 8433DT	52	85.99	98
Arize Bold	41.2	72.12	119
TCN	34	61.00	31
BCN	30.4	63.80	25
IR 20 x Mahulata	46	66.57	198
		Total	**471**

Development of tolerance to herbicide resistance in popular rice varieties through tissue culture

A method for *in vitro* mutation for rapid development of mutants from *indica* rice line Shaktiman using 0.2% ethyl methane sulfonate (EMS) was standardised. A total of ~180 mutants were developed by this mutagenesis and screened with different concentrations of glyphosate (2 ppm, 4 ppm, 6 ppm) (Fig. 1.18).

Development of robust seed based universal protocol for regeneration of indica rice under in vitro condition

A robust *in vitro* protocol was standardized for the

Table 1.7. List of 12 Promising DHs of 27P63.

DHs	Days to flowering	Plant height (cm)	Fertile seeds (nos.)	Spikelet fertility (%)	Grain yield (kg)	Grain type
M-104-2	99	113	330	78	5680	Long slender
M-124-1	98	90	409	88	4080	Short slender
M-41-2	103	94	525	85	5790	Medium slender
M-31-1	105	113	494	70	4320	Long slender
M-128-1	98	87	473	77	4430	Short slender
M-81-2	106	115	470	92	4410	Short slender
M-78-1	102	81	369	76	4670	Short slender
M-111-1	103	90	467	86	4320	Medium slender
M-104	91	115	555	85	7080	Medium bold
M-114-1	98	83	541	89	4950	Short slender
M-153-2	104	87	511	89	4620	Medium slender
M-102-1	101	111	430	76	4180	Medium slender
27P63	92	112	477	77	7100	Medium slender

Fig. 1.16. TCN- RP-5599-312-63-5-1 x IR42266-29-R and BCN (CRMS32B x *O.longistaminata*).

Fig. 1.17. DHs of IR20 x Mahulata; A: IR20 x Mahulata regenerants; B: DHs in net house.

regeneration in *indica* rice lines using embryogenic calli (Fig. 1.19).

Identification of candidate genes for sheath blight tolerance

List of differentially expressed genes (DEGs) during sheath blight tolerance has been identified using multiple RNAseq data available with public domain (Fig. 1.20). Primers were designed for validation of DEGs identified for sheath blight tolerance from available RNAseq data.

Development of genomic resources for rice improvement

Four anthocyanin genes, anthocyanidin synthase, chalcone isomerase, anthocyanin reductase and UDP-glycosyltransferase were annotated and several SNPs and InDels were identified using sequence of Mummy Hunger and IR 64. Phenotyping of RIL mapping population developed from Mummy Hunger and IR 64 showed wide variations in protein, anthocyanin and antioxidants contents. *In silico* analysis followed by expression analysis using real time PCR of 13 selected genes in QTL regions led to the identification of two candidate genes (*LOC_Os04g02920* and *LOC_Os04g21890*) for *qBPH4.3*, and two candidate genes (*LOC_Os04g32940* and *LOC_Os04g34250*) for *qBPH4.4* associated with BPH resistance in Salkathi. Marker-trait association analysis identified 74 SNP markers associated with 15 traits related to seedling vigour, explaining 5.56% to 12.39% phenotypic variance in a panel of 96 rice genotypes. Two novel donors, Ratnagiri 4 and TG19 along with three known donors, N22, Annapurna and ADT53 were identified for tolerance to heat stress. Nested association mapping population in seven different cross combinations was developed using N22 as common parent, which would be useful for identification of QTLs for heat and drought stress tolerance. 59K SNPs and ~10K InDels were identified in N22 cultivar against reference genome Nipponbare, which would be useful for development of markers for heat and drought stress tolerance.

Fig. 1.18. ***In vitro*** **mutant development: A) culture of rice line with 0.2% EMS. (B) Mutants and wild type plants, and mutant plants treated with 6 ppm (C), 4 ppm (D) and 2 ppm (E) glyphosate.**

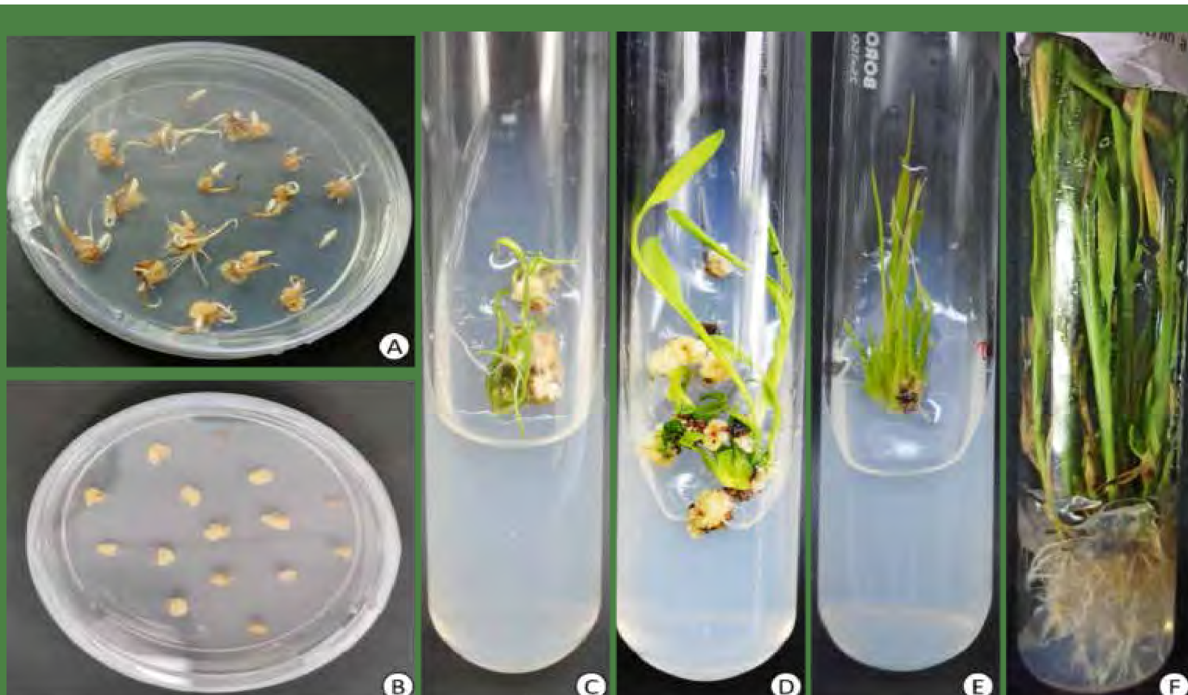


Fig. 1.19. ***In vitro*** **rice seed culture. A&B: Callus induction in seeds. C, D&E: Stages of shoot regeneration. F: Root induction in regenerants.**

Whole genome sequencing of donors and elite rice cultivars

Mummy Hunger (Manipuri black rice) and IR 64 were sequenced, and a large number of DNA polymorphisms (SNPs and INDELs) were discovered between these cultivars and reference genomes. Four anthocyanin genes (*Anthocyanidin synthase, Chalcone isomerase,*

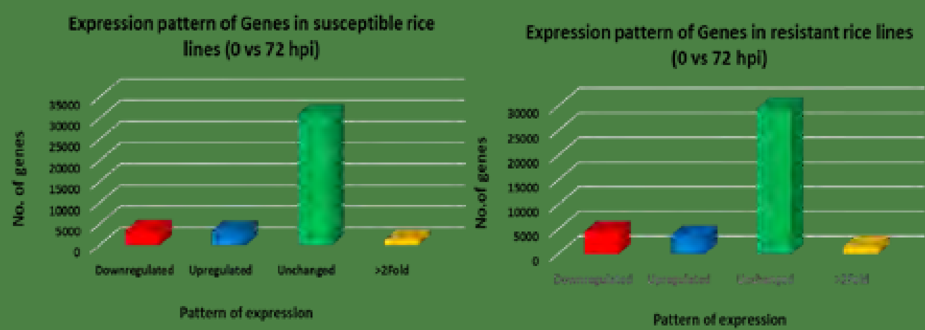


Fig. 1.20. Identification of differentially expressed genes (DEGs) during rice- ShB interaction.

Anthocyanin reductase, UDP-glycosyl transferase) were annotated, and several SNPs and InDels were identified.

Identification and mapping of genes/ QTLs associated with pigmentation, antioxidants, proteins and fine mapping of QTLs for resistance to BPH

Phenotyping of RIL mapping populations developed from Mummy Hunger (Manipuri black rice) and IR64 showed wide variations in protein, anthocyanin and antioxidant contents like *gamma-oryzonal*, grain phenolic, grain flavonoid and ABTS radical scavenging in grains. Survey of parental polymorphism led to the identification of 83 out of 672 polymorphic SSR markers. Genotyping of RILs and linkage analysis to identify genes/QTLs associated with pigmentation, antioxidants and proteins are in progress. Linkage analysis using phenotype and SNP genotype data of 450 $F_{2:3}$ lines confirmed and narrowed down BPH resistance QTL regions (*qBPH4.3* and *qBPH4.4*) present in Salkathi.

Association mapping to identify genes/ QTLs associated with seedling vigour

Association mapping panel consisting of 96 genotypes (selected from 1500 genotypes based on the phenotypic data) were precisely phenotyped for seedling vigour traits in three seasons and genotyped with 174 SNP and 48 SSR markers (Fig. 1.21). Wide variations were found in seedling vigour traits. Marker-trait association (MTA) analysis identified 74 SNP markers associated with 15 traits related to seedling vigour, explaining 5.56% to 12.39% phenotypic variance. Three genotypes (IR 93341:13-B-2-21-21-1RGA-2RGA-1-B-B, IR 93351:9-B-6-5-10-1RGA-2RGA-1-B-B and ARC 6101) having good seedling vigour traits were utilized for breeding programs for direct-seeded conditions as well as for developing mapping populations with ASD6.

Gene prospecting and allele mining for tolerance to heat stress

59K SNPs and ~10K In Dels were identified in N22 cultivar against reference genome Nipponbare. Out of 225 genotypes screened for heat tolerance, two novel heat stress tolerant donors, Ratnagiri 4 and TG19 along with three known heat tolerant donors, N22, Annapurna and ADT53 were identified. Nested association mapping population in seven different cross combinations was developed using N22 as common parent. A total of 700 segregating lines were generated, which would be useful for identification of QTLs for heat and drought stress tolerance (Fig. 1.22).

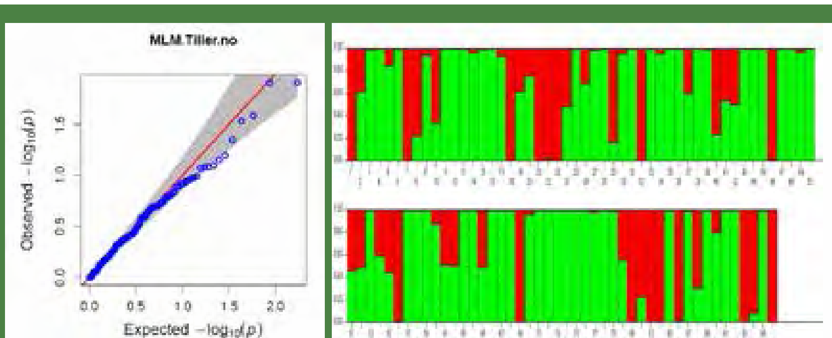


Fig. 1.21. a) QQ plot for tiller number, b) Population structure analysis showing two sub-populations in 96 genotypes.

Fig. 1.22. Dense and small panicles with high grain number targeting high yield.

The different activities undertaken through the projects under this programme are very important for keeping the pace with changing climatic conditions and the emerging socio-economic ambitions of the rice stakeholders and to achieve novel breakthroughs in the field of rice cultivation. The various technologies developed, including varieties and the hybrids would enable the rural rice farmers to be self-sufficient in rice cultivation and production, besides providing nutritionally enhanced food grain. The quality seed produced and supplied to different stakeholders will enable farmers to cultivate modern rice verieties and help them harvest the bounty of yield. The findings of these projects may also help the policy makers at regional and national levels to make necessary amendments in the future agricultural policies to address the emerging challenges.

PROGRAMME-2

Enhancing Productivity, Sustainability and Resilience of Rice Based Production System

Efficient use of resources *viz.*, nutrient, water, labour and management of adverse climatic stresses plays important role for higher productivity and sustainability of the rice production system. The resource use efficiency 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 resource use efficiency in rice

Map based site specific nitrogen management in rice

Map based site specific nitrogen recommendation was developed for two blocks in Bhadrak district using remote sensing approach (Fig 2.1). The N recommendation was made using the moderate-resolution imaging spectroradiometer (MODIS), leaf area index (LAI) and normalized difference vegetation index (NDVI) satellite data. A univariate regression relationship was established between MODIS NDVI data and the measured rice leaf content. Using the regression relationship, MODIS NDVI data were extrapolated and spatial map of leaf N content was generated. Fertilizer N recommendation was made on the basis of N uptake of rice at different locations. The preliminary results of this study suggest that multispectral data provided by the MODIS satellite series can be used to predict leaf N status in rice to improve the rice production and a minimum requirement of 60 kg N ha^{-1} and maximum of 120 kg N ha^{-1} was estimated through this approach.

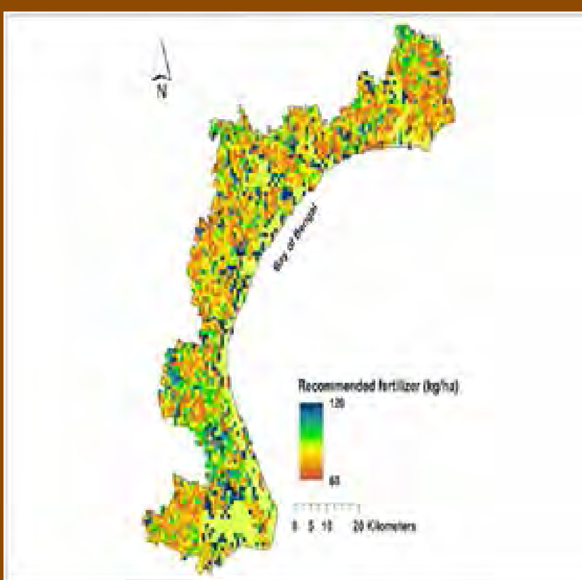


Fig. 2.1. N recommendation map for coastal areas of Bhadrak district of Odisha.

Micronutrient atlas for Odisha

In order to make site specific secondary and micronutrient requirements, block-wise soil micronutrient maps of Odisha classifying the area into different groups have been prepared (Fig 2.2) and recommendations for different crops were made and a book was published in collaboration with AICRIP micronutrient and OUAT, Bhubaneswar.

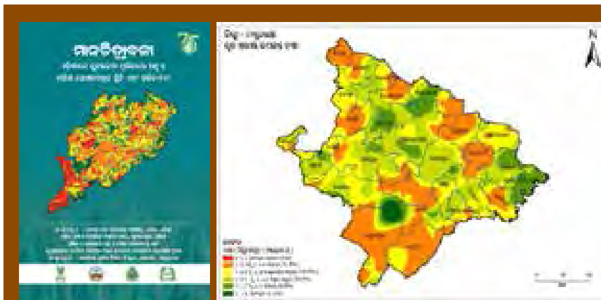


Fig. 2.2. Block level micronutrient (Zn) map of Mayurbhanj district of Odisha.

Biofortifiation of rice for high protein with agronomic management

One field experiment was conducted during dry season with two irrigation methods [(I_1- Irrigation of ± 2 cm (ponded water), I_2- Irrigation at hair line crack stage (-30 KPa)] and six N levels of nitrogen [N1-0 (no nitrogen), N2 -60 kg ha^{-1}, N3- 80 kg ha^{-1}, N4-100 kg ha^{-1}, N5-120 kg ha^{-1}, N6-150 kg ha^{-1}] to assess yield-N response and protein concentration of high protein rice (CR Dhan 310) vis-à-vis Naveen. The experiment was laid out in split plot design and all the treatments were replicated thrice. $ZnSO_4$ @ 25 kg, 50 kg P_2O_5 and 50 kg K_2O ha^{-1} were common for all treatments. Both CR Dhan 310 and Naveen responded up to 100 kg N ha^{-1}, beyond which there was no significant increase in yield and the trend was similar for both the irrigation methods. Yield was significantly lower under I_2 than I_1 at all N level for both the varieties. Across the N level, the protein concentration in grain ranged from 7.0 % -10.85% in CR Dhan 310, whereas in Naveen it was 5.83-9.52%. A positive relationship between N level and grain protein content till N rate 120 kg ha^{-1}, was observed for both the varieties.

Evaluation of rice varieties for phosphorus use efficiency under diversified ecology

Eleven rice varieties *viz.,* IR-36 (P susceptible check), Kasalath (P tolerant check), Ajay, Phalguni, Shatabdi, CR 304, CR 205, Heera, Naveen, Swarna and Lalat were evaluated for the P use efficiency. All the varieties showed yield response up to 60 kg P_2O_5 ha^{-1}. The highest average yield was recorded in Ajay and Naveen, however, the agronomic efficiency was higher in Ajay. The recovery efficiency of Heera, CR 205 and Kasalath were at par and higher than other varieties.

Agronomic and nutrient management practices for abiotic stress condition

Agronomic practice involving plant population and spacing was evaluated for their impact on survival and post-submergence recovery of high yielding and submergence tolerant variety (Fig 2.3). Rice cultivars IR 64 and IR 64 *Sub1*, grown with six different spacings of row-row×plant-plant {10x10 cm (S1); 15×10 cm (S2); 15×15 cm (S3); 20×10 cm (S4); 20×15 cm (S5); 20×20 cm (S6)} were subjected to 12 days of complete submergence. It was observed that wider crop spacing (20x15 cm, 20x20 cm improved survival and post-submergence recovery of both IR 64 and IR 64 *Sub 1* and the improvement in submergence tolerance capacity was more pronounced in IR 64 (Fig 2.4). Better underwater penetration of light in wider crop canopy delayed leaf senescence and sustained carbohydrate utilization, enabling healthier plant growth.

Fig. 2.3. Field view of submergence experiment (1. Before imposing treatment 2. post-submergence recovery).

In another study on improving anaerobic germination potential through nutrient priming, it was observed that osmo-priming of seeds of rice cultivar IR 64 and IR 64 AG with KH_2PO_4 (1.5%) and recommended dose of fertilizer along with calcium improved anaerobic germination potential under prolonged submergence stress at the germination stage.

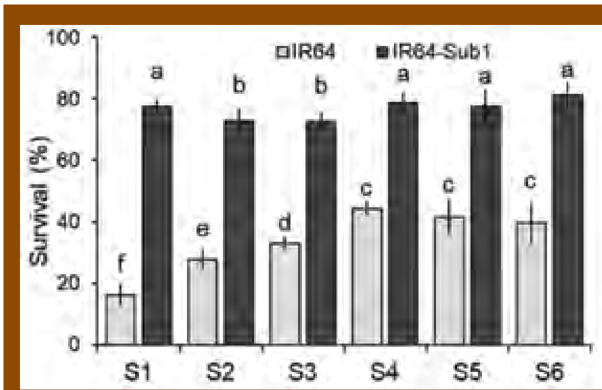


Fig. 2.4. Variation in plant survival from closer to wider spacing.

Nitrous oxide emission under combined effect of elevated CO_2 and water deficit stress

It could be demonstrated that atmospheric CO_2 enrichment condition had the capacity to mitigate the negative effect of water deficit stress on rice soil enzymatic activity as well as grain yield of rice. By using "path modeling approach" the study revealed that nitrifiers and denitrifiers populations directly affected N_2O emission and the effect was more pronounced under elevated CO_2 as compared to ambient CO_2 concentration (Fig 2.5). The predictive models for N_2O emission developed during this study provides evidence that the effect of varying CO_2 levels was more pronounced at vegetative than reproductive stage.

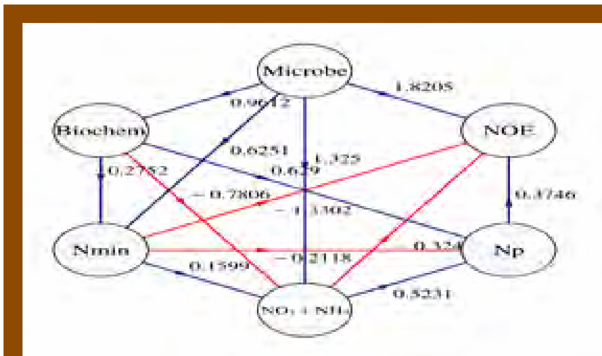


Fig. 2.5. PLS (partial least square) model of different parameters at elevated CO_2 (550 ± 20 μmol mol^{-1}). Microbes represented by the variables like population of soil nitrifiers and denitrifiers and soil biochem represented by variables like FDA = fluorescein diacetate, β-glucosidase and urease. N_{min} = nitrogen mineralization, NO_3^- N = nitrate nitrogen, NH_4^+ -N = ammonical nitrogen, Np = nitrification potential, NOE = nitrous oxide emission. Lines with blue colour represent positive relation, whereas red colour represents negative relation. The numbers represent coefficient values.

Fungal community in a long-term fertilized rice-rice system

Fungal community was quantified by using three fungal-specific growth media and q-RT PCR in 50 years old long-term fertilizer experiment (LTFE). The fungal colony forming unit (CFU) were ranged from $1.0x10^3$-$5.5x10^3$, $1.0x10^3$-$3.0x10^3$ and $1.0x10^3$-$3.5x10^3$ in potato dextrose agar (PDA), rose bengal and czapek dox agar media, respectively. Maximum fungal counts were observed in NK treatments with and without FYM. The quantification of fungal ITS gene (300 bp) was ranged from 3.0-5.78 x 10^6 copy number g^{-1} soil and the maximum fungal abundance observed in NK-treated soil compared to other treatments.

Enhancing water use efficiency in rice-based cropping system

Simulating soil water movement in paddy field using HYDRUS-1D model

Hydrus 1D simulation was done for the water flow in the rice field subjected to deficit irrigation. As pre-processing inputs, soil water potentials (measured by tensiometer) were taken. For water flow boundary condition, atmospheric boundary condition was taken as upper boundary and free drainage was taken as lower boundary. Irrigation along with precipitation was taken as time variable boundary conditions. Among parameters, θr (residual water content), θs (saturated water content), α (the hydraulic shape parameter), *n* (the hydraulic parameter), *Ks* (the saturated hydraulic conductivity) and *l* (Mualem's pore connectivity) were taken for soil profile of 60 cm having four layers with different water retentive properties. Inverse solution was used and α, *n* and *Ks* were optimized to obtain best fit. In post processing, outputs like observation points, profile information, soil hydrological information, mass balance information, run time information and inverse solution information were obtained for each irrigation treatment. Among all the simulations, the best fit was found for 30 kPa, with α, n, and Ks as 0.139, 1.11 and 1.36 cm/day, respectively (Fig. 2.6). Inverse solution information gave the R^2 and RMSE value as 0.68 and 0.0023, respectively, for the best simulation.

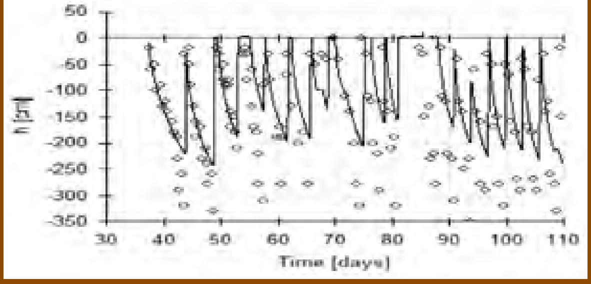


Fig. 2.6. Observed and predicted curve of pressure head using Hydrus 1D model. On vertical axis h represents the pressure head. Circle represents the observed pressure head and line represents the predicted pressure head.

Customized colour coded tensiometer for scheduling irrigation in rice

For real time measurement of soil water potential (SWP), tensiometer tubes and measuring gauge are required. Since, the cost of measuring gauge is high, the farmers are not able to afford it. A simplified and farmer friendly version of tensiometer tube for irrigation management based on real time measurement of soil water potential was developed. In this tensiometer tube, the usual gauge has been replaced by the stripes of light blue, deep blue (Fig 2.7), orange and brown colour. The water level in tensiometer tube up to light blue stripe signifies no need for irrigation, there is need to irrigate when the water level enters the deep blue stripe. The entry into the orange and brown stripe may adversely affect the crop yield and hence should be avoided.

Colour Stripe	Interpretation
Light Blue	No need of Irrigation
Deep Blue	Irrigation should be applied
Orange	Immediate need of irrigation
Brown	Adverse effect on grain yield and hence should be avoided

Fig. 2.7. Customized colour coded tensiometer for scheduling irrigation in rice.

Ecosystem services quantification and analysing the nexus of climate change-land use change-food security in rice production systems

Temporal and spatial variations in land use land cover change from 1990 to 2018

The temporal land use and land cover maps at 5-years intervals from 1990 to 2018 were prepared for six coastal districts of Odisha using multispectral Landsat 5 TM (for the year 1990, 95, 2000, 2005 and 2011) and Landsat 8 OLI imagery (for the year 2018) using ERDAS Imagine. The highest (36.21%) forest cover of total geographical area of the district was found in Ganjam and lowest (1.74%) in Bhadrak. During 1990 to 2000, Puri, Kendrapada and Ganjam recorded 38.3%, 24.6% and 10.8% reduction in forest cover, respectively. A gradual reduction from 1990 to 2018 in agricultural area was observed in all the districts. But the highest reduction in agricultural area was recorded in Baleswar (17.6%) followed by Jagatsinghpur (12.9%), Puri (9.9%), Kendrapada (6.9%), Bhadrak (6.6%) and lowest in Ganjam (5.8%) over study period of 28 years. The rate of decrease in the agricultural area is showing an increasing trend from 1990 to 2018. There was continuous increasing pattern of built-up area over 28 years from all the coastal districts.

Impact of land use land cover changes (LULC) on ecosystem services in last three decades

Assessment of ecosystem service valuation was done by the method proposed by Costanza et al. (2014). There was increase in total ecosystem service (ES) from 1990 to 2018 in all the coastal districts of Odisha except Kendrapada. From agricultural land, a decrease of 0.1% in ES was estimated for Kendrapada, whereas the highest increase (120.0%) in ES was recorded in Bhadrak from 1990 to 2018. A steady increase of ecosystem services was observed only in Baleswar and Bhadrak over study period, whereas a non-uniform pattern was observed in other districts. During 1990-2000, the highest decrease (25.3%) in ES from agricultural land was observed in Kendrapada followed by Ganjam (19.8%). There was increase in ES from forest from 1990 to 2018 for all the districts with Bhadrak recording the highest increase (201.7%) and Kendrapada the lowest (3.3%) increase. The ES from forest decreased during 1990-2000. During 1990-2000, highest decrease in ES from forest cover was recorded in Puri (46.2%), Jagatsinghpur (43.8%), Kendrapada (42.1%) and Ganjam (26.4%). The ES of waterbodies also increased from 1990 to 2018, Baleswar showing the highest increase (185.0%), whereas lowest in Ganjam (16.7%). Among the three land use types, agricultural land provided highest ES followed by forests and waterbodies in Baleswar and Ganjam districts, whereas the contribution of ESs was highest in agricultural land followed by waterbodies and forest in rest four districts of study area.

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

Carbon footprint assessment for rice-green gram system under different resource conservation technologies

Measuring the carbon footprint of a product across the supply chain is a recent trend that has several benefits. This study was undertaken to identify, proportionate and evaluate all sources contributing to GHG emissions from rice cultivation and assess the carbon footprint of the system. Life Cycle Assessment (LCA) is an emerging and appropriate mechanism to achieve this objective. A profiling study was carried out to analyze the output (impact of GHG) from the LCA inventory. Based on the inventory and actual measurements of the methane and nitrous oxide emission from the field under different treatments, cradle to farm gate carbon footprint (CF) was calculated (Fig. 2.8). The CF of a product is the quantity of greenhouse gases (GHG), expressed in carbon dioxide equivalent (CO_2eq) units, emitted across the supply chain for a single unit of that product. Higher total emission of GHG for rice based on per unit area (t ha^{-1}) was observed in green manuring treatment and lower value was found in zero tillage, however, based on per unit production (t/t) higher emission was for the control treatment having no application of nitrogen, whereas the lower emission was observed in zero tillage. Similar trend was also observed for the green gram. The carbon footprint (net emission) for whole system (rice-green gram) was higher in green manuring treatment based on per unit area, however, on per unit production basis, higher CF was observed in control followed by green manuring.

Cyanobacterial *nif*H gene abundance in rice field and resource conservation technologies

The influence of resource conservation technologies under direct-seeded rice-green gram cropping system on cyanobacterial structural diversity, q-PCR-

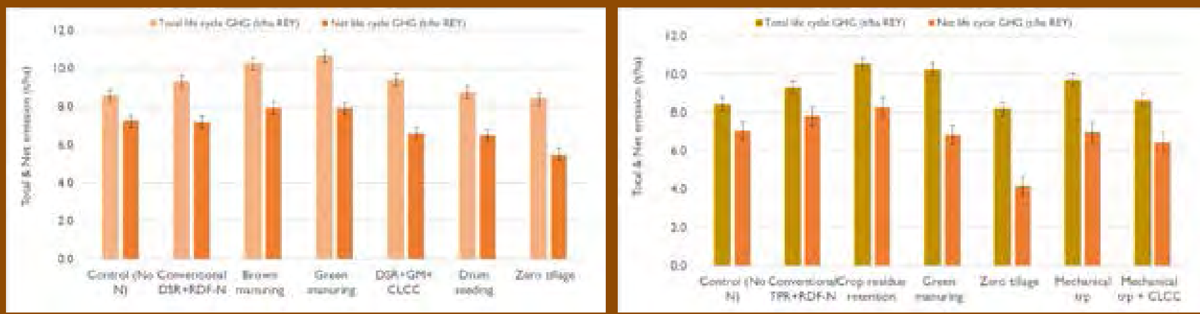


Fig. 2.8. Carbon footprint of rice-green gram cropping system under a) direct seeded (DSR) and b) transplanting (TPR) conditions.

based *nifH* gene abundance, soil physico-chemical properties and soil microbial enzymes activity was investigated. Treatments include *viz.*, conventional direct sowing (CDS) + no nitrogen, CDS + 100% RDF-N, brown manuring (BM) + 75% RDF-N, green manuring (GM) + 75% RDF-N, paired row rice + GM + 75% RDF-N, wet-DS (Drum Seeder) + 100% RDF-N and zero tillage (ZT) + 100% RDF-N. Results revealed that cyanobacteria, *nifH* gene abundance, mineralizable carbon and microbial biomass carbon were found to be higher in GM plus 75% RDF-N (Fig. 2.9) under direct sowing condition.

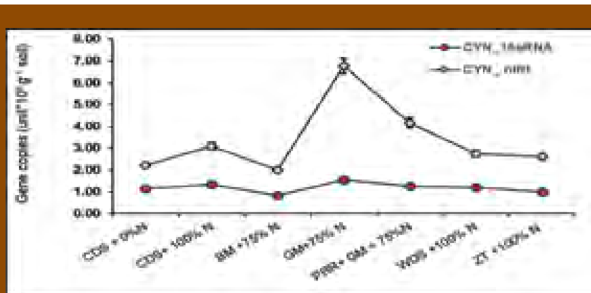


Fig. 2.9. Cyanobacterial 16srRNA and nifH gene copies under direct sowing.
*CDS=Conventional Direct Sowing; BM=Brown Manuring; GM=Green Manuring; PRR=Paired Row Rice; WDS=Wet Direct Sowing; ZT=Zero Tillage

Weed diversity, density and distribution under different resource conservation technologies

Weed diversity, density and distribution was studied in direct seeded rice under different resource conservation technologies. It was observed that highest weed density (Fig. 2.10) was found in zero tillage and lowest was under brown manuring followed by wet dry sowing with drum seeder. Highest number of weed species were in conventional direct sowing (CDS) without N application followed by brown manuring + 75% RDF-N and zero tillage +100% RDF-N. Simpson diversity index was found maximum in paired row rice with green manure with 75% RDF-N and minimum in brown manured crop with 75% RDF-N. Shannon and Marglef index was highest in brown manured crop and least in green manured crop, with similar dose of nitrogen in both (75% RDF-N). With regard to weeds distribution, broad leaved weeds population was more under zero tillage followed by conventional, direct sowing and wet drum seeding. Under brown and green manuring, sedges population was higher than broad leaved weeds (BLW). Under most of the cases weed population followed the trend as: BLW>Sedges>Grassy weeds.

Evaluation of components of conservation agriculture for resource efficient rice based system

A field experiment on components of conservation agriculture was conducted at NRRI farm to study the impact of different components of conservation (minimum soil disturbance/zero tillage, crop residues, and crop diversification) either alone or in combination with yield and energy use. The experiment was conducted in rice-rice system and for diversification treatment rice-green gram system was taken. In *rabi*, Sahbhagidhan of rice and IPM 2-3 of moong were grown, while in *kharif* Pooja was grown. Highest yield of rice (Pooja) was recorded in residue + diversification which is at par with zero tillage + diversification and residue + zero tillage + diversification (Fig. 2.10). When moong is grown in the diversification component in the succeeding season, the rice equivalent yield (REY) was lower than the rice as a sole crop (Fig. 2.10). On system basis, higher energy productivity (0.38 kg MJ^{-1}) and energy ratio (8.40) was recorded in the zero tillage + diversification which was the most energy efficient system (Fig. 2.11).

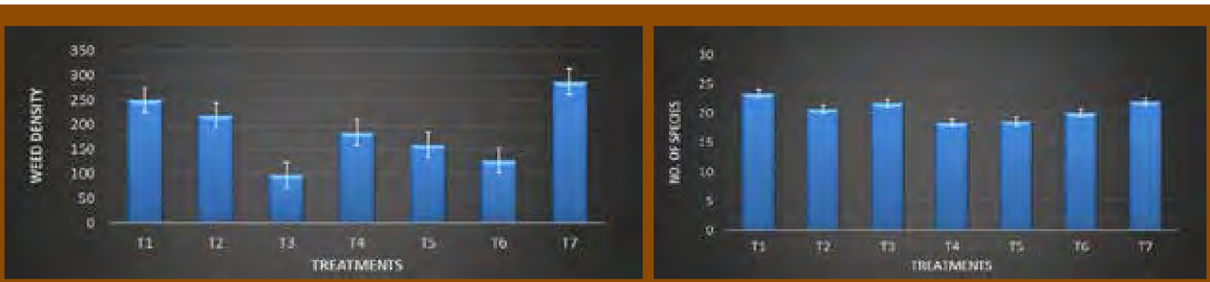


Fig. 2.10. a) Weed density and b) weed species under different RCTs.
Treatment details: T1: conventional direct sowing (CDS) without N app; T2:CDS +100% RDF-N; T3: Brown manuring + 75% RDF-N; T4: Green manuring +75% RDF-N; T5: GM+75%RDF-N+CLCC; T6: Wet DS (Drum seeder)+100% RDF-N; T7:Zero tillage +100% RDF-N

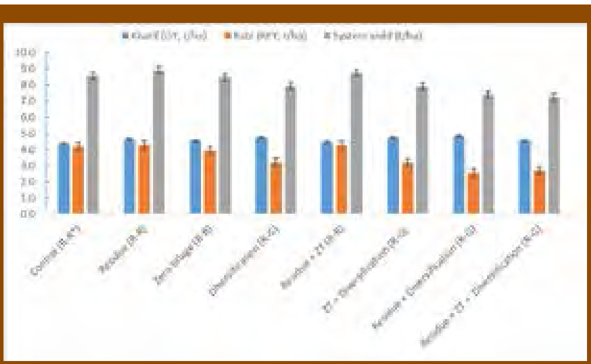


Fig. 2.11. Yield of rice in *kharif*, moong and rice in *rabi* and the system yield.
*R-R=Rice-Rice; R-G=Rice-Green gram; ZT=Zero Tillage

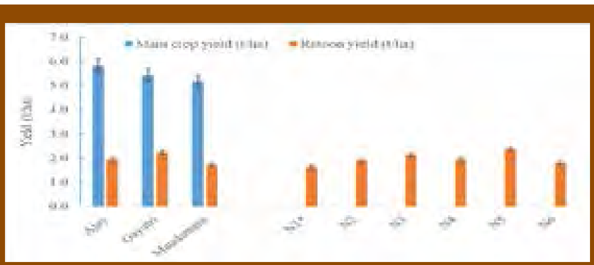


Fig. 2.12. Grain yield of rice and rice ratoon under different nutrient management practices
***N1: Control (No N); N2: 40 kg N ha^{-1} one week before harvesting (1WBH); N3: 40 kg N ha^{-1} one week after harvesting (1WAH); N4: 40 kg N ha^{-1} at harvesting; N5: 20 kg N ha^{-1} at harvesting + 20 kg N ha^{-1} 2WAH; N6: 20 kg N ha^{-1} at 1WBH + 20 kg N ha^{-1} 2WAH**

Nutrient management practices for rice ratooning

Ratooning is the practice of harvesting grain from tillers originating from the stubble of already harvested crop (main crop). It enhances rice grain yields without increasing land area. Cultural practices and condition of the main crop at harvest usually impact the growth and development of the ratoon crops. Suitable nutrient management practices are required for optimizing successful ratoon crop. To develop suitable nitrogen management practice for rice ratoon, a field experiment was conducted in split plot design with three varieties (Ajay, Gayatri and Maudamani) in main plots and six nitrogen management options in sub plots with three replications. The results indicated that among the rice varieties, ratoon of Gayatri produced higher yield as compared to other varieties (Fig. 2.12). Among the nutrient management treatments, application of 20 kg N at harvesting and 20 kg N at 2 weeks after harvesting (N5) recorded significantly higher yield as compared to control.

Developing agronomy for new generation rice and rice-based cropping system

Water and crop productivity of zero till rice-maize system

Effect of conservation agriculture practices on the yield, water use, water productivity of rice-maize cropping system was studied. The experiment was laid out in split plot design with two tillage systems *i.e.* conventional and zero tillage in main plots and three residue management systems *i.e.* RDF + No residue, RDF + residue mulching (3 t ha^{-1}) and RDF + residue mulching (6 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. Grain yields of rice and maize were on par in zero tillage and conventional tillage. Mulching with rice straw @ 6 t ha^{-1} in maize significantly increased the maize yield by 14 and 34 %, respectively compared to no residue and residue @ 3 t ha^{-1}. The residual effect of mulching in maize @ 6 t ha^{-1} increased the rice grain yield by 11 and 26 % over mulching @ 3 t ha^{-1} and control. However, rice straw mulching in maize system productivity in terms of rice equivalent yield of conservation tillage system was at par with that of conventional tillage in rice-maize cropping system but significantly higher with application of rice residue as mulch to maize. Zero tillage and conventional tillage treatments recorded similar water productivity. Residue mulching at 6 t ha^{-1} to maize increase the water productivity of rice - maize system by 36.6% compared to no residue treatment but variation in nitrogen level in rice did not change the water productivity of the system.

Effect of establishment methods and hydrogel on productivity of rainfed rice-green gram system

A field experiment was conducted to study the effect of stand establishment methods and hydrogel on productivity of rainfed rice - green gram cropping system. The experiment was laid out in split plot design with two stand establishment methods in rice *i.e.* transplanted rice (TPR) and direct seeded rice (DSR) in main plots and seven stand establishment methods in green gram *i.e.* conventional, conservation agriculture and pyra cropping in subplots and hydrogel in sub-sub plots replicated thrice. The variety Swarna *Sub1* of rice and IPM 2-3 of green gram were used in the experiment. The system productivity of rice-green gram cropping system was increased by 7.0% after DSR compared to transplanted rice because of increase in yield of green gram. Seed yield of green gram from conservation agriculture practices (zero tillage + residue retention) and conventional tillage practices were comparable but significantly higher than pyra cropping of green gram. Hydrogel application significantly increased the seed yield of green gram. Cultivation of green gram after direct seeded rice (DSR) following conservation agriculture practices (zero tillage with residue retention) was profitable but hydrogel application was not economical.

Effect of nutri-priming and stand establishment on performance of green gram cultivars

The effect of zero tillage and nutri-priming with phosphorus and molybdenum on two cultivars of green gram (different duration and yield potential) was studied in rice fallow areas. A field experiment was laid out in split plot design with two tillage systems *i.e.* zero tillage and conventional tillage in main plots, two cultivars *i.e.* IPM 02-03 and Virat in subplots and four nutripriming *i.e.* with P, Mo, P+Mo and no nutripriming in sub-sub plots and replicated thrice. Conventional tillage recorded significantly higher (18.0%) seed yield of green gram compared to zero tillage. Green gram variety IPM 02-03 performed better than Virat. IPM 02-03 produced 8.65 q ha^{-1} whereas Virat produced 6.61 q ha^{-1}. Nutripriming with P+Mo significantly increased the seed yield of the green gram compared to no nutripriming and nutripriming with P or Mo alone. Energy use efficiency was higher in conventional tillage compared to zero tillage although zero tillage reduced the energy consumption without any significant difference in B:C ratio. IPM 02-03 performed better than Virat economically as well as in efficient use of energy. Nutripriming with P and Mo individually or in combination did not differ significantly in energy output:input ratio but combined application improved the net return and B:C ratio.

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

Herbicide-based weed control with safest molecule in direct-sown rice

A field experiment was conducted during dry season, 2020 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 602. The treatments included bispyribac sodium *fb* ethoxysulfuron (25 & 15 g ha^{-1} at 7 and 21 DAS), cyhalofop butyl *fb* ethoxysulfuron (100 & 15 g ha^{-1} at 10 and 21 DAS), flucetosulfuron *fb* ethoxysulfuron (25 & 15 g ha^{-1} at 7 and 21 DAS), fenoxaprop-p-ethyl + ethoxysulfuron (50 + 15 g ha^{-1} at 15 DAS), ready-mix of XR 848 benzyl ester+cyhalofop butyl (150 g ha^{-1} at 15 DAS), ready-mix of penoxsulam + cyhalofop butyl (130 g ha^{-1} at 15 DAS) and tank mix of bispyribac sodium + ethoxysulfuron (25 + 15 g ha^{-1} at 15 DAS) with recommended herbicide of bispyribac sodium (30 g ha^{-1} at 10 DAS) and herbicide mixture of bensulfuron methyl + pretilachlor (60+600 g ha^{-1} at 7 DAS) along with weed free and weedy check. There was excellent control of complex weed flora in bispyribac sodium *fb* ethoxysulfuron treated plots with WCE of 90.0% and this treatment also recorded 11-15% yield advantage than recommended herbicides application (Fig 2.13 and 2.14). The yield reduction due to weed competition in weedy plots was more than 48%.

Alternate weed control options for transplanted rice

A field experiment was conducted during the dry season, 2020 to study the weed spectrum and efficacy of different weed control options in transplanted

Fig. 2.13. Field view of Bispyribac sodium *fb* ethoxysulfuron treated plots.

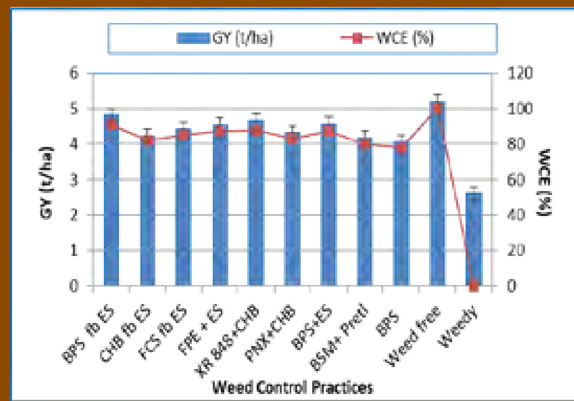


Fig. 2.14. Performance of different herbicide combinations in direct sown rice.

rice with cv. CR Dhan 602. The treatments included bispyribac sodium *fb* mechanical weed control by stihl power weeder (30 g ha^{-1} and at 12 and 30 DAT), bispyribac sodium *fb* mechanical weed control by NRRI power weeder (30 g ha^{-1} and at 12 and 30 DAT), bispyribac sodium *fb* mechanical weed control by cono weeder (30 g ha^{-1} and at 12 and 30 DAT), bispyribac sodium *fb* ethoxysulfuron (25 & 15 g ha^{-1} at 10 and 25 DAT), cyhalofop butyl *fb* ethoxysulfuron (100 & 15 g ha^{-1} at 10 and 25 DAT), fenoxaprop-p-ethyl + ethoxysulfuron (50 + 15 g ha^{-1} at 18 DAT), penoxsulam + cyhalofop butyl (130 g/ha at 18 DAT) with recommended herbicide mixture of bensulfuron methyl + pretilachlor (60+600 g ha^{-1} at 7 DAT) along with mechanical weed control by cono weeder (21 DAT), weed free and weedy check. There was excellent control of complex weed flora in early post application of bispyribac sodium (30 g ha^{-1}) at 12 DAT *fb* mechanical weed control (by Stihl weeder) at 30 DAT with WCE of 90.0% (Fig 2.15) and this treatment recorded the grain yield (5.19 t ha^{-1}) was significantly at par with weed free check (5.31 t ha^{-1}). Integration of early post application of bispyribac-sodium *fb* mechanical weed control by power weeder showed 16% yield enhancement with Rs. 4300/- ha^{-1} additional net return over recommended practice of BSM + pretilachlor.

Design and developed contact-type herbicide applicator

The herbicide applicator was designed to apply selective herbicide by wiping on to weeds and minimize herbicide drift, loss, and non-target impact (Fig. 2.17). It is easily adaptable to varying brush conditions and safe for the environment and operator. The complete specification and performance parameters of the designed prototype is given in table 2.1.

Fig. 2.15. Performance of different herbicide combinations in transplanted rice.

Fig. 2.16. Power weeder operation in transplanted rice.

Table 2.1. Specification parameters of the designed prototype herbicide applicator.

Sl. No	Specification	Details
1	Tank capacity	2 l
2	Application rate	4 l h^{-1}
3	Weight (empty)	4.40 kg
4	Weight (Ready to use)	6.4 kg
5	Material used	MS rod, Pipes and Plastic
6	Width of the applicator	20 cm
7	Diameter of roller	28 cm

Fig. 2.17. NRRI herbicide applicator.

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

Dynamics of diazotrophs in integrated rice-based farming system

Diazotrophic population were analysed in soil collected from 10 years old multi-tier rice based farming system under six components (i) orchard (ii) vegetable (iii) rice followed by other crop (iv) rice-fish (v) agroforestry (vi) pond using two different N-free agar media *viz*., Jensens and Asbhy's Medium. Results indicated that diazotrophs population was found to be highest in rice-fish component (6.40 log CFU g^{-1}soil and 11.47 log CFU g^{-1}soil), which was at par with agroforestry (6.45 log CFU g^{-1}soil and 11.46 log CFU g^{-1}soil) in respective media, as compared to other components (Fig. 2.18).

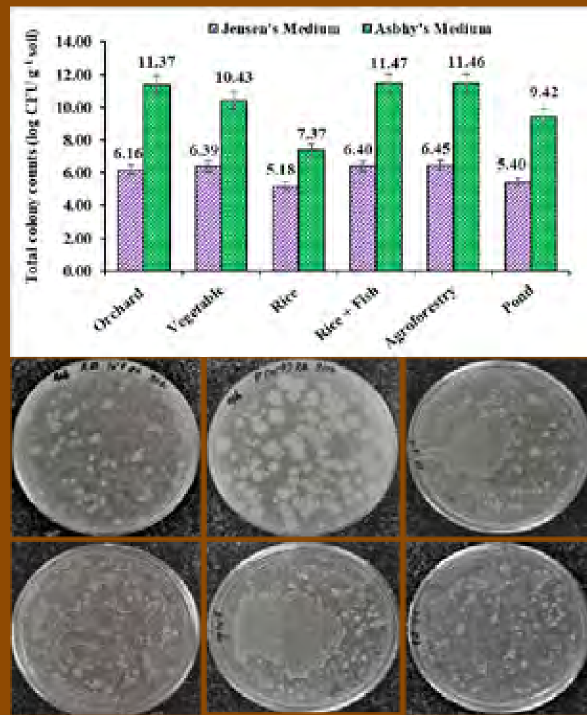


Fig. 2.18. Diazotrophs population under different components of rice-based IFS.

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 for the second year. The treatments included were *viz*., rice alone; rice + fish, rice + fish + cow dung; rice + fish goat dung; rice + fish + poultry dropping; rice + fish + duck dropping; rice + fish + azolla compost; rice + fish + plant compost; rice + fish + pig dung; rice + fish + pigeon dropping. Polyculture of fish was reared for 120 days of growth. Results revealed that maximum grain yield (7.94 t ha^{-1}) was observed in rice + fish + Azolla compost followed by rice + fish + duck dropping treatment. Treatment with sole rice crop exhibited lowest grain yield of 5.23 t ha^{-1} among all the other treatments. The net body weight (after 120 days) of fish was 344, 378 and 381 gms for rohu, catla and mrigal, respectively in rice + fish + duck dropping (Fig. 2.19).

Life cycle assessment of integrated farming system (IFS) in eastern India

Life cycle assessment (LCA) has been widely used for eco-efficiency analysis of different production systems, including in agriculture. Computation of collected data was done with different integrated farming system (IFS) models differing in farm size,

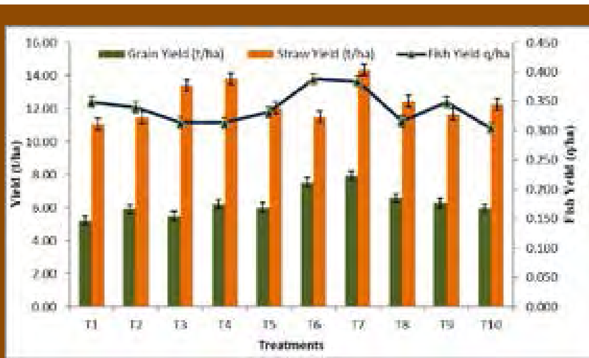


Fig. 2.19. Different sources of nutrient for growth of fish in the rice field.

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.

number and type of enterprises in eastern India by computing eco-efficiency using partial life cycle analysis and technical efficiency by using stochastic production frontier with Cobb-Douglas function for optimizing the operational farm size and number of enterprises. Results showed that marginal and medium farms were relatively more eco-efficient as they obtain higher income with less impact on the environment. Marginal farms are more eco-efficient than the other categories because lesser reliance on the off-farm resource and better utilisation of on farm resource. Farm sizes and number of enterprises govern the productivity and eco-efficiency of the IFS.

Economic and environment friendly use of rice straw

During 2019-20, straw characterization of 30 rice varieties based on cellulose, hemicellulose, lignin was done. The large-scale composting (20 tons) with two microbial consortiums was carried out with modified techniques. The i*n-situ* decomposition with microbial consortium on spread-out straw showed promising results.

The characterization of straw of 62 rice varieties which includes popular 19 varieties of eastern India on the basis of cellulose, hemicellulose, lignin, Si, functional group present (FTIR) was done and grouping for biochar, bio-ethanol, mushroom production and composting was framed. The large-scale composting (30 tons) with three microbial consortiums were carried out and got promising result in 40 days of composting. The method of large composting in tank was standardized and the GHGs emissions during composting were also quantified. In another alternative use of rice straw for mushroom production (Fig. 2.20), around ~1.1 kg mushroom yield was obtained from 5600 gm of rice straw with B:C ratio of 2.2. CR Dhan 310 recorded highest mushroom yield of 1158 g bed^{-1} with B:C ratio of 2.33 followed by Swarna *Sub1* (1093 g bed^{-1}) with B: C ratio of 2.2. The rice straw biochar was also prepared and its characterization was done in limited extent. Weight loss of rice straw after pyrolysis of 2 hours duration varied from 25% (Varshadhan) to 91% (CR Dhan 310).

Fig. 2.20. Rice-straw mushroom production at ICAR-NRRI, Cuttack.

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

Performance evaluation of battery power weeder

The developed battery-power weeder was evaluated at the NRRI field and during evaluation different parameters were considered *i.e.* plant row spacing (20 cm, 22.5 cm, and 25 cm), weeding date after transplanting (25 and 40 DAT) and cutting unit speed (150-200 rpm). The ideal power consumption of a developed weeder usually ranges between 2-4 A. The power consumption of the DC motor increases with an increase in the speed of the cutting unit and the maximum power delivered by the DC motor at its rated speed was 250 watts (at 14 A current). The average current required for weeding operation was 6-8 A and a set of batteries (14 Ah) are required to run the developed prototype at a stretch for 2 h. The actual field capacity of the weeder was observed 0.030 ha h^{-1} at a row spacing of 20 cm and the depth of cut was 4 cm. The weeding efficiency of battery power weeder was found highest (77.32%) in plant spacing of 20 cm with cutting unit width of 14 cm. The performance evaluation of battery power weeder in comparison to different weeding machine (Fig 2.21) and cost details & energy required in weeding operation in rice cultivation revealed that the cost of the machine and the cost of operation was found Rs. 15000/- and Rs. 1062/- ha^{-1}, respectively with an energy requirement of 112.46 MJ ha^{-1}.

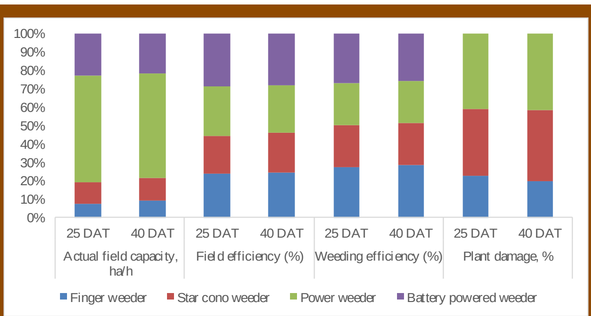


Fig. 2.21. Field performance of different weeding machine.

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

Induction of Azolla-sporocarp germination

A unique methodology was developed to induce the germination of soil-based sporocarp of *Azolla*. In this process, the compost form of matured *Azolla* sporocarp containing megasporocarp and microsporocarp was sieved through 753, 353 and 180 microns sieves. Sieved compost under 753 micron was discarded, whereas remaining two sieved composts were kept in water-containing pots. Megaspore attached with massulae was observed in 353 micron sieved compost after 1-2 days and these were germinated after 13-15 days in water under suitable condition (Fig. 2.22).

Development of low-cost *Azolla* pellet making machine

Though *Azolla,* a fresh water fern is a good source for livestock feed but it is not widely adopted because of problems associated with its shelf life, transportation and storage facilities. An attempt was made to prepare *Azolla* pellet for livestock feed by using a pellet making machine. *Azolla* pellet was prepared by mixing suitable additives and bringing its moisture

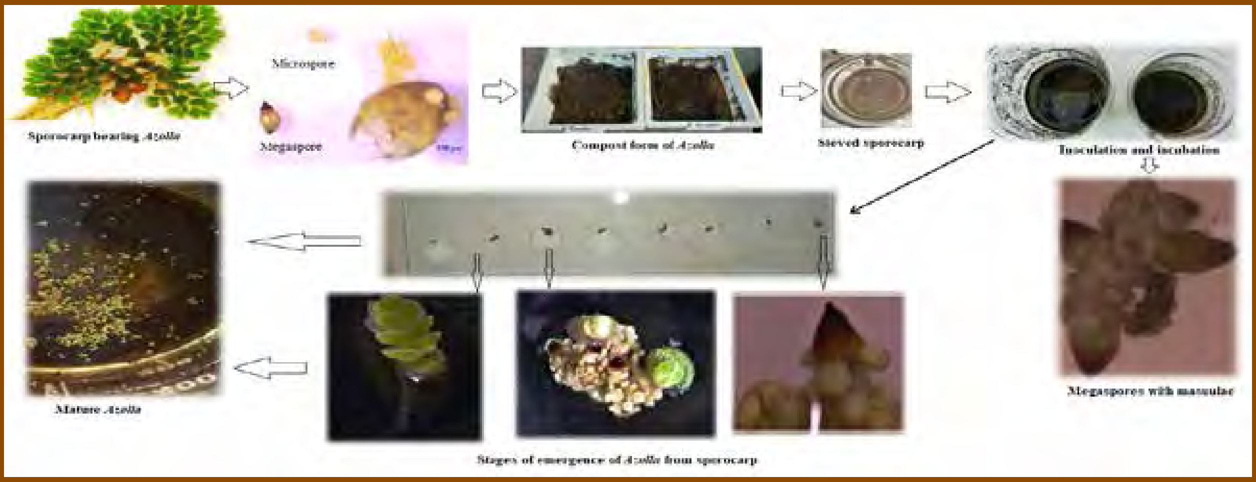


Fig. 2.22. Methodology for induction of *Azolla* sporocarp germination.

content to a range that prolongs its shelf life. The pellet making machine is manually (hand) operated having overall length, width, and height as 310 mm, 100 mm and 610 mm, respectively (Fig 2.23). The number of hopper is one with 2 kg capacity. The briquette size coming out from this machine is 30-50 mm long with 10 mm diameter.

Harnessing microbiome for enhancing rice productivity and improving soil health

Evaluation of entomopathogens against rice leaf folder

Bacterial strains *viz., B. thuringiensis* (BT160- NRRI-CPD-BIOCB7, BT161- NRRI-CPD-BIOCB8, BT261-NRRI-CPD-BIOCB9) and *Skermanella* sp (SK1-NRRI-CPD-BIOCB11) were used for preparation of liquid and solid based formulations and their shelf life were assessed under room condition at different intervals. The survival of bacteria was recorded in the range of 4.2-3.9 x10^{10} CFU per gram or ml after three months in both solid and liquid based formulations under room condition. For the selection of efficient bacterial strain, all the formulations were tested for their larvicidal potential against rice leaf folder in susceptible rice variety (TN 1) under glass house condition with the five-fold higher insect population (*i.e.* 10 larva per plant). Among the four bacterial strains, BT160 and SK1 inoculated plants recorded significantly higher larval mortality (70.0-80.0%) compared to other bacterial strains, the selected two bacterial strains (BT160 and SK1) will be validated under field conditions.

Development of carrier based microbial consortium for rice straw residue management

Three microbial strains *Aspergillus awamori* (NRRI-CPD-COMF5), *Trichoderma viridi* (NRRI-CPD-COMF6) and *Streptomyces sp* (NRRI-CPD-COMA4) were selected based on their decomposing potential of paddy straw under *ex situ* condition and used for consortium preparation using sterile talc as carrier material. The prepared microbial consortium was packed in airtight containers for shelf life assessment, the maximum population of 10^8 CFU of fungi and 10^9 CFU of *Streptomyces* per gram of carrier was recorded after three months of storage under normal room condition. To enhance the attachment and proliferation of introduced microbial inoculants during decomposition of paddy straw, the following amendments *viz.,* CMC, starch, jaggery were evaluated. Application of microbial consortium (@ 1.0 kg per ton of paddy straw) plus 5 kg urea along with 0.1% CMC plus 0.5% jaggery (w/v 100 lit water) found superior in increasing microbial growth and decomposition rate as compared to only microbial culture application.

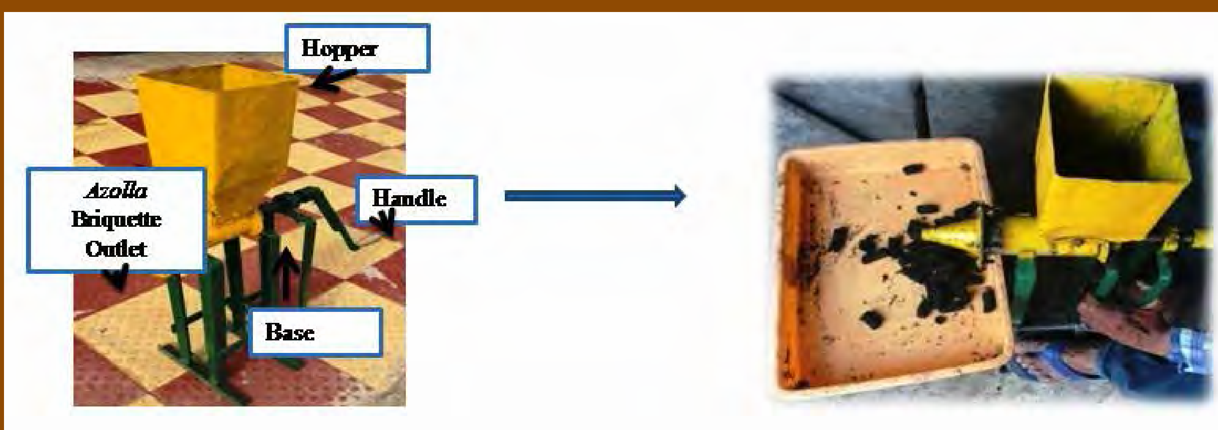


Fig. 2.23. Manually-operated low-cost *Azolla* pellet making machine.

Site specific secondary and micronutrient recommendation, block-wise soil micronutrients maps of Odisha prepared, which will enhance the nutrient use efficiency of rice production system. A simplified and farmer friendly colour coded tensiometer has been developed for irrigation management in rice. In conservation agriculture, the higher energy productivity (0.38 kg MJ^{-1}) and energy ratio (8.40) was found in zero tillage plus diversification system. In direct sown rice, application of bispyribac sodium followed by ethoxysulfuron is recommended for efficient weed management. The low-cost *Azolla* pellet making machine has been developed to produce livestock feed. Developed decomposing microbial consortium for ex-situ decomposition of paddy straw.

PROGRAMME-3

Rice Pests and Diseases – Emerging Problems and their Management

The research projects of Crop Protection Division are so designed as to improve productivity and profitability of rice farmers by reducing enormous losses caused by pests and diseases. Sustainable pest and disease management being the focal theme, the major thrust of the programme was to search for new sources of resistance and their genetic characterization, coupled with strategies to develop integrated pest management (IPM)-based bio-intensive climate smart protection of rice crop health. The Division has state-of-the-art research facilities including a sophisticated Pesticide Residue Laboratory. In addition to carrying out research in cutting edge science, the Division equally strives to empower the rice farmers with specialized need-based trainings in different areas of pest and disease management.

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

Identification of new sources of resistance against insect pests

Brown plant hopper (BPH)

Out of 120 genotypes screened against BPH, eight genotypes (RMS-HWR-39, CR 4206-4-11-2, CR 4206-5-1-1-2, CRCPT 3, CRCPT 4, RP 2068-18-3-5, MTU-1308, IC 75975) were found resistant with 1 score.

Asian rice gall midge

Sixty five Sikkim and Tripura genotypes, 36 TRB genotypes and 37 Odisha landraces were phenotyped for Asian rice gall midge (Biotype-2) resistance. Among AC 39738 (Sikkim and Tripura genotype); TRB-17, 18, 329 (TRB genotypes); Jhul Puagi, Donur, Saruchina (Odisha landraces) were found.

Angoumois grain moth

Among 20 rice varieties tested, Bina Dhan 8 was found to be resistant to test insect by registering nil value for tested parameters under lab condition. Durga, Kalajeera and CR Dhan 310, Luna Sampad, Nua Chinikamini were found to be moderately resistant.

Characterization of resistance to insect pests

Phenotyping and mechanism of resistance to BPH

Among 74 rice genotypes screened for BPH, AC 39843 was categorized as resistant and AC 39842, AC 39877 were categorized as moderately resistant. AC 39843 recorded the lowest sugar content followed by AC 39842 and AC 39877 compared to TN1. Total phenol content was highest in AC 39843 followed by AC 39877 and AC 39842. Among 24 microsatellite markers used for understanding the polymorphism between the resistant and susceptible genotypes, only 14 had shown polymorphism.

Genetic dissection and identification of candidate genes resistant to BPH

A total of 600 farmers' varieties (FVs) were phenotyped against BPH and subsequently 104 panel populations were genotyped using 87 molecular markers linked to 34 different BPH resistance genes for marker-trait association and genetic diversity to understand the genetic basis for BPH resistance (Fig. 3.1). The average polymorphism information content was 0.354 for 34 genes with 0.018 to 0.750 threshold level. One hundred and four FVs were categorized into three main genetic groups according to cluster analysis and population structure (Fig. 3.2). Resistant and moderately resistant FVs were separately distributed according to principal co-ordinate analysis. Analysis of molecular variance results displayed within population had maximum diversity (83%) and between populations had minimum (17%) diversity. Further, only ten markers were significantly associated with different phenotypic parameters among 87 markers tested. In both generalized linear model (GLM) and multi linear model (MLM), eight markers linked to BPH genes *viz.*, RM 222 (Bph30), RM 6997 (Bph6), RM 17006 (Bph 33), RM 6308 (bph19), RM 463 (bph2), RM 28561 (Bph21), RM 586 (bph4), RM 309 (Bph 26) were found to be common for four different phenotypic parameters. Two markers (RM 586 and RM 222) linked to resistance against BPH biotype 4 for bph4 and Bph 30 genes showed significant association for all the four phenotypic parameters.

Identification of new sources of resistance to diseases

Sheath blight

Out of 80 FVs, 81 NRRI Released Varieties, 42 New

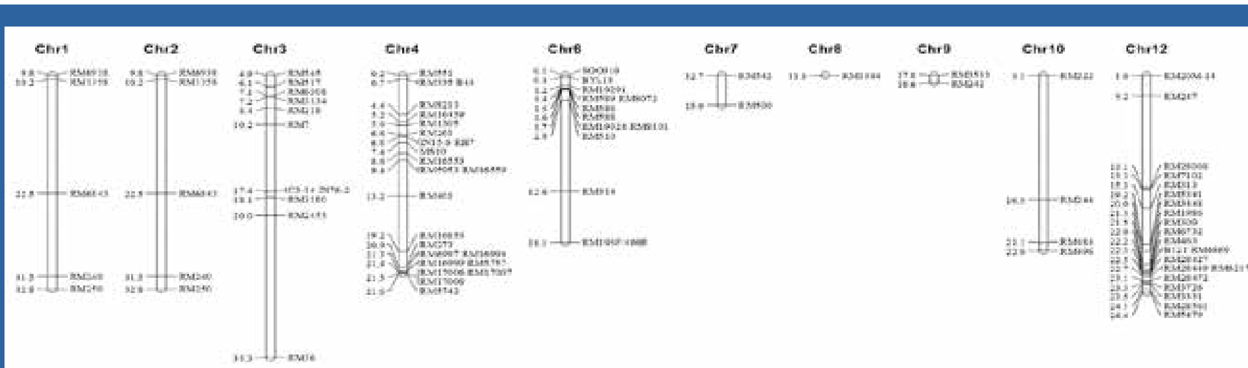


Fig. 3.1. Position of marker loci used in the genetic dissection of candidate genus.

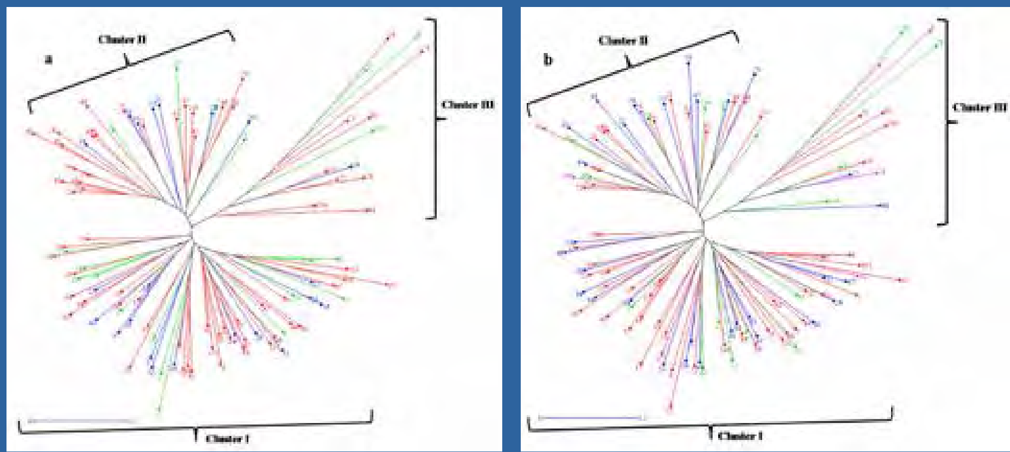


Fig. 3.2. Unrooted neighbor-joining tree based on molecular markers linked to BPH resistance in 107 FVs. These FVs are represented corresponding to (a) subpopulations determined from structure analysis (SG1, red; SG2, pink; SP3, blue; admixture, green); (b) BPH resistance reaction (resistant, green; moderately resistant, blue; susceptible, red).

Generation Rice Lines, 72 Assam Rice Collections and 17 Double Haploid Lines, 5, 10, 3, 3 and 2 entries, respectively were observed as moderately resistant to sheath blight disease under artificial inoculation.

False Smut

Among 174 rice genotypes collected from different locations of the country, only 19 genotypes were infected with false smut. Most of the infected genotypes fall into the category of moderately susceptible. However, vast majority of 155 genotypes were infection free.

Characterization of resistance to diseases

Phenotyping and genotyping of aromatic lines and ARCs against bakanae disease

Out of 150 ARCs, 23 accessions were found moderately resistant and 12 accessions were found resistant. Among 108 aromatic rice collections, 18 were found moderately resistant and three were resistant. These accessions were further evaluated for their genetic diversity using 12 reported microsatellite markers (Fig. 3.3). Except one (RM 10153), all markers produced polymorphic amplicons (from 2 to 8 bands). A total of 37 alleles have been shown with a mean of 3.08. Polymorphism information content (PIC) ranged from 0.031 (RM 10153) to 0.374 (RM 3698) with an average value of 0.264. Genetic diversity ranged from 0.032 (RM 10153) to 0.449 (RM 3698). Analysis of molecular variance showed that, more variance (95%) was observed among the individuals and less (5%) among the populations.

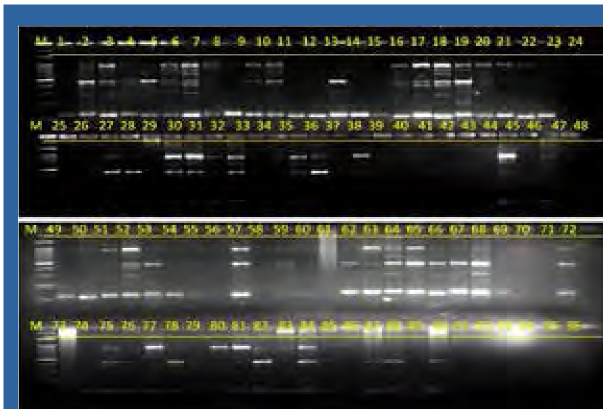


Fig. 3.3. Amplification pattern of microsatellite primer RM486; M: Marker, 1-96: rice genotypes.

Identification of new sources of resistance against nematodes

Rice root-knot nematode (RRKN)

Forty five different rice lines/varieties were screened and only LD 24 (an indica rice from Sri Lanka) was found to be highly resistant to RRKN, while KPM (Khao Pahk Maw; an aus from Thailand) was found resistant against the nematode, *Meloidogyne graminicola* (Fig. 3.4).

Effect of potassium silicate soil application on rice plant, soil microbes and enzymes

Soil application of potassium silicate @ 250, 400 and 1000 kg ha^{-1} on nine varieties comprising of DSR and Non-DSR i.e., TN 1, TKM 6, PTB 33, Salkathi, CR 200, CR 201, CR 203, CR 204, CR 206 improved different plant parameters like shoot length, root length and shoot and root weight. Potassium silicate application (even @ 1000 kg ha^{-1}) on soil microbes (Bacterial, PSB, Fungal population and MBC) showed positive effect, recording corresponding enzyme activities (FDA, β glycosidase, alkaline and acid phosphatase) (Fig. 3.5).

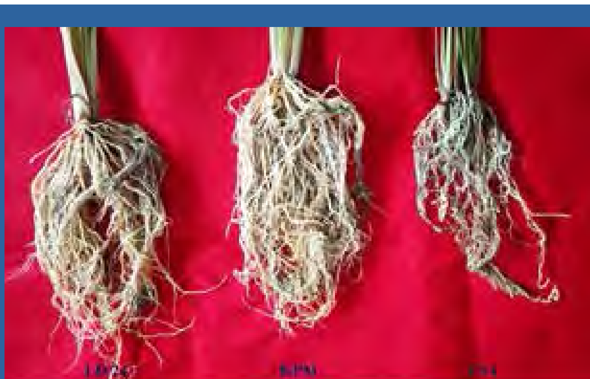
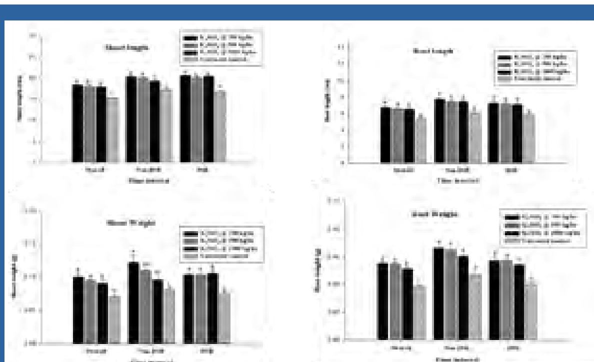


Fig. 3.4. LD 24 and KPM are resistant compared with TN1 (susceptible check).



Varieties used: Non-DSR - TN1, TKM6, Salkathi, PTB33; DSR - CR 200, 201, 203, 204, 206

Fig. 3.5. Effect of potassium silicate application on plant parameters in DSR and Non-DSR varieties.

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

Genetic diversity study of different yellow stem borer (YSB) population of India

Analysis of Molecular Variance using 10 EST-SSRs had shown existence of good diversity in YSB populations collected from 16 different locations of India and structural analysis also revealed existence of two groups of YSB population. The phylogenetic tree analysis of COX-1 gene marker shown grouping of studied population in to two clades. The network analysis (Fig. 3.6a and 3.6b.) indicated presence of 25 haplotypes of which two major haplotypes from Indonesia and one is from India. This is the first report of showing genetic diversity in YSB populations of India using EST-SSRs and COX-1 gene based markers.

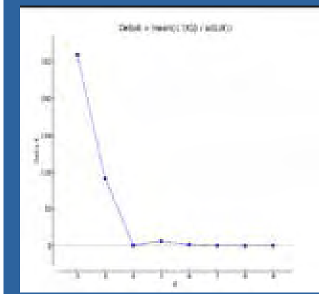


Fig. 3.6a. Structural analysis

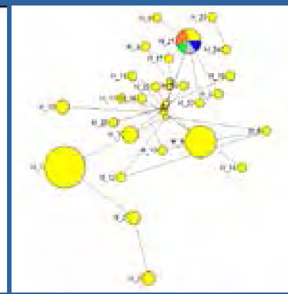


Fig. 3.6b. Haplotype network analysis

Distribution of BPH under current and projected climate change scenario

A species distribution model, *viz.,* MaxEnt (maximum entropy modeling) program was used to record suitable habitat for BPH under current and future climatic scenarios for 2050 and 2070. The predictions were mapped in ArcGIS, for spatio-temporal mapping and analyzing area under suitability ranges. Southern India and parts of eastern India are currently suitable for BPH with the area of 2.3 lakh square kilometer. The most vulnerable areas for BPH outbreaks are parts of Tamil Nadu, Andhra Pradesh, Telangana and some parts of Karnataka and Odisha. Our projection provides an initial estimate of the potential expansion of suitable habitat for BPH in 2050 and 2070 (Fig. 3.7). The projected of high habitat suitable area of BPH was doubled up at 2050 and tripled up at 2070.

Genetic analysis of Indian populations of BPH based on mitochondrial *cox1* and *its1* gene sequences

Genetic diversity indices [number of haplotype *(H),* haplotype diversity *(Hd),* nucleotide diversity *(π)* and average number of nucleotide difference *(k)*] of

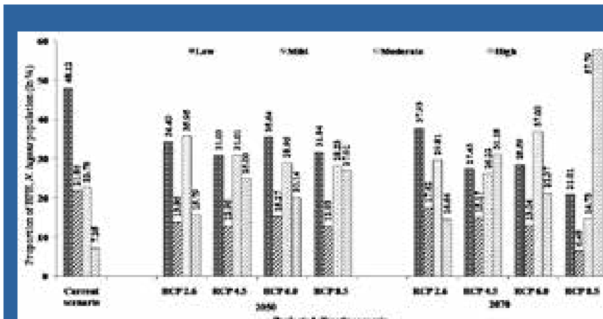


Fig. 3.7. Proportion of BPH in India during current and projected (2050, 2070) climatic scenario.

populations revealed that BPH maintains fairly high level of genetic diversity without isolation by distance among the geographic regions. Demographic analysis indicate the possibility of recent sudden expansion of species and is further supported through distinctively star-like distribution structure of haplotypes among populations (Fig. 3.8 and 3.9) indicating that both ongoing and historical factors have played important role in determining the genetic structure and diversity of the species in different places of India.

Cultural variability of *Ustilaginoidea virens* isolates collected from different states of India

Seventy nine *U. virens* isolates were collected from major rice growing states of India *viz.,* Bihar, Odisha, West Bengal, Assam, Meghalaya, Tripura and Jharkhand. Cultural characteristics *viz.,* colony size, colony colour and texture were recorded at an interval of seven days. Size of mycelial growth was too variable *viz.,* very slow, slow, moderate to fast (Fig. 3.10). Lowest growth was 15 mm (FSM-85) and highest was 54 mm (FSM-5) after 21 days and both the isolates belong to Assam. Colony texture of most of the isolates (39) were compact, 29 were fluffy and remaining 11 were cottony. Yellowish green was at mature spores, whereas blackish green was on the verge of producing pseudosclerotia. Colony colour of 15 isolates did not change even after 20 days. Sixteen isolates were yellow as they were at spore producing stage. *U. virens* isolates had shown wide variation in incubation period.

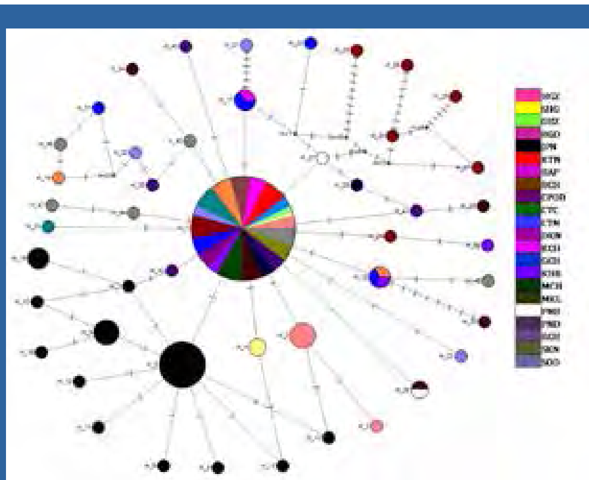


Fig. 3.8. Median joining network of mtDNA (*COX1*) haplotypes of *BPH.*

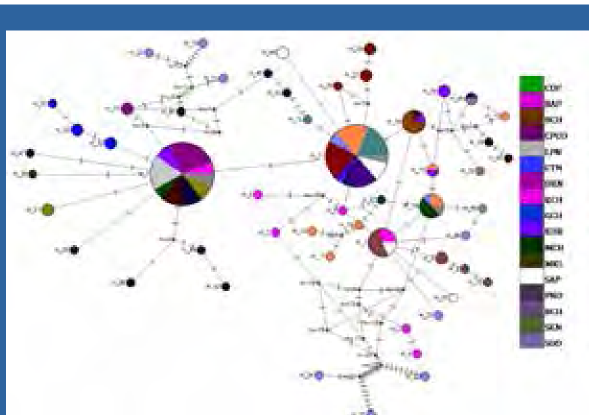


Fig. 3.9. Median joining network of mtDNA (*ITS1*) haplotypes of *BPH.*

(Each circle represents a haplotype, and circle diameter is relative to haplotypes frequency. Colors represent the geographic origin of specimens and size also indicates the proportion of individuals sampled in different populations within the study area. Smaller red squares represent median vectors)

Genetic diversity and population structure of *U. virens* of northern India

Genetic diversity of *U. virens* isolates from north India ranged from 0.1 to 0.36. The dendrogram showed two main clusters (Fig. 3.11). Cluster I was a small group mostly from the central and northern Uttar Pradesh and cluster II represented large number of isolates from different regions of Uttar Pradesh, Madhya Pradesh, Uttarakhand and Himachal Pradesh. The principal coordinate and structure analysis reflected similar populations, identified two genetic clusters with some degree of distinctness according to locations. The value of K=3 also indicated that optimum number of subpopulation was three which indicated that sample population belonged to three inferred genome fraction.

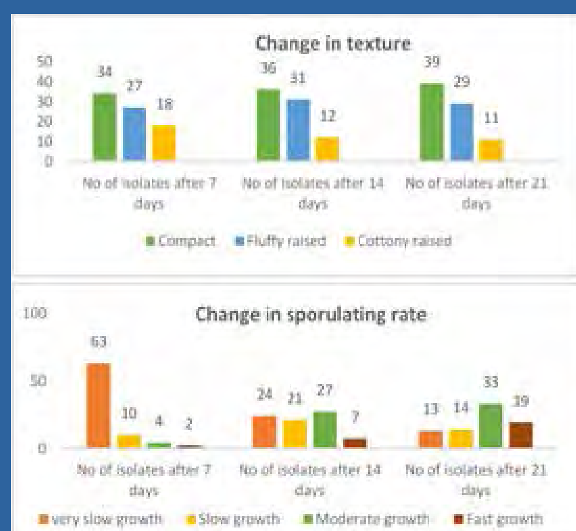


Fig. 3.10. Cultural variation of isolates of *U. virens* collected from different states of India.

Combine marker study also showed the K=2 with peak at K=3. Analysis of molecular variance revealed more genetic variation within population (95%) and less among population (5%).

Spectral discrimination of healthy and leaf folder infested rice plants using ground-based hyperspectral data

The *in situ* electromagnetic spectral curve over healthy and infested crop is shown in Fig. 3.12. This spectral curve was obtained after removal of noise. A sharp peak was seen at 550 nm indicating the presence of anthocyanins.

Perusing above graph, it was found that there was slight change in magnitude in visible range for both healthy and infested samples but the change is quite obvious in near infrared (NIR) region. The maximum value was at 815 nm for both healthy and infested samples on original spectra.

On the first order derivative spectral curves (Fig. 3.13a), maximum difference obtained between healthy and leaf folder infested samples was just after the visible region *i.e.* from 700 to 760 nm and to be precise, it was exactly located between 713 to 754 nm. This phenomenon shows that the red edge appears in the wavelength of 680-750 nm.

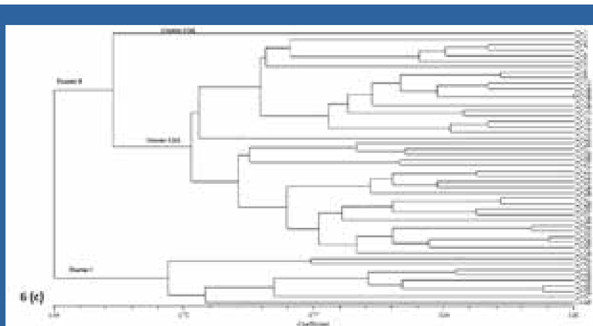


Fig. 3.11. SHAN UPGMA clustering using NTSYS software RAPD & SSR combined data.

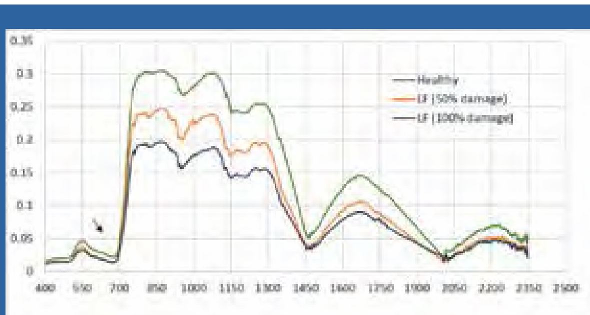


Fig. 3.12. Spectral curve for healthy vs leaf folder infestation at different damage level.

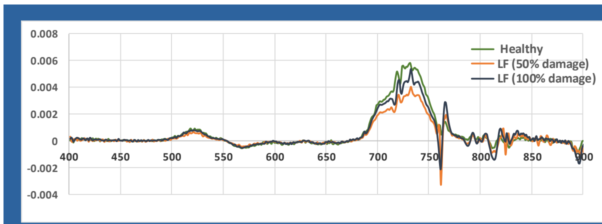


Fig. 3.13a. First order derivative for Healthy vs Leaf folder

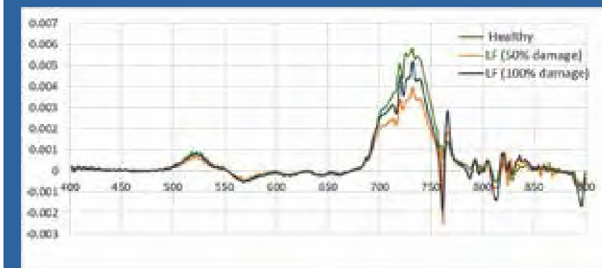


Fig. 3.13b. Second order derivative for Healthy vs Leaf folder.

In case of the second order derivative spectra, considering a wavelength range from 650-800nm, the maximum change in slope for leaf folder infested samples were found at 716, 720, 733, 762 and 766 nm. From the wavelength range of 800-900 nm we found maximum change of slope for Leaf folder affected samples were at 814 and 896 nm. Summary of analysis reveals the difference of spectral reflectance was significant for different damage levels, but they were obviously different in different spectral regions (visible and NIR). Comparatively, the spectral difference in the NIR region was the most obvious and difference in the visible region was very negligible and hence, no significant difference was found.

3.3 Bio-intensive approaches for pest management in rice

Identification and characterization of novel bio-control agents including rice endophytes

The effect of seed biopriming with *Trichoderma* based formulation 'TrichoVit' was tested at the experimental field of the as well as in the farmers' field of Ganeshpur, Chandol, Kendrapara. In the farmers field, the seed biopriming resulted in enhancement of the all agronomical parameters (Table 3.1), which resulted in an increase of yield by 15.8% over the control plot. Higher chlorphyll content was observed in the treated plants in comparison with that of non-treated one.

Identification of bacterial bio-control agents (BCAs) against rice pathogens

Among 12 bacterial BCAs tested, four strains *viz.*, RB 12 (MH257581) *B. subtilis,* RB 26 (MH251872) *B.*

amyloliquefacians, RB 28 (MH251943) *B. subtilis and* RB 32 (MH257583) *B. megaterium* antagonistic effect in inhibiting the mycelial growth of rice blast pathogen.

Bacillus subtillis and *Trichoderma harzianum* (NRRI-T1) were observed to be effective against false smut disease of rice (Table 3.2).

Seed priming with salicylic acid (SA) and potassium silicate (PS) controls bakanae disease by inducing resistance

Seed priming with SA and PS showed that these two elicitors were effective even when applied at lower concentration. Seed priming either in combination (SA @ 100 mg l^{-1} and PS @ 1%) or sequential application, not only enhanced plant growth parameters like germination, root length, shoot length, seedling vigor, fresh and dry weight yield, but also reduced bakanae disease incidence in highly susceptible variety Pooja (Fig. 3.14). Scanning electron microscopic (SEM) observation for histopathological studies revealed higher colonization of pathogen inside the control plants as compared to that of treated one and resistant structures like papilla.

Natural zeolite for eco-friendly management of rice weevil

Laboratory studies with natural zeolite formulation against rice weevil at different dosages *viz.,* 0.25, 0.50, 0.75, 1.00, 1.25 and 1.50 g kg^{-1} of grain stored showed that the natural zeolite formulation was very good control of test insect by registering 83% mortality when treated @ 1.5 g kg^{-1} grain stored after 21 days of treatment imposition.

Molecular detection confirmed widespread occurrence of rice tungro disease

Widespread occurrence of rice tungro disease (RTD) was detected during *kharif* 2020 at ICAR-NRRI experimental farm in different rice genotypes. The presence of vector (green leaf hopper) was also recorded (Fig. 3.15a). Few of the infected genotypes were maintained in glass house (Fig. 3.15b). Confirmation of RTD incidence was done at regional station CRURRS, Hazaribag by PCR assay using rice tungro bacilliform virus specific primer, designed to amplify ~1.1 kb region spanning the partial RT/RNAse H and ORF IV of the RTBV genome. All the symptomatic leaf samples showed virus-specific amplification of ~1.1 kb in PCR assay. No amplification was found in healthy rice plant and water control (Fig. 3.15c).

Modified version of the theory of planned behavior (TPB)

An attempt was made with a modified version of

Table 3.1. Growth promotion in CR Dhan 101 in farmers field of Ganeshpur, Chandol, Kendrapara as an effect of seed bio-priming with *Trichoderma* (NRRI-T2).

Treatment	Fresh weight (g)	Dry weight (g)	Plant length (cm)	Effective tillers/ plant	Panicle length (cm)	Panicle weight (g)	1000 grain weight (g)	No. of grains/ panicle	No. of chaffs/ panicle
Trichoderma	420.65^A	127.86^A	29.24^A	28.20^A	29.24^A	8.21^A	29.52^A	252.40^A	103.20^A
Control	123.54^B	45.68^B	25.34^B	13.40^B	25.34^B	4.14^B	24.71^B	148.00^B	57.80^B
p-Value	272.10	86.77	27.29	20.80	27.29	6.17	27.11	200.20	80.50

Table 3.2. Efficacy of BCAs against false smut in rice.

Sl. No.	Bio-agent	No. of grains/ panicle	No. of chaffy grain	No. of smut ball	Disease severity (%)
1	*Bacillus amyloliquefaciens*	285(2.45)	83(1.92)	6.60(2.57)	2.32(1.52)^b
2	*Bacillus subtilis*	287(2.46)	41(1.61)	1.00(1.00)	0.35(0.59)^f
3	*Trichoderma harzianum*	319(2.50)	60(1.78)	1.67(1.29)	0.52(0.72)^e
4	*Trichoderma atroviride*	350(2.54)	20(1.30)	4.00(2.00)	1.14(1.07)^d
5	*Dendryphiella sp*	236(2.37)	70(1.85)	3.00(1.73)	1.27(1.13)^c
6	Control	226(2.35)	70(1.85)	6.33(2.52)	2.80(1.67)^a
	p-Value				<.0001

Fig. 3.14. Effect of seed priming with SA and PS. 1. SA alone (100 mg l^{-1}), 2. PS alone (1%), 3. Sequential application of SA (100 mg l^{-1}) followed by PS alone (1%), 4. Sequential application PS (1%) followed by SA (100 mg l^{-1}), 5. SA (100 mg l^{-1}) + PS (1%), 6. Carbendazim 50% WP @ 2 g l^{-1}, 7. Pathogen control, 8. Distilled water control.

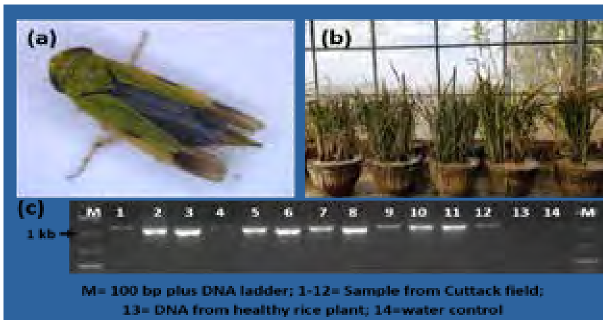


Fig. 3.15. Rice tungro virus incidence (a) The vector green leaf hopper and (b) Symptomatic plant samples maintained at glass house condition. (c) PCR based detection of RTBV using genome specific primer.

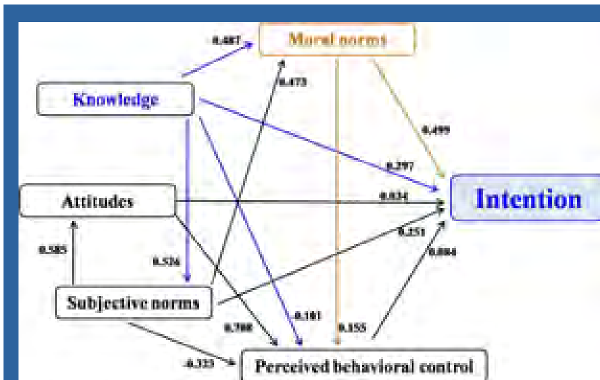


Fig. 3.16. Path analysis of factors affecting farmers' intention to use pesticides in Odisha.

TPB to assess the Indian rice farmers' pesticide use intention. Results indicated that a majority of the farmers showed positive attitude towards pesticides use and is attributed to relatively high social pressure as revealed through subjective norms. Further, a majority exhibited quite low level of perceived ability and knowledge towards pesticide use (Fig. 3.16).

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

Sorption and leaching potential of chlorantraniliprole in two distinct rice growing soils

Microcosm investigations were conducted to study sorption behaviour and leaching potential of chlorantraniliprole (CAP) in two common Indian soils, *viz.*, inceptisol (NRRI soil) and alfisol (RC-CTCRI soil). Adsorption isotherms of S-type were obtained in both the tested soil types and data were well fitted into Freundlich model (Fig. 3.17). The result showed strong adsorption of CAP with K_f value of 1.43 and 1.32 and 1/n value as 1.29 and 0.57 in NRRI soil and RC-CTCRI soil, respectively. Higher sorption of CAP occurred in NRRI soil (34.88 %) as compared to RC-CTCRI soil (24.68%). Leaching study indicated that CAP was slightly mobile insecticide and its mobility is higher in RC-CTCRI soil as compared to NRRI soil. Adsorption of CAP was strongly influenced by soil physiochemical properties and leaching of CAP was positively correlated with the amount of rainfall.

Role of climate change variables (standing water and rainfall) on dissipation of chlorantraniliprole from a simulated rice ecosystem

Highest concentration of CAP residues in soil and plant under saturated condition followed by 5 and 10 cm standing water conditions (Fig. 3.18). Whereas, the highest concentration of CAP in leachates was detected under 10 cm standing water (12.19 ng mL^{-1}). The results revealed large amount of leaching (21.99 ng mL^{-1}) and surface runoff (42.25 ng mL^{-1}) losses of CAP when 100 mm rainfall occurred at 4 h after pesticide application. The total quantity of CAP residues in soil and plant was highest when rainfall occurred at 24 h after pesticide application under both the rainfall amounts. Water stagnation and high intensity rainfall shortly after pesticide application would contribute to pesticide loss to non-target sites through surface run-off and leaching. There will be less pesticide available in soil for plant uptake which may not be sufficient to kill the target organisms.

Preparation of novel insecticide mixtures effective against brown plant hopper (BPH) and yellow stem borer (YSB)

Compatibility of different group of insecticides i.e., chlorantraniliprole (CAP), flonicamid (FCD), pymetrozine (PMZ) and triflumezopyrim (TFZ) in mixtures, and their combined toxicity against BPH and YSB were studied. The pesticide mixtures of CAP

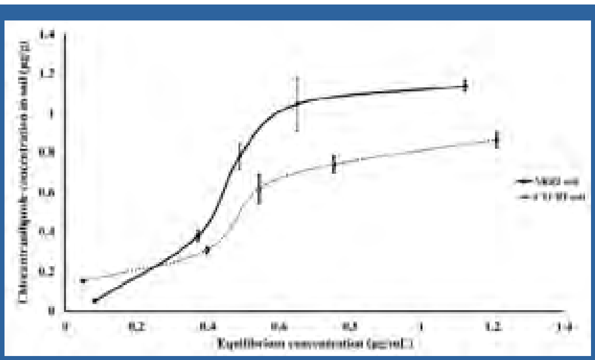


Fig. 3.17. Adsorption isotherm of chlorantraniliprole in NRRI soil & RC-CTCRI soil.

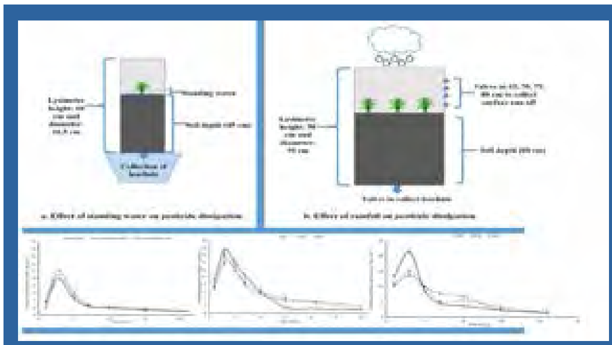


Fig. 3.18. Role of climate change variables (standing water and rainfall) on dissipation of chlorantraniliprole from a simulated rice ecosystem.

with FCD, PMZ and TFZ, respectively were physically and chemically compatible and had no phytotoxic effect. The LD_{50} were 17.22 ng insect^{-1} for CAP, 0.059 ng insect^{-1} for FCD, 0.18 ng insect^{-1} for PMZ and 0.047 ng insect^{-1} for TFZ against BPH. The LD_{50} were 2.737 ng larva^{-1} for CAP, 0.073 ng larva^{-1} for FCD, 0.313 ng larva^{-1} for PMZ and 0.061 ng larva^{-1} for TFZ against YSB. In combined toxicity studies against BPH, the total mortality was ranged from 50-90 % out of different mixtures, among which combination of 10 ng CAP + 0.05 ng FCD per insect had shown maximum mortality of BPH i.e., 90 % (Fig. 3.19). In case of YSB, the mortality ranged between 60-83.33 %.

Insecticidal responses against different BPH populations

Populations of BPH showed significant differences in the LC_{50} values of tested insecticides, *viz*., imidacloprid, dinotefuran and buprofezin (Fig. 3.20). Populations of BPH from Sambalpur, Karnal and Ludhiana recorded lesser susceptibility to imidacloprid compared to Kerala, Raipur and Cuttack (susceptible check) populations. Based on resistance ratio (RR), Karnal and Ludhiana populations developed moderate level of resistance, whereas Sambalpur, Moncompu and Raipur categorized in to low level of resistance against imidacloprid. Similar results were observed with dinotefuran. With regard to buprofezin, except Moncompu population, all other populations displayed moderate level of resistance.

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

Among the seven fungicide candidates, isoprothiolane 40EC @1.5 ml l^{-1} was best to control the sheath blight with 18.4% disease severity and 22.5% disease incidence. The untreated control showed 69.4% disease severity and 72.5% disease incidence.

Lumivia: A novel seed treatment formulation (CAP 625 g l^{-1} FS) for YSB and leaf folder management in direct seeded rice (DSR)

Among all concentrations, Lumivia @ 75 g ai ha^{-1} recorded best result in terms of dead heart reduction and registered highest yield. Lumivia @ 150 g ai ha^{-1} did not record any phytotoxicity symptoms like chlorosis, wilting, hyponasty and epinasty. Thus, CAP 625 g l^{-1} FS (Lumivia @ 75 g ai ha^{-1}) may be recommended for managing stem borer and leaf folder under DSR.

IPM validation in farmers' field

Validation and promotion of IPM module under shallow lowland ecosystem in the farmers' fields were undertaken involving 26 farmers during *kharif*, 2020 with Swarna and Pooja varieties in total 20 acres. In IPM practice, seed treatment was done with carbendazim 50 WP @ 2.0 g kg^{-1} seed before sowing. Need based application of pesticides was undertaken by the farmers in the affected areas only. The fungicide, carbendazim 50 WP @ 1.0 g l^{-1} was applied against brown spot, sheath blight, sheath rot diseases; cartap hydrochloride @ 1 kg ai ha^{-1} was used against YSB, leaf folder, BPH; and chloropyriphos 20% EC @ 0.5 kg ai ha^{-1} used against gundhi bug. Also, YSB sex pheromone traps @ 8 nos. ha^{-1} and bio-control agents (*Trichoderma viride* and *Pseudomonas fluorescens*) were provided to the farmers. In need based IPM practice in both varieties less infestation of targeted diseases and insect pests were observed as compared to farmer's practice of pest management. With regards to yield parameters, in both varieties IPM (need based) treatment out performed the farmers' practice of pest management with yield advantage of 2.0 t ha^{-1}.

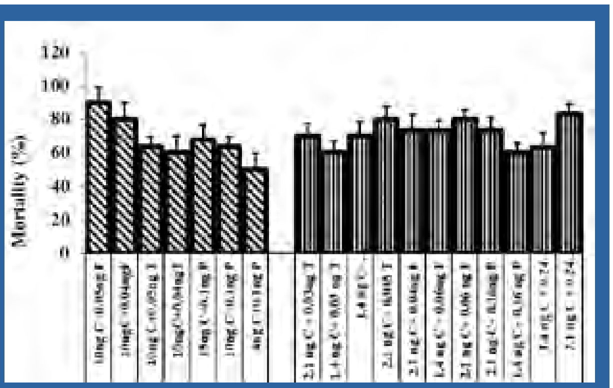


Fig. 3.19. Efficacy of different insecticidal mixtures against BPH and YSB.

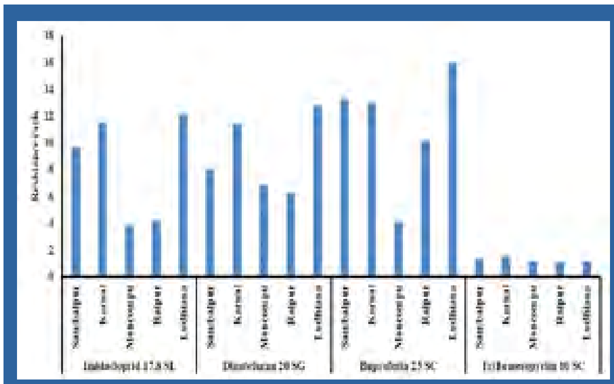


Fig. 3.20. Insecticidal responses against different *Nilaparvata lugens* populations.

The Crop Protection Division undertook distinctive research on holistic management of rice pests and diseases through a series of articulated projects. The Division identified new resistant donors against pests and diseases, unraveled pest and disease resistance mechanism, utilized hyperspectral data to identify healthy & leaf folder infested rice plants, developed IPM and bio-intensive strategies to manage the pests & diseases, optimized pesticide use in different ecosystems and conducted a series of training programs for the farmers. Currently, the Division is poised to take on new challenges posed by pests and diseases, by revamping its research programs incorporating latest advancements in molecular biology including gene sequencing and genome editing tools, coupled with artificial intelligence, internet of things and big data analytics.

PROGRAMME-4

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

Rice being staple food for majority of the population, sometimes lead to obesity and type-II diabetes, exhibiting relatively high glycemic index (GI) value compared to other carbohydrate rich foods. Moreover, being grown under diverse ecosystems, under changing climatic conditions, it gets exposed to different environmental stresses reducing grain yield and quality. Addressing the problems, this programme was developed with three objectives *viz.*, i) study of GI and high protein rice ii) identify suitable donors and understand the physiological and molecular mechanism of abiotic stress tolerance; iii) enhance photosynthetic efficiency by introduction of C4 pathway and minimizing photorespiration. The division with its cadre strength of nine scientists and five technical staff operates three institute research projects and four externally aided projects.

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

Effect of Phytic acid and household cooking processes on minerals (Fe and Zn) bioavailability

Phytic acid (PA) is the most abundant storage form of phosphorus in rice grains which acts as a strong chelator of metal cations (mainly Fe and Zn) and reduces their bioavailability. Therefore, reducing the PA content in rice grain could be a potent strategy for increasing micronutrient bioavailability. Food processing by heat generally alters the bioavailability of nutrients, both at macro and micro level in addition to the inherent factors that inhibit mineral absorption. Phytic acid content was estimated in the brown (BR) and milled rice (MR) of 58 NRRI rice varieties where large variation was found in the BR (0.30-2.37 g^{-1}100g^{-1}) and MR (0.20-1.12 g^{-1}100g^{-1}). After milling, the PA content was reduced up to 70%. Among the genotypes studied, Khira showed lowest PA (0.30 g^{-1}100g^{-1}) while the highest PA (2.37 g^{-1}100g^{-1}) was found for Phalguni (Fig. 4.1). Effect of processing (milling) and various household cooking methods (boiling, pressure cooking and microwave cooking) were investigated for the reduction of Fe, Zn content and changing in their bioavailability in four rice genotypes having contrasting PA contents. After milling, Fe content and its bioavailability were reduced. Zn content was reduced and bioavailability was found 24-46% in BR while 40-54% in MR. Khira with lowest PA has shown highest Fe and Zn bioavailability.

Evaluation of sensory and physico-chemical properties of some quality rice varieties

Nine rice cultivars (black, red and white) *i.e.* (i) Manipuri Black, Chakhao, Mamihunger (black), (ii) Balam, Annapurna (red) (iii) Naveen, CR Dhan 310, Govindabhog and Swarna (white) were taken to analyse grain physico-chemical properties, colour, texture, viscosity and antioxidant properties in raw and parboiled rice, which are directly related to human preference as well as health (Fig. 4.2). Significant differences in the physio-chemical and cooking quality of these rice cultivars were observed. The changes in color in parboiled rice indicate that some components might have been moved during soaking process from the inner layers to the surface, while others, especially bran compounds moved towards endosperm. Amongst different pasting properties accomplished by Rapid Visco Analyzer, the highest final viscosity of parboiled brown rice flour was observed in Balam, followed by Manipuri black and Chakhao, whereas the lowest was obtained from Annapurna and the peak viscosity was highest in Chakhao and Balam. In case of grain hardness measured by Texture Analyzer, the raw brown rice had lower values than the parboiled rice due to solidification of starch. In case of raw rice, the highest hardness was found in the red rice variety Balam, whereas Manipuri Black rice possessed the lowest. However, in case of parboiled rice, CR Dhan 310 ranked first and lowest was obtained in Chakhao. The reduction of antioxidant capacity along with total phenolic and flavonoid content was observed in parboiled brown rice as compared to raw rice. The

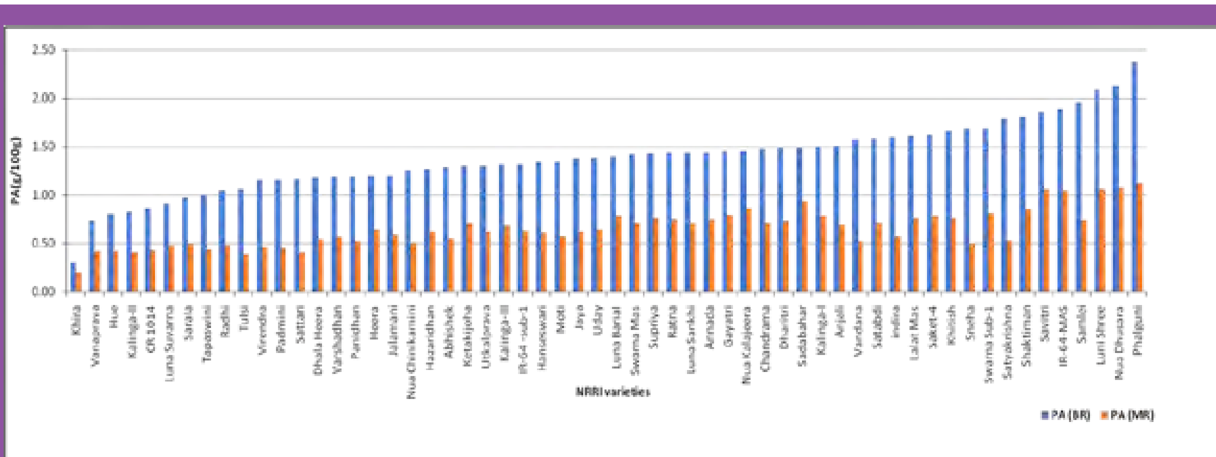


Fig. 4.1. Screening of NRRI rice varieties for low Phytic acid content.

amylose content of pigmented rice is generally low as compared to the white rice.

Fig. 4.2. ***Un-milled rice of different pigmented and non-pigmented rice cultivars. (AN-Annapurna, GB-Gobindabhog, MH- Mamihunger, BA-Balam, CRD310-CR Dhan310, CH- Chakhao, SW-Swarna, MB- Manipuri Black, NA- Naveen).***

Mechanism of N-uptake and assimilation in high protein rice and its parents

Nitrogen uptake in varieties with contrasting grain protein content (ARC 10075 and CR Dhan 310: high grain protein varieties, Naveen: low grain protein variety) was found to significantly differ with ARC 10075 showing highest nitrate reductase (NR) and nitrite reductase (NiR) activity both in 21-day seedling stage as well as during different plant growth stages (*viz*., active tillering, panicle initiation, flowering); followed by CR Dhan 310 and Naveen. Nitrogen assimilation pattern in the same varieties were studied focusing on amino acid and protein content in grains. An HPLC method was standardized for studying grain amino acid content using fluorescence detector. The content of glutamate (Glu) and aspartate (Asp), the primary assimilates have been found to be higher in ARC 10075 followed by CR Dhan 310 (Table 4.1) and Naveen. The high content of Glu and Asp in the grains may be considered to be an indication of the higher activity of nitrogen assimilating enzymes GS/GOGAT. The high amino acid content may also translate into higher protein content as observed in the grains of the three varieties.

Table 4.1. Amino acid content in mature grains of the three varieties.

Amino acid content ($g^{-1}100g^{-1}$)	ARC 10075	CR Dhan 310	Naveen
Glutamate (Brown rice)	0.416	0.238	0.159
Aspartate (Brown rice)	0.312	0.262	0..84

Biochemical changes in rice grains during long term storage

During storage many biochemical changes takes place in the rice grain which is reflected through the change in cooking and eating quality. One of the important biochemical parameters largely affected due to storage is lipid peroxidation. The study showed that the dynamic procedure of lipid peroxidation occurs during early storage but becomes constant after 8-12 months of storage which could be the reason of stabilizing others factors directly affecting the grain quality. Hence minimum 12 to 15 months of aging could be preferred to attain the best quality of rice for consumption. Though the aging affects the lipid peroxidation but no strong correlation was observed between storage and level of lipid peroxidation.

Physiology of rice for individual and multiple abiotic stress tolerance

Screening of elite rice cultures for drought tolerance under rainfed condition

Twenty-five rice genotypes from *IVT-E-DS* trial and five released varieties were tested for drought tolerance under rainfed condition without any supplementary irrigation along with a trial on recommended irrigation. Based on the reduction in grain yield under rainfed condition, IET 28240, IET 28247, IET 28254, IET 28256 and US 314 with Vandana and Gangavati Ageti, among released varieties could be identified as relatively drought tolerant with lowest relative yield reduction (RYR, 4.45-10.70%), low drought susceptibility index (DSI, 0.16 -0.40) and higher grain yield (2.85-4.03 t ha^{-1}) compared to other genotypes. Based on stability analysis, IET 28247, IET 28254, IET 28256 and US314 were also selected as stable genotypes which performed well across five locations.

Variation in stomatal density and size in rice varieties in response to drought

Leaf impression obtained from adaxial surface as a thin film of fully expanded and exposed flag leaf of 50 genotypes were screened for stomatal density (number of stomata /unit leaf area) at flowering stage and number of stomata for each film strip were counted under Carl Zeiss Light microscope system (Fig. 4.3). Among 50 genotypes, AC 42997 followed by AC 43020 had significantly fewer stomata and low stomata density (374.6 mm^2 and 385.6 mm^2) with low aperture length and width (6.67 and 2.30 µm,

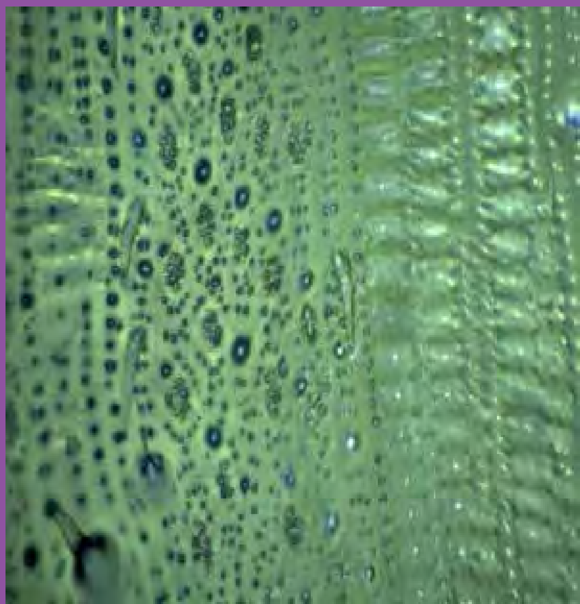


Fig. 4.3. Leaf imprint for stomatal density in AC 42997.

respectively) helping slow transpiration loss and high WUE indicating higher drought tolerance efficiency as compared to others. However, 10 best genotypes with lower stomatal aperture and density helping slow transpiration loss, high WUE leading to high tolerance to drought (Table 4.2).

Identification of relative contribution of ion exclusion and tissue tolerance strategies for overall salt-tolerance of rice genotypes

Salt tolerance through Na^+-exclusion is a highly energy requiring process, which often results in yield penalty upon its transfer to elite background. One genotype, Kamini showed similar level of salt-tolerance as Pokkali rice, but with much higher mesophyll Na^+ load (Fig. 4.4). A comparison between Kamini (a landrace from mangrove region) and FL478 (Pokkali type) was made. Kamini possessed greater tissue tolerance ability and could use Na^+ as osmoticum for stress tolerance. Its suggested that Kamini might have used inorganic osmolytes like Na^+ for osmotic adjustment, which cut down the cost of salt-tolerance *i.e.* (i) less energy consumption due to reduced ion exclusion and (ii) lesser requirement of organic osmolyte for osmotic adjustment.

Rice containing *Sub1* QTL possesses thicker leaf gas film aiding submergence tolerance

Submergence tolerance in rice is primarily attributed to *Sub1* gene action. However, association of traits *viz*. leaf gas film (LGF) thickness, leaf hydrophobicity and tissue porosity with *Sub1* QTL is not known. Therefore, 12 rice genotypes (including both *Sub1*

Table 4.2. Performance of ten best genotypes with lower stomatal aperture and density compared with one tolerant and susceptible check each.

Sl. No.	Genotypes	Stomata density (mm^2)	Aperture length (µm)	Aperture width (µm)
1	AC 42997	374.60	6.67	2.30
2	AC 43020	385.67	7.08	2.77
3	JOHABORA	435.23	11.75	2.65
4	AC 43012	451.72	9.03	2.91
5	IC 346880	484.40	10.46	2.85
6	BASUMATI	485.03	11.75	5.02
7	AC 43029	492.33	9.57	3.97
8	AC 43019	495.68	9.79	4.01
9	BIROHI	513.22	12.83	5.02
10	BADAJANGIA	518.64	8.52	3.62
11	IR 64 (Sus check)	567.71	10.32	2.84
12	CR 143-2-2 (Tol check)	295.62	7.11	2.81
	MEAN	539.97	10.50	2.94
	LSD at 5%	54.32	2.10	0.23

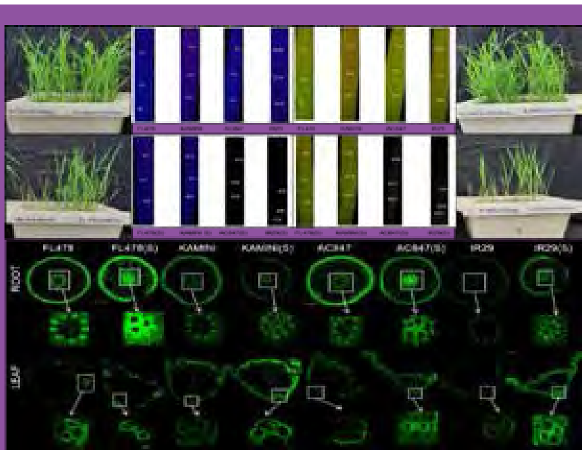


Fig. 4.4. The upper panel shows phenotypic variations and difference in chlorophyll fluorescence trait in four rice genotypes in response to salt stress (12 dS m^{-1}). The lower panel shows relative distribution of Na^+ through confocal microscopy images of cross sections of root and leaf tissues stained with CoroNa Green fluorescent dye.

and non-*Sub1* types) were tested to work out the relation of these traits with *Sub1* QTL. Initial thickness of LGF and hydrophobicity showed high positive correlation with presence of *Sub1* QTL in the genetic background of rice; although, other leaf traits like porosity and density seemed to be independent of it. Presence of *Sub1* QTL positively influences surface hydrophobicity and leaf gas film (LGF) thickness in rice (Fig. 4.5). This LGF acts as a physical barrier which delays perception of submergence stress. Artificial removal of LGF resulted in partial loss of tolerance showing increased ethylene production and early induction of anoxia related genes.

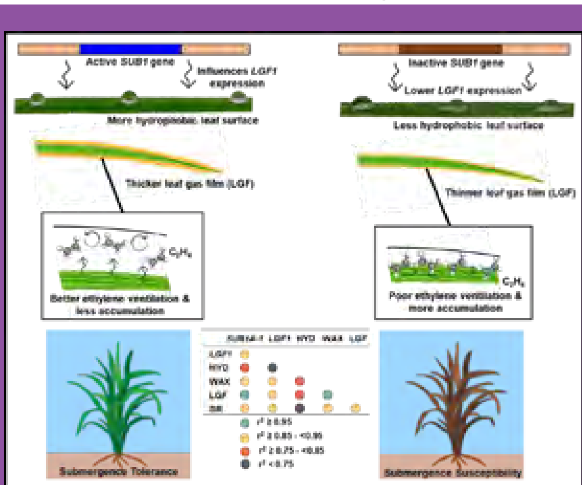


Fig. 4.5. A typical representation of ***SUB1*** influenced ***LGF1*** gene action leading to increased leaf hydrophobicity in ***Sub1*** (left panel) and non-***Sub1*** (right panel) rice genotypes.

Effect of heat stress of grain physico-chemical properties of rice

Studies on heat stress induced alterations in grain physico-chemical properties estimated in seven varieties grown under normal temperature (P1) and elevated temperature (P4) conditions showed that elevated temperature conditions affect various grain quality traits. A 4-5% decrease in protein content was observed with a decrease in its quality too; the maximum decrease is observed in Naveen and Shatabdi and the least in Ratna and N22 (Fig. 4.6, Table 4.3). Significant decrease in amylose content was seen with the maximum in Lalat and the least in Annapurna and N22 with a reduction in the textural attributes. Antioxidant content (phenol and flavonoid) and activity (CUPRAC, FRAP) was found to decrease in varieties grown under high temperature.

Temperature induction response: A high throughput screening technique to dissect the genetic variability in acquired thermo-tolerance of rice genotypes

A rapid and reliable lab protocol that allows simultaneous screening of large number of genotypes was developed to evaluate large number of genetic variations that exist for intrinsic tolerance among the rice genotypes. Ninety six NRRI released varieties were used in this study. Based on the absolute growth of control as well as treated seedlings, the per cent reduction in recovery growth (% RRG) was determined as measure of tolerance at cellular level (TCL). The genotypes showed significant genetic variability in parameters linked with intrinsic tolerance. Per cent reduction in recovery growth varied from 45 per cent in N22 to 100 per cent in Moroberekan and other 19 genotypes, with a mean of 78.9 per cent (Table 4.4).

RRG (%) = {AGC-RGI}/AGC

Where,
AGC= Absolute growth of control seedlings
RGI= Recovery growth of induced seedlings

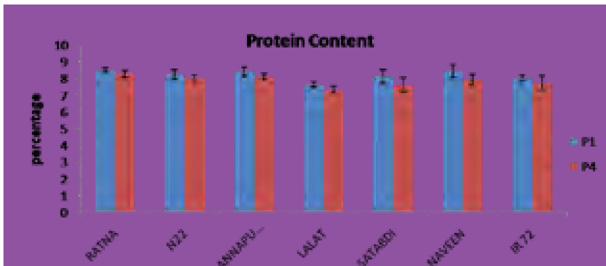


Fig. 4.6. Protein content as affected by elevated temperature.

Table 4.3. Protein quality as affected by elevated temperature.

	Albumin (%)		Globulin (%)		Glutelin (%)		Prolamine (%)	
	P1	**P4**	**P1**	**P4**		**P1**	**P4**	**P1**
SM	0.459	0.385	2.388	2.282	**SM**	0.459	0.385	2.388
SEM	0.033	0.038	0.064	0.062	**SEM**	0.033	0.038	0.064
	Most	**Least**	**Most**	**Least**		**Most**	**Least**	**Most**
	Lalat	Naveen	IR 72	Naveen		Lalat	Naveen	IR 72
	Shatabdi	Annapurna	Lalat	N22	N22	Satabdi	N22	Shatabdi

Table 4.4. Variability in intrinsic tolerance among rice genotypes.

Parameters	Mean	Minimum	Maximum
AGC	7.23	3.56	13.31
RGI	1.27	0.57	2.16
% RRG	78.9	45	100
% Survival of the seedlings	50.48	0	100

AGC- absolute growth of control, RGI- recovery growth of induced and % RRG – per cent reduction in recovery growth.

Performance of multiple abiotic stress tolerant rice genotypes at multiple locations

Screening of superior stress tolerant rice genotypes were tested in 11 locations *viz*., Cuttack, Coimbatore, Karjat, Faizabad, Pantnagar, Rewa, Pattambi, Titabar, Ranchi, Maruteru and Karaikal for multiple abiotic stress tolerance including salinity (12 dS m^{-1} at vegetative stage), osmotic stress (1% and 2% mannitol at vegetative stage) and anaerobic germination potential at germination stage. Out of 23 genotypes, one genotype, Mahulata performed well under all the stress conditions at majority of the locations, while another Rashpanjor performed well for salinity and showed high anaerobic germination potential in multi-locational testing. Hence, these genotypes could be identified as potential donors possessing multiple abiotic stress tolerance ability required for unfavorable rice ecologies.

Improvement of photosynthetic efficiency of rice

Physiological characterization of rice plants transformed with C4 photosynthetic gene, *Setaria italica PPDK* (*Si PPDK*)

The high photosynthetic capacity of C4 plants is due to their exclusive mode of CO_2 incorporation, featuring stringent compartmentation of photosynthetic enzymes into two distinctive cell types, mesophyll and bundle-sheath. Firstly, CO_2 assimilation is carried out in mesophyll cells. The chief carboxylating enzyme, phosphoenolpyruvate carboxylase (PEPC), in concert with carbonic anhydrase (CA), is vital to create rapid equilibrium between CO_2 and HCO_3^-. This step is responsible for the hydration and fixation of CO_2 to produce the C4 acid, oxaloacetate. In NADP-ME-type C4 species, oxaloacetate is converted to another C4 acid -malate, catalysed by malate dehydrogenase (MDH). Malate then diffuses into chloroplasts in the proximal bundle sheath cells, where CO_2 is released to yield pyruvate by the decarboxylating NADP-ME. The released CO_2 concentrates around the secondary carboxylase - Rubisco, and is reassimilated by it through the Calvin cycle which is a C3 pathway. Pyruvate is transferred back into mesophyll cells and catalyzed by pyruvate orthophosphate dikinase (PPDK) to regenerate the primary CO_2 acceptor, phosphoenolpyruvate. It was tried to integrate the C4 gene *viz*. *Setaria italica PPDK (Si PPDK)* in to rice and T1 generation plants were analysed for their photosynthetic efficiency and other related parameters.

Light response curve

Curve fitted for light response showed that the transgenic plants (PPDK 26 and PPDK 27) showed continuous increase in net photosynthetic rate (*A*) with respect to increase in photosynthetic active radiation (PAR) while in non-transgenic and empty vector control plants a plateau was observed at PAR 1000-1200 µmol m^{-2} sec^{-1} (Fig. 4.7).

CO_2 response curve

The CO_2 response (A/Ci) curve of transgenic plant showed a linear increase in photosynthesis rate with respect to increase in CO_2 concentration, while in non-

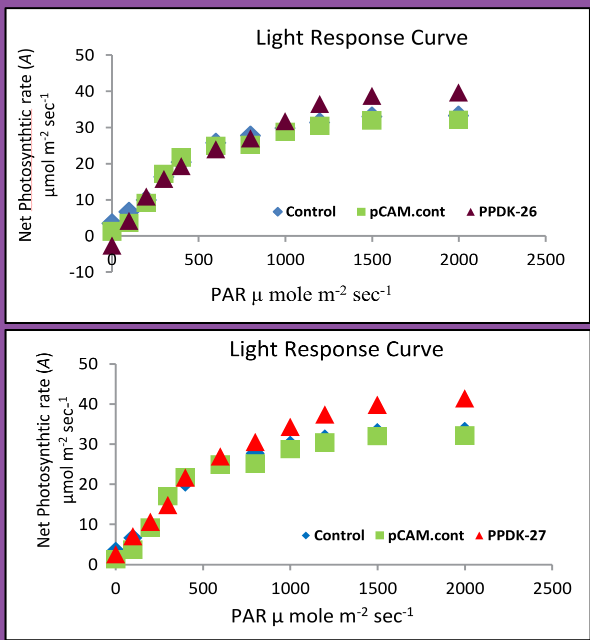


Fig. 4.7. Light response curve of two transgenic plants (PPDK-26 and PPDK-27) with control plants.

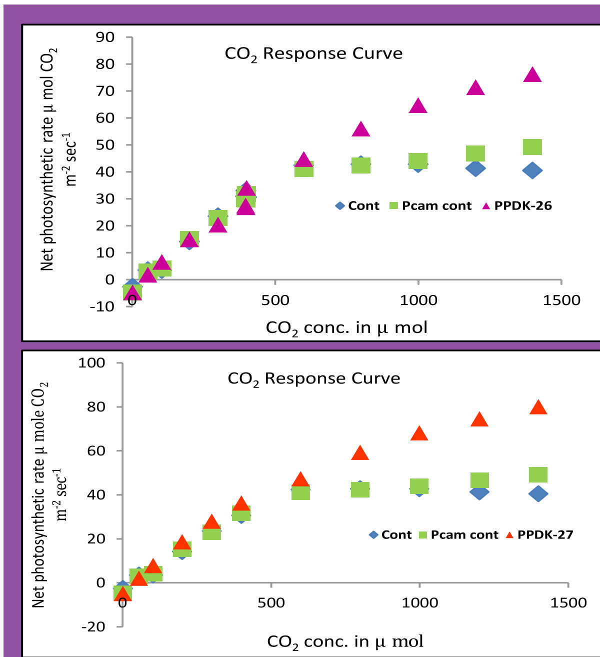


Fig. 4.8. CO_2 response curve of two transgenic plants (PPDK-26 and PPDK-27) with control plants.

transgenic and empty vector control plants a plateau was observed at CO_2 conc. of 600 µ mol (Fig. 4.8).

Photosynthetic pigment accumulation

The photosynthetic pigment accumulation in *SiPPDK* carrying transgenic plants showed higher level of total chlorophyll content both at vegetative and flowering stages (Fig. 4.9) compared to both control and pCAMBIA control plant. However, in terms of carotenoid accumulation, significant difference was not observed among the transgenic and the control plants.

Introduction of photorespiratory bypass mechanism in rice to enhance CO_2 fixation

Five chloroplast-targeted bacterial genes encoding glycolate dehydrogenase (GDH), glyoxylate carboligase (GCL) and tartronic semialdehyde reductase (TSR) have been amplified by PCR from *E. coli* gDNA using suitable oligonucleotides and cloned in pGEMT vector. Rice RuBisCO smaller subunit (RBCS) transit peptide (~300 bp) nucleotide sequence was used for tagging into the GDH, GCL and TSR in order to facilitate transferring integrated genes product from nuclear genome to chloroplast genome. Gene constructs were designed under constitutive promoter (CaMV35S), tagged with transit peptide into binary vector (pCAMBIA-1302). These gene constructs were transferred into *agrobacterium* using tri-parental transformation method with the support of helper plasmid. Using step-wise (*agrobacterium* mediated) nuclear transformation with these chloroplast-targeted genes, rice plants were generated. After the selection through PCR of T0 plant, the plants were again regenerated for T1 and reconfirmed using southern analysis (Fig. 4.10).

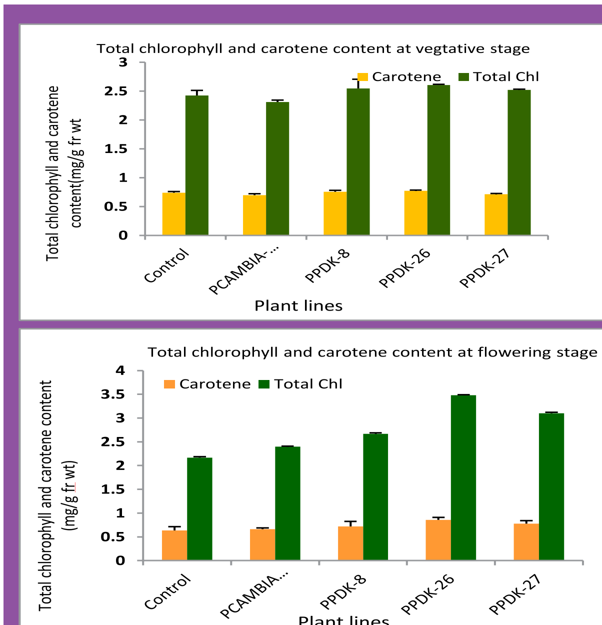


Fig. 4.9. Chlorophyll and carotenoid pigment accumulation in *SiPPDK* carrying transgenic plants.

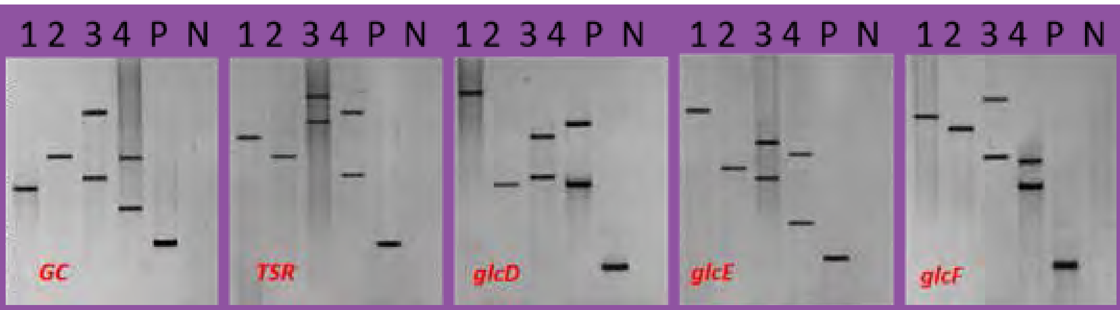
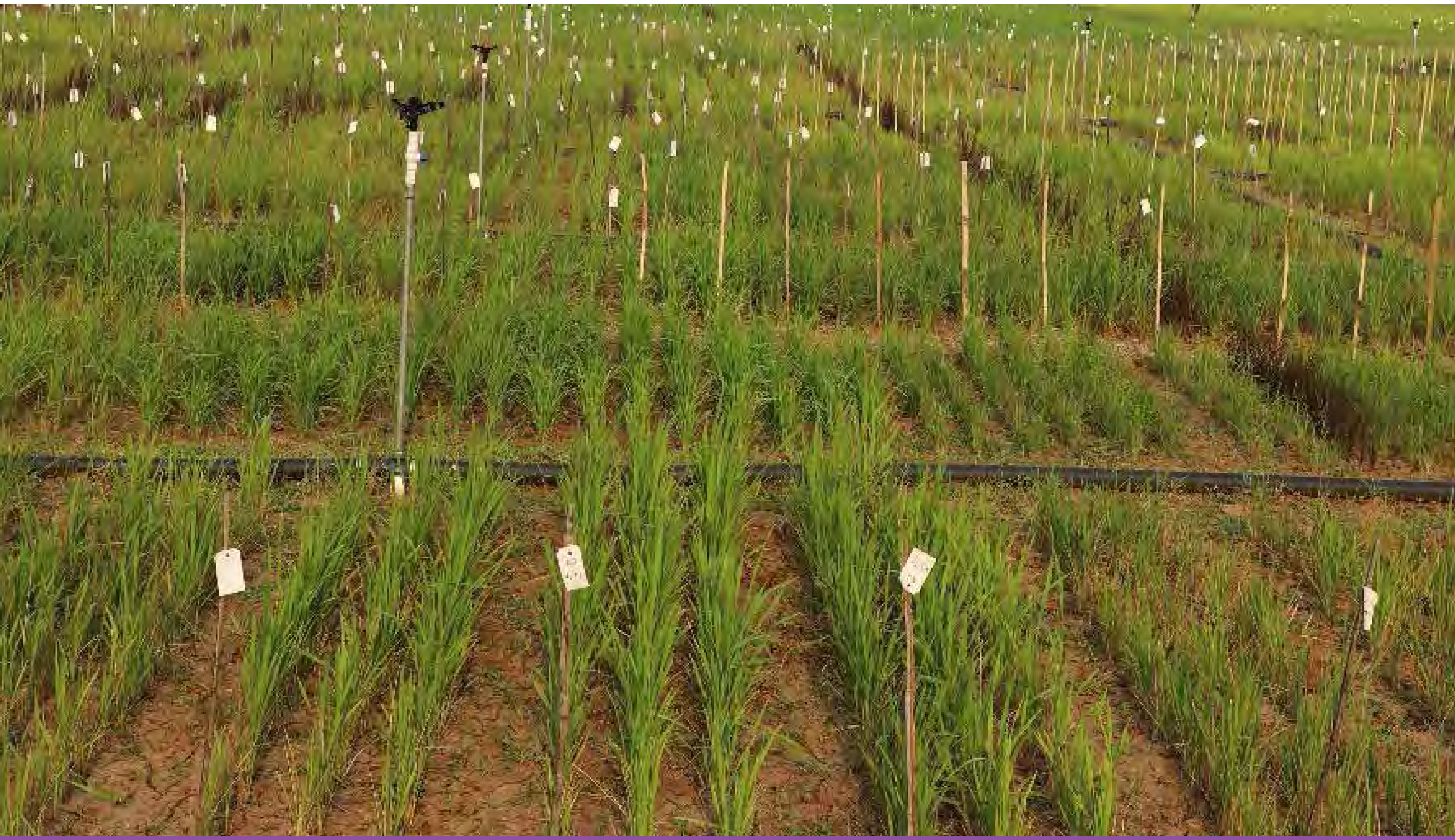


Fig. 4.10. Southern-blot analysis of rice plant (T1) genomic DNA.



Different activities undertaken through the Crop Physiology and Biochemistry programme could identify rice varieties with low phytic acid content and having greater bioavailability of essential minerals. Improved nitrogen assimilatory pathway of high protein rice and its donor were also worked out. Apart from the identification of new sources of multiple abiotic stress tolerance in rice, the unique genotypes were characterized for key physiological traits *viz.* presence of leaf gas film for submergence tolerance, lower stomatal density and higher WUE for drought tolerance and dual presence of tissue tolerance and ion exclusion traits for energy-saving salt-tolerance strategy in rice. Besides, enhancement of photosynthetic traits was targeted by the introduction of key C4 pathway genes like *SiPPDK* apart from attempt to bypass the futile photorespiratory cycle for improving productivity of rice.

PROGRAMME-5

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

Development and testing of new extension models, approaches and strategies for technology transfer and socioeconomic research in rice sector are the thrust areas of Social Sciences Division. 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 staff strength of six scientists and 11 technical staff operates two institute research projects and six externally aided projects. During the year 2020, thirty newly released rice varieties have been demonstrated through 903 field demonstrations in ten states. A total of 3290 participants including farmers, extension officials, administrative personnel and others were benefitted through 102 training programmes of different durations conducted physically or through virtual mode. The Division participated in exhibitions in different locations of the country, extended visitors advisory services, coordinated agro-advisory services, *Mera Gaon Mera Gaurav* programme, Scheduled Caste Sub-Plan programme and supported Tribal Sub-Plan programme. Apart from above, available database has been used to prepare various reports, provided database to others and updated the database on rice.

Developing Extension Approaches to enhance Rice Farmers' Income

Developing extension approaches for fast spread of rice varieties and innovations in different states (INSPIRE-1.0 and INSPIRE 2.0 Models)

The institute has developed and is validating an INnovative extension model for fast SPread of varieties In Rice Ecosystems (INSPIRE 1.0 Model) since 2017-18 to narrow down the gap between new rice varieties and their extensive adoption. Under this model, on-farm demonstrations were conducted in farmers' fields during *kharif 2019* with 21 newly released NRRI varieties benefiting over 800 farmers and covering about 190 ha area in 26 districts of eight states namely, Odisha, West Bengal, Bihar, Jharkhand, Assam, Madhya Pradesh, Chhattisgarh and Maharashtra through close convergence with respective Krishi Vigyan Kendras (KVKs) and state agriculture departments, apart from participating farmers. Despite alarming COVID-19 pandemic situation during *kharif* 2020, on-farm demonstrations of 30 rice varieties (including five aromatic varieties) could be conducted in the fields of 555 participating farmers covering about 120 ha area in 30 districts of 10 states namely, Odisha (9 districts), West Bengal (2 districts), Bihar (4 districts), Jharkhand (4 districts), Assam (2 districts), Madhya Pradesh (2 districts), Chhattisgarh (3 districts), Maharashtra (2 districts), Andhra Pradesh (1 district) and Telangana (1 district).

All the participating farmers were provided with paddy seed minikits of 5 kg each at their doorstep by post through respective collaborating KVKs and District Agriculture Offices. Necessary technical guidance and monitoring were done through mobile and digital platforms. As per the module, crop cutting experiments were organized by the collaborating centres adhering to all COVID-19 guidelines. Preliminary reports revealed that all the newly released NRRI varieties out performed the popular check varieties by giving an average yield advantage of 10-20% with better crop stand, better tillering and fewer incidences of diseases and pests.

Micro-level impact of the model

KVK, Raipur multiplied quality seeds of the high protein and zinc rice CR Dhan 311 from 10 kg seed provided to them during *kharif* 2019 to 480 kg and distributed the seeds to the farmer's in the region to grow during *kharif* 2020. They have planned to launch high protein rice sale hubs in selected retail outlets in Raipur city. The KVK, Raipur procured about one quintal of breeder seeds of CR Dhan 311 during *kharif* 2020 on farmers' demand. One farmer in Durg district of Chhattisgarh multiplied CR Dhan 201 and CR Dhan 206 from 5 kg seed minikits given during *kharif* 2019 and sold these seeds during *rabi 2019-20* to the fellow farmers in the village, which covered an area of 4 ha under each variety.

After seeing the performance of high protein CR Dhan 310, KVK, Balaghat of Madhya Pradesh introduced the variety in tribal pockets of the district to ensure nutritional security in the region and augment tribal farmers' income. Similarly, KVK Sundargarh of Odisha multiplied and distributed the seeds of high protein CR Dhan 311 and high yielding CR Dhan 304 varieties in succeeding *rabi* season, 2019-20 in the adopted villages. Being influenced with the performance, KVK, Gondia of Maharashtra requested to procure more quantity of seeds of aerobic varieties CR Dhan 201 and CR Dhan 206 for demonstration in *kharif* 2020. More satisfying impact was found when KVKs had undertaken the demonstrations of varieties supplied during previous year at their own during *kharif* 2020 apart from the current season supply.

Looking at the success of INSPIRE 1.0 model, which was basically designed for varietal popularization in collaboration with public institutions, another participatory technology demonstration and dissemination module in the name of INSPIRE 2.0 was initiated during 2020 with the collaboration of private institutions, like non-government organizations (NGOs), farmers producers organizations (FPOs) and corporate social responsibility (CSR) organizations for demonstration and dissemination of rice innovations including varieties to end users. About 1955 kg of paddy seeds of seven varieties, namely, CR Dhan 203, 204, 206, 304, 307, 309 and 312 were demonstrated in the fields of 348 farmers from seven districts of Odisha (Cuttack, Jagatsinghpur, Jajpur, Kendrapara, Nayagarh, Bargarh and Sambalpur) during *kharif* 2020 in collaboration with four NGOs and three FPOs and average yield advantage over popular varieties was recorded to be 12.58%.

Thus, INSPIRE models have the potential to rapidly carry forward the new technologies from lab to land in a short span of time and could be an important vehicle for enhancing seed as well as varietal replacement rates of various crops and in rapid spread of innovations through multi-stakeholders' convergence.

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 the 3rd year validation, i.e., *kharif* 2020, about 1305 quintals of foundation, certified and truthfully labeled seeds of seven popular rice varieties, *viz.,* Pooja, Gayatri, Maudamani (CR Dhan 307), Swarna *Sub* 1, Swarna (MTU 7029), Sarala and Lalat were produced in 87.3 acres area by 79 seed growers. The total cost of production of one kg of quality seed was calculated to be in the range of Rs. 23 to Rs. 27 based on local situation and was sold at Rs. 40 to Rs. 60 per kg. (Fig. 5.1). Altogether, 238 Farmers Interest Groups (FIGs) have been formed during last three years with 4663 participating rice growers as members.

Fig. 5.1. Farmers carrying seeds procured from FPCs established under 4S4R model.

Yield gap analysis and impact assessment to aid rice research and policies

Estimation of yield gaps of recently released NRRI varieties

Aiming at quantification of average on-farm yield and yield gaps as well as to understand the influencing factors, experiments were conducted in eight states, *viz.,* Assam, Bihar, Chhattisgarh, Jharkhand, Madhya Pradesh, Maharashtra, Odisha and West Bengal by providing seed kits of recently released varieties of the Institute without altering farmers' own crop management practices. Apart from participating farmers, about 15 neighboring farmers in each cluster were chosen as control. Data were collected from both the groups of farmers to calculate farm-level yield, frontier yields, yield gap and identification of yield influencing factors. The gap in yield from the potential yields of respective varieties were ranged between 3% and 51%. Likewise, the observed yields compared to research stations yield, i.e. yield gap at NRRI plots were -76 to 20%, as many of the varieties performed better at farmer's field than the NRRI plots.

The potential yields are often over-estimated because they are based on optimal condition and often ignore regional and farm level constraints, hence, frontier yield was estimated using stochastic frontier model and deviations of individual farm from the frontier were considered as technical inefficiency of the farm which is the yield gap of a particular cultivar in a given location. Based on analysis done using farmers' data collected from 5 states, i.e. Bihar, West Bengal, Chhattisgarh, Madhya Pradesh and Maharashtra, technical inefficiency was calculated to the extent of 5% to 18% (Fig. 5.2). Farmers from Madhya Pradesh were more technically efficient followed by farmers from Chhattisgarh, Maharashtra, West Bengal and Bihar. In variety wise, higher yield gap was observed for CR 203 followed by CR 201, CR 300, CR 206, CR 307 and CR 310 (Fig. 5.3). Finally, it was inferred that the yield gap as technical inefficiency was moderate than the yield gap-I (deviation from potential yield) & yield gap-II (deviation from research station yield) calculated earlier.

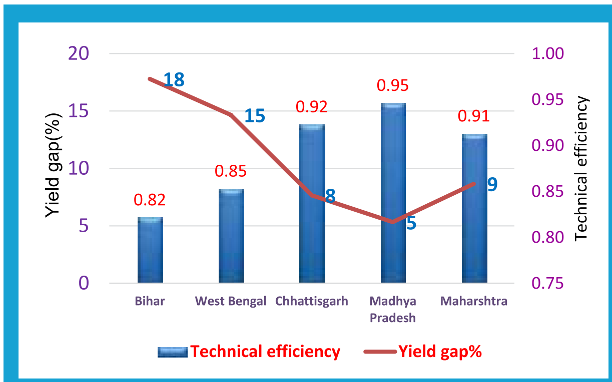


Fig. 5.2. Mean technical efficiency and yield gap at farmers' field.

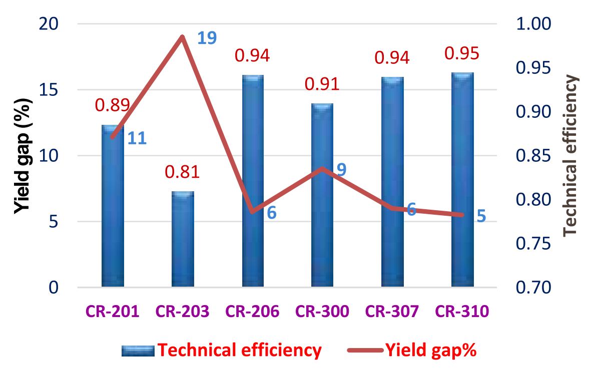


Fig. 5.3. Variety wise technical efficiency and yield gap of NRRI varieties at farmers' field.

Table 5.1. Cost of paddy cultivation and returns ('000 Rs. ha^{-1}) in different states.

Particulars	Bihar	West Bengal	Chhattisgarh	Madhya Pradesh	Maharashtra
Cost A1	34.93 (23.02)	46.19 (39.79)	27.25 (26.63)	27.93 (23.61)	32.38 (52.27)
Cost B1	40.53 (25.30)	48.92 (41.93)	32.01 (29.78)	32.70 (25.77)	37.04 (56.98)
Cost B2	55.53 (36.58)	65.38 (58.08)	50.01 (40.85)	50.61 (35.34)	52.21 (67.38)
Cost C1	47.17 (32.21)	61.55 (61.47)	37.02 (38.15)	38.11 (35.18)	43.21 (67.70)
Cost C2	62.17 (43.49)	78.00 (77.63)	55.02 (49.23)	56.03 (44.75)	58.38 (78.10)
Gross Returns	65.52	86.50	67.99	70.65	73.53
Net Returns	3.34	8.50	12.97	14.61	15.16
Family labour income	9.98	21.12	17.98	20.03	21.32

Figures in parenthesis indicates costs pertains to 2016-17 collected from cost of cultivation scheme

Assessment of cost of cultivation of rice from field data

Primary data were collected from treatment and control farmers on different aspects of rice cultivation and various items of costs were calculated and compared with the compiled data available from cost of cultivation scheme. Though, the latest available data from cost of cultivation scheme was for the year 2016-17 and the primary data pertain to last year, a general trend can be discerned and it is observed that there are differences among various categories of costs. However, it is noticeable that farmers used to get moderate remuneration only when family labour income is calculated, i.e. imputed value of family labour added to the net returns from rice cultivation (Table 5.1). When various cost-items have been categorized, significant differences (5% level) between the states were observed, however, general trend was found to be similar with higher allocation to human labour, which entails the necessity to promote mechanization further to cut-down the cost of rice cultivation.

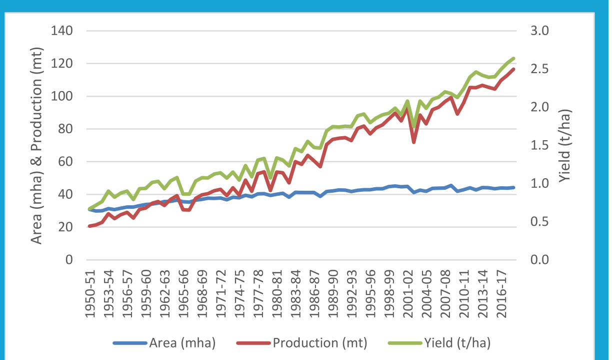


Fig. 5.4. Area, production and yield of rice in India.

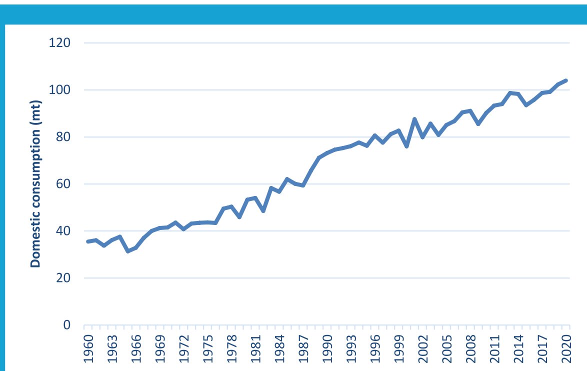


Fig. 5.5. Trend of domestic consumption of rice in India.

Trend of rice production and consumption in India

India is leading producer of rice, including brown rice and white rice which is grown mostly in the eastern and southern region of the country. Rice production was augmented from 20 million tons during 1950-51 to 116.6 million tons during 2018-19, i.e. more than five-fold increase over few decades (Fig. 5.4). It indicates that growth in rice production was stable and steady in spite of very low growth in area under rice in India. Fig. 5.5 presents the domestic consumption of rice which has been increased from 35 million tons during 1960 to 102 million tonnes during 2019. State wise analysis of rice consumption data as collected from NSSO indicated that per capita consumption was higher for few southern and eastern/north-eastern states and it is more in rural areas than urban areas.

Global rice production and consumption

China and India are the largest rice producers in the world. In spite of lower area harvested in China than India, rice production in China is higher due to higher productivity as almost entire rice area in

China is irrigated, whereas, in India the irrigated rice covers less than half of total area under rice cultivation. Apart from China and India, the other major rice producing countries are Bangladesh, Indonesia, Vietnam, Thailand and Philippines. These countries' production together account for more than 80% of world production. The major rice consuming countries are China, India and Indonesia. During 2018-19, rice consumption in China was to the extent of 146.7 million tons, followed by India at 102 million tons (Table 5.2).

Asian countries dominate in rice production and consumption, though rice is also important in other parts of the world. In African countries, rice is considered as primary food – that supplies the largest amount of calories because of the availability of affordable imports from Asia and easier preparation of rice-based foods and snacks, which is specifically significant in urban regions. In Africa, though rice production has grown over the years, but consumption of rice has increased at faster pace through growing amounts of imports. Worldwide consumption of rice per capita has persisted unusually, unchanging since the year 2000, and accounted to about 54 kilograms per annum in 2018-19.

Reasons for decline in rice area in few states of India

Decade wise compound annual growth rate (CAGR) of area, production and yield (APY) of rice was calculated w.r.t. various states for the period from 1980-81 to 2015-16 and observed decline in area in Odisha (Eastern region), Himachal Pradesh and Rajasthan (Northern/Western region) and Kerala (Southern region). Through focus group discussion, stakeholders meet and meta-analysis, following reasons were enumerated:

- Ecological factors: (a) irregularity in rainfall (delayed monsoon is mostly affecting rice sowing), and (b) resurgence of new diseases and pests in new areas.
- Socio-economic factors: (a) migration of youths in nearby towns in search of alternative employments with higher marginal wages, (b) increasing input costs and low availability of labour in rural areas for farming, (c) low and unstable income in rice farming, and (d) crop substitution (rice with maize in less rainfall region).
- Institutional factors: (a) very low percentage of farmers do get minimum support price (MSP), (b) remote areas associated with rice farming do not have market infrastructure, (c) provision of food security entitlements (rice and wheat) has affected tenancy arrangements in rice farming as a result, otherwise cultivated areas remain fallow, (d) delay and irregular payments forces vulnerable farmer to shift to other regular income activities like goatery, poultry and dairy farming, (e) ceiling on procurement has significant impact on area allocation.

Table 5.2. World Trend of rice production (million tons).

Countries	2015	2016	2017	2018	2019
China	148.5	147.8	148.9	148.5	146.7
India	104.4	109.7	112.8	116.5	117.9
Bangladesh	34.5	34.6	32.7	34.9	35.9
Indonesia	36.2	36.9	37.0	34.2	33.5
Vietnam	27.6	27.4	27.7	27.3	27.4
Thailand	15.8	19.2	20.6	20.3	18.0
Myanmar	12.2	12.7	13.2	13.2	12.7
Philippines	11.0	11.7	12.2	11.7	11.4
Japan	7.9	7.9	7.8	7.7	7.6
Brazil	7.2	8.4	8.2	7.1	7.4
Pakistan	6.8	6.8	7.5	7.3	7.2
World	**474.1**	**478.0**	**489.3**	**497.0**	**496.0**

Data source: USDA

Various activities undertaken through this programme is expected to hasten varietal popularization through demonstrations, create awareness and builds capacity in adopting resilient technologies, make the rural villages self-sufficient in seeds and also opens the localized employment avenues for the rural youth. The technology dissemination in the form of newly released rice varieties help in bridging the yield gap between potential yield and observed yield at farmer's field. The various cost estimates and return analysis will support the policy to reduce manual labour through selective mechanization and enhance profitability. Analysis of trend of rice production and consumption will guide to allocate area and resources to rice optimally and releasing the unsuitable areas for alternate crops while maintaining the food security of the country.

PROGRAMME-6

Development of Resilient Production Technologies for Rainfed Upland Rice Systems

Agricultural systems must change with time for becoming climate resilient and adaptable to the rapidly changing scenarios. Upland rice research is increasingly guided by concerns for environmental protection and sustainability owing to the new challenges in the ecological and climatic fronts. The NRRI Research Station, Hazaribag has strived to address these concerns through development of stress tolerant varieties, suitable crop production and protection technologies for small farmers cultivating rice in marginal, rainfed, drought prone environments. The station has focused on direct seeded rice as part of an enterprise 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 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 2020, the station developed and promoted 12 multiple stress tolerant lines in AICRIP trials. Notable among them, IET 26337 (CRR 747-12-3-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 and novel alleles of major QTLs/ genes imparting drought tolerance and blast resistance were another focus of research. Altogether, 227 diverse germplasm accessions were characterized and evaluated for multiple stress tolerance. The station has been also popularizing recently released varieties like IR 64 *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 been met.

Breeding resilient HYVs

Germplasm evaluation for abiotic stress tolerance

Altogether 227 were characterized for agro-morphological and abiotic stress tolerance traits, and 345 rice accessions were multiplied.

In order to identify reproductive stage drought tolerant genotypes, 57 germplasm along with checks were evaluated under both rainfed moisture stress and irrigated control conditions. Significant differences were observed among the germplasm for grain yield under moisture deficit as well as under control conditions and different drought tolerant indices were computed to identify the stable tolerant genotypes. Average yield reduction under stress was 45.7% and association between grain yield under stress and control was moderately positive (0.47*). Promising genotypes identified based on drought tolerant index were IC 515117, Lal dhan, IC 75844, IC 568303 and Chhatri dhan. Molecular genetic diversity was assessed with 35 random SSR primers. Two distinct clusters were observed and IC 568303, IC 568237, DT10, DT14, DT35, Vandana, Sahbhagidhan and Sadabahar were separated from rest of the genotypes (Fig. 6.1).

Eighty-eight rice germplasm collected from Majuli islands, Assam were evaluated for 26 agro-morphological traits and evaluated for submergence stress tolerance. The collection was comprised of *Bao*/ deep-water (25), *Aman* and *Ahu* (6), *Sali* (32), *Bora*/ sticky (24) and *Joha*/ aromatic (6) accessions. *Bao* accessions had highest submergence survival (65%) (Fig. 6.2). Aromatic *Joha* types recorded the highest elongation (202%). Agro-morphologically *bao* rices were distinct from the rest of accessions (Fig. 6.3). Considerable variation was observed for grains/ panicle (% CV = 26.2) and tiller number (% CV = 27.7). Further characterization is being carried out for grain quality and tolerance to submergence and low phosphorus.

A set of 82 rice accessions of Nagaland were characterized for 25 agro-morphological traits. Days to flowering varied from 66 – 111 days, and grain numbers per plant ranged from 38–217. Considerable variation was observed for grains per plant, panicle weight, leaf length and width and 100-grain weight. Principal component analysis (PCA) extracted four components explaining 75.4% of the total phenotypic variance. PCA grouped the accessions according to ecologies i.e., wet rice cultivation and hill (*jhum*) rice (Fig. 6.4)

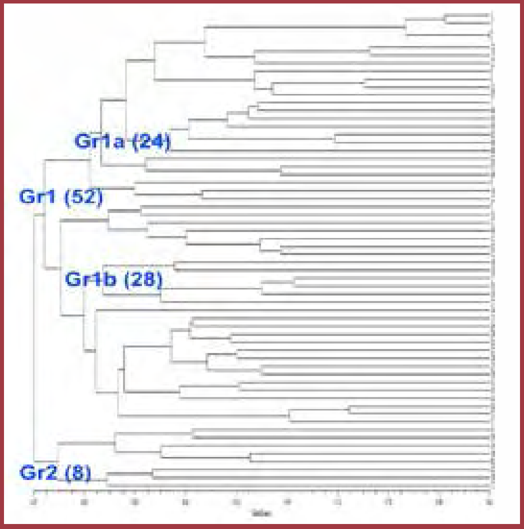


Fig. 6.1. Genetic diversity within 57 drought tolerant accessions.

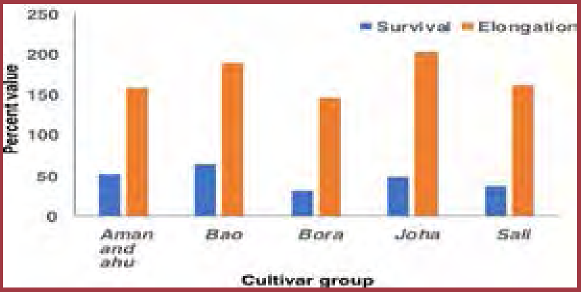


Fig. 6.2. Submergence tolerance in different rice cultivar groups collected from Majuli, Assam.

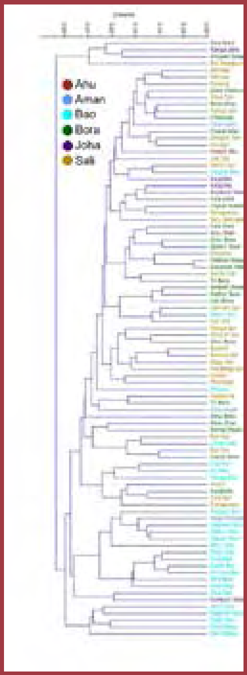


Fig. 6.3. Clustering of Majuli rice accessions based on 26 agro-morphological traits.

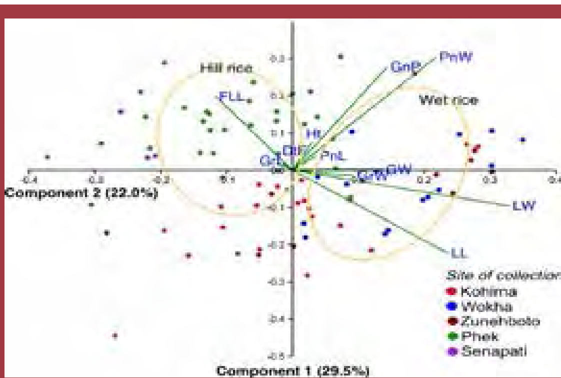


Fig. 6.4. Principal component analysis on agro-morphological traits of Nagaland rice cultivars showing distribution of rice accessions based on ecology and site of collection.

Screening of gora rice germplasm for blast and brown spot resistance

Forty-nine *gora* accessions were screened for blast resistance under UBN during *kharif* 2020. Twenty-nine blast resistant lines were identified with a resistance score of 2-3, while 18 lines were moderately resistant. Presence of seven blast *R* genes - *Pi2, Pi5, Pi9, Pita-2, Pi54, Pikh* and *Pib* revealed the highest frequency for *Pi5* (90%) (Fig. 6.5), followed by *Pi54*/*Pikh* (35%), *Pib* (6%) and *Pita-2* (2%). None of the accessions were positive for *Pi2* and *Pi9.* The same set was also screened for brown spot resistance under natural conditions and only a single accession (Brown gora- HRC91) recorded score of 3.

Varietal development

A new breeding line CRR 747-12-3-B (IET 26337), derived from the cross Vandana*4/ C101A51//IR 84984-83-15-862-B showed high reproductive stage drought tolerance and out performed the checks (Sahbhagidhan and Vandana) across locations under severe drought stress condition by registering yield advantage of 51-102% and 15-292% in different years. This line showed moderate resistance to leaf blast (scored 4.1 to 5.4) based on multi-location screening in NSN1 & NSN2 and also possesses excellent grain quality parameters such as high HRR (56.1%), intermediate AC (23.3%), soft GC (51) and long slender grains. Molecular marker assisted screening confirmed the presence of 3 DTY QTLs for grain yield under reproductive stage drought stress (*qDTY*2.3, *qDTY*3.2 and *qDTY*12.1), *Phosphorus starvation tolerance 1* (*PSTOL1*) gene for tolerance to low-Phosphorus and blast resistance gene *Pi-2* (Fig. 6.6), indicating its usefulness as multiple stress tolerant genetic stock in breeding programme.

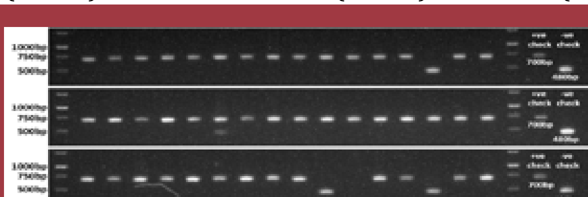


Fig. 6.5. Molecular screening of Pi5 in 49 gora rice accessions. Positive check: Moroberekan and negative check Co-39.

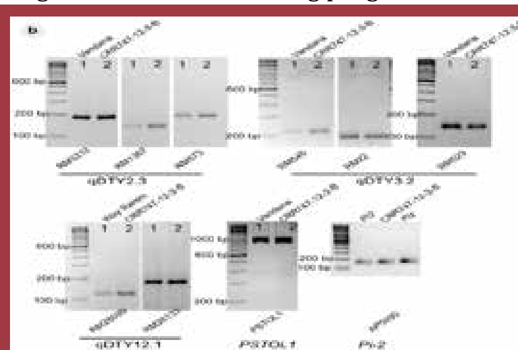


Fig. 6.6. Presence of DTY QTLs (qDTY2.3, qDTY3.2, qDTY12.1) and PSTOL1 & Pi2 gene in CRR747-12-3-B.

Hybridization, generation advancement and evaluation of breeding lines

Thirty-one new crosses were made targeting varietal development for rainfed drought-prone ecology, blast *R* gene NIL development and genetic mapping for brown spot resistance, root system architecture, cold tolerance and clustered panicles traits.

Three F_2 (Anjali/IET 26110, Abhishek/IET 4786, Sahbhagidhan/IR 64CG425), three F_3 (DRR Dhan 44/ Pratikshya, Sahbhagidhan/ BPT 5204 and Swarna/ Nadia phula), seven F_4 (Anjali/ Ngahongra, Anjali-NIL/SR-1-5-1, Kalyani 2/ NPTPSR 15, Anjali/ NPTPSR 15, Sahbhagidhan/NPTPSR 8, Black Gora/IR 64CG425 and Kalyani 2/NPTPSR 13) and two F_6 (Swarna/Nadia Phula and Naveen/ Nadia phula) populations were generation advanced following SSD method.

Altogether, 551 breeding lines from 81 crosses in F_6 generation were evaluated under both DSR and transplanted conditions and 237 lines were selected based on duration, plant type, grain type, disease and pest reactions besides grain yield for preliminary yield evaluation trial.

Forty advanced breeding lines along with five checks were evaluated under preliminary yield trial (PYT) following alpha-lattice design with three replications in rainfed direct seeded condition. Among 40 test entries only 2 entries *viz.,* CRR 783-B-B-4 (3721 kg ha^{-1}) and CRR 667-19 (3329 kg ha^{-1}) significantly out-yielded the best check variety Sahbhagidhan (2554 kg ha^{-1}). These two entries are being seed multiplied for nomination to initial evaluation trial of AICRIP.

One hundred and twenty-eight RILs from Sahbhagidhan X IR 87707-446-B-B population were evaluated under drought stress and non-stress conditions and also genotyped with the linked SSR markers of three *DTY* QTLs (*DTY2.2, DTY4.1* & *DTY12.1*) and blast resistance gene *Pita2*. Best RIL, CRR 759-1-B-1 yielded 2276 kg ha^{-1} as compared to Sahbhagidhan (1583 kg ha^{-1}) under rainfed drought stress condition and at par with IR 64 *Drt1* under non-stress condition. Several RILs containing one or more *DTY* QTLs & blast R-gene outperformed the parents under both stress and non-stress conditions. They were promoted for further testing.

Strategize management options for sustainable productivity under drought-prone ecology

Evaluation of soil management options for sustainable rice production under DSR

Under rice based cropping system, different nutrient management options (inorganic, organic and integrated) were evaluated and it was found that under sole rice system highest grain yield (Sahbhagidhan) of 3.18 t ha^{-1} was recorded in inorganic nutrient management (T_2) (100% RDF (60:30:30) followed by 2.71 t ha^{-1} in T_4 (50% RDF +FYM @ 5 t ha^{-1}+VAM 1.5 q ha^{-1} + PSB 4 kg ha^{-1}) and 2.33 t ha^{-1} for T_3 (50% RDF +FYM @ 5 t ha^{-1}). Similar trend was observed in rice-pigeon pea system, where rice grain yield of 2.28, 2.01, and 1.69 t ha^{-1} and pigeon pea yield of 0.46, 0.39, and 0.36 t ha^{-1} were recorded, respectively. Lowest grain and straw yield was recorded from control (T_1) where no other inputs were applied.

Arbuscular mycorrhiza (AM) supportive crop management technology for improving P nutrition of DSR

Residual effect of AMF inoculums was validated under AMF supportive crop rotation (first year: maize-horse gram and second year: rice). First year application of AMF will sustain beneficial effects for at least two years. Application of improved (with first phase of improvement) mass inoculums (prepared from nucleus inoculums developed on 'vermiculite-FYM-soil' based substrate with initial spore load of 1 spore g^{-1} and periodical Hogland solution fortification) of AMF (source: CRURRS, Hazaribag) @ 0.5 t ha^{-1} resulted 19.3% yield increase in direct seeded upland rice (cv. Sahbhagidhan) over untreated control in tribal village (Chichikala of block Churchu, Dist-Hazaribag) of Jharkhand.

Biotic stress management strategies for rainfed drought-prone ecologies

Integrated disease management of blast and brown spot

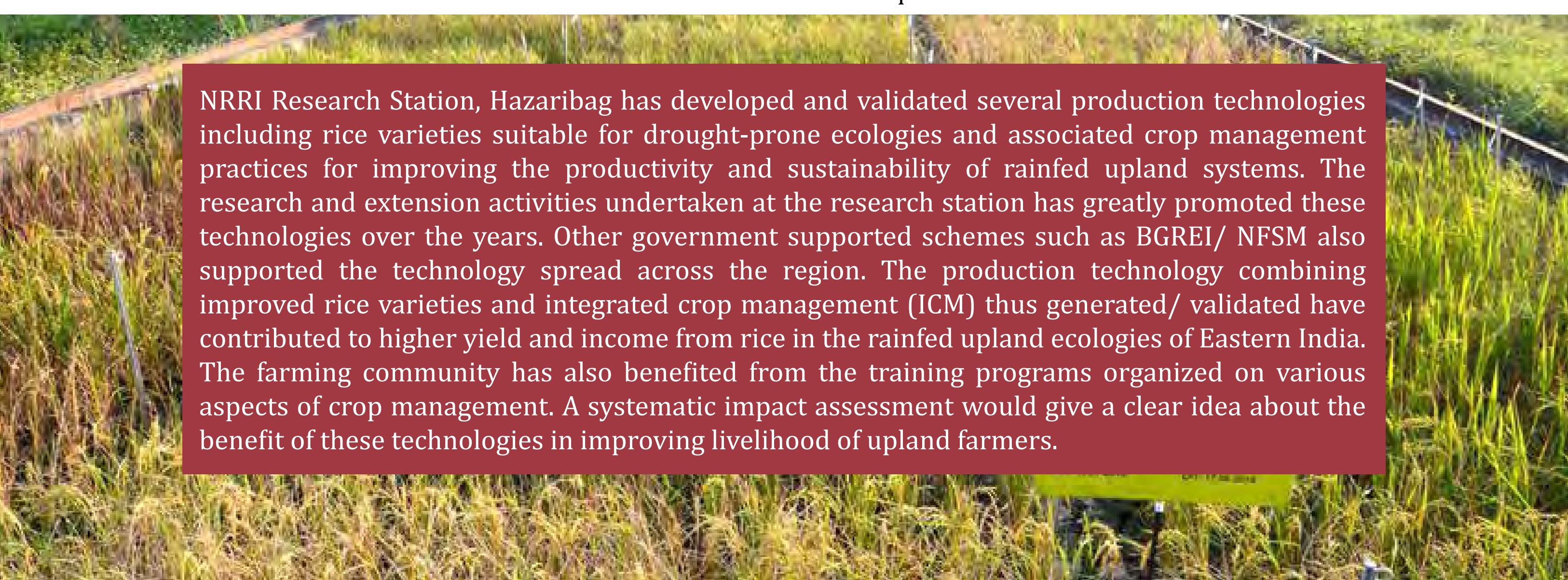
Six integrated management options: T1 (seed treatment with *Trichoderma* @10 g kg^{-1} seed), T2 (T1+biocontrol agents at 15 DAT), T3 (T1 + One spray of Propiconazole at booting stage), T4 (T2 + One spray of Propiconazole at booting stage), T5 (Seed treatment with carbendazim @ 2 g kg^{-1}) + spray of Nativo @ 0.4 g/l at booting stage), and T6 (control) were evaluated for management of blast and brown spot of rice. T3 treatment was most effective in reducing blast (56%) & brown spot (67%) severity and corresponding yield increase of CO-39 (82%) and Sahbhagidhan (62%), respectively.

Integrated management strategy for False smut under shallow rainfed ecology

Management options for controlling false smut in hybrid rice (PHB71) revealed that early transplanting (20 July) and the fungicide Nativo (Trifloxystrobin + Tebuconazole) was the most effective in management of false smut of hybrid rice with uniform moderate fertilizer dose (NPK= 80:40:40).

Breeder seed production

Altogether 227.77 quintals of breeder seeds of nine varieties (Anjali, Abhishek, CR Dhan 40, Hazaridhan, IR 64 *Drt1*, Sadabahar, Sahbhagidhan, Vandana and Virendra) were produced to fulfil the DAC indent and other requirements.



NRRI Research Station, Hazaribag has developed and validated several production technologies including rice varieties suitable for drought-prone ecologies and associated crop management practices for improving the productivity and sustainability of rainfed upland systems. The research and extension activities undertaken at the research station has greatly promoted these technologies over the years. Other government supported schemes such as BGREI/ NFSM also supported the technology spread across the region. The production technology combining improved rice varieties and integrated crop management (ICM) thus generated/ validated have contributed to higher yield and income from rice in the rainfed upland ecologies of Eastern India. The farming community has also benefited from the training programs organized on various aspects of crop management. A systematic impact assessment would give a clear idea about the benefit of these technologies in improving livelihood of upland farmers.

PROGRAMME-7

Genetic Improvement and Management of Rice for Rainfed Lowland

Rice is grown mainly under rainfed condition in Assam in three distinct seasons *viz.*, *sali* or winter rice (June/July to November/December), *ahu* or autumn rice (March/April to June/July) and *boro* or summer rice (November/December to May/June). Occurrence of extreme environmental events like drought, floods, severe pest incidence in the state and farmers' non-adoption of high yielding varieties and shyness towards improved production technology resulted in low productivity of rice in state of Assam (2.1 t ha^{-1}) than national average 2.75 t ha^{-1}. Flood is also a recurrent problem in Assam and annually more than five lakh hectares of rice land plunge under varying depths of flood water causing drastic reduction in production and productivity of rice.

Low temperature at early vegetative stage in *boro* season prolongs the crop harvest and recurrent pre-monsoon flood causes heavy crop loss to *boro* and early *ahu* paddy cultivated in lowland of Assam. Development of *boro* rice varieties of 145-160 days duration having low temperature tolerance at early vegetative stage and early *ahu* varieties of 100-120 days duration with quick vegetative growth can escape pre-monsoon flood. Similarly, photo-insensitive winter rice varieties of 130-140 days duration would perform better in rainfed lowland of Assam. Development of high yielding *Bora* rice varieties would improve the productivity of glutinous rice. Insect-pests, diseases and weeds are important constraints to rice production in rainfed ecosystems. Information on geographical distribution of these biotic factors along with their natural enemies can help mapping the pest population.

Collection and Maintenance of rice germplasm

Altogether 30 aromatic *Joha* and 97 deepwater *Bao* rice varieties have been collected from different parts of Assam during 2020. Evaluation of 803 lines from previous collection and 127 newly collected lines were done and data were recorded on days to 50% flowering, plant height, number of effective tillers and grain yield during *boro* and *kharif* season.

Seed production of high yielding varieties

A total of 15,834 kg breeder seed and 5,270 kg TL seed was produced during 2019-20 (Table 7.1).

Table 7.1. Seed production at RRLRRS, Gerua during 2019-20.

Season	Breeder Seed (kg)	TL Seed (kg)
Boro, 2019-20	5,970	3,477
Kharif, 2020	9,864	1,793
Total	15,834	5,270

Survey on the incidence of major insect-pest and diseases of rice in rainfed lowland of Assam

Survey was conducted in rainfed lowland rice fields of Kamrup and Baksa districts of Assam during *kharif* 2020 for recording the incidence of insect-pests and diseases of rice. Rice leaf folder (*Cnaphalocrosis medinalis*) (Fig. 7.1), stem borers (*Scirpophaga incertulas* and *S. innotata*) and gundhi bug were found to be the major insect pest. Infestation of mealy bug (4.7 nos./hill) was observed on *kharif* rice in Kamrup district (Fig. 7.3). Sporadic incidence of swarming caterpillar on paddy was observed in Baksa district of Assam during *kharif* 2020 (Fig. 7.2). Major diseases observed in farmer's field were blast, sheath blight, bacterial blight and brown spot.

Fig. 7.1. Severe infestation of rice leaf folder at Kamrup district of Assam.

Fig. 7.2. Sporadic incidence of swarming caterpillar on *kharif* paddy.

Fig. 7.3. Mealy bug infestation on kharif paddy.

Evaluation of insecticides against rice stem borer

Four different combinations of insecticides and botanical pesticides were applied at 25-30 days after transplanting (DAT), 45-50 DAT and 60-65 DAT against rice stem borer during *boro,* 2019-20. Application of Chlorantraniliprole (0.2 ml l^{-1}) at 25-30 DAT, Cartap hydrochloride (2 ml l^{-1}) at 45-50 DAT and Triflumezopyrim (0.48 ml l^{-1}) at 60-65 DAT recorded the 0.78, 0.33 and 0.13 per cent dead heart at 45, 65 and 75 days after transplanting, respectively as compared to control where, they are 1.52, 5.42 and 2.21 per cent (Table 7.2).

Efficacy of fungicide against bakanae disease of rice

Five treatments were laid and it was observed that, root dip treatment with propiconazole @ 0.2 ml l^{-1} of water for 2 hours before transplanting was most effective with 83.5% prevention of disease spread followed by carbendazim @ 2 gm l^{-1} of water with 75.4% prevention of disease spread (Table 7.3). However, spray of propiconazole at 2 ml l^{-1} of water after 15 days of transplanting could reduce the spread of disease by 50.8% and carbendazim at 2 gm l^{-1} of water prevented spread of disease to the extent of 34.6% and there was no significant difference of yield among the treatments.

Establishment of Bio-tech KISAN HUB at RRLRRS, Gerua

Bio-tech KISAN Hub (under DBT funded program) established at RRLRRS, Gerua with the goal to create awareness on scientific products and methodology for higher productivity and production in lowland situation. The Project is sanctioned with a total outlay of Rs. 214.0 lakhs involving three partners like KVKs in Barpeta, Baksa and Darrang districts covering minimum 100 farm families in each district. Interventions of the project were mainly demonstration of climate smart rice varieties (CR Dhan 801, CR Dhan 802) during *sali (kharif* season) followed by biofortified rice varieties (CR Dhan 310, CR Dhan 311) during *boro* and *sali* season, high value, low volume vegetables like cucumber, capsicum, broccoli, tomato, papaya under protected cultivation technique, integration of poultry, duckery and fishery through farming system approach.

Table 7.2. Evaluation of insecticides against rice stem borer.

Treatment	Per cent dead heart		
	45 DAT	65 DAT	75 DAT
Spraying of Neemazal (2 ml l^{-1}) at 25-30 DAT, Eucalyptus oil (2 ml l^{-1}) at 45-50 DAT and Cartap hydrochloride (2 ml l^{-1}) at 60-65 DAT	1.26	4.37	1.19
Neemazal (2 ml l^{-1}) at 25-30 DAT, Neem oil (10 ml l^{-1}) at 45-50 DAT and Triflumezopyrim (0.48 ml l^{-1}) at 60-65 DAT	1.10	4.61	1.27
Neemazal (2 ml l^{-1}) at 25-30 DAT, Eucalyptus oil (2 ml l^{-1}) at 45-50 DAT and Neem oil 10 ml l^{-1}) at 60-65 DAT	0.97	4.16	1.34
Chlorantraniliprole (0.2 ml l^{-1}) at 25-30 DAT, Cartap hydrochloride (2 ml l^{-1}) at 45-50 DAT and Triflumezopyrim (0.48 ml l^{-1}) at 60-65 DAT	0.78	0.33	0.13
Water sprays at 25-30 DAT, at 45-50 DAT and at 60-65 DAT	1.52	5.42	2.21

Table 7.3. Efficacy of fungicide against bakanae disease of rice.

Treatment	Per cent disease incidence on three dates of observation			Yield (t ha^{-1})
	25-02-2020	13-03-2020	30-03-2020	
Root dip treatment by soaking in carbendazim @ 2 g l^{-1} for 2 hrs before transplanting	1.73	0.82	0.31	3.85
Root dip treatment by soaking in propiconazol @ 2 ml l^{-1} for 2 hrs before transplanting	1.16	0.87	0.31	4.11
Spraying of arbendazim @ 2 g l^{-1}	4.60	1.13	0.62	4.03
Spraying of propiconazol @ 2 ml l^{-1}	3.46	2.01	0.78	4.52
Control	7.03	3.43	2.28	4.02
SEd (±)	1.30	0.24	0.14	0.54
CD (p=0.01)	2.72	0.51	0.29	1.14

The research results related to rainfed lowland ecologies has immense value to the farmers in the zone through enhanced knowledge on insect-pest and disease management, better package of practices and advisory services, which helped the farmers to increase productivity.

NRRI-Regional Coastal Rice Research Station (RCRRS) Naira, Srikakulam, Andhra Pradesh

The Regional Coastal Rice Research Station was established in the campus of Agricultural College, Naira, Srikakulam, Andhra Pradesh under the Acharya NG Ranga Agricultural University (ANGRAU) in May 5, 2017. The ANGRAU has entered into a Memorandum of Understanding (MoU) with ICAR-NRRI to allocate 25 Acres of land initially from its constituent Agricultural College, Naira in Srikakulam District of Andhra Pradesh under a lease for 30 years. Later, as per revised rules of ICAR, ANGRAU, Guntur, agreed to raise the lease period from the existing 30 years to 99 Years. Accordingly, the District Collector & Magistrate, Srikakulam has issued orders in Sept, 2020 for execution of lease deed between ANGRAU, Guntur and ICAR-NRRI, Cuttack free of cost.

Research Activities

Eighteen upland genotypes evaluated at RCRRS, Naira farm and the highest yield (6.07 t ha^{-1}) was recorded in CR Dhan 203, followed by CR Dhan 206 (5.9 t ha^{-1}), CR Dhan 101, Priya (5.8 t ha^{-1}) and CR Dhan 209 (5.6 t ha^{-1}) and lowest was in Sada Bahar and Anjali (2.0 t ha^{-1}).

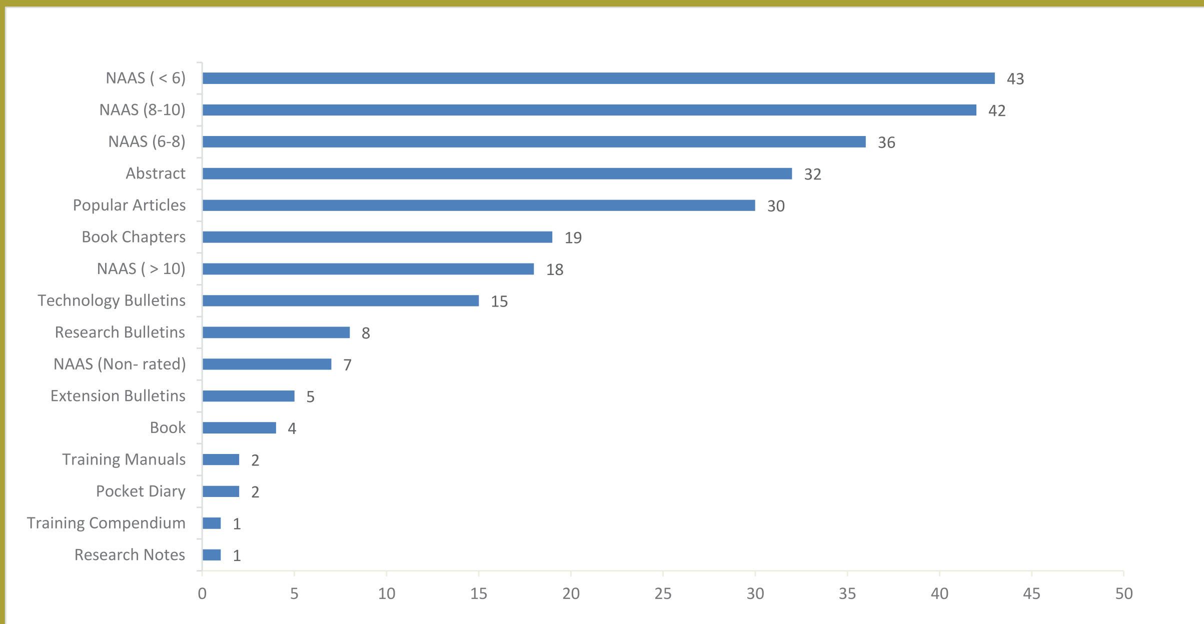
The saline tolerant genotypes were evaluated in saline fields of farmers in Santhabommali coast, Srikakulam district of Andhra Pradesh. The genotypes recorded yield of 6.0 t ha^{-1} (IET-27865) and 6.2 t ha^{-1} (IET-27852) and the farmers grown MTU -1061 (Indra), which yielded only 4.5 t ha^{-1} in the same field. The genotypes were directly sown adjacent to shrimp/ prawn ponds. The NRRI genotypes were found resistant to pests like BPH, GLH, stem borer and gall midge besides other diseases. Deep water rice variety CR Dhan 506 was evaluated in collaboration with KVK, Amadalavalasa, SKML in flood prone areas of Kottur Mandal, Srikakulam. CR Dhan 506 yielded 7.0 t ha^{-1} in farmers' fields in Kottur.

Fig. 1. Farmers evaluated low land rice variety CR Dhan 506 in Kottur, Srikakulam, AP.

Fig. 2. Farmers evaluated the performance of saline tolerant genotypes IET-27865 and IET-27852 in Santhabommali coast, Srikakulam.

Publications

During the year 2020, the institute has published different research, technology and extension materials which is shown by the below given figure.



For More Details, Please Visit - http://icar-nrri.in/publications/

Activities and Events

During the year 2020, ICAR-NRRI has 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 are as follow-

A) Activities:

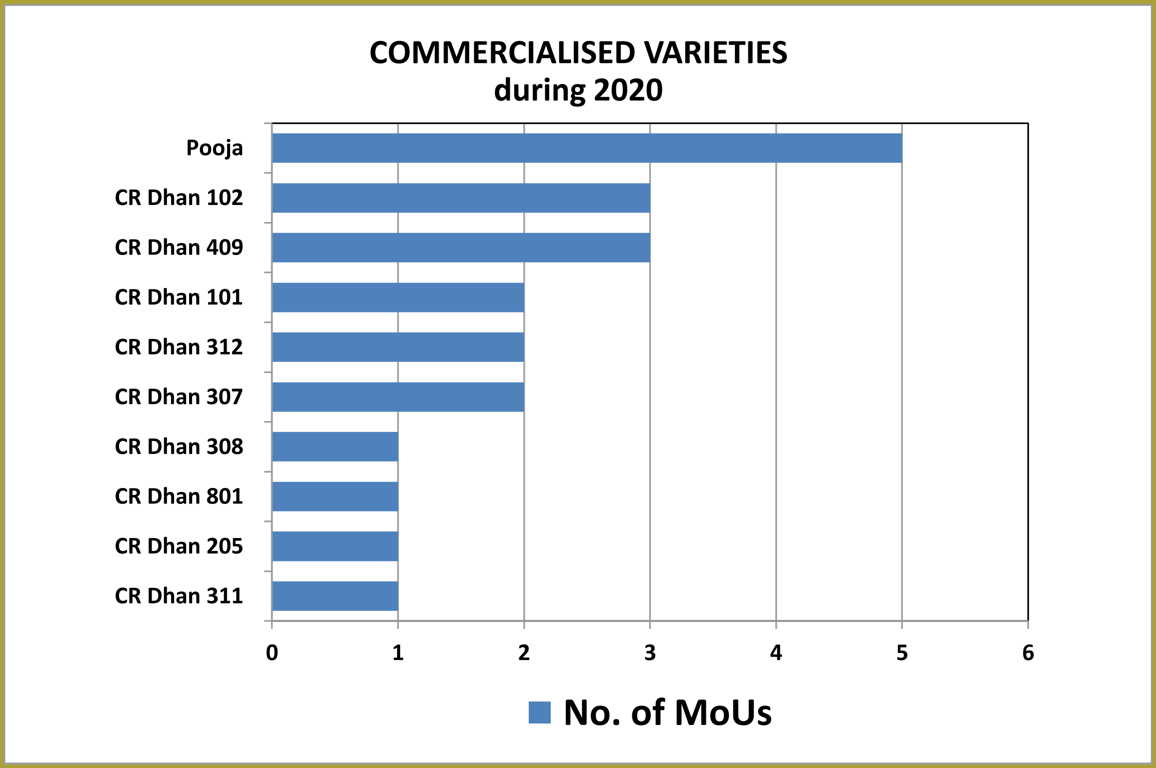
Activities	Distinguished participants
26th Research Advisory Committee, 18 December 2020	Prof. SK Sopory (C), Dr. KK Jena (M), Dr. BC Viraktamath (M), Dr. AR Sharma (M), Dr. VV Sadamate (M), Dr. Chandish R Ballal (M), Shri SK Panigrahi (M), Shri A Mishra (M), Dr. D Maiti (M), ADG (FFC) (M), Dr. SR Voleti (SI), Dr. BC Patra (MS).
33rd IMC Meeting, 27 April 2020	Dr. D Maiti (C), Dr. YP Singh, ADG (FFC), ICAR, New Delhi (M), Shri A Mishra, Bhubaneswar (Non-Official) (M), Shri SK Panigrahi, (Non-Official) (M), Dr. D Sarkar, Principal Scientist, CRIJAF, Kolkata, (M), Shri VK Sahoo, F&AO, IIWM, Bhubaneswar, (M), Dr. AK Nayak (M), Dr. (Mrs.) P Swain (M), Dr. LV Subba Rao, Principal Scientist, ICAR-IIRR, Hyderabad, (M), Shri SK Das, Sr. F&AO (I) and Shri BK Sahoo, Head of Office, NRRI, (MS).
40th Institute Research Council Meeting, 10-12 November 2020	Dr. D Maiti (C), Dr. (Mrs.) Padmini Swain (MS), Heads of Divisions and Scientists of the Institute and KVKs
2nd Institute Joint Staff Council meeting, 11 June 2020	Dr. D Maiti, (C), Dr. (Mrs.) Padmini Swain, (M), Dr. M Shahid (M), Dr. NKB Patil (M), Shri SK Das, (M), Shri NC Parija, Secretary (Official Side), Shri M Swain, Member (CJSC), Shri SK Sahoo, (M), Shri P Moharana, (M), Shri AK Moharana, (M), Shri B Pradhan, Member & Secretary (Staff Side), Shri J Marndi, (M), and Shri B Naik, (M), Dr. SK Pradhan, Vigilance Officer (I), Dr. BC Patra, Transparency Officer (I)
The 21st Scientific Advisory Committee meeting of KVK, Cuttack, 26 June 2020	Dr. D Maiti (C)

C: Chairman; M: Member; MS: Member Secretary; I: Invitee; SI: Special Invitee

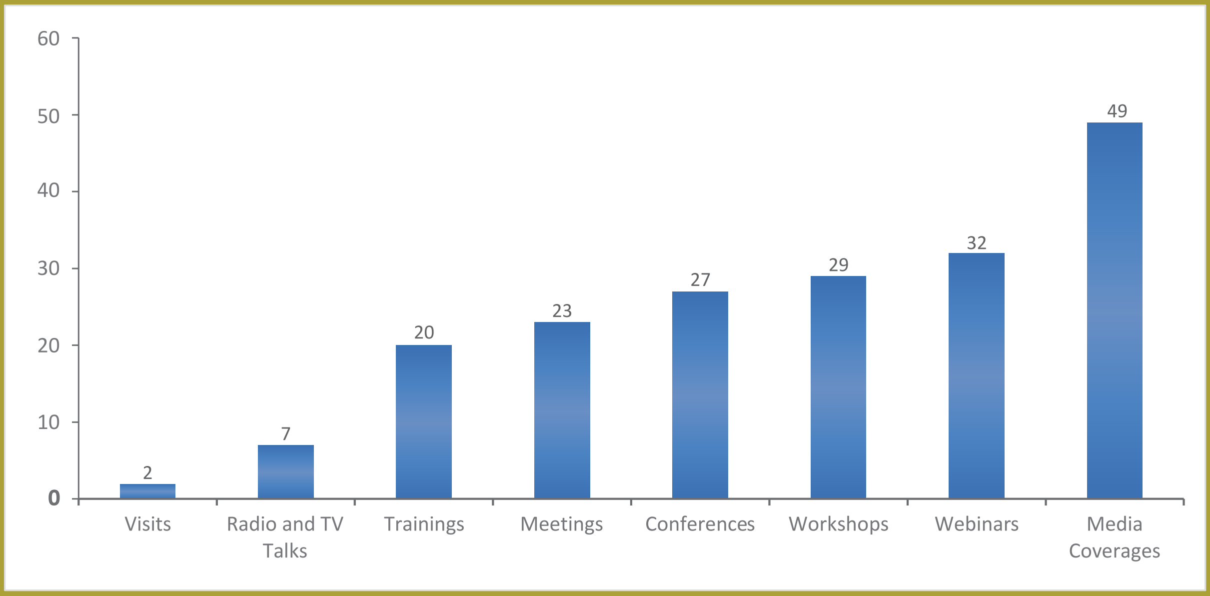
B) Programmes and Events:

Sl. No.	Events	Participants
1.	3rd Global Potato Conclave, 28 January 2020, NRRI-KVK, Cuttack	45
2.	Acquainting the citizens with important constitutional amendments and Agricultural legislations, 29 January 2020, ICAR-NRRI, Cuttack	100
3.	Hindi Workshop on Unicode system & Hindi typing in computer, 26 February 2020, ICAR-NRRI, Cuttack	14
4.	National Workshop on "Rice research and development for doubling farmers' income" at NRRI, Cuttack, 28 February 2020, ICAR-NRRI, Cuttack	150
5.	National Science Day 2020, 28 February 2020, NRRI-KVK, Cuttack	87
6.	International Women's Day, 9 March 2020, ICAR-NRRI, Cuttack	60
7.	Organic Awareness Mela, 12 March 2020, Ananta-prasad, Narsinghpur block of Cuttack district	200
8.	World Milk Day 2020, 12 June 2020, NRRI-KVK, Cuttack	1048
9.	ABC of Scientific Writing, 22 July-5 August and 18 August-2 September, 2020, NRRI-KVK, Cuttack	1089
10.	Hindi Fortnight-2020, 11-25 September 2020, ICAR-NRRI, Cuttack	70
11.	Mahila Kisan Diwas, 15 October 2020, ICAR-NRRI, Cuttack	134
12.	Vigilance Awareness Week 2020, 22 October-2 November 2020, ICAR-NRRI, Cuttack	65
13.	1st Indian Rice Congress – 2020, 8-9 December 2020, ICAR-NRRI, Cuttack	70

Commercialization of ICAR-NRRI Technologies



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



Awards and Recognition

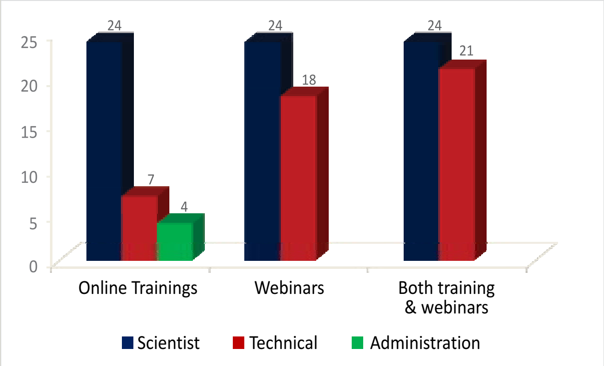
During the year 2020, ICAR-National Rice Research Institute and its staff members have bagged several prestigious awards. The details of the awards are given below.

Sl. No.	Award Title and Conferred By	Awardee
1	2nd Prize for the prestigious Ganesh Shankar Vidyarthi Hindi Patrika Puraskar-ICAR	NRRI
2	NAAS Associateship - NAAS, New Delhi	Dr. Koushik Chakraborty
3	ICAR-Lal Bahadur Shastri Outstanding Young Scientist Award - ICAR	Dr. M Shahid
4	Venus International Women Award-2020- Venus International Foundation, Chennai	Dr. Padmini Swain
5	ISSN Research Award, 2020–ISSN, USA	Dr. Padmini Swain
6	Fellow of ARRW - (ARRW), ICAR-NRRI, Cuttack	Dr. P Bhattacharyya
7	Fellow award, Society for Biocontrol Advancement, Bengaluru	SR Prabhukarthikeyan
8	INSA Medal for Young Scientist 2020 – INSA, New Delhi	Dr. Molla KA
9	Young Scientist Award - The Mosaic Company Foundation, Mosaic India Private Limited, Haryana	Dr. M Shahid
10	Research Excellence Award-2020- Institute of Scholars, Bengaluru, Karnataka	Dr. Awadhesh Kumar
11	Outstanding Scientist award- VDGOOD Professional Association	Dr. M Shahid
12	Young Scientist Award -GAP	Dr. U Kumar
13	Research Excellence Award-2020-The Society for Biotic & Environmental Research, Tripura	Dr. BC Verma
14	Best Paper Award - International Conference on Soil and Water Resource management for climate smart agriculture, Global food and Livelihood Security at New Delhi,	Dr. D Chaterjee
15	2nd position in best scientific poster award - Guru Gobind Singh Indraprastha University, New Delhi	Dr. Anjani Kumar
16	Olympiad winner (2nd place) - Soil Conservation Society of India	Dr. Anjani Kumar
17	Best Poster Award - ISWS Biennial Conference	Dr. S Saha
18	Best oral presentation award - Chemical Science Review and Letters, Salem, India	Dr. M Shahid
19	First prize of poster presentation award - Society for Fertilizers and Environment in collaboration with BCKV, Kalyani	Dr. R Khanam
20	Oral presentation award (Second) - Crop and Weed Science Society (CWSS), BCKV, Kalyani	Dr. R Khanam
21	ISSLUP best doctoral research presentation award – 2020"- Indian Society of Soil Survey and Land Use Planning	Dr. Anjani Kumar
22	Best Paper Award - International Web-Conference on resource management and biodiversity conservation to achieve sustainable development goals	Dr. U Kumar
23	Associate Guest Editor in Frontiers in Agronomy	Dr. U Kumar
24	Academic Editor, Plos One, USA	Dr. D Bhaduri
25	Editorial Advisory Board member in Physiological and Molecular Plant Pathology (Elsevier)	SR Prabhukarthikeyan
26	IMC Member of ICAR-CSSRI, Karnal from 2018-21	Dr. Padmini Swain
27	**1st Indian Rice Congress** Best Poster Award	Aashish Kumar Anant *et al.*
28	Best Poster Award	SK Mishra *et al.*
29	Best Poster Award	SH Majumder *et al.*
30	Best Poster Award (3rd Position)	Raghu S *et al.*
31	Second Best Oral Presentation Award in International E-Conference" on 'Advances and Future Outlook in Biotechnology and Crop Improvement for Sustainable Productivity'	Baite M S *et al.*

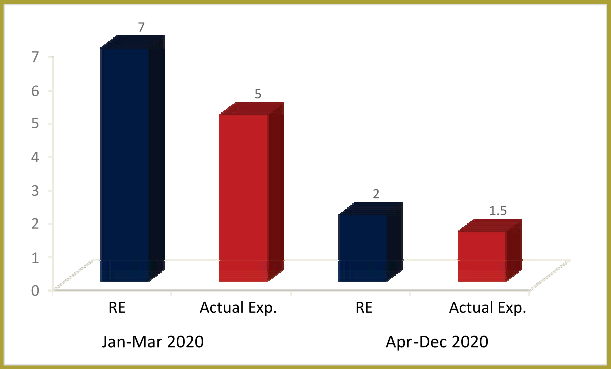
Human Resources Development and Capacity Building

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 2020



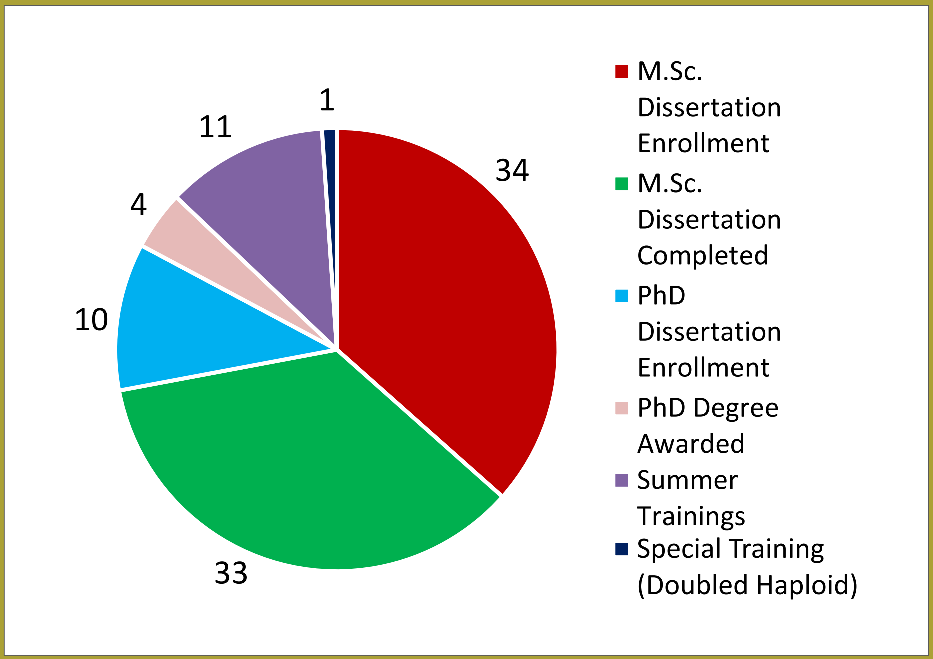
Financial targets and achievements of HRD cell for the year 2020



Capacity building of the students

During the year 2020, 34 MSc students have completed their dissertation; 10 students have enrolled for PhD programme; four PhD students have completed dissertation among other achievements of the HRD cell.

Achievements of the HRD programmes for the students during 2020



Extension Activities

Extension Activities

With the aim of imparting knowledge to different stakeholders on diverse areas, ICAR-NRRI, Cuttack has undertaken several extension activities during the year 2020. The activities ranged 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), Tribal Sub Plan (TSP), Scheduled Caste Sub Plan (SCSP), etc. The brief report of the activities are presented below:

Field demonstrations

ICAR-NRRI, Cuttack has conducted about 900 field demonstrations of newly released rice varieties and crop production as well as protection technologies in the farmers' field during the year 2020. About 30 promising rice varieties were demonstrated in the states of Assam, Andhra Pradesh, Bihar, Chhattisgarh, Jharkhand, Madhya Pradesh, Maharashtra, Odisha and West Bengal through these activities. Front Line Demonstration on drought tolerant rice variety was conducted in *kharif* 2020 by CRURRS, Hazaribag in which three varieties Abhishek, Sahbhagidhan and IR 64 *Drt1* were distributed to the farmers/ farmwomen of Parbad and Fusari villages, Churchu block, Hazaribag.

Exhibitions

The institute participated in seven exhibitions at different locations in the country and showcased its promising technologies and significant milestones to the visitors in the exhibitions during this pandemic year.

Fortnightly agro-advisory services

Altogether 27 agro-advisories on rice were issued on fortnightly basis in English as well as Odia language during the year 2020. The advisories were sent by e-mail to the officials of agriculture and related departments of the state as well as uploaded in Institute website for public awareness and reference. Further, block wise weather forecast based agro met advisory bulletin of Cuttack district were issued 4-5 times per month since January 2020.

Visitor's advisory services

A total of 1376 visitors including 850 farmers, 338 farmwomen, 110 students and 79 agriculture officers from the states of Jharkhand, Karnataka, 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 2020 and during their visit advisory on different aspects of rice cultivation were provided.

Training programmes for farmers and extension professionals

Altogether 3290 participants including farmers, extension officials, administrative personnel and others were benefitted through 102 training programmes of different durations (2-8 days) conducted physically or through virtual mode 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 by providing requisite information, knowledge and advisories. Regular visits were made by different groups in their respective clusters and provided technical backstopping, training, advisories, etc.

Tribal Sub-Plan (TSP) Programme

Two tribal villages, 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 were organized on regular basis and feed supplements distributed for development of livestock. Farm tools were also distributed among the beneficiaries besides hands-on training on fruits plants and tuber crops, inter-culturing, integrated pest management and paddy straw mushroom cultivation practices, etc. During the *kharif* 2020, about 5 quintals paddy seeds of improved varieties were distributed to the beneficiaries and monitored during different stages of the production.

Under TSP programme at RRLRRS, Gerua 2100 kg of breeder seeds (CR Dhan 310, 309, 311, 801, 802, 909, 307, 506, 601 and Chandrama) were distributed to 180 beneficiary farmers belonging to Thanguri, Pub-Thanguri, Lakhipur, Muktapur and Debachara villages of Baksa district for production of certified seeds during *kharif* in about 55.2 ha areas. Further, vegetable seeds of okra, cucumber, bottle gourd and ridge gourd were also distributed to 50 beneficiary farmers of Debachara VCDC, Baksa during *kharif* season. During *rabi* season, seeds of tomato, capsicum, broccoli, cucumber and papaya were distributed to 120 farmers covering six villages in Baksa District with the collaboration of NGO namely SANJOG.

Scheduled Caste Sub-Plan (SCSP) Programme

The Scheduled Caste Sub-Plan (SCSP) conceived at ICAR-NRRI, Cuttack with the aim of uplifting the scheduled caste community through various area-oriented activities (area with majority of scheduled castes population) or even individual-centric activities or distribution of inputs and other benefits. Three villages were chosen during 1st phase and activities started during beginning of the year. Awareness meetings were conducted at every village to sensitize about the programme. Training programmes were also organized at all the three villages for boosting the knowledge and awareness about high yielding rice varieties and improved package of practices for better livelihoods among the scheduled caste communities. Two thousand numbers of 21-day old chicks were distributed to 100 beneficiaries of one village and during *kharif* 2020, about 23 quintal paddy seeds of improved varieties were distributed to 240 farmers of two villages. User Groups were created (all farmers are member of one or other group) through Gramsabha meeting and large machines distributed to the groups for creation of custom-hiring centre. Farm tools/equipments like sprayer, power thresher, pump sets, etc. were distributed to the beneficiaries as per the need assessed. Small tool like cono-weeders were distributed to all the beneficiaries. Some were distributed with items other than farm tools as per their occupation like wood cutter, saw cutter, drill machine, sander machine, iron rod cutter, chicken dressing machine, deep freezer, electric paint sprayer, sewing machine, etc. Household items like thermosflask, grain storage container, face mask, hand-wash, sanitizers were also distributed to all the beneficiaries.

In-Charge and Members of Different Committees

Research Advisory Committee

Prof. SK Sopory, Chairman

Dr. KK Jena, Member

Dr. BC Viraktamath, Member

Dr. AR Sharma, Member

Dr. VV Sadamate, Member

Dr. Chandish R Ballal, Member

Shri SK Panigrahi, Member

Shri A Mishra, Member

Dr. D Maiti, Member

ADG (FFC), ICAR, Member

Dr. SR Voleti, Special Invitee

Dr. BC Patra, Member Secretary

Institute Management Committee

Dr. D Maiti, Chairman

Dr. YP Singh, ADG (FFC), ICAR, Member

Dr. AK Nayak, Member

Dr. (Mrs.) Padmini Swain, Member

Dr. D Sarkar, Member

Dr. LV Subba Rao, Member

Shri VK Sahoo, Member

Shri A Mishra, Member (Non-Official)

Shri SK Panigrahi, Member (Non-Official)

Dr. SK Das, Invitee

Shri BK Sahoo, Member Secretary

Personnel (January-December 2020)

Dr. Dipankar Maiti, Director (Acting)

Crop Improvement Division

Scientist								
BC Patra (I/C Head)	ON Singh (on deputation)	MK Kar	SK Pradhan	LK Bose	K Chattopadhyay	S Samantaray	L Behera	SK Dash
H Subudhi	A Anandan	RK Sahu	M Chakaraborti	J Meher	RL Verma	S Sarkar	Md Azharudheen TP	RP Sah
BC Marndi	P Sanghamitra	JL Katara	K Ali Molla	Parameswaran C	Devanna	Anil Kumar C	Reshmi Raj KR	
Technical Staff								
R Chandra	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	B Mondal
M Patra	S Sarkar	AK Dulet	A Choudhary	P Pandit	G Soren			
Administrative Staff								
M Swain								
Skilled Support Staff								
G Dei	FC Sahoo	J Biswal	SK Bhoi	P Dei	R Dei			

Crop Production Division

Scientist								
AK Nayak (I/C Head)	PK Nayak	S Saha	BB Panda	P Bhattacharya	A Poonam	R Tripathi	P Pannee -rselvam	S Mohanty
M Shahid	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 Sivashankari	S Priyadarsani	
Technical Staff								
PK Sahoo	KK Suman	A K Mishra	B Das	JP Behura	SK Ojha	KC Palaur	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 Samantaray	S Mohanty	G Bihari	D Behera	PK Ojha	D Parida	PK Parida
R Beshra	CK Ojha	S Pradhan	JK Sahu	AK Suman	Md H Alam	KK Meena	S Kumar	SP Sahoo
TK Behera	MK Parida							
Administrative Staff								
S Sur	SK Bhoi							
Skilled Support Staff								
S Biswal	B Marandi	B Khatua	M Dei	K Dei	PK Das	J Marandi		

Crop Protection Division

Scientist								
PC Rath (I/C Head)	SD Mohapatra	KR Rao	S Lenka	AK Mukherjee	MK Bag	S Mondal	NKB Patil	Basan Gowda G
GP Pandi G	G Prasanthi	M Anna malai	MK Yadav	Aravindan S	Raghu S	Prabhu Karthikey-an SR	MS Baite	Keerthana U
SS Pokhare	Sankari Meena K	T Adak	B Gayatri					
Technical Staff								
R Swain	S Pradhan	P Moha rana	SK Sethi	SK Rout	MK Nayak	A Panda	C Majhi	H Pradhan
A Mohanty	EK Prad-han	A Malik	M Meena	S Biswal	AK Naik	D Dash	JP Das	KC Barik
S Das	Md Shadab Akthar	NK Meena						
Administrative Staff								
B Maharana								
Skilled Support Staff								
L Murmu	B Bhoi	D Naik						

Crop Physiology & Biochemistry Division

Scientist								
P Swain (I/C 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								
Nil								
Skilled Support Staff								
G Sahoo	J Dei							

Social Science Division

Scientist								
GAK Kumar (I/C Head)	NC Rath	SK Mishra	B Mondal	NN Jamb-hulkar	JP Bisen	AK Pradhan		
Technical Staff								
P Kar	B Behera	SR Dalal	G Sinha	DR Sahoo	AK Parida	SK Mohapatra	A Anand	SK Tripathy
AK Panda	HS Sahoo	SK Roul						
Administrative Staff								
L Trivedi								
Skilled Support Staff								
Surubali Hembram								

NRRI Research Station, Hazaribag

Scientist								
D Maiti (HEAD)	NP Mandal	S Bhagat	SM Psrasad	S Roy	BC Verma	A Banerjee		
Technical Staff								
AN Singh	R Tirky	S Oran	U Saw	J Kumar	J Prasad	HR Meena	SC Meena	S Akhtar
Administrative Staff								
CP Murmu	R Paswan	S Kumar	CR Dangi	AK Das	SK Pandey			
Skilled Support Staff								
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 (I/C Head)	K Saikia	BR Goud						
Technical Staff								
H Thakuria	S Baruah	D Khan	B Kakita					
Administrative Staff								
J Das								
Skilled Support Staff								
M Das								

NRRI Research Station, Naira

Scientist								
KR Rao (I/C HEAD)								
Technical Staff								
KC Munda								

KVK, Santhpur

Technical Staff								
S Sethy (OIC)	DR Sarangi	RK Mohanta	P Pradhan	TR Sahoo	A Bisoi	K Pradhan		
Administrative Staff								
BB Polai								

KVK, Koderma

Technical Staff								
C Kumari (OIC)	S Sekhar	B Singh	R Ranjan	M Kumar	S Kumar	BK Khuntia		
Skilled Support Staff								
M Ram								

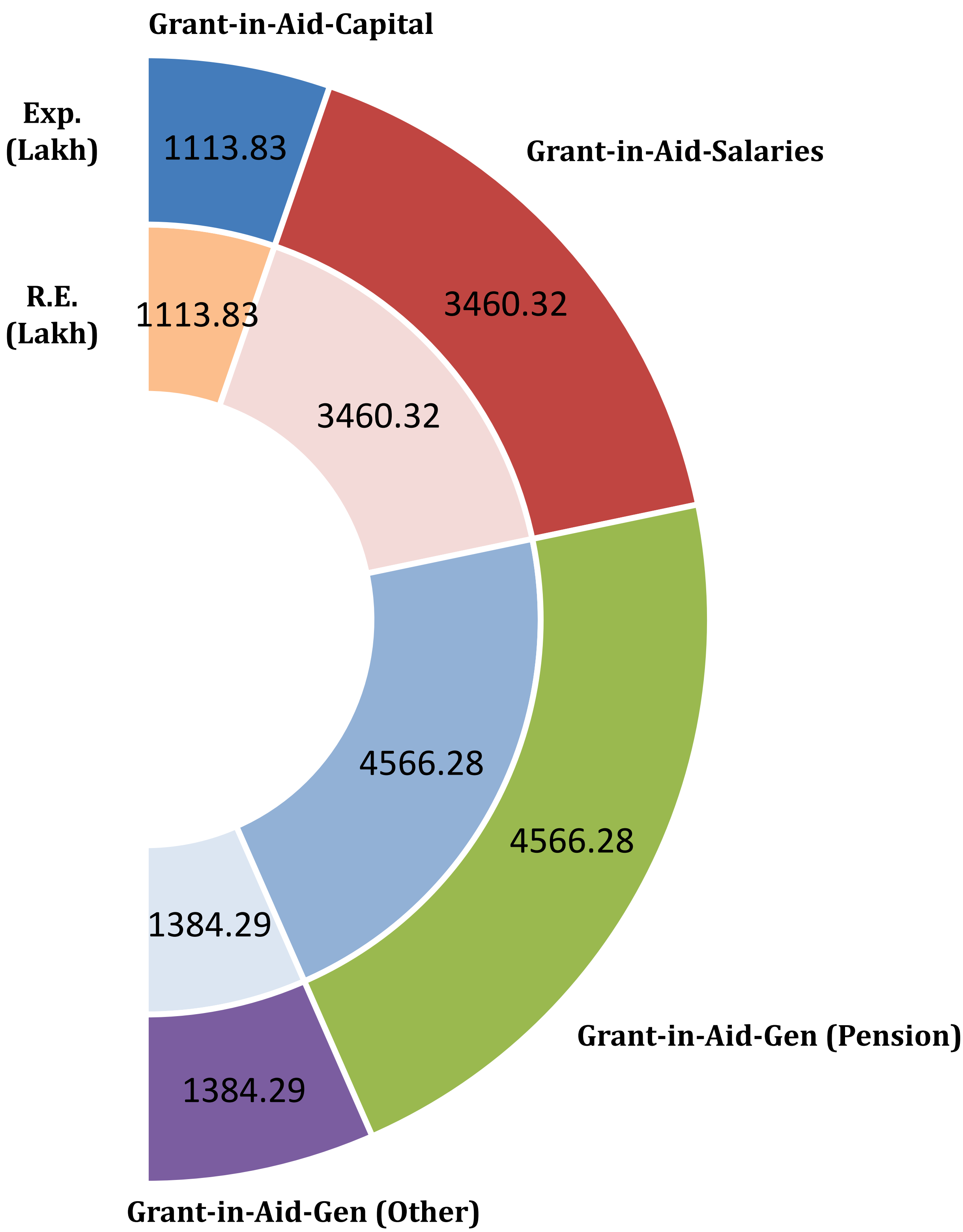
Administrative Section

Administrative Staff								
I Muduli (HOO)	BK Sahoo	SK Das	SK Mathur	J Pani	NC Parija	SK Dash	NK Swain	DK Mohanty
CP Murmu	SK Jena	SK Behera	S Nayak	SK Sahu	RK Behera	N Mahavoi	D Khuntia	N Jena
MB Swain	SP Sahoo	S Sahoo	KK Sarangi	RC Das	R Kido	NP Behura	SK Sahoo	M Mohanty
SK Nayak	DK Parida	SK Satapahy	MK Sethi	KC Behera	PC Das	AK Pradhan	RC Pradhan	V Kumar
G Dei	R Dutta	SK Lenka	SK Sahoo	M Das	RC Nayak	S Pradhan	A Sethi	R Sahoo
D Muduli	AK Sinha	BK Gochhayat	H Marandi	RK Singh	RPS Sabarwal	SK Patra	SK Das	
Technical Staff								
BK Mohanty	SK Sinha	KC Das	PK Sahoo	B Pradhan	N Biswal	AK Nayak	B Sahoo	B Sethi
S Mohapatra	R Behera	S Mishra	S Kumar					
Skilled Support Staff								
K Naik	D Naik	R Naik	P Naik	D Naik	B Naik			

Canteen Staff

A Jena	M Sahu	M Nayak	M Pradhan	N Naik		

Financial Statement (January-December 2020)



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 CRURRS, Hazaribag- NP Mandal	AP Cess
2	EAP 36	National Seed Project (Crops)- BC Marndi, RP Sah, P Sanghamitra	NSP
3	EAP 49	Revolving fund scheme for breeder seed production- BC Marndi, 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- BC Verma	DAC
5	EAP 100	Seed Production in Agricultural Crops- BC Marndi, RP Sah, P Sanghamitra	ICAR
6	EAP 130	All India Network Project on Soil Biodiversity – Biofertilizers- D Maiti	ICAR
7	EAP139	AICRP on energy in agriculture and agro-based industries- PK Guru, NT Borkar	AICRP (DRET-SET/ DRET-BCT)
8	EAP 140	Intellectual Property Management and Transfer/ commercialization of agricultural technology under National Agricultural Innovation Fund (NAIF)- BC Patra	ICAR
9	EAP 141	DUS Testing of Rice and documentation- BC Patra	PPV&FRA
10	EAP 161	Monitoring of the new initiative of "Bringing Green Revolution to Eastern India (BGREI) under the Rashtriya Krishi Vikas Yojana" - D Maiti, BB Panda	DAC, GOI
11	EAP 178	National Initiative on Climate Resilient Agriculture	NICRA (ICAR)
12	EAP 183	Characterization of toxins of *Bacillus thuringiensis* isolated from rice genotypes and their virulence assessment against leaf folder (*Cnaphalocrocis medinalis* Guenee)- S Acharya (TK Dangar)	DST Inspire
13	EAP 184	Utilization of fly ash on amelioration and source of nutrients to rice-based cropping system in eastern India- S Maharana (AK Nayak)	DST Inspire
14	EAP 186	Use of microbes for management of abiotic stresses in rice- AK Mukherjee	ICAR-IRRI
15	EAP 189	Front Line Demonstrations under NFSM- AK Pradhan, SK Mishra, B Mondal	DAC –IIRR (NFSM)
16	EAP 191	NRRI-NCIPM collaborative project on development and validation of IPM module for rice- SD Mohapatra, S Lenka, J Berliner, K Saikia, T Singh, U Kumar, T Adak	CRRI/NCIPM
17	EAP 192	DNA marker based pyramiding and study of interactions among QTLs for higher grain number in rice (*Oryza sativa* L.)- G Gouda (L Behera)	DST Inspire
18	EAP 193	Future rainfed lowland rice systems in Eastern India 15 (T3) (Development of crop and nutrient management practices in rice)- AK Nayak, M Shahid, R Tripathi, D Bhaduri, K Chakraborty	STRASSA South Asia
19	EAP 195	Artificial induction of chlamydospore in *Trichoderma* sp. and identification of genes expressed during the process- HK Swain (AK Mukherjee)	DST Inspire
20	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
21	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
22	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, G Kumar, A Kumar, KA Molla	ICAR Plan

23	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
24	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, Devanna, KA Molla	ICAR Plan
25	EAP202	Associated mapping of genes/QTLs for yield under reproductive stage drought stress in rice (*Oryza sativa* l.)- L Behera, P Swain, SK Dash, SK Pradhan, BC Patra	BIRAC
26	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)
27	EAP 204	CRP on Agro biodiversity: PGR Management and Use of Rice (Component I & II)- BC Patra, GP Pandi G, AK Mukherjee, K Chakraborty	CRP – Agrobiodiversity (ICAR)
28	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, PK Guru, R Khanam	CAP - ICAR
29	EAP 209	CRP on hybrid technology- RL Verma, JL Katara	CRP - ICAR
30	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
31	EAP 211	CRP on molecular breeding- MK Kar, L Behera, GP Pandi G, A Mukherjee, M Chakraborti, S Aravindan, PC Rath	CRP - ICAR
32	EAP 212	Multilocational monitoring of Rynaxypyr 20SC against *Scirpophaga incertulas* in rice and rice hopper susceptibility survey in India for DPH-RAB55 106SC against *Nilaparvata lugens* and *Sogatella furcifera*- SD Mohapatra, M Jena, B Gowda G	M/s Du Pont India Pvt Ltd
33	EAP213	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
34	EAP215	Agri-Business Incubation Centre- GAK Kumar, BC Patra, NC Rath, S Saha, BB Panda, B Mondal, AK Mukherjee, PK Guru, JP Bisen, GP Pandi G, NN Jambhulkar	NAIF, IP&TM – ICAR
35	EAP217	Development of high yielding, water and labor saving rice varieties for dry direct seeded aerobic conditions utilizing recent discoveries on traits, QTLs, genes and genomic technologies- A Anandan, S Sarkar, SK Dash	DBT
36	EAP220	Delivering food security on limited land (DEVIL)- AK Nayak, M Shahid, R Tripathi, B Mondal, SD Mohapatra, P Bhattacharyya	Min. Earth Science, GOI
37	EAP223	Marker-assisted introgression of yield-enhancing genes to increase yield potential in rice- L Behera, MK Kar, SK Dash, SK Pradhan	DBT
38	EAP224	Understanding mechanism of tolerance to low light intensity in rice- MJ Baig, P Swain, SK Pradhan	NASF -ICAR
39	EAP225	Forewarning of major crop pests on special scale for their integrated management- SD Mohapatra, MK Yadav, GP Pandi G, S Bhagat	SAC-ISRO
40	EAP227	Creation of seed hub for increasing indigenous production of pulses in India- DR Sarangi, TR Sahoo, M Chourasia, RK Mohanta	DAC &FW
41	EAP228	Increasing productivity and sustaining the rice-based production system through farmer FIRST approach- SK Mishra, B Mondal, SK Pradhan, S Saha, PK Nayak, S Lenka, R Tripathi, NT Borkar, G Prasanthi, M Sivashankari, L Das, GC Acharya, SC Giri	ICAR-Farmer FIRST
42	EAP 229	Phenomics of moisture deficit stress tolerance and nitrogen use efficiency in rice and wheat – Phase II- P Swain, SK Dash, J Meher	NASF – ICAR
43	EAP230	Developing microbial consortium for horticultural crops in rice based cropping system to promote growth, nutrient uptake and disease management in organic farming in Sikkim- P Paneerselvam, U Kumar	DBT (NER-BPMC)

44	EAP233	Accelerated decomposition of rice straw using novel *Trichoderma* strain and its mutants- A Mukherjee, T Adak	BRNS – DAE
45	EAP234	Gene staking for submergence tolerance, bacterial blight resistance and yield potential in rice variety Swarna through classical and molecular breeding approaches- SK Pradhan, S Mohapatra	DST, Gov. Odisha
46	EAP236	ICAR-CSISA collaborative project (phase III) – Research to quantify near and long term effects of sustainable intensification technologies at NRRI- R TripathI, AK Nayak, BB Panda, M Shahid, D Chatterjee	CSISA
47	EAP238	Efficacy of phosphine fumigant against storage pests of pulses, wheat, rice and coffee beans and residue analysis for quarantine and long term storage purpose- NB Patil, T Adak	DAC
48	EAP239	Pyramiding and understanding the interaction of QTLs for deeper rooting and phosphorous uptake in rice (*Oryza sativa* L.)- E Pandit (SK Pradhan)	DST (WOS-A)
49	EAP240	Potential gene mining from salt tolerant grasses for improvement of stress tolerance in crops- C Parameswaran	NASF-ICAR
50	EAP241	Genetic improvement of hybrid rice parental lines for enhancing yield heterosis- RL Verma, RP Sah, JL Katara, LK Bose, S Samantaray	ASEAN
51	EAP242	Targeting rice- fallows: a cropping system based extrapolation domain approach- BB Panda, R TripathI, AK Nayak	IRRI - Odisha
52	EAP243	Phenotyping based on chlorophyll fluorescence imaging under salinity-stagnant flooding stress and identification of quantitative trait loci of chlorophyll fluorescence traits in rice- RK Sarkar	ICAR Emeritus scheme
53	EAP244	Validation and promotion of IPM in Rice in Tribal Region of Jharkhand- S Bhagat, A Banerjee, D Maiti	ICAR-NCIPM
54	EAP245	Strategic research component of National Innovation in climate resilient agriculture (NICRA)- P Swain, AK Nayak, P Bhattacharyya, K Chattopadhyay, A Anandan, S Mohanty, D Chatterjee, K Chakraborty, H Pathak	ICAR Net work
55	EAP246	Raising productivity and profitability of rice-based cropping system in Odisha through rice crop manager- S Saha, S Munda, BS Satapaty	IRRI
56	EAP247	Bio-efficacy evaluation of 'Agri-Booster™KSi' against major insect pests and diseases of rice- M Annamalai, T Adak, GP Pandi G, B Gowda G, MK Yadav	Noble Alchem Pvt. Ltd., Indore
57	EAP248	Accounting greenhouse gases (GHGs) emission and carbon flow in temporal shift of tropical mangrove to agriculture- P Bhattacharyya	ICAR- National Fellow
58	EAP249	Strengthening seed system of STRVs through innovative demonstrations and extension approaches in Odisha- BC Marndi, RP Sah, P Sanghamitra	IRRI-Odisha
59	EAP250	Validation and promotion of IPM in rice based cropping system- SD Mohapatra, S Lenka , U Kumar, BS Satapathy, Raghu S, Prasanthi G, S Bhagat , D Maiti, A Banerjee, SM Prasad	NRRI-NCIPM
60	EAP 251	IT-enabled Self-sufficient Sustainable Seed System for Rice- GAK Kumar, BC Patra, B Mondal, AK Mukherjee, P Sanghamitra, RP Sah, NB Patil, BS Satapathy	RKVY, Odisha
61	EAP-252	Development and demonstration of Rice based integrated farming system for livelihood security of small and marginal farmers in coastal Odisha- A Poonam, AK Nayak, S Saha, BS Satpathy, GAK Kumar, PK Sahu, K Chattopadhyay, SK Lenka, LK Bose, PK Guru	RKVY, Odisha
62	EAP-253	Genomics-assisted breeding for increasing yield potential and durable resistance to major biotic stresses (BPH, Blast, BB, Sheath blight) of Indian elite cultivars- MK Kar, L Behera, SK Pradhan, SK Dash, LK Bose, GP Pandi G, AK Mukherjee, PC Rath	IRRI
63	EAP-254	Cereal Systems Initiative for South Asia (CSISA)- KVK, Cuttack- DR Sarangi, TR Sahoo, RK Mohanta	IRRI- CSISA Project
64	EAP-256	Utilization and refinement of haploid / doubled haploid induction systems in rice, wheat and maize involving molecular and *in-vitro* strategies- S Samantaray, JL Katara, Parameswaran C, RL Verma, A Anandan, K Chattopadhyay, Awadhesh Kumar	NASF
65	EAP-257	Genetic improvement of rice for yield, NUE, WUE, abiotic and biotic stress tolerance through RNA guided genome editing (CRISPR-cas 9/ Cpf 1)- Parameswaran C, N Umakanta, S Samantaray, Awadhesh Kumar	NASF

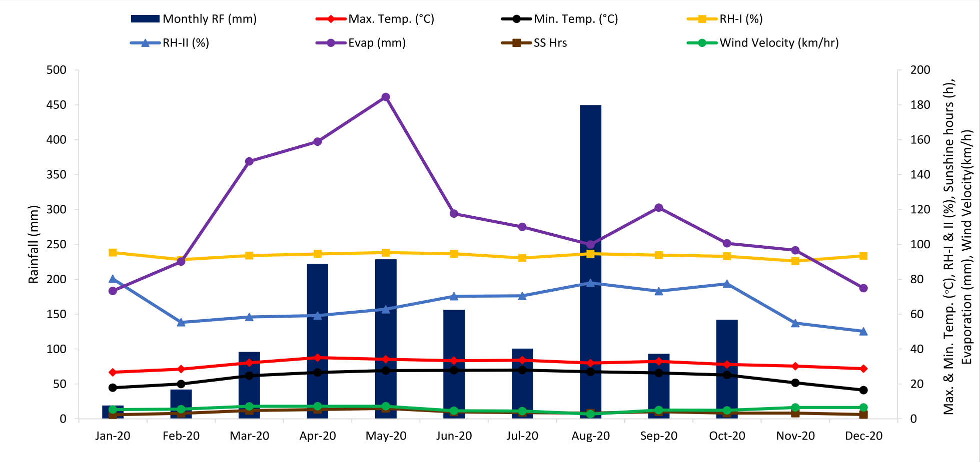
66	EAP-258	Evaluation of different formulations of Penoxsulam alone and Penoxsulam+ Cyhalofop butyl for broad spectrum weed control in rice- S Saha, BS Satapathy, S Munda, D Bhaduri	Dow Agro Sciences India Pvt. Ltd.
67	EAP-260	Development of climate smart practices for climate resilient varieties- Anjani Kumar, AK Nayak, S Saha	IRRI
68	EAP-261	Establishment of State of Art of Pesticide Residue Analysis in Odisha for its Optimum and Safe Use- T Adak, GP Pandi G, NB Patil, B Gowda G, Raghu S, S Munda, PC Rath, Prabhukarthikeyan SR	RKVY
69	EAP-262	Enhancing resilience of rice based production system to climate change- AK Nayak, SK Pradhan, P Bhattacharya, MK Bag, GAK Kumar, K Chakraborty, Anjani Kumar, PK Nayak	DST
70	EAP-263	From QTL to variety: Genomics-Assisted Introgression and field evaluation of rice varieties with genes/ QTLs for yield under drought, flood and salt stress- JL Katara, BC Marndi, P Swain, K Chakraborty	DBT
71	EAP-264	From QTL to variety: Genomics-Assisted Introgression and field evaluation of rice varieties with genes/ QTLs for yield under drought, flood and salt stress- NP Mandal, S Roy, A Banerjee	DBT
72	EAP-265	Prospects of interactions of multistrain stress resilient beneficial phytotonic microbes and rice to improve productivity under environmental adversities (Emeritus Scientist Project)- TK Dangar	ICAR Emeritus scheme
73	EAP-266	A comparative study on the effect of cold and histone deacetylase inhibitor pre-treatment on the callus inducing ability in anthers of elite rice hybrids- B Cayalvizhi, S Samantaray	N-PDF (SERB)
74	EAP-267	SPDT Transporter based identification of low Phosphorus / phytate rice to reduce the removal of phosphorus from soil and eutrophication of waterways- Awadhesh Kumar	SERB
75	EAP-268	Development and implementation of Rice Doctor for Odisha- PC Rath, AK Mukherjee, S Lenka	IRRI
76	EAP-269	Identification and mapping of QTLs / genes associated with high grain number in rice- N Mohanty (L Behera)	DST, Odisha (Biju Pattanaik Research Fellowship)
77	EAP-270	Evaluation and utilization of BPH resistant rice gene pool for multiple insect resistant traits- M Jena	ICAR Emeritus scheme
78	EAP-271	Harvest Plus Programme : Biofortification of rice- K Chattopadhyay, A Kumar, P Sanghamitra, G Kumar, LK Bose	IFPRI & CIAT
79	EAP-272	Strengthening entrepreneurs in marketing and export of value added agricultural products by establishing a state of art quality assessment laboratory in Odisha- S Sarkar, N Basak, P Sanghamitra, T Adak, B Mondal, M Chakraborty, M J Baig, G Kumar, S Priyadarsani, Sivashankari M	RKVY-Odisha
80	EAP-273	Introgression of *saltol* and *Sub 1* genes into restorer line of popular rice hybrid Ajay and Rajalaxmi through marker assisted selection- JL Katara	SERB, DST, Govt. of India
81	EAP-274	Bio-Bank: Production and promotion of biocontrol agents and entrepreneurship development in aspirational districts of Odisha- B Gowda G, NB Patil, GP Pandi G, T Adak, Prasanthi G, Annamalai M, Raghu S, Prabhukartikheyan SR, PC Rath, AK Mukherjee	RKVY-Odisha
82	EAP-275	Setting up of model bio-fertilizer production unit for supply of quality bio-inoculants for rice and rice-based cropping systems in Odisha- U Kumar, P Panneerselvam, AK Nayak, SK Mishra, PK Nayak, Anjani Kumar	RKVY-Odisha
83	EAP-276	Inclusive development through knowledge, innovative extension methods, networks and capacity building in Odisha- R Tripathi, S Samantray, GP Pandi G	IRRI
84	EAP-277	New high yielding rice varieties for irrigated and rainfed ecosystem through TRB- SK Dash, RL Verma, JL Katara, S Sakar, RP Sah, J Meher	IRRI
85	EAP-278	Efficacy of Chlorantraniliprole 625g/l FS (Lumivia) for the management of stem borer and leaf folder in paddy crop- NB Patil, B Gowda, Annamalai M, PC Rath	E I Dupont India Pvt. Ltd.

86	EAP-279	Performance Evaluation of rice pure lines and hybrids- RP Sah, RL Verma, BC Patra, Raghu S, NB Patil	Pan Seed Pvt. Ltd.
87	EAP-280	Impact of futuristic climate change on weed dynamics, herbicide efficacies and developing adaptive solutions for direct-seeded rice- S Saha, BS Satapathy	IRRI
88	EAP-281	Upgradation and validation of existing alternate energy (solar) light trap developed by ICAR-NRRI- SD Mohapatra	M/s Fine trap India
89	EAP-282	Application of Next-Generation breeding, Genotyping and digitalization approaches for improving the genetic gain in Indian staple crops- SK Pradhan, L Behera, SK Dash, M Chakraborti	ICAR-BMGF
90	EAP-283	Building climate resilience of Indian small holders through sustainable intensification and agro-ecological farming systems to strengthen food and nutritional security (RESILIENCE)- AK Nayak, BB Panda, SD Mohapatra, R Tripathi, MD Shahid, S Mohanty, S Priyadarshini, S Saha, DR Sarangi	Norwegian Institute of Bioeconomy Research (NIBIO), Norway
91	EAP-284	RKVY-RAFTAAR-Agribusiness incubation- GAK Kumar, BC Patra, AK Mukherjee, S Saha, BB Panda, N Borkar, M Sivashankari, B Mondal, RP Sah	RKVY
92	EAP-285	Early detection and estimation of biotic stresses in rice due to major insect pests and diseases using hyperspectral remote sensing from field to landscape scale- SD Mohapatra, R Tripathi, U Keerthana	SAC-ISRO
93	EAP-286	Bio-efficacy of triflumezopyrim 5% w/v + spinetoram 9% w/v (14% SC) and and triflumezopyrim 5% w/w + spinetoram 12% w/w(22%) WDG against yellow stem borer, leaf folder and sucking pests (BPH & WBPH)- SD Mohapatra	M/s Du Pont India Pvt. Ltd.
94	EAP-287	Enhancement of reproductive stage salinity tolerance in rice- K Chattopadhyay, BC Marndi, K Chakraborty, LK Bose, AK Nayak	IRRI
95	EAP-288	Study and investigation of molecular mechanism of ethylene and its downstream signaling during grain filling stage in rice- S Sekhar (L Behera)	DBT-RA Fellowship
96	EAP-289	Newton Bhaba virtual centre on nitrogen efficiency of whole-cropping systems for improved performance and resilience in agriculture (NEWS Project)- D Chatterjee, S Mohanty, AK Nayak	DBT
97	EAP-290	Advance breeding technologies to speed up genetic gain, create durable resistance to biotic stresses and increase indian farmers and consumers' food and nutritional security- SK Pradhan	IRRI-India
98	EAP-291	Attracting and Retaining Youth in Agriculture (ARYA)- DR Sarangi, TR Sahoo, RK Mohanta	ICAR
99	EAP-292	Paramparagat Krushi Vikas Yojana (PKVY)- TR Sahoo, RK Mohanta	ICAR
100	EAP-293	New Extension Methodologies and Approaches (NEMA)- GAK Kumar	ICAR
101	EAP-294	Efficacy of Chlorantraniliprole 625g/l FS (Lumivia) for the management of stem borer and leaf folder in Direct Seeded Rice (DSR)- NB Patil, B Gowda G, Annamalai M , PC Rath	E I Dupont India Pvt. Ltd.
102	EAP-295	Greenhouse gas emission, mitigation & adaptation: strategies for better inventory and management of such gases in rice ecosystems of two agro-climatic zones of Assam- P Bhattacharya, S Chatterjee	DBT
103	EAP-296	Development of multiple stress tolerant versions of rice varieties Gomati and Tripura Chikan Dhan through molecular breeding- SK Pradhan, M Chakraborti, AK Mukherjee	DBT
104	EAP-297	Exploration and utilization of endophyte diversity in wild rice for health management of rice crops- R Jena (AK Mukherjee)	DST Inspire
105	EAP-298	Amelioration of soil borne diseases in rice using endophytic community of wild rice of Odisha for benefit of rice farmers- S Samanta (AK Mukherjee)	DST- Women Scientist (B)
106	EAP-299	Leveraging institutional innovations for inclusive and market led agricultural growth in Eastern India- B Mondal, BS Satapathy, AK Pradhan, SK Rout (Associate)	ICAR
107	EAP-300	Performance evaluation of PAN Seed rice varieties- RP Sah, L Verma, BC Patra, Raghu S, NB Patil, Awadesh Kumar	PAN Seed

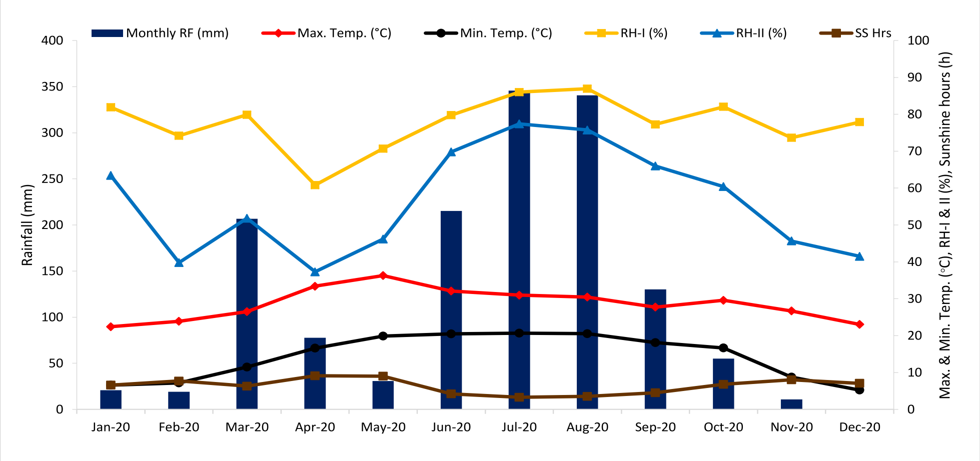
108	EAP-301	Effect of Biogas digestate on rice growing and greenhouse gas emission- Anjani Kumar, D Chatterjee, S Mohanty	KSBT, Bhubaneswar
109	EAP-302	Establishment of Biotech KISAN Hub at Central Rainfed Upland Rice Research Station (CRURRS), ICAR-NRRI, Hazaribag, Jharkhand- D Maiti, SM Prasad	DBT
110	EAP-303	Insect Pest and disease forecasting and decision support system (ICAR-IRRI Collaborative Project- SD Mohapatra	ICAR-IRRI
111	EAP-304	CRISPR / Cas based editing of susceptibility gene promoters to develop bacterial blight and sheath blight resistant rice plants avoiding pleiotropic effects- S Karmakar	DBT-RA
112	EAP-305	To evaluate the bio-efficacy of PIX 10082 44% EW against insect pest of rice- GP Pandi G, PC Rath, Annamalai M, Sankari Meena, S Pokhare	PI Industries Pvt. Ltd.
113	EAP-306	Develop and validate crop establishment practices for drought-tolerant/ new varieties in a rainfed upland environment of Jharkhand. (Under programme: Climate smart management practices)- BC Verma	IRRI
114	EAP-307	Climate Smart Management Practices under DSRC- S Saha, BS Satpathy, K Kumari, V Kumar-IRRI, S Singh-IRRI, P Sagwal-IRRI	IRRI
115	EAP-308	IRRI-ICAR collaborative Project- "Accelerating impact and equity"- Sivashankari M	IRRI
116	EAP-309	Establishment of Biotech KISAN Hub at Regional Rainfed Lowland Rice Research Station (RRLRRS), ICAR-NRRI, Gerua, Hajo, Kamrup, Assam- R Bhagawati	DBT
117	EAP-310	Development of superior haplotype based near isogenic lines (Haplo- NILs)- SK Pradhan, L Behera, Devanna	DBT
118	EAP-311	Paddy straw residues management through *in situ* microbial decomposition with mechanical interventions- P Paneerselvam, U Kumar, A Kumar, M Shahid	NASF
119	EAP-312	Mainstreaming rice landraces diversity in varietal development through genome wide association studies: A model for large scale utilization of gene bank collections of rice- SK Pradhan, L Behera, JL Katara, BC Marndi, Devanna, A Banerjee, S Ray, K Chakraborty, MK Bag, PS Hanjagi, G Kumar, Aravindan S, Annamalai M	DBT
120	EAP-313	Integration of *in vitro* based Doubled Haploid, Marker Assisted Selection, Transgenic and CRISPR- Cas 9 technology in rice improvement (Training Project)- S Samantaray, JL Katara, Parameswaran C, Devanna, RL Verma	DBT
121	EAP-314	Adaptive study trial of Council Active 30EG (Triafamone 20%+ Ethoxysulfuron 10%) for broad spectrum weed control in rice- S Saha	Bayor Crop Science Ltd.
122	EAP-315	ICAR-IRRI collaborative Project on climate smart management practices- Development of appropriate machinery systems for rice mechanization- N Borkar, S Priyadarshi	IRRI
123	EAP-316	Double haploid breeding in development of rice variety for enhancing resilience against biotic and abiotic stresses- S Samantaray, A Anandan, JL Katara, Parameswaran C, Devanna, RL Verma	BIRAC, India
124	EAP-317	Bio-efficacy studies of E2Y45828-R120 5% tablet against Yellow stem borer (*Scirpophaga incertulas*) and rice leaf folder (*Cnaphalocrocis medinalis*) in rice- SD Mohapatra	FMC India Pvt. Ltd.
125	EAP-318	Exploring insecticide induced hormesis to develop superior strain of egg parasitoid, *Trichogramma japonicum* and its molecular characterization- B Gowda G., T Adak, NB Patil	Science and Technology Deptt., Odisha

Weather

NRRI, CUTTACK



NRRI REGIONAL STATION, HAZARIBAG



NRRI REGIONAL STATION, GERUA