ANNUAL REPORT 2023

भाकृअनुप-राष्ट्रीय चावल अनुसंधान संस्थान

ICAR-National Rice Research Institute

वार्षिक प्रतिवेदन
Annual Report 2023

NRRI

भाकृअनुप - राष्ट्रीय चावल अनुसंधान संस्थान
कटक (ओडिशा) 753 006, भारत
ISO 9001:2015 प्रमाणित संस्थान

ICAR - National Rice Research Institute
Cuttack (Odisha) 753 006, India
An ISO 9001:2015 Certified Institute

Correct Citation
NRRI Annual Report 2023
ICAR-National Rice Research Institute Cuttack

ISBN 81-88409-09-X

Published by
Dr. A.K. Nayak
Director, NRRI

Editorial Committee
Dr. G.A.K. Kumar
Dr. S.D. Mohapatra
Dr. B. Mondal
Dr. K. Chattopadhyay
Dr. K. Chakraborty
Dr. Debarati Bhaduri

Editorial Assistance
Mrs. Sandhya Rani Dalal
Shri Sworaj Kumar Roul

Cover Page Design
Shri Arun Kumar Parida
Shri Sunil Kumar Sinha

Photography
Shri Bhagaban Behera

Cover page theme
Empowering the rice stakeholders through advanced rice research

Contacts
ICAR-National Rice Research Institute
Cuttack - 753 006
Odisha
Phone : +91-671-2367768-83
Fax : +91671-2367663
E-mail : crrictc@nic.in
director.crri@icar.gov.in
directorcrricuttack@gmail.com

NRRI Regional Station
Hazaribag - 825 301
Jharkhand
Phone : +91-6546-222263
Fax : +91-6546-223697
E-mail : crurrs.hzb@gmail.com
oic_crurrshazaribag@icar.gov.in

NRRI Regional Station
Gerua, Kamrup - 781 102
Assam
Phone : +91-361-2820370
Fax : +91-361-2820370
E-mail : oicrrlrrsgerua@rediffmail.com
oic_rrlrrsgerua.nrri@icar.gov.in

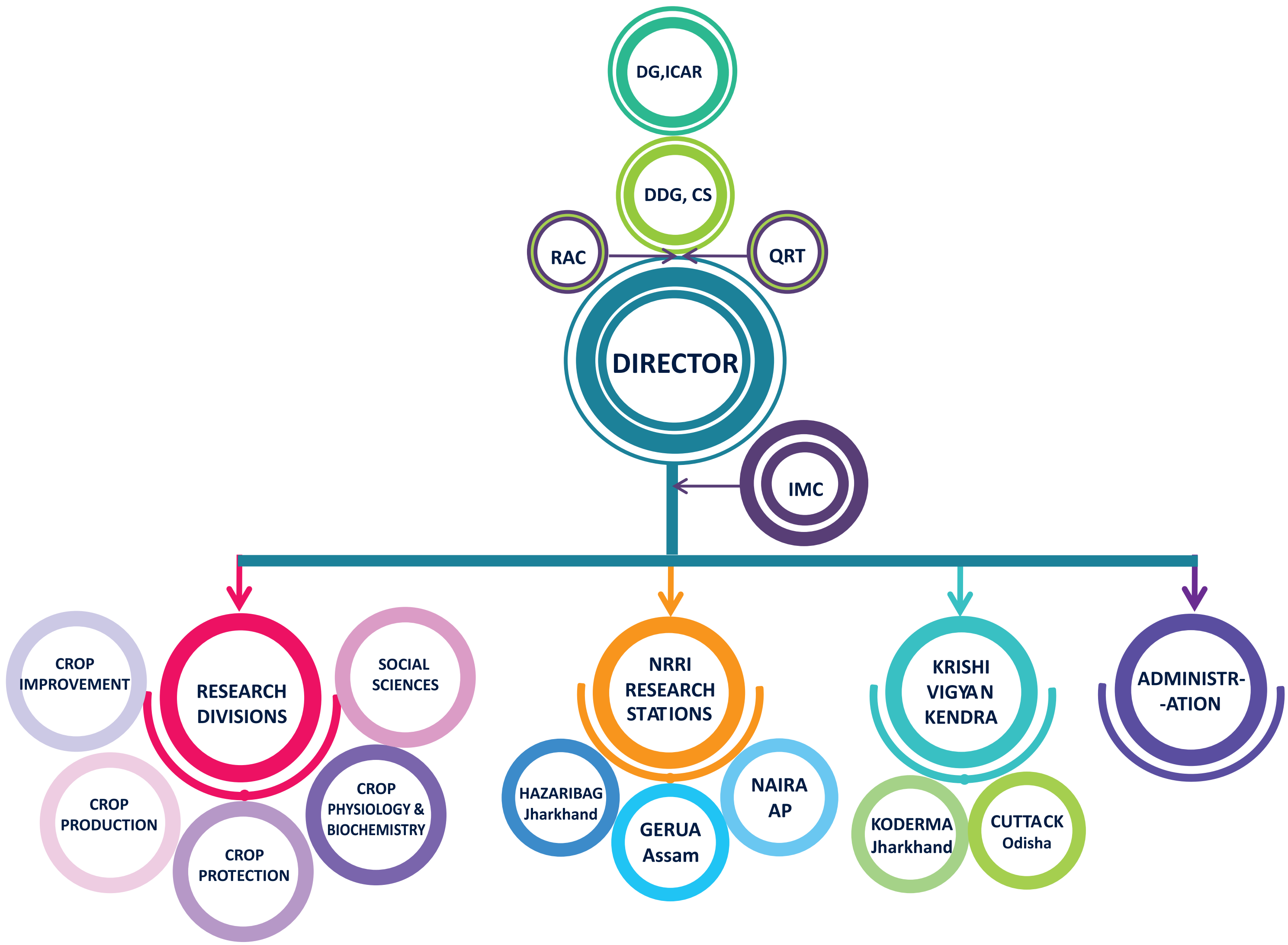
NRRI Regional Station
Naira, Srikakulam - 532 185
Andhra Pradesh
Phone : +8895585994
Fax : 91-671-2367777/2367663
E-mail : rcrrs.naira@icar.gov.in

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

Published and Printed by the Director for ICAR-National Rice Research Institute, Cuttack-753006,
Odisha at Print-Tech Offset Pvt. Ltd., Bhubaneswar-751024, Odisha

CONTENTS

ORGANOGRAM


DG,ICAR
DDG, CS
RAC
QRT
DIRECTOR
IMC
RESEARCH DIVISIONS
CROP IMPROVEMENT
SOCIAL SCIENCES
CROP PRODUCTION
CROP PROTECTION
CROP PHYSIOLOGY & BIOCHEMISTRY
NRRI RESEARCH STATIONS
HAZARIBAG Jharkhand
GERUA Assam
NAIRA AP
KRISHI VIGYAN KENDRA
KODERMA Jharkhand
CUTTACK Odisha
ADMINISTR- -ATION

PREFACE

Rice is of immense importance worldwide and serves as a staple food on which millions of people feed, especially in Asia where it is a main diet. It is known for its nutritional profile, rich in carbohydrates and essential nutrients, proving to be a vital source of energy. Its versatility extends to different cuisines and adapts seamlessly to different culinary preferences. Beyond its nutritional value, rice plays a central role in the agricultural economy, providing livelihoods for millions of farmers worldwide.

With the ICAR National Rice Research Institute (NRRI) Annual Report for 2023, we proudly present the remarkable achievements and contributions of this leading institution dedicated to promote research and development in rice agriculture. Founded in 1946, the Institute is at the forefront of pioneering work to improve rice varieties, farming practices and sustainable agricultural technologies. With its decades-long legacy, the institute has played a crucial role in the development of rice cultivation. The targeted research and direct collaboration with farmers addressed the specific challenges of the farming community in the region as well as at national level.

In 2023, the NRRI continues to focus on improving rice varieties (19 numbers), improving farming practices (23 numbers of technology/ products/procedures/concepts) and promoting the development of sustainable agricultural practices. The Institute also organized 89 numbers of training programs for 3871 participants during 2023. In addition, 4 patents were granted to the Institute during the year. Scientists of the institute have also published 203 research articles; 43 popular articles; 29 book chapters; 4 books; 12 research/technology/extension bulletins; and delivered 12 radio and TV talks. Scientists (15 numbers) visited abroad in countries such as, Philippines, Australia, Italy and Sri Lanka.

The institute express heartfelt gratitude to Dr. Himanshu Pathak, Director General (DG), ICAR, and Secretary, DARE, for his direction, guidance and encouragement. We sincerely thank Dr. Trilochan Mohapatra, the former secretary of DARE and DG of ICAR, for his unwavering guidance and assistance during the institute's development. We sincerely thank chairman and other distinguished members of the Research Advisory Committee (RAC), Institute Management Committee (IMC) and Institute Research Council (IRC) for their valuable suggestions, encouragement, and support.

It remains an inspiration of innovation, making significant contributions not only to ensure India's food security but also to the global rice research community. The institute's initiatives aim to address broader challenges related to food sustainability and environmental resilience as well as to improve productivity. As we reflect on the past year's accomplishments, we express our thanks to the Heads of the Divisions, Officers In-Charges of Regional Stations, Administration & Finance sections of the Institute and Chairpersons/ Members of various committees at NRRI, our valued collaborators, and the farming community, whose combined efforts have propelled us forward. I sincerely appreciate the efforts and commitment of all the staff to serve this premier Institute. I hope that the Annual Report will be useful for the researchers, policy makers, development functionaries, farmers, farmwomen and students in promoting rice research and development. We remain committed to advancing rice agriculture and look forward to a future marked by continued growth and impact.

Amaresh Kumar Nayak
(Director)

Executive Summary

The programme genetic improvement of rice contributed significantly in developing new high yielding rice varieties with noble traits and generating scientific knowledge using modern techniques with the aim of achieving sustainable rice production, ensuring food and nutritional security. Twenty-one species of wild rice were maintained *in situ* in the *Oryza* reference garden. Ten germplasm of Assam rice were identified with multiple favorable alleles for multiple abiotic stress tolerance. Around 466.17 q breeder seed of 43 varieties were produced. Crop Improvement programme in this year released 19 rice varieties through CVRC and SVRC, which is remarkable in the history of this Institute. Five varieties derived from marker-assisted selection were released. Among those, an herbicide (Imazethapyr) tolerant variety CR Dhan 807 in the 'Sahbhagidhan' background, a biotic stress tolerant variety, CR Dhan 805 with brown plant hopper resistance and a submergence tolerant variety, CR Dhan 806 (Varshadhan *sub1*) were noteworthy. Hybrid rice variety CR Dhan 704 suitable for both transplanted and DSR conditions was released. A new generation rice variety with high yielding potentiality CR Dhan 328 was released for Odisha. Three varieties, including a biofortified variety (CR Dhan 324) and aromatic rice variety (CR Dhan 911) derived from double haploid techniques were notified for Odisha. Three varieties (CR Dhan 211, CR Dhan 212 and CR Dhan 214) for aerobic condition and nine varieties for irrigated condition including CR Dhan 331 with high head rice recovery and CR Dhan 326 with five BB resistant genes were notified. Pyramided lines with seven gene combination for submergence, drought and bacterial blight resistance in the background of Swarna was detected. A few unique QTLs for salinity tolerance at reproductive stage were identified. Through marker-trait association (MTA) analysis, 103 MTA for seed germination traits, 8 MTAs for germination rate and early seedling growth rate, 10 MTA for yield attributing traits, 10 MTA for drought tolerance and another 8 MTA for straw quality were detected. Three putative candidate genes, *OsSND2, OsNADH-GOGAT2* and *OsMYB55* were identified for dry matter, nitrogen, and cellulose content. CRISPR-*Cas9* based edited lines of Gobhindabhog and Nua Kalajeera for *SD1* gene, Swarna for *GRF4* and *IPA1* gene were derived.

The programme enhancing productivity, sustainability and resilience of rice based production system is actively involved in multi-dimensional research with a focus of natural resource management, and energy-efficient rice cultivation. Starting from regional analysis of N-use efficiency of rice crop, standardization of precision nitrogen application using optical sensors, and the devising of an IoT-based real-time irrigation scheduling system for rice production. To address the recent challenges related to rice cultivation, drought vulnerability and precipitation index has been estimated and an analysis of rice straw burning scenario was assessed for districts in Odisha over a period of time. In the realm of rice straw management, an innovative patented technology involving microbial-mediated rice straw pulp preparation has been devised, having the potential to reduce energy consumption by 65-70%. The microbial-mediated technology has been standardized for both *in-situ* and *ex-situ* management of paddy straw residues. Nutritionally enriched rice cookies, boasting high protein, zinc, and anthocyanin content, have been formulated and standardized using biofortified rice varieties.

The programme biotic stress management in rice accomplished various aspects of rice insect, disease and nematode pest management. The rice lines IC 316446 found moderately resistant to both brown planthopper and white-backed planthopper. Thirty-two, ten and sixteen rice genotypes were found resistant against rice leaf folder, false smut and sheath rot, respectively. Lines NEH5, TRB406, and TRB438 found moderately resistant to the rice root knot nematode. The marker-trait association analysis showed significant association of markers, RM 162 and RM 284 with leaf folder resistance. The genetic diversity study of 112 *Ustilaginoidea virens* isolates of north, east and north-eastern India shown highest genetic diversity (0.493) for isolates of eastern coastal plains and lowest (0.311) for north-eastern hills isolates. Hyperspectral spectrometry study revealed bands at 522, 684 and 730 nm to be the sensitive spectral region for rice false smut disease severity identification. The compound, 6-Pentyl-2H-pyran-2-one (6-PP) possessing growth-promoting, and antimicrobial property was the major volatile (84.10%) emitted by *Trichoderma erinaceum*. Liquid formulation of biocontrol agent, RBS-57 (*Bacillus cereus*) exhibited less per cent disease index (14.42%) against rice sheath blight disease. Three *Bacillus* species isolated from the rhizosphere of medicinal plant improves rice plant growth and reduces sheath blight disease. Out of 55 pesticides analysed, 25 pesticides showed risk quotient values greater than 1 necessitates to develop pesticide pollution reducing strategies in small streams. Synthesized purple colored rice variety (Crossa) leaves-based magnesium oxide nanoparticles (MgO NPs) and magnesium oxide loaded rice husk biochar composite to efficiently remove pesticides from water. Exposing *Trichogramma chilonis* Ishii to sub-lethal dose of imidacloprid increases the searching efficiency, per capita parasitization efficiency and lowering the handling time of parasitoids. Resistance study of *Tribolium castaneum* (Herbst) populations from 12 different regions of Odisha to phosphine gas shown resistant development in all the populations except Bolangir (Madhiapali) population comparing to laboratory susceptible population.

The programme photosynthetic enhancement, abiotic stress tolerance and grain nutritional quality in rice, four unique rice accessions having tolerance to multiple abiotic stresses *viz.,* drought, submergence salinity and osmotic stresses were identified and registered as novel genetic stock through PGRC, New Delhi. Besides, two and seven rice accessions were identified to possess tolerance to high temperature and stagnant flooding stresses, respectively. In another study, the dosage effect of the *Sub1* gene in submergence tolerance of rice was studied, where we found that a single favourable allele of *Sub1A-1* can impart as good tolerance as double allelic form. Another study showed that that seed priming with 3% KNO_3, 150 ppm Thiourea, and 2 mM SA were more effective in improving seed germination and seedling growth under osmotic stress conditions. Understanding the role of *OsCCA1* under low light stress was targeted using CRISPR-*Cas9* multiplexing system. Ninety-six rice genotypes were tested for pre-harvest sprouting resistance and categorized in four groups based on the duration of dormancy. Transgenic lines carrying *SiPEPC* fragment downstream of the *ZmPPDK* promoter were developed which showed stable copy number. These lines were further evaluated for yield and photosynthesis related traits and found to be superior for P_N, WUE and yield. The role of endogenous *OsPEPC* & *OsME* genes in enhancing the yield and photosynthetic ability in rice were tested using CRISPR-*Cas9* multiplexing system. Besides, through conventional screening a few rice accessions having superior photosynthetic traits along with increased culm strength were identified. In our quest to improve the physico-chemical and nutritional properties of rice several rice genotypes having diverse amylose content with similar starch digestibility were characterized. It was found that activities of GBSS-I and Pullulanase plays key role in determining the GI value of rice. It was also found that average GI value of parboiled cooked rice was the lowest while the raw fermented (FR) rice showed the highest value. Kalinga Dhan 1202 and Govinda found to have the highest Fe content (>75 ppm).

The programme socio-economic research to aid rice stakeholders in enhancing farm income, a linkage-based extension model, INSPIRE was designed, through which farmers' field demonstrations on 19 rice varieties of the institute were conducted in 193.01 acres area across 31 districts from 8 states of the country. A majority of the demonstrated varieties outperformed the existing popular varieties in the same ecology with a grain yield advantage up to 66.67%. The highest average return was found for rainfed shallow lowland varieties (₹48,787 ha^{-1}) followed by irrigated (₹48,083 ha^{-1}), medium deep water (₹46,891 ha^{-1}), rainfed upland (₹44,235 ha^{-1}), semi-deep water (₹40,179 ha^{-1}) and coastal saline varieties (₹38,038 ha^{-1}). The relative priorities suggest that taste (85.28), followed by price (68.33), grain quality (67.50), cooking quality (48.61), and aroma (48.06) dictate the consumption preferences. Socioeconomic contribution of 14 NRRI varieties was estimated using an economic surplus model which ranged from INR 4 to 33 crores. Employing the contingent valuation method, economic value of specialty rice and premium seed varieties was estimated. The maximum increment in willingness-to-pay (WTP) was observed to be Rs. 10, 12, and 20 for high-protein rice, scented non-basmati rice, and premium seeds, respectively. Decade wise trend of rice area, yield and production was estimated for two states - Maharashtra and Chhattisgarh. The CAGR, instability index, and decomposition of production growth for both the states were estimated. The major factors influencing availing of MSP by rice farmers were identified and prioritized using the AHP methodology. The results indicated that convenience of disposal of produce and lack of awareness are the main impediment.

The programme development of climate resilient rice technologies for rainfed upland, rainfed lowland and coastal saline ecologies deals with upland, coastal and lowland rice ecology focused on developing stress tolerant varieties, and improved integrated crop production and protection packages for the small and marginal farmers. During 2023 NRRI-CRURRS, Hazaribag released three varieties suitable for diverse ecologies. Germplasm resources have been characterized for abiotic and biotic stresses. The NRRI-RRLRRS, Gerua has systematically undertaken Front Line Demonstrations (FLDs) focused on climate-smart rice varieties characterized by resilience to both flooding and drought conditions. This station has collected and maintained rice germplasm suitable for this region for further breeding programme.

कार्यकारी सारांश

चावल के आनुवंशिक उन्नयन कार्यक्रम के अंतर्गत उत्कृष्ट गुण एवं अधिक उपज देने वाली नई किस्में विकसित करने, चावल के स्थिर उत्पादन प्राप्त करने, खाद्य और पोषण सुरक्षा सुनिश्चित करने की उद्देश्य से आधुनिक तकनीकों द्वारा कई महत्वपूर्ण परीक्षण किए गए। जंगली चावल की इक्कीस प्रजातियों को ओराइजा रेफरेंस गार्डन में इन-सीटू संरक्षित रखा गया है। विभिन्न अजैविक तनाव सहिष्णुता वाली कई अनुकूल एलील्स सहित असम चावल के दस जननद्रव्यों की पहचान की गई। चावल की 43 किस्मों से लगभग 466.17 क्विंटल प्रजनक बीज का उत्पादन किया गया। इस वर्ष फसल उन्नयन कार्यक्रम में केंद्रीय किस्म विमोचन समिति और राज्य किस्म विमोचन समिति के माध्यम से चावल की 19 किस्में विमोचित की गईं जो इस संस्थान के इतिहास में उल्लेखनीय विषय है। मार्कर-सहायता चयन से प्राप्त पांच किस्में विमोचित की गईं। उनमें से, ‹सहभागीधान› पृष्ठभूमि में एक शाकनाशी (इमेजेथापायर) सहिष्णु किस्म सीआर धान 807, एक जैविक तनाव सहिष्णु किस्म, भूरा पौधा माहू प्रतिरोधी वाली सीआर धान 805 और एक जलमग्नता सहिष्णु किस्म, सीआर धान 806 (वर्षाधान सब1) उल्लेखनीय थे। रोपाई और सीधी बुआई धान दोनों स्थितियों में खेती के लिए उपयुक्त संकर चावल किस्म सीआर धान 704 विमोचित की गई। उच्च उपज क्षमता वाली नई पीढ़ी के चावल किस्म सीआर धान 328 ओडिशा में खेती के लिए विमोचित की गई। बायोफोर्टिफाइड किस्म (सीआर धान 324) और डबल हैप्लोइड तकनीक से प्राप्त सुगंधित चावल की किस्म (सीआर धान 911) सहित तीन किस्मों को ओडिशा के लिए अधिसूचित किया गया। एरोबिक स्थिति में खेती के लिए तीन किस्में (सीआर धान 211, सीआर धान 212 और सीआर धान 214) और सिंचित स्थिति के लिए नौ किस्में अधिसूचित की गईं, जिनमें मुख्य चावल की प्राप्ति सहित सीआर धान 331 और पांच जीवाणुज अंगमारी प्रतिरोधी जीन सहित सीआर धान 326 किस्में शामिल हैं।

जलमग्नता, सूखा और जीवाणुज अंगमारी प्रतिरोधी के लिए स्वर्णा की पृष्ठभूमि में सात जीन संयोजन वाली पिरामिड वंशों का पता लगाया गया। प्रजनन चरण में लवणता सहिष्णुता के लिए कुछ विशिष्ट क्यूटीएल की पहचान की गई। मार्कर-ट्रेट एसोसिएशन (एमटीए) विश्लेषण के माध्यम से, बीज अंकुरण लक्षणों के लिए 103 एमटीए, अंकुरण दर और प्रारंभिक अंकुर विकास दर के लिए 8 एमटीए, उपज के गुणों के लिए 10 एमटीए, सूखा सहिष्णुता के लिए 10 एमटीए और पुआल की गुणवत्ता के लिए अन्य 8 एमटीए का पता लगाया गया। शुष्क पदार्थ, नाइट्रोजन और सेल्युलोज मात्रा के लिए तीन अनुमानित कैंडीडेड जीन, OsSND2, OsNADH-GOGAT2 और OsMYB55 की पहचान की गई। CRISPR-*Cas9* आधारित *SD1* जीन के लिए गोबिंदभोग और नुआ कालाजीरा, *GRF4* और *IPA1* जीन के लिए स्वर्णा की संपादित वंश प्राप्त की गईं।

चावल आधारित उत्पादन प्रणाली की उत्पादकता, स्थिरता और अनुकूलनीयता को बढ़ाने हेतु इस कार्यक्रम के अंतर्गत प्राकृतिक संसाधन प्रबंधन और ऊर्जा-कुशल चावल की खेती पर ध्यान केंद्रित करने के साथ, चावल की फसल में नाइट्रोजन उपयोग दक्षता का विश्लेषण से लेकर ऑप्टिकल सेंसर का उपयोग द्वारा सटीक नाइट्रोजन प्रयोग का मानकीकरण और चावल उत्पादन के लिए इंटरनेट ऑफ थिंग्स आधारित वास्तविक समय सिंचाई शेड्यूलिंग प्रणाली तैयार करने के लिए बहुआयामी अनुसंधान शामिल है। चावल की खेती से संबंधित हाल में उभरी चुनौतियों का समाधान करने के लिए, सूखे की ग्राह्यशीलता और वर्षा सूचकांक का अनुमान लगाया गया है और समय-समय पर ओडिशा के जिलों में धान पुआल जलाने के परिदृश्य का विश्लेषण किया गया है। धान पुआल के प्रबंधन में, माइक्रोबियल-मध्यस्थता वाले धान पुआल के अवशेषों को तैयार करने वाली एक नवीन पेटेंट तकनीक तैयार की गई है जिसमें ऊर्जा की खपत को 65-70% तक कम करने की क्षमता है। धान पुआल के अवशेषों के इन-सीटू और एक्स-सीटू प्रबंधन दोनों के लिए माइक्रोबियल-मध्यस्थता तकनीक को मानकीकृत किया गया है। उच्च प्रोटीन, जस्ता और एंथोसायनिन मात्रा एवं पोषण से भरपूर बायोफोर्टिफाइड चावल की किस्मों का उपयोग करके चावल की कुकीज़ तैयार और मानकीकृत किया गया है।

चावल में जैविक तनाव प्रबंधन कार्यक्रम के अंतर्गत चावल के कीट, रोग और सूत्रकृमि प्रबंधन के विभिन्न पहलुओं को पूरा किया गया। भूरा पौध माहू और सफेद पीठवाला पौध माहू दोनों के लिए चावल की वंश आईसी 316446 मध्यम रूप से प्रतिरोधी पाया गया। चावल की पत्ती फ़ोल्डर के विरुद्ध बत्तीस जीनप्ररूप, आभासी कंड के विरुद्ध दस जीनप्ररूप और चावल की आच्छद विगलन के विरुद्ध सोलह जीनप्ररूप प्रतिरोधी पाए गए। वंश NEH5, TRB406, और TRB438 चावल की जड़गाँठ सूत्रकृमि के लिए मध्यम प्रतिरोधी पाया गया। मार्कर-ट्रेट एसोसिएशन विश्लेषण ने पत्ती फ़ोल्डर प्रतिरोधिता सहित मार्कर, आरएम 162 और आरएम 284 का महत्वपूर्ण संबंध दिखाया। उत्तर, पूर्व और उत्तर-पूर्वी भारत के 112 यूस्टिलागिनोइडिया विरेन्स वियुक्त के आनुवंशिक विविधता अध्ययन में पूर्वी तटीय मैदानों के वियुक्तों के लिए उच्चतम आनुवंशिक विविधता (0.493) और उत्तर-पूर्वी पहाड़ी वियुक्तों के लिए सबसे कम (0.311) देखी गई। हाइपरस्पेक्ट्रल स्पेक्ट्रोमेट्री अध्ययन से पता चला कि चावल की आभासी कंड रोग की गंभीरता की पहचान के लिए 522, 684 और 730 एनएम पर बैंड संवेदनशील वर्णक्रमीय क्षेत्र हैं। 6-पेंटाइल-2H-पाइरान-2-वन (6-पीपी) यौग जिसमें विकास को बढ़ावा देने वाला और रोगाणुरोधी गुण है, ट्राइकोडर्मा एरिनेसम द्वारा उत्सर्जित प्रमुख अस्थिर (84.10%) था। जैवनियंत्रण कारक, आरबीएस-57 (बैसिलस सेरेस) के तरल सूत्रण ने चावल आच्छद अंगमारी रोग के विरुद्ध कम प्रतिशत रोग सूचकांक (14.42%) प्रदर्शित किया। औषधीय पौधे के राइजोस्फीयर से अलग की गई तीन बैसिलस प्रजातियां चावल के पौधे की वृद्धि में सुधार करती हैं और आच्छद अंगमारी रोग प्रकोप को कम करती हैं। विश्लेषण किए गए 55 कीटनाशकों में से, 25 कीटनाशकों ने जोखिम

भागफल मान 1 से अधिक दिखाया, जिससे छोटी धाराओं में कीटनाशक प्रदूषण कम करने की रणनीति विकसित करना आवश्यक हो गया। पत्ति आधारित मैग्नीशियम ऑक्साइड नैनोकण और मैग्नीशियम ऑक्साइड युक्त चावल की भूसी मिश्रित बायोचार से संश्लेषित बैंगनी रंग के चावल की किस्म (क्रॉसा) में पानी से कीटनाशकों को कुशलतापूर्वक हटाया गया। ट्राइकोग्रामा चिलोनिस इशी को इमिडाक्लोप्रिड की उप-घातक मात्रा के संपर्क में लाने से खोज दक्षता, प्रति भाग परजीवीकरण दक्षता बढ़ जाती है और पैरासाइटोइड्स के प्रबंधन का समय कम हो जाता है। ओडिशा के 12 अलग-अलग क्षेत्रों से फॉस्फीन गैस के लिए ट्राइबोलियम कैस्टेनियम (हर्बस्ट) संख्या की प्रतिरोधिता अध्ययन से प्रयोगशाला ग्राह्यशील संख्या की तुलना में बलांगीर (माधियापाली) संख्या को छोड़कर सभी संख्या में प्रतिरोधी विकास देखा गया है।

इस कार्यक्रम के अंतर्गत प्रकाश संश्लेषक वृद्धि, चावल में सूखा, जलमग्न लवणता जैसे अजैविक तनाव सहिष्णुता, आसमाटिक तनाव के प्रति सहिष्णुता एवं अनाज की पोषण गुणवत्ता वाली चार विशिष्ट चावल प्रविष्टियों की पहचान की गई और पीजीआरसी, नई दिल्ली में नवीन आनुवंशिक संग्रह के रूप में पंजीकृत किया गया। इसके अलावा, दो चावल की किस्में उच्च तापमान और सात चावल की किस्में स्थिर बाढ़ तनाव के प्रति सहिष्णुता वाली पहचान की गई। एक अन्य अध्ययन में, चावल की जलमग्नता सहनशीलता में *Sub1* जीन की मात्रा प्रभाव का अध्ययन करने पर यह पाया गया कि *Sub1A-1* का एक अनुकूल एलील डबल एलील फॉर्म के रूप में अच्छी सहिष्णुता प्रदान कर सकती है। एक अन्य अध्ययन से पता चला है कि 3% KNO_3, 150 पीपीएम थियोरिया और 2 एमएम एसए सहित बीज प्राइमिंग आसमाटिक तनाव स्थितियों के तहत बीज अंकुरण और अंकुर वृद्धि में सुधार करने में अधिक प्रभावी था। CRISPR-*Cas9* मल्टीप्लेक्सिंग सिस्टम का उपयोग करके कम प्रकाश के तनाव में *OsCCA1* की भूमिका को समझने का लक्ष्य रखा गया था। कटाई से पहले अंकुरण प्रतिरोधिता के लिए छियानवे चावल जीनप्ररूपों का परीक्षण किया गया और सुप्त अवधि के आधार पर उन्हें चार समूहों में वर्गीकृत किया गया। *ZmPPDK* प्रमोटर के डाउनस्ट्रीम में *SiPEPC* वाली ट्रांसजेनिक वंश विकसित की गईं, जिन्होंने स्थिर प्रतिलिपि संख्या दिखाई। इन वंशों का आगे उपज और प्रकाश संश्लेषण संबंधी लक्षणों के लिए मूल्यांकन किया गया और पीएन, जल प्रयोग दक्षता और उपज के लिए बेहतर पाया गया। चावल में उपज और प्रकाश संश्लेषक क्षमता बढ़ाने में अंतर्जात *OsCCA1* और *OsME* जीन की भूमिका का परीक्षण CRISPR-*Cas9* मल्टीप्लेक्सिंग प्रणाली का उपयोग करके किया गया। इसके अलावा, पारंपरिक परीक्षण के माध्यम से बेहतर प्रकाश संश्लेषक गुणों के साथ-साथ बढ़ी हुई कल्म शक्ति वाले कुछ चावल के वंशों की पहचान की गई। चावल के भौतिक-रासायनिक और पोषण संबंधी गुणों को बेहतर बनाने की खोज में समान स्टार्च पाचनशक्ति के साथ विविध एमाइलोज मात्रा वाले कई चावल जीनप्ररूप की लक्षणवर्णन किया गया। यह पाया गया कि GBSS-I और पुलुलानेज़ की गतिविधियाँ चावल के ग्लाइसेमिक इंडेक्स मूल्य को निर्धारित करने में महत्वपूर्ण भूमिका निभाती हैं। यह भी पाया गया कि उसना चावल का औसत ग्लाइसेमिक इंडेक्स मूल्य सबसे कम था जबकि कच्चे किण्वित चावल का मूल्य सबसे अधिक था। कलिंग धान 1202 और गोविंदा किस्मों में लौह की मात्रा सबसे अधिक (>75 पीपीएम) पाया गया।

कृषि आय बढ़ाने में चावल हितधारकों की सहायता के लिए इस कार्यक्रम के अंतर्गत सामाजिक-आर्थिक अनुसंधान प्रयास द्वारा एक लिंकेज-आधारित विस्तार मॉडल, इंस्पायर की परिकल्पना की गई जिसके माध्यम से संस्थान की 19 चावल किस्मों का देश के आठ राज्यों के 31 जिलों के किसानों के खेतों में 193.01 एकड़ क्षेत्र में प्रदर्शन आयोजित किए गए। प्रदर्शित किस्मों में से उसी पारिस्थितिकी में मौजूदा लोकप्रिय किस्मों की तुलना में अधिकांश ने 66.67% तक बेहतर उपज प्रदर्शन किया। सबसे अधिक औसत आय वर्षाश्रित उथली निचलीभूमि की किस्मों (₹48,787/ है.) के लिए पाया गया, इसके बाद सिंचित (₹48,083/है.), मध्यम गहरा जल (₹46,891/है.), वर्षाश्रित ऊपरीभूमि (₹44,235/है.), अर्ध-गहरा जल (₹40,179/ है.) और तटीय लवणीय किस्में (₹38,038/है) का स्थान रहा। सापेक्ष प्राथमिकताओं से पता चलता है कि स्वाद (85.28), उसके बाद कीमत (68.33), दाने की गुणवत्ता (67.50), खाना पकाने की गुणवत्ता (48.61) और सुगंध (48.06) उपभोग प्राथमिकताओं को निर्धारित करते हैं। आर्थिक अधिशेष मॉडल का उपयोग करके 14 एनआरआरआई किस्मों के सामाजिक आर्थिक योगदान का अनुमान लगाया गया जो 4 से 33 करोड़ रुपये तक है। आकस्मिक मूल्यांकन पद्धति का उपयोग करते हुए, विशेष चावल और प्रीमियम बीज किस्मों के आर्थिक मूल्य का अनुमान लगाया गया। उच्च-प्रोटीन चावल के लिए 10 रुपये, सुगंधित गैर-बासमती चावल के लिए 12 रुपये और प्रीमियम बीजों के लिए 20 रुपये भुगतान करने की इच्छा में अधिकतम वृद्धि देखी गई। चावल के क्षेत्र, उपज और उत्पादन की दशकवार प्रवृत्ति का अनुमान दो राज्यों - महाराष्ट्र और छत्तीसगढ़ के लिए किया गया। दोनों राज्यों के लिए सीएजीआर, अस्थिरता सूचकांक और उत्पादन वृद्धि के अपघटन का अनुमान लगाया गया। चावल किसानों द्वारा न्यूनतम समर्थन मूल्य का लाभ उठाने को प्रभावित करने वाले प्रमुख कारकों की पहचान की गई और एएचपी पद्धति का उपयोग करके प्राथमिकता दी गई। परिणामों ने संकेत दिया कि उपज के निपटान की सुविधा और जागरूकता की कमी मुख्य बाधा है।

वर्षाश्रित ऊपरीभूमि, वर्षाश्रित निचलीभूमि और तटीय लवणीय पारिस्थितिकी के लिए जलवायु अनुकूल चावल प्रौद्योगिकियों का विकास कार्यक्रम उच्च भूमि, तटीय और निचली भूमि चावल पारिस्थितिकी से संबंधित है, जो तनाव सहिष्णु वाली किस्मों को विकसित करने तथा छोटे और सीमांत किसानों के लिए बेहतर एकीकृत फसल उत्पादन और सुरक्षा पैकेजों पर केंद्रित है। 2023 के दौरान एनआरआरआई-सीआरयूआरएस हजारीबाग ने विविध पारिस्थितिकी के लिए उपयुक्त तीन किस्में विमोचित की हैं। जननद्रव्य संसाधनों को अजैविक और जैविक तनावों के लिए चिन्हित किया गया है। एनआरआरआई-आरआरएलआरआरएस, गेरुआ ने बाढ़ और सूखे दोनों स्थितियों के प्रति अनुकूल विशेषता वाले जलवायु-प्रतिरोधी चावल की किस्मों पर ध्यान केंद्रित करते हुए अग्रिम पंक्ति प्रदर्शन आरंभ किया है। इस केंद्र ने आगे के प्रजनन कार्यक्रम के लिए इस क्षेत्र के लिए उपयुक्त चावल जननद्रव्य को एकत्र और संग्रह को बनाए रखा गया है।

VISIT OF HON'BLE PRESIDENT OF INDIA SMT. DROUPADI MURMU

MAJOR RESEARCH AREAS

1
- Germplasm Exploration & Conservation
- Super Rice
- Hybrid Rice
- Bio-fortified Rice
- Climate Smart Varieties

2
- Input Management
- Resource Conservation Technologies
- Farm Mechanization
- Climate Resilience
- Harnessing Microbial Potentials
- 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
- Training and Advisory Services

6
- Climate Resilient Technologies:
- Rainfed Upland
- Rainfed Lowland
- Coastal Ecology

NRRI AT A GLANCE

1. 19 New Rice Varieties Released
2. 2 Unique Rice Germplasm Registered with ICAR-NBPGR
3. 16 Memorandum of Understanding (MoU) signed
4. 23 Technologies Commercialized and 4 Patent Granted
5. 203 Peer Reviewed Research Papers Published
6. 8 States Covered through Extension Activities
7. 19 New Rice Varieties Demonstrated in Farmers Field
8. 4408 Personnels including Farmers Visited the Institute
9. 89 Trainings Conducted & 3871 Persons Attended
10. 58 Agromet Advisory Bulletins Released
11. 24 Agro Advisory Services & 24 Video Barta Released
12. 410 Field Demonstrations Conducted

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, and the NRRI regional substation, Gerua for problems in rainfed lowlands and floodprone ecologies. Two Krishi Vigyan Kendras (KVKs) also function under NRRI, one at Santhpur in Cuttack district of Odisha and the other at Jainagar in Koderma district of Jharkhand. The research policies are guided by the recommendations of the Research Advisory Committee (RAC), Quinquennial Review Team (QRT) and the Institute Research Council (IRC). The NRRI also has an Institute Management Committee (IMC) to support implementation of its plans and programmes.

VISION

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

GOAL

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

MISSION

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

MANDATE

Conduct basic, applied and adaptive research on crop improvement and resource management for increasing and stabilizing rice productivity in different rice ecosystems with special emphasis on rainfed ecosystems and the related abiotic stresses.

Generation of appropriate technology through applied research for increasing and sustaining productivity and income from rice and rice-based cropping/ farming systems in all the ecosystems in view of decline in per capita availability of land.

Collection, evaluation, conservation and exchange of rice germplasm and distribution of improved plant materials to different national and regional research centres.

Development of technology for integrated pest, disease and nutrient management for various farming situations.

Characterization of rice environment in the country and evaluation of physical, biological, socio-economic and institutional constraints to rice production under different agro-ecological conditions and farmers' situations and develop remedial measures for their amelioration.

Maintain database on rice ecology, ecosystems, farming situations and comprehensive rice statistics for the country as a whole in relation to their potential productivity and profitability.

Impart training to rice research workers, trainers and subject matter/extension specialists on improved rice production and rice-based cropping and farming systems.

Collect and maintain information on all aspects of rice and rice-based cropping and farming systems in the country.

LINKAGES

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

LOCATION

The institute is located at Cuttack about 35 km from Bhubaneswar airport and 7 km from the Cuttack railway station on the Cuttack-Paradeep State Highway. The institute lies approximately between 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 24m above the MSL. The annual rainfall at Cuttack is 1200 mm to 1500 mm, received mostly during June to October (*kharif* or *wet* season) from the southwest monsoon. Minimal rainfall is received from November to May (*rabi* or *dry* season).

PROGRAMME

01

Genetic Improvement of Rice

Genetic Improvement of Rice extensive research and development under the Crop Improvement programme of the Institute could be easily comprehended by release of significant number of novel varieties, hybrids, and inventing modern technologies in 2023 to escalate the research on climate resilience, reduce malnutrition and increase productivity and profitability of rice and rice based ecosystem. Twenty scientists along with 20 technical staff of this division are efficiently managing 11 Institutional and 36 externally funded projects. The remarkable achievements during 2023 is being visualized in releasing of 10 rice varieties with CVRC (CR Dhan 211, CR Dhan 212, CR Dhan 214, CR Dhan 322, CR Dhan 329, CR Dhan 331, CR Dhan 332, CR Dhan 804, CR Dhan 807, CR Dhan 808) and 9 rice varieties with SVRC (CR Dhan 323, CR Dhan 324, CR Dhan 326, CR Dhan 327, CR Dhan 328, CR Dhan 704, CR Dhan 805, CR Dhan 806, CR Dhan 911). Besides, 223 new promising elite entries were nominated in 2023 and 68 entries were found promising in AICRIP testing 2022. About 21.34 q nucleus seed of 91 varieties and 466.17 q breeder seed of 43 varieties were produced. Additionally, around 160 kg breeder seeds of 13 parental lines of hybrid were also produced and distributed. A germplasm, Mamyhanger, possessing high anti-oxidant content was registered in NBPGR. Two semi-dwarf, high yielding and non-lodging derivatives of Chakhao, have been nominated for the colored rice trial. Biofortified lines such as carrying favourable alleles for NAS3 and Wx genes were identified. Pyramided lines with 7 gene combination for submergence, drought and bacterial blight resistance in Swarna and 4 mutant salinity tolerant lines of Satabdi with similar grain and plant type were identified. A new generation rice entry (CR 3856-44-22-2-1-11-4-1-1) showed the potentiality in achieving yield of 12 t ha^{-1} in both *kharif* and *boro* seasons. Unique QTLs for panicle length under salinity stress at reproductive stage were detected. Identified 3 DH for multiple stress tolerance were tested in 8 locations. Mutants of Acharmati and Kalajeera with reduced height and mutated plants (T_0) of Gobhindabhog and Nua Kalajeera with a deletion in *SD1* locus were developed using CRISPR/Cas9. Development of two thermo-sensitive genic male sterile edited plants of the *tms5* gene in Lalat and two edited lines of the *GRF4* gene in Swarna for enhancing NUE and yield were also noteworthy achievements through CRISPR-*Cas9* approach. Through expression analysis of BPH resistant (Salkathi) and susceptible parent and derived lines, three genes, *LOC_Os04g02920, LOC_Os04g02920,* and *LOC_Os04g34250* were identified as the potential candidate genes.

Managing Rice genetic resources for sustainable utilization

Germplasm conservation and seed supply

Altogether 3352 rice accessions were characterized and conserved in MTS of NRRI gene bank. The conserved materials include, National germplasm received from ICAR-NBPGR, New Delhi, DUS testing materials, newly collected cultivated and wild rice germplasm. Twenty-one species of wild rice of four *Oryza* species complex and 2 species (*O. coarctata and O. brachyantha*) of unclassified group have been maintained *ex situ* field gene bank by establishing one '*Oryza* reference garden' (Fig. 1.1). Besides, 4110 accessions of rice germplasm were shared with researchers, out of which 475 accessions were shared with different other institutes/ organizations through signing MTA (material transfer agreement).

Fig. 1.1. Field gene bank for *ex situ* conservation of wild rice.

Characterisation of rice germplasm from eastern India

A set of 352 accessions of rice germplasm collected from Bihar, WB and Chhattisgarh were characterized based on qualitative and quantitative characters and data were documented (Fig. 1.2). This set was represented as-: tall plant

Fig. 1.2. Variability in qualitative traits in germplasm from Bihar, Chhattisgarh and West Bengal.

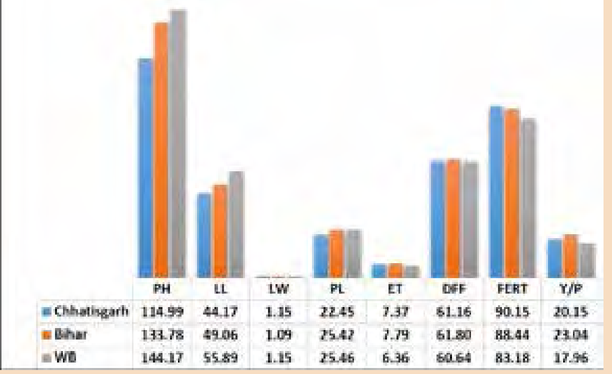


Fig. 1.3. Variability in quantitative traits of germplasm from Bihar, Chhattisgarh and West Bengal.

(>130 cm), medium panicle length (21-25 cm), low tiller no. (5-9) and high spikelet fertility (75.0-89.0%). Chhattisgarh region was identified with highest spikelet fertility (%), higher leaf width; Bihar region was identified with longer panicle and highest yield; West Bengal region was identified with tallest plant, highest leaf length, higher leaf width, and longer panicle (Fig. 1.3). AC 41726 (Chhattisgarh) was identified with highest yield (86.52 g plant^{-1}).

Agro-morphological and genetic diversity of rice landraces collected from Majuli and adjoining areas of Assam

Genetic diversity of 87 accessions (*Bao, Bora, Joha, Ahu* and *Sali* cultivar group) collected from Majuli and adjoining areas of Assam were analysed. A total 271 alleles were detected using 66 SSRs. Thirty six markers showed PIC values > 0.50. On an average 4.26 alleles were detected per marker. Both population STRUCTURE and distance-based analyses indicated presence of two clusters: *indica* and *aus* (*Bao*) (Fig. 1.4). *Bao* landraces were distinct from the other landraces for all agro-morphological characters while *sali* and bora landraces formed their own cluster. Genetic affinity of *bao* landraces with wild spp was observed.

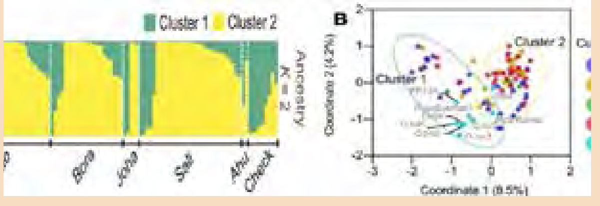


Fig. 1.4. Structure analysis(A) and principal coordinate analysis(B) of rice accessions.

Assessment of Assam rice collections (ARC) for the multiple favourable alleles for abiotic stress tolerance

Five hundred twenty four ARC germplasm were subjected to K means clustering (based on morphological data) by machine learning approach. Ten clusters were identified through clustering (Fig. 1.5). Out of 10 clusters, 78 genotypes were selected. Another, 48 genotypes were selected based on yield data. Total 126 ARC collections were screened for the multiple favourable alleles for abiotic stresses by using trait linked marker. Ten accessions, ARC 11108, ARC 11330, ARC 11305, ARC 11065, ARC 6102, ARC 6551, ARC 5842, ARC 6006, ARC 11133 and ARC 11309 with the favourable alleles of QTLs/genes for multiple abiotic stresses tolerance such as drought (*DTY1.1, DTY2.1, DTY2.2, DTY3.1*) submergence (*Sub1*), heat (*QHTSF4*), salinity (*saltol*) and phosphorous use efficiency (*PSTOL*) were identified.

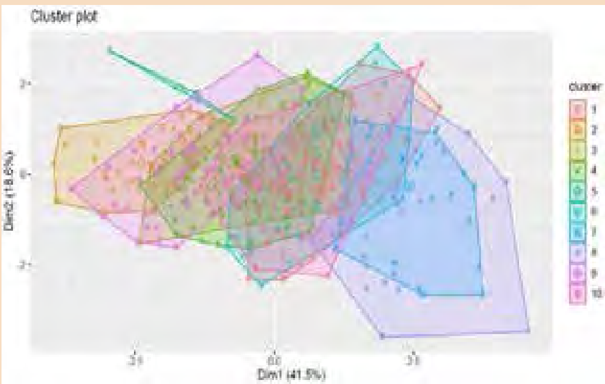


Fig. 1.5. K-means clustering analysis of ARC collections.

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

Seed production and maintenance

The nucleus seed of 91 varieties released from the institute was multiplied using the standard method of panicle-progeny row. A total of 21.34 q nucleus seed was produced. To meet the demand of breeder seed by DAC and other organizations, a total of 466.17 q breeder seed of 43 varieties were produced. Further, to cater the seed demand of the popular variety by farmers, truthfully labeled seeds were also produced. An MoU has been signed with three Farmers group i.e., Sahayogi, Saharpur, Kendrapada; Mahatma Gandhi Krushak Club, Bhandilo, Kendrapada and Kalyani Bio Tech Farmers group, Alabol, Jagatsinghpur. Through participatory seed production approach, a total of 558.15 q seed was produced. The seed so produced was subsequently procured back and was made available to other farmers for purchase as TL Seed from the institute.

AMP-PCR assay: a simplified approach for detection and quantification of genome-wide natural methylation in rice

The methylation-based epigenetic variations are known to inherit more consistently than other types of epigenetic variation which played a crucial role in the process of

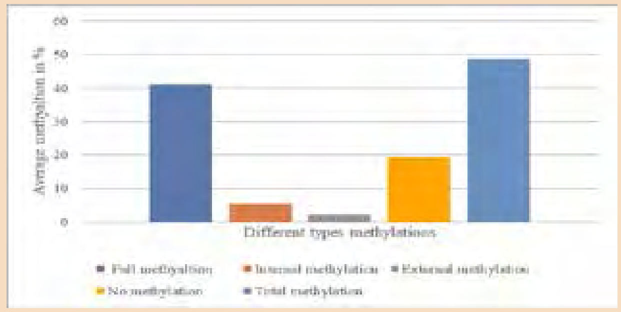


Fig. 1.6. Quantification of type of methylation in the population. AMP-PCR assay differentiated the type of methylation based on the cytosine molecule methylated. The percentage of methylated alleles of different methylation groups from among the total methylation alleles was used to estimate the percent methylation in each category.

evolution of modern-day crop plants. The detection and quantification of methylation in the plant genome is costly. A low-cost but effective approach for detecting and quantification of natural DNA methylation variation in the rice genome by employing custom-designed markers called amplified methylation polymorphism polymerase chain reaction markers (AMP-PCR markers) was devised. The methylation detected was scored in an effective method which was further used for quantification (Fig. 1.6). The natural methylation in the diverse population of rice was used to showcase the methylation diversity. Furthermore, the methylation in germplasm accessions, breeding lines, and released varieties indicated the significant influence of artificial breeding efforts on methylation in the rice genome (Fig. 1.7). The genotypes cultivated in different ecologies exhibited different types of methylations. The results ensure the utility of the AMP-PCR assay approach in the detection and utilization of methylation variation at lower costs in crop improvement programs for complex economic traits.

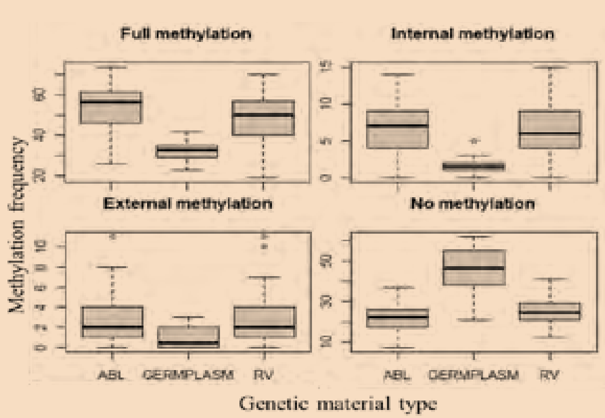


Fig. 1.7. Differential methylation in different genetic materials. The quantum of methylation in each methylation type was compared among different genetic materials used in the study. ABL: advanced breeding lines, RV: released varieties.

Marker trait association for seed germination related traits in rice

The marker trait association (MTA) for nine seed germination-related traits was identified using a set of 295 markers, in a panel of 163 rice germplasm. The nine seed germination traits are MGT-Mean Germination Time, FGT-First day of germination, LGT-Last day of Germination, CVG-Co-efficient of velocity, GRI-Germination Rate Index, GI-Germination Index, FGP-Final Germination Percentage, TSG-Time Speed of Germination, GP%-Germination Percentage. The significant markers derived from the 3 genes *OsBAK1*, *THIS1*, *OsMIK* and, 2 random markers RM 3643 and RM 490 were pleiotropically linked to a multiple seed germination trait. The Q-Q plot and Manhattan plot obtained also confirmed the significant association of markers with the traits. The Q-Q plot distribution depicted that the data is symmetric and the distributions of p-values according to the most of the traits were normally distributed (Fig. 1.8). Through marker-assisted breeding programmes, the new candidate gene markers linked to seed germination traits could be used to incorporate variable alleles for these traits.

CgSSR marker-based trait associations for *Sitotroga cerealella* (Olivier) resistance in stored paddy

Physicochemical characteristics of grain influence stored grain insect susceptibility and resistance. Identification of gene/ QTLs and introgression in the cultivars would provide the desired solution for varietal resistance against *S. cerealella*. A group of 80 rice varieties was used for genetic analysis for the identification of candidate genes responsible for *S. cerealella* resistance. Marker allele based trait regression detected two CgSSR markers associated with resistance. Two cgSSR markers, derived from genes *SDG725* and *FLO2*, were linked to the attributes responsible for conferring resistance against *S. cerealella* infestation. This is the first report of association and that would help in the development of cultivar with *S. cerealella* resistance.

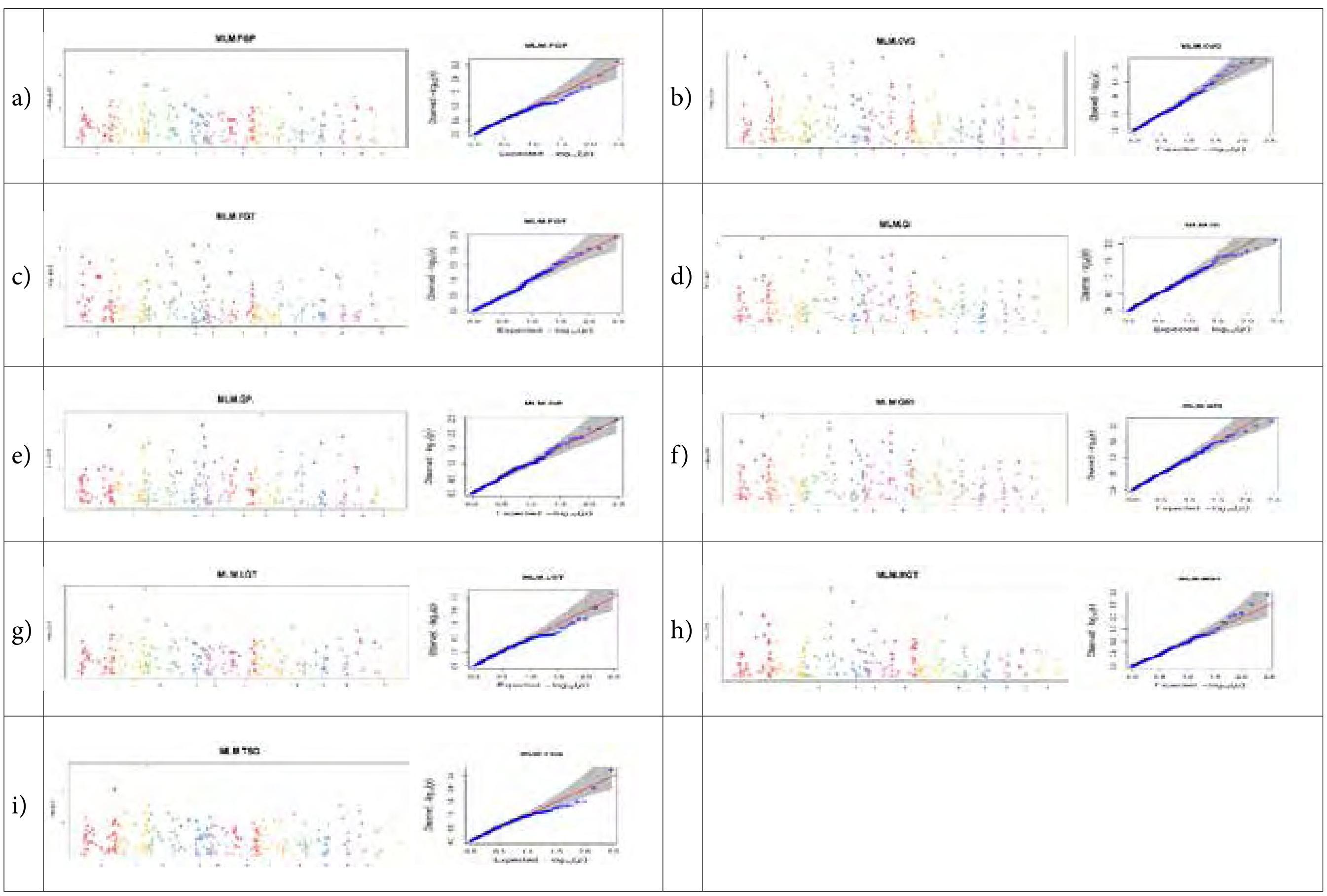
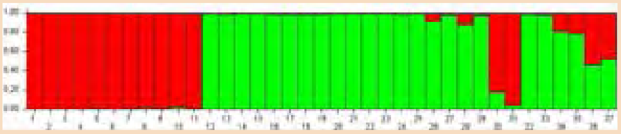


Fig. 1.8. Quantile-Quantile plots for markers associated with the traits across the genome. In Manhattan plots, x-axis represents chromosomes and explains chromosome-wise marker distribution and –log(p) values on y-axis indicates significant associations. Quantile-Quantile plots shows deviation of observed –log(p) values and expected –log(p) values indicating the significant marker trait associations. (a) FGP (b) CVG (c) FGT (d) GI (e) GP (f) GRI (g) LGT (h) MGT (i) TSG.

Pre-breeding for broadening the genetic base of rice by utilizing wild species of *Oryza*

Population structure of wild species accessions from genus *Oryza*

A core set of STMS markers between *O. coarctata* and eight species of *O. sativa* complex was earlier identified. After testing a subset of 29 markers from the core markers of *O. coarctata* and *O. sativa* complex, majority of the markers showed cross amplification across the species of other species complexes. The population structure and admixture patterns also supported the broader classification of genus *Oryza* (Fig. 1.9).



1-11: *Oryza sativa* complex; **12-27**: *O. officinallis complex*; **28-29**: *O. meyeriana* complex; **30-33**: *O. ridleyi* complex; **34-37**: Unclassified/outgroups represented through single representative species

Fig. 1.9. Population structure of wild rice accessions based on cross transferable markers.

Reinduction of transient dormancy in wild rice accessions under submergence stress during germination

Traditionally, anaerobic germination potential measures the seed germination percentage with emergence of coleoptile 10 cm above water within 21 days. Anaerobic germination potential was found to be absent among 86 wild rice accessions among 87 and only one *Oryza nivara* accession (AC 100042) collected from Ganjam district of Odisha showed moderate anaerobic germination potential. Its germination percentage was still significantly lower than the tolerant *O. sativa* checks. However, as a unique feature, several wild rice accessions could germinate when water was removed after 21 days of treatment and seeds didn't decompose unlike the accessions of *O. sativa*. The results clearly indicate that several wild *Oryza* species adapt to germination stage submergence stress by reinducing transient dormancy under water which helps them prevent decomposition of the seeds and regains ability to germinate when the stress is removed (Fig. 1.10).

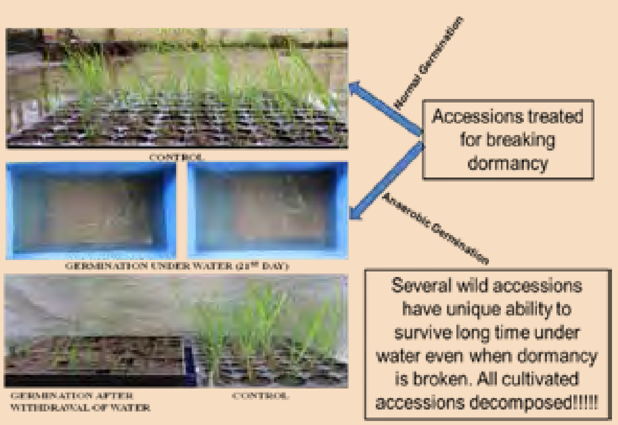


Fig. 1.10. Reinduction of transient dormancy in wild rice accessions under submergence stress for 21 days during germination.

Mapping of genetic loci for submergence tolerance derived from the pre-breeding line of *O. nivara*

Using bulk segregant analysis, the genetic loci responsible for submergence tolerance in the near isogenic lines derived from *O. nivara* have been mapped to *Sub1* locus of chromosome 9, but it was found that it has a unique haplotype. In place of tolerant allele *Sub1*A_1, the susceptible allele *Sub1*A_2 was detected based on profile of AEX-1 marker and Sanger sequencing of *Sub1A* gene. The profile is exactly same as susceptible genotype at Sub1A region. However, one polymorphic marker linked with *Sub1A* has been identified which can distinguish the *O. nivara* derived submergence tolerant Swarna-NILs (developed from NPS-95) from both Swarna and Swarna *Sub1*. Swarna can be distinguished from the NILs and tolerant CSSLs based on Sub1A203 profile (Fig. 1.11). The earlier identified tolerant CSSLs (NPS-17, NPS-18, NPS-43, NPS-71 and NPS-95) along with18 NILs were evaluated for submergence tolerance using Swarna as susceptible check and Swarna *Sub1* as tolerant check. Swarna showed complete mortality under submergence for 15 days whereas Swarna *Sub1* showed 80% survival. Among CSSLs, lowest survival was showed by NPS-43 (30.00%) followed by NPS-71 (55%) and NPS-95 (75%). Both NPS-17 and NPS-18 showed 90% survival. Among the 18 NILs tested, 100% survival was recorded in seven NILs.

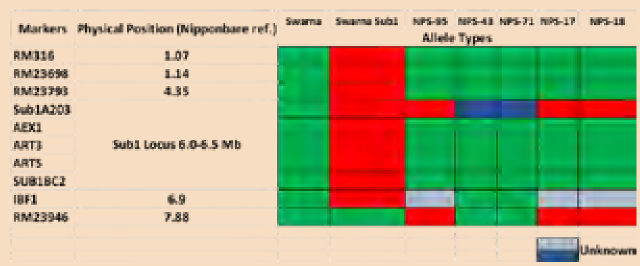


Fig. 1.11. Haplotyping of Sub1A locus and adjoining genomic region in Swarna, Swarna Sub1 and tolerant CSSLs derived from O. nivara (obtained from ICAR-IIRR).

CR Dhan 807- A herbicide (Imazethapyr) tolerant rice variety released for Direct Seeded rainfed upland areas

CR Dhan 807 (IET 30438) was released and notified by CVRC in 2023 for direct seeded rainfed upland areas of Jharkhand, Odisha, Andhra Pradesh, Tamil Nadu, Chhattisgarh and Gujarat. This variety is a non-GMO herbicide (Imazethapyr) tolerant near isogenic line (NIL) of rice mega variety Sahbhagidhan. The herbicide tolerance gene (*AHAS*) from the donor parent Robin (INGR 19002, N22 mutant) was introgressed through marker assisted backcross breeding. This variety will enable complete mechanization of rice cultivation and address the major issues of labour scarcity and increased cost of cultivation (Fig. 1.12).

Fig. 1.12. Effect of herbicide (Imazethapyr) treatment on donor parent Robin, recurrent parent Sahbhagidhan and Herbicide tolerant variety CR Dhan 807 (IET 30438).

CR Dhan 326 (Panchatatva) - A bacterial blight resistant variety with five resistance genes released for Odisha

CR Dhan 326 (IET 28491) was released by SVRC (Odisha) in 2023 for bacterial blight endemic areas of the state for irrigated medium ecology (Fig. 1.13). This variety is a recombinant line derived from the cross Naveen / IRBB 66 through marker assisted pedigree breeding and carry five resistance genes (*Xa4*, *xa5*, *Xa7*, *xa13* and *Xa21*) against bacterial blight disease.

Fig. 1.13. Field view of CR Dhan 326 (IET 28491).

CR Dhan 805 (Naveen Shakti) - A brown plant hopper (BPH) resistant variety with resistance QTLs (*qBph4.3* + *qBph4.4*) released for Odisha

CR Dhan 805 (CR 4331-85-1-1-1, IET 29203) was released by SVRC (Odisha) in 2023 for BPH endemic areas of the state (Fig. 1.14). It is a near isogenic line (NIL) of popular variety 'Naveen' with resistance to the major pest i.e. brown plant hopper (BPH). This variety carries two interacting BPH resistant QTLs (*qBph4.3* + *qBph4.4*) derived from the BPH resistant landrace Salkathi.

Fig. 1.14. Field view of CR Dhan 805 (IET 29203).

Developing genetic solutions for enhancing input use efficiency in rice for rainfed and irrigated rice ecologies

Genetic diversity study of irrigated *indica* rice genotypes using 21 NUE gene based SSR markers

The genetic diversity of 96 irrigated and early-maturing indica rice genotypes was assessed using a set of 21 SSR markers associated with nitrogen use efficiency, distributed across different chromosomes. The Jaccard similarity coefficient was employed to assess the relatedness among the genotypes. This dendrogram categorized the genotypes into four clusters: CI, CII, CIII, and CIV. Cluster I comprised the highest number of genotypes (37), followed by CII (22), CIII (19), and CIV (18). Principle Coordinate Analysis highlighted the maximum correlation among markers and genotypes in quadrant II, with most markers fall within this quadrant. Among the markers, four gene-specific markers (OsNRT1.1, OsNRT2.1, OsNRT2.2, and OsGS1.1) played a significant role in contributing to divergence. This suggests that hybridization among genotypes associated with these specific markers could further enhance nitrogen use efficiency.

Molecular screening for Tolerance of Nitrogen Deficiency 1 (TOND 1) using two closely linked SSR markers

Molecular screening of sixty rice genotypes using RM 171 and another markers M1 revealed the presence of favourable allele of TOND 1 genes linked to nitrogen deficiency tolerance indirectly increases nitrogen use efficiency. Among the genotypes, Konark, Lalat, CR Dhan 203, CR Dhan 205, and IET 28523 (K283-1) are potential carriers of the TOND

1 allele. Additionally, J 509 and J590 may possess the TOND 1 allele, with a probable linkage to the RM 171 marker, particularly evident in the advanced breeding line J509 and J590. This molecular information provides insights into the potential nitrogen deficiency tolerance in these rice varieties, which could contribute to improved nitrogen use efficiency.

Performance of promising rice genotypes at moderate N level (60 kg /ha)

In the *kharif* 2022, thirty promising rice genotypes were evaluated. The genotypes include one nitrogen-use-efficient variety CR Dhan 319, two nitrogen-use-inefficient varieties Jhilli and Sunakathi, few breeding lines and various landraces of Odisha. The average grain yield of 0.530 kg m^{2-1} was recorded. The breeding line CR 4353-2-2-1-1-1-1 showed as the top performer, achieving the highest grain yield of 0.778 kg m^{2-1} followed by CR 3504-19-2-2-1-1-1 with 0.734 kg m^{2-1} and CR 4428-1-1-2-1-3-1 with 0.709 kg m^{2-1}. The check variety CR Dhan 319 demonstrated a yield of 0.600 kg m^{2-1} and the non-efficient checks, Jhilli and Sunakathi showed yield of 0.352 kg m^{2-1} and 0.383 kg m^{2-1}, respectively. Two other lines, IET 29579 and IET 28523, previously promoted in the Low Nitrogen Tolerance Trial (LNT) of AICRIP, showed better efficiency with yields of 0.665 kg m^{2-1} and 0.648 kg m^{2-1}, respectively.

Genomic Region Identification for Low P and low N tolerance

One hundred thirty-two genotypes were grown under low P (3 kg ha^{-1}) and low N (165 kg ha^{-1}) under P and N starvation condition in controlled plot. At 28 days after sowing, data were recorded on SPAD value, Shoot Length (SL), No. of leaves (NL), Shoot Area (SA), Shoot Dry Weight (SDW) and Specific Shoot Area (SSA) and these traits were correlated among themselves. The NL and SDW were highly and positively correlated with all other traits and SPAD value indicated that these traits could be the selection criteria for selecting plants for P and N deficiency tolerance from the segregating generations under P and N starve condition. The marker S11_ 4084490 identified genomic region that showed significant percent change in trait value of 54.27 and probably contains the candidate gene *Os 11g 0178800,* which will further be validated in chromosome 11.

Evaluation of rice genotypes for low phosphorus tolerance

A set of 57 rice germplasm taken out, from NRRI gene bank, were evaluated for low phosphorus (P) tolerance in P control plot during Rabi, 2021 and data were recorded on days to 50% flowering, plant height (cm), number of tillers $plant^{1}$, flag leaf length (cm), flag leaf width (cm), panicle length (cm) and single plant yield (g). The days to 50% flowering ranged from 95 (IC 459115) to 121 days (IC 15114). The plant height ranged from 62 (IC 46031) to158 cm (IC 461825). The number of tillers $plant^{1}$ ranged from 6 (IC 215231) to 20 (IC 277228) and the flag leaf length ranged from 19.1 cm (IC 467627) to 56.3 cm (IC 555117). The flag leaf width ranged from 1.0 (IC 467627) to 1.2 cm (IC 426097) and panicle length ranged from 16.2 (IC 311014) to 30.0 cm (IC 467627). The single plant yield ranged from 1.69 (IC 215231) to 20.10 (IC 467627). These genotypes can be used as donors for improving low P tolerance in rice.

GWAS for grain yield of rice under optimum and low-nitrogen stress in aerobic direct seeded condition

A rice diversity panel consisting of 147 lines of *O. sativa*, including landraces, breeding lines, and released varieties, was genotyped using an Affymetrix single nucleotide polymorphism (SNP) array containing 44 K-chip SNPs. ls data on grain yield under two doses of nitrogen: optimal (80 kg ha^{-1}) and low (40 kg ha^{-1}) was recorded. The grain yield ranged from 6.74-26.43 g $plant^{-1}$ in optimal nitrogen conditions and 2.09-15.35 g $plant^{-1}$ under low nitrogen conditions. A yield penalty of 0.10-17.86 g $plant^{-1}$ due to low nitrogen was observed. A total of 64 significant ($p \leq 0.001$) marker-trait associations were identified in a genome-wide association study with two different N levels. GWAS analysis revealed 29 significant SNPs for grain yield under optimal nitrogen and 35 significant SNPs for grain yield under low nitrogen. This is based on one-season experiment data, which will be repeated for confirmation.

Breeding for aerobic condition, early maturity and DSR condition

Based on yield parameters, maturity type and DSR traits, the 315 lines selected last year were re-evaluated for the second year, and the 33 best-performing lines were identified. Out of the 315 lines, the donors for low N and low P tolerance under DSR conditions were also identified and will be rescreened for the second season. A bi-parental mapping population for seed vigour and the phytic acid trait was developed through the cross of Manipuri black and Bindli. This population has been established to gain insights into the genetic basis of grain seed vigour and phytic acid content.

Promising lines in AICRIP

Seven entries were promoted to AVT 2 trials i.e. 3 in AVT 2 LNT (IETs 29578, 37270 and 37273), one in ETP (IET 29939), one in EDS (IET 30238) and 2 in IM (IETs 28523 and 29877). Twenty-nine promising lines have been promoted to AVT-1. The IET number are IETs 31161, 31163, 31130, 31134, 30735, 31100, 30677, 30637, 30638, 30932, 30904, 31097, 31117, 30328, 30346, 30643 and 30667. A total of 54 entries have been nominated in the All India Coordinated Rice Improvement Programme (AICRIP) for 2023.

Rice varieties for aerobic condition

CR Dhan 211

CVRC recommended CR Dhan 211 for irrigated aerobic conditions of several states, including Odisha, Bihar, Jharkhand (Zone III), Maharashtra, Gujarat (Zone VI), Tripura (Zone IV), Chhattisgarh (Zone V), and Haryana (Zone II) (Fig. 1.15). With a maturity duration of 114-118 days and a long slender grain type, it reaches a height of 95-102 cm. The variety ensures a robust yield potential of 4.20-5.50 t ha^{-1}, displaying resilience against pests and diseases. Highly tolerant to key pests like leaf folder, stem borer (dead heart), and whorl maggot, it also shows moderate tolerance to gall midge (Biotype 1) and stem borer affecting white ear heads. In terms of diseases, it exhibits moderate resistance to false smut, neck blast, and leaf blast, coupled with field tolerance for sheath rot, rice tungro disease (RTD), and bacterial blight.

Fig. 1.15. Field view of CR Dhan 211 at dough stage and rice grain.

CR Dhan 212

CVRC recommended CR Dhan 212 for the states of Odisha, Bihar, Jharkhand (Zone III), Haryana (Zone II), Gujarat (Zone VI), and Chhattisgarh (Zone V), shows versatility across agro-ecological zones (Fig. 1.16), having yield potential of 4.00-5.30 t ha^{-1}, maturity duration of 110-113 days, and plant height of 90-108 cm. Its long bold grains enhance visual appeal and market value. Moderately resistant to key pests (stem borer, leaf folder, whorl maggot, gundhi bug) and diseases (neck blast, leaf blast, brown spot, sheath rot, RTD, grain discoloration), CR Dhan 212 offers a resilient and productive option for farmers in the specified regions.

Fig. 1.16. Field view of CR Dhan 212 at dough stage and rice grain.

Rice varieties for irrigated ecology

CR Dhan 327 (Madhumita)

CR Dhan 327, developed for irrigated medium ecosystems in Odisha, stands out with a plant height of 101 cm, maturity in 135 days, and an impressive yield of 8.00 t ha^{-1}. Released by SVRC, Odisha it is photo-insensitive, semi-dwarf, and resilient to lodging (Fig. 1.17). Noteworthy disease resilience includes resistance to false smut and moderate resistance to neck blast, bacterial blight, and brown spot. Exhibiting high tolerance to whorl maggot and leaf folder, and moderate tolerance to stem borer and plant hopper, CR Dhan 327 could be one of the top choices for Odisha farmers in irrigated medium ecosystems.

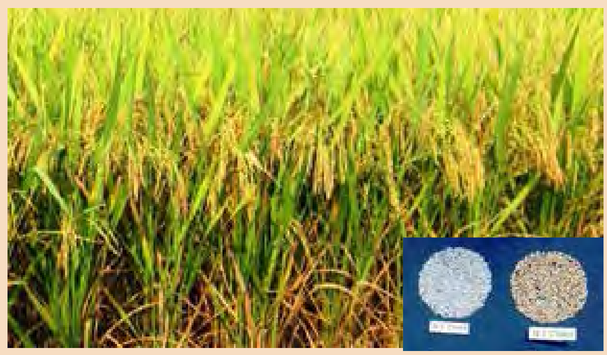


Fig. 1.17. Field view of CR Dhan 327 at Dough Stage.

CR Dhan 329

CVRC recommended CR Dhan 329, for Gujarat, Maharashtra (Zone VI), and Odisha (Zone III), it excels in diverse agro-ecological zones (Fig. 1.18). With a short bold (SB) grain,

Fig. 1.18. Field view of CR Dhan 329 at dough Stage.

100-110 cm height, and a yield potential of 5.30-6.10 t ha^{-1}, it offers balanced traits. Photo-insensitive and maturing in 125-132 days, it suits both *kharif* and *rabi* seasons. It also exhibits resilience to false smut, moderate resistance to neck blast, brown spot, and sheath rot. High tolerance to pests like leaf folder, whorl maggot, rice thrips, and moderate tolerance to stem borer (Dead Heart), BPH, and other plant hoppers make CR Dhan 329 a robust choice for farmers.

Breeding for Aroma and Grain Quality in Rice

Development of aromatic genotypes with short/ medium/ long slender grains

Development of biofortified rice varieties with higher zinc, protein, amino acids and antioxidant traits

Biofortified high protein rice variety, CR Dhan 310 was found promising for Assam with 4.59 t ha^{-1} and 4.82 t ha^{-1} grain yield at FLD programme in Assam and at station trial at NRRI Gerua station, respectively with around 5-19% advantage in grain yield and 33% advantage in protein content over the checks. Another biofortified variety, CR Dhan 311 (Mukul) was also found promising for Assam with 4.71 t ha^{-1} and 4.92 t ha^{-1} grain yield in station trial and at FLD programme in Assam, respectively. The protein content and protein yield of Mukul (CR Dhan 311), were found significantly higher in Assam. CR Dhan 310 with high grain protein content (10.2%) and CR Dhan 311 (Mukul) with high protein (10.1%) and Zn (20 ppm) content have been released and notified for Assam under area extension in 2022.

CR 4107-1-B-4-1-B derived from BPT-5204 *Sub-1*/CR Dhan 310//Kalinga III cross, CR 4225-B-1-1-2 derived from CR Dhan 310/Bindli cross and CR 4199-2-B-1-2-B-2 derived from Maudamani/CR Dhan 310 cross with high protein or zinc content were found promising and nominated to AICRIP IVT-Biofortification trial in 2023.

Improvement of biofortified genotypes with better grain quality and biotic stress tolerance

Among high zinc content donors Shena, ARC 6027, ARC 10063 contained favourable allele I for *NAS3* gene, reported for micronutrient biosynthesis. Breeding lines such as CR 4102-1-2-1-3-1 (derived from CR 2829-PLN-32/ Mamyhanger), CR 4088-2-2-1-B-2-1 (CR 2829-PLN-37-13/ PB-140 cross), CR 4199-2-2-1-2 (Maudamani/CR Dhan 310), CR 4226-2-1-1 (CR Dhan 310/ARC-6027), CR 4110-2-B-15-1-1, CR 4110-2-B-3-1-1 (CR 2830-PLS-17/BPT 5204 *Sub-1*// SWARNA SUB 1) were detected with favourable alleles for *NAS3* and *Wx* genes (Wx-GBSS-ex10, Wx-A_group). On the other hand, lines selected through MAS, such as CR 4169-19-2, CR 4169-80-2, CR 4169-52-2-2, CR 4169-169-2, CR 4169-168-1 in the background of Swarnanjali were identified with the favourable alleles of *xa5* and *Xa21* as well as favourable alleles for *Wx-A-Swarna* gene. Another genotype, CR 4197-3-B-2-2 derived from Improved Samba Mahsuri/CR Dhan 310 was carrying favourable alleles of *xa13* and *Xa21* along with favourable alleles for *Wx* locus.

Germplasm registered for high anti-oxidant activity

Mamyhanger (IC0646727: AC43160), a landrace from Tripura with high total anthocyanin, gamma oryzanols and total phenolic content was registered by PGRC. This contains high total flavonoid and ABTS Activity with low phytic acid.

Breeding for specialty rice, pigmentation, slender grains and sensory qualities

Semi-dwarf, high yielding and non-lodging derivative of Chakhao (the black aromatic rice from Manipur) CR4450-48-1-1-10-26-1-21-7-19, CR4450-65-15-3-5-2, derived from a across ChakhaoAmubi/ Ratna have been nominated for the Colored rice trial under AICRIP-2023. They were found to be rich in antioxidant compounds

Ninety-eight breeding lines (Ratna X Chakhao derivative lines) were evaluated for seed antioxidant traits. Highest variability (15.22%) was observed in total anthocyanin content (TAC) followed by total flavonoid content (TFC:13.70%). One breeding line CR4450-1-14-11-9-26-6-13-53 was identified with higher content of all the antioxidant compounds (TAC-454.10 mg $100g^{-1}$, GO-128.62 mg $100g^{-1}$, TPC-750.49 mgCE 100g $^{-1}$, TFC-732.37 mgCEt $100g^{-1}$).

Breeding rice for superior grain type

CR 4375-1-4-1-1-2-2 (IET 30957) a cross combination of CR 3522-1-2-1-1 -1-1-2/ CR 3497-7-1-3-2-2-1) is promoted to AVT 1-MS on overall basis and also in Zone IV and Zone VI. Similarly, CR 3741-1-1-2-1-1-2 (IET 30969) a cross between Pooja and Surendra has been promoted to AVT1- MS for zone VI. Around 120 fixed lines (F_7/ F_8) were developed from various crosses involving parent like Swarna *Sub 1*, Tapaswini, CR Dhan 308, IR 64, Sambha Mahsuri *Sub 1*.

CR Dhan 331, a rice variety with superior grain quality (high head rice recovery)

CR Dhan 331 derived from the cross Swarna/ ARC 10075 has been released and notified for irrigated-late ecology of Chhattisgarh and Maharashtra. It has excellent grain quality with high head rice recovery (70%), good hulling and milling percentages, short bold grain, good cooking quality with intermediate amylose content (24.55%) combined with high GC (49). Husk colour of this variety is also similar to Swarna. Over the years in AICRIP trials, the mean yield of this variety was recorded 5.51 t ha^{-1} in Maharashtra and 5.67 t ha^{-1} in Chhattisgarh which was 16.37% and 8.94% higher than the check variety Swarna in irrigated-late trial. It has semi-dwarf plant type with long maturity duration (140 days) (Fig. 1.19)

Fig. 1. 19. CR Dhan 331, a variety released for irrigated-late ecology.

Screening of quality rice accessions against brown spot (*Bipolaris oryzae*)

A total of ten rice accessions (both aromatic and non-aromatic) were screened against brown spot pathogen (*Bipolaris oryzae*) under poly-house condition during (September, 2022; Avg Temp. 25°C and Avg RH 88%). Challenge inoculation was performed with virulent isolate of *B. oryzae* (BS-Hzb1, identified through pathogenicity test) at 3-4 leaf stage (15-21 days old). None of the accessions showed complete resistance to brown spot (Fig. 1.20). However, out of 10 rice accession, only three (IR64, QCR-48-47, Ratna, and Gobindabhog: T4) showed moderate resistance against *B. oryzae* upon challenge inoculation.

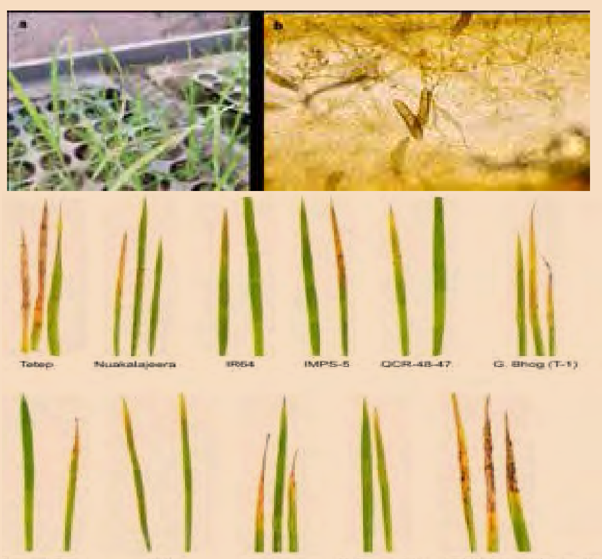


Fig. 1.20. Appearance of disease symptom on inoculated seedlings (a) and microscopic observation of conidia of B. oryzae (b) Disease reaction of 10 rice accessions against B. oryzae (BS-Hzb1) under challenge inoculation condition (c).

Breeding for high yielding glutinous rice

A panel of 87 rice landraces from Assam (Majuli and adjoining areas) was screened for *Amy* and *Waxy* gene polymorphism. Around 32 rice cultivars were selected from 87 acc., based on their amylose content. Nucleotide polymorphism for the loci was detected using reported markers.

Twenty cultivars with amylose content varying from 3.3 to 17% were detected with G toT SNP in Intron1 while Kalabora with 14.01% amylose was found to harbor A to C SNP in Exon6 SNP C to T was detected in Exon10 among 8 cultivars with amylose content varying from 4.1 to 18.54%. The SSR marker RM190 detected four alleles 119bp, 130bp, 132bp, 137bp for the CT microsatellite locus in Exon1.The 119 bp allele was mostly found in cultivars with 'G' SNP in Intron 1 splice donor mutation while, 137 bp allele found in cultivars with 'T' SNP at the site. None of the tested cultivars were found to have 23 bp duplication in Exon 2.

Hybridization program for breeding of glutinous rice have been initiated during *kharif*-2021. The crosses were generated using the mega varieties, such as, Swarna, Sahabhagidhan, Maudamani, Sovini, CR Dhan 800 and Aghanibora as the glutinous rice parent.

Suitability of NRRI Rice varieties for the development of rice-based products

Flavored rice milk formulation was standardized using aromatic rice varieties, *Gobindabhog* and CR-Sugandh Dhan 910 in different ratios such as (1:1, 1:2, 1:3, 2:1 and 3:1). Rice milk formulation containing 1:1 of each of the rice varieties was found to be the best with better product acceptability due to the higher values of sensory parameters such as appearance, taste, aroma, mouth feel and overall preference). Incorporation of aromatic rice varieties like Gobindhabhog and CR Sugandha Dhan 910 with the added flavors such as Cardamom, Kesar, Chocolate and Vanilla had the acceptability of the product on par with the control (flavored milk - market sample).

Gene mapping and precision breeding for enhancing climate resilience in lowland varieties

CR Dhan 806: A lowland Variety Released and Notified for Odisha

CR Dhan 806 a variety developed through marker-assisted selection with submergence tolerance gene *Sub1* was introgressed in Varshadhan and was released in Odisha with an average yield of 5.34 t ha^{-1}over the situation. The average yield of this variety was 3.93 t ha^{-1} under submergence stress condition in Odisha state. The genotype is photo-sensitive with average maturity duration of 150 days. It possesses long bold grain with a test weight of 24g. It was resistant to stem borer (dead heart) and BPH. Besides it is resistant to false smut and moderately resistant to neck blast. Varshadhan-*Sub1* (CR Dhan 806) has high hulling, milling and head rice recovery like the recipient parent and qualifying varieties.

Pyramiding genes for submergence, drought and bacterial leaf blight

Pyramiding of 7 gene combinations for tolerance/resistance to submergence (*Sub1*), drought (*qDTY1.1, qDTY2.1, qDTY3.1)* and BB (*xa5, xa13, Xa21*) has been done in popular variety "Swarna". This has been achieved using bi-parental mating where 16 plants with 7 gene combinations for submergence, drought and BLB; 32 plants with 6 genes combinations and 73 plants with 5 gene combinations have been obtained in F_3. Among them two were found with homozygous for 7 genes. This has been tested with the help of SNP markers (snpOS00040, snpOS00071, snpOS00085, snpOS00075, snpOS00002, snpOS00054, snpOS00061). These are being tested in advance generation for potential varieties with a target of replacing Swarna.

Pyramiding genes for, deeper rooting and phosphorus efficiency

Through marker assisted backcrossing programme, eleven plants (BC_2F_1) with different combinations of *Dro1, Dro3, Pup1* has been detected as pyramided lines in the background of popular rice variety Maudamani. Among these lines, 11 were pyramided with *Dro1, Dro3, Pup1,* 3 with *Dro1, Pup1* and another 3 with *Dro3, Pup1.* Pyramiding of QTLs/genes will help the plants to fight water scarcity with deeper rooting and phosphorus deficiency tolerance (uptake) through MAS breeding approach.

Genome wide association study for locating novel genes/QTLs controlling seed vigour, seed viability, and seedling vigour

Phenotyping: seed quality traits under moisture stress during seed germination

About 120 germplasm lines were phenotyped for germination related traits under moisture stress by using PEG 6000 (20%). These genotypes were grown at 30ºC for ten days. Then seed quality traits were estimated (Table 1.1). Among the traits studied, highest reduction in shoot length (70%) and lowest reduction in germination percentage (30%) was observed. Two genotypes, Magura and Kalimekri were observed with highest seedling vigour index (763.43 SVI I; 2.53 SVI II, respectively) under moisture stress condition.

Table 1.1. Phenotypic variability in seed quality traits under moisture stress condition.

Trait	Mean	Range	CV (%)
GER (%)	61.19	45.0-72.67	3.49
SOG(seed/day)	2.96	2.0-4.76	2.03
T50(hr)	221.32	182.7-247.0	3.34
SL(cm)	1.59	0.82-3.28	2.34
RL(cm)	5.75	2.74-7.63	1.98
SEEDL(cm)	7.35	3.69-10.90	1.66
SDW(g)	0.02	0.01-0.04	6.02
SVI I	457.18	189.02-763.43	3.72
SVI II	1.54	0.51-2.51	7.05
DTI(G)	65.27	48.43-74.59	4.39
DTI(SOG)	18.68	12.36-29.18	2.85

Note: Percentage reduction in seed quality traits (Germination Percentage) (GER), Speed of Germination (SOG), Time for 50% Germination (T50), Shoot length (SL), Root Length (RL), Seedling length (SEEDL), Seedling Dry Weight (SDW), Seed Vigour index I (SV-I), Seed Vigour index II (SV-II), Drought tolerant index based on germination % [(IDT (G), Drought tolerant index based on peed of germination (DTI(SOG)].

Genotyping: Twenty-six significant MTAs (some are novel) were identified for seed vigor, seed viability and seedling vigour under moisture stress conditions explaining 5.91-17.29% of PVE. Eight novel MTAs were identified for germination rate and early seedling growth rate under normal conditions explaining 5.41-11.59% PVE (Fig. 1.21).

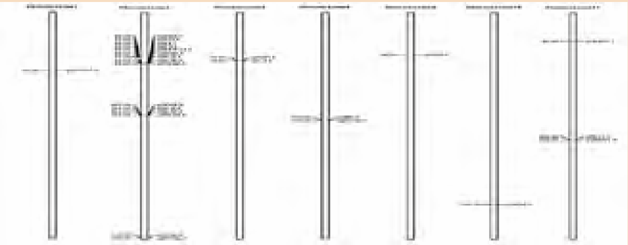


Fig. 1.21. The positions of the QTLs on the chromosomes for GER%, SOG, T50, SL, RL, SEEDL, SDW, SV-I, SV-II, DTI(G), and DTI(GS) traits detected by association mapping in rice.

Major QTLs/ MTA such as *qGER2.2, qRL2.1, qSEEDL2.1, qSDW2.1, qSVI2.1, qSVII2.1, qDTI(G)2.1* located on chromosome 2 and 8 were detected.

Identification of QTLs/genomic regions controlling germination rate and early seedling growth rate using association mapping approach

Here 124 genotypes were phenotyped and genotyped for four germination rate and early seedling growth rate *viz.*, Absolute growth rate (AGR), Relative growth rate (RGR), Rate of shoot growth (RSG), Mean germination rate (MGR) using 143 SSR markers. The analysis could reveal association of 9 QTLs/genomic regions (Fig. 1.22). One major QTL *qRSG8.1* was detected on chromosome 8 (Table 1.2).

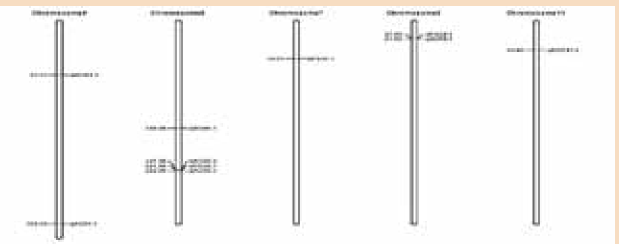


Fig. 1.22. Chromosomal positions of the 9 QTLs/linked markers for RSG, RGR, AGR and MGR detected by association mapping approach.

Table 1.2. MTAs associated Absolute growth rate (AGR), Relative growth rate (RGR), and Rate of shoot growth (RSG) for germination rate and early seedling growth rate.

Sl No	Trait	QTL	Marker	Chrom#	Position	Novel/ Known	PV
1	RSG	qRSG8.1	RM337	8	27	Novel	10.256
2	RSG	qRSG7.1	RM22034	7	56	Novel	5.4255
3	RSG	qRSG6.1	RM494	6	221	Novel	7.8975
4	RGR	qRGR11.1	RM1812	11	44	Novel	6.5395
5	AGR	qAGR8.1	RM337	8	27	Novel	9.3425
6	AGR	qAGR6.1	RM7179	6	159	Novel	7.991
7	AGR	qAGR4.1	RM494	4	221	Novel	6.9045
8	AGR	qAGR4.2	RM16686	4	300	Novel	8.5525
9	MGR	qMGR4.1	RM3735	4	80	Known	10.333

Genetic enhancement for multiple stress tolerance in rice for coastal ecosystem

Development of elite lines suitable for coastal ecology

IET 30201 (CR4283-274-6-2-1-3) derived from CR Dhan 310/Getu cross has been promoted to AVT-2- CSTVT. The average yield was recorded 4.90 t ha^{-1} with 110 days to 50% flowering. It showed significant superiority over best check on overall basis. Another line, IET 31067(CR 4283-274-6-2-1) was also promoted to AVT-1-CSTVT. Ten elite lines were nominated in AICRIP trials for coastal salinity in *kharif* 2023.

Phenotyping and trait-based SNP genotyping for multiple stress tolerance

About 400 lines were phenotyped for salinity, submergence and yield traits. Among them 374 genotypes were genotyped using SNP markers for salinity, grain number and anaerobic germination ability. These were Saltol –aus (snpOS00397), qSES1-2_1 (snpOS00405), qSES1-2_2 (snpOS00409), qSES1-2_3 (snpOS00410), qSES1-2_4 (snpOS00411), AG3 (snpOS00459, snpOS00460), AG1 (snpOS00473, snpOS00474) and Gn1a (snpOS00396). Few submergence tolerant lines were identified with a few positive alleles for salinity tolerance and anaerobic germination ability. Some of them are CR-3466-L-4-8-1-2-S-2-2, CR-4215-2-5-2-M-1-1-5-S-3-Sub-2-2, CR-4215-2-5-2-M-3-1-1-2-5-4-Sub-3-2, CR-3483-29-M-4-B-Sub-62-1-S-1.

Selection of breeding lines under control facility

In *kharif* season, 366 lines (F4-F7) derived from 38 cross combinations were tested under salinity stress at seedling stage (EC=12 dSm-1. One-line CR 4215-2-5-2-M-4-Sub-2-S-1 was detected with highly tolerant with SES score of 3. Another 97 lines were identified with tolerant to moderately tolerant. Around 3000 single plants with tolerance and moderately tolerance to salinity were rescued and transferred to field for multiplication.

In *rabi* season, 18 genotypes from 14 cross combinations were evaluated for salinity tolerance at normal field condition. Nine genotypes were yielded more than both saline and sensitive checks. Highest yield was recorded from CR 4285-276-6-3-1-1-1-1 (4.22 t ha^{-1}) followed by CR 4256-247-9-2-2-1-1-1 (4.07 t ha^{-1}).

Salinity tolerant mutant lines derived from Shatabdi

Few M_4 (derived from gamma radiation) tolerant/moderately tolerant salinity lines of cv. Shatabdi and moderately susceptible lines of FL 478 were detected at seedling stage at salinity microplot under stress (EC= 12 dSm^{-1}). Tolerant lines (SES score- 3 or 5) such as Satabdi-300Gy-1, Shatabdi-

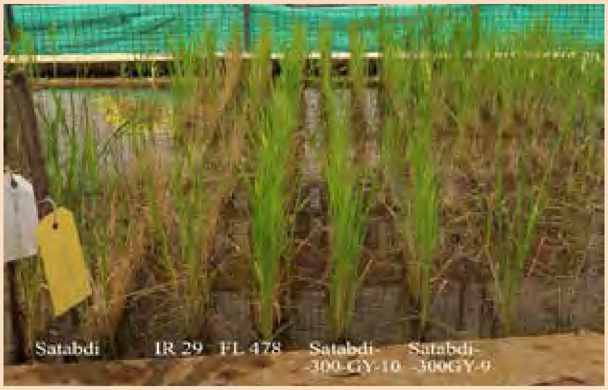


Fig. 1.23. Evaluation of mutant lines of Shatabdi for tolerance to salinity at seedling stage under salinity microplot condition.

300Gy-10 (Fig. 1.23), Shatabdi-500Gy-1, Shatabdi-400Gy-2, Shatabdi-400Gy-3, Shatabdi-400Gy-6 of cv. Shatabdi with desirable grain type and yield were detected. One the other hand one line FL-478-400gy-5 derided from tolerant check FL 478 was found moderately susceptible (SES score- 7). These lines have been selected for confirmation and further analysis. These can also be used in breeding programme as well as in basic study for detection of genomic region for salinity tolerance.

Detection of QTLs for reproductive stage salinity tolerance using Savitri/ AC39416a RIL population:

Pokkali (AC 39416a) is a donor for tolerance to salinity, stagnant flooding, anaerobic germination ability, submergence, drought, and combined stress (salinity + stagnant flooding). RIL population derived from Savitri/ AC 39416a was phenotyped for salinity tolerance at the reproductive stage (EC= 8 dS m -1). Most of the traits were normally distributed (Fig. 1.24). Genotyping of RILs was

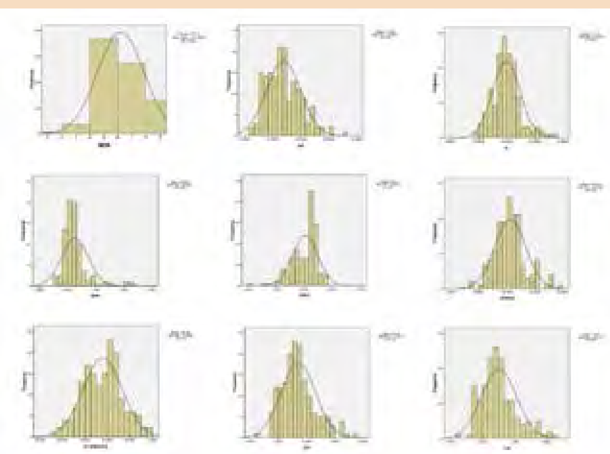


Fig. 1.24. Distribution of component traits for salinity tolerance at reproductive stage in RIL population from Savitri/ AC39416a.

done using a 50K SNP chip. Finally, 1122 markers were selected by X^2 testing. Ten QTLs were identified for panicle length, days to flowering, panicle number /plant under stress, grain weight/plant, potassium concentration in flag leaf, spikelet degeneration under stress. *qK_S-1-1, qGWT_S-4-1, qDEG_S-3-1* were located at similar position of QTLs as identified in the previous study. *qPL_S-1-1*, *qPL_S-7-1* (panicle length under stress) were some of the unique QTLs identified through both 'R' and 'QTL-IcMapping' software.

Hybrid rice for enhancing yield, quality and sustainability

Development of CMS, restorer and hybrid combinations

A total of 894 test crosses of 12 CMS and 138 pollen parents (with >5.0 GEBVs) were evaluated and 47 heterotic hybrids, 19 maintainers and 51 good restorers were identified. Besides, 63 heterotic hybrids were re-evaluated under station trials. Medium duration CMS, CRMS59A (WA) (BCN282-18) was characterized to have 41% out crossing (Fig. 1.25). In addition, 36 sterile backcrosses (BC_2 -BC_{12}) with enhanced

Fig. 1. 25. CRMS 59A (BCN282-18) (a) single plant view, (b) panicle with stigma exertion (c) single spikelet view, and (d) sterile pollens.

seed producibility and sustainability (BLB, BPH resistance, wide compatibility and enhanced outcrossing traits) were advanced in generation.

Hybrid release/New promising hybrid in station and adoptive trials

Medium duration hybrid (130-135 days), CR Dhan 704 (CRHR150; IET 28187) possessing short slender (SS) grains was notified through SVRC, Odisha (Fig. 1.26). In AICRIP trials, CRHR 156 (IET 29752) has been promoted to AVT2-M and CRHR-168 (IET 30629), CRHR-168 (IET 30613), CRHR-

Fig. 1.26. Field view of rice hybrid, CR Dhan 704.

175 (IET 30617) and CRHR166 (IET30882) recording requisite yield superiority over checks were promoted to second year of testing in IHRT-MS, IHRT-M, IHRT-M and IVT-Late trials, respectively. Parental line, CR 4350-7-5-1-17 (CRL22R / MTU1071) has been promoted to AVT1-Late. In addition, two hybrids, CRHR-150 (IET 28187) and CRHR105 (IET28124) were evaluated under adoptive trials in Bihar, recorded average yield of 8.24 t ha^{-1} and 7.17 t ha^{-1}, respectively with requisite yield superiority and promoted to the final year of testing. Another three hybrids, CRHR154, CRHR156 and CRHR 173 were promoted to the 2^{nd} year of testing under adoptive trials in Bihar.

Fig. 1.27. a. Performance of rice hybrids under DSR condition and b. Performance of rice hybrids under adoptive trials in Odisha.

Under station trial at NRRI under DSR condition, five hybrids were recorded yield superiority over HC and promoted to the next year of evaluation (Fig. 1.27a.). Under adoptive trials in Odisha, total 10 hybrids were evaluated in 6 locations in 3 districts, Bhadrak, Balasore and Khordha, and CRHR156, CRHR 160, CRHR 166, CRHR 174, CRHR 169 and CRHR145 recorded yield superiority and promoted to the 2^{nd} year of testing (Fig. 1.27b).

Trait development/genetic diversification of parents and hybrids

Improved lines of restorers, CRL 22R (15 lines) and Pusa 33-30-3R (13 lines) pyramided with 4 BB resistant genes, *Xa4*, *xa5*, *xa13* and *Xa21* were bio-assayed with 8 virulent pathotypes, all recorded perfect product profile and resistance reaction. Introgressed lines with salinity and submergence tolerance in IR 42266-29-3R (restorer line) were advanced to BC_3F_5. Introgression of BPH resistant hybrid Rajalaxmi was advanced to BC_2F_5; and in CRL22 it was advanced to BC_2F_1 generation to BC_1F_2. Introgression of WC genes in partial restorer but good combiner line SR 11-3-1 from Khawo-Hawm (donor) was advanced to BC_2F_6; in CR 1033 it was advanced to BC_2F_1 generation. Introgression of long stigma trait in CRMS 31B and CRMS 32B from donor *O. longistaminata* was advanced to BC_3F_8. Twelve genetically fixed lines having long stigma were under CMS conversion, population is advanced to BC_4F_1.

Restorer and maintainer breeding

Total 4768 single plant progenies (F_3 to F_{12}) of 138crosses (AxR, RxR and BxB) were evaluated, 43 of those were utilized in crossing. Six random mating populations (RMP) of parents (04-maintainers, 02 restorers) were advanced to 11^{th}RMP and two *inter-subspecific* MAGIC (B and R; each with 10 parental genotypes) were advanced to IC_3F_3.

Speed breeding and breeding modernization strategy adoption

Under Field RGA, total 107 breeding populations (BC_2-BC_6) were advanced. A total of 60 ABLs (F7-8 generation of 28 families) were phenotyped under parental line selection trial-03 (PST-03) over 4 locations; NRRI, Cuttack, IGKV-Raipur, RARS Maruteru and RSS-Bapatla. Among those lines 15 ABLs recorded > 5.0 t ha^{-1} yield and >5.0 BLUP across the locations.

Seed production of parents/hybrids

Total 11.60 q truthful labeled (TL) seeds of 39 hybrids were produced. Besides, 1.60 q breeder seeds of 13 CMS; and nucleus seeds of released hybrids were produced. Agro-practices for seed production of 10 new combinations were refined.

DNA fingerprinting of parent/hybrid

DNA fingerprinting profile of hybrids, CR Dhan 704 and CR Dhan 705 were developed. Besides, 60 BC_3F_5 lines of CRMS31B x *O. longistaminata* were genotyped through Bulk-QTL-Seq approach, data to be analyzed for genomic region associated with high outcrossing.

Development of New Generation Rice for enhancing yield potential in favourable ecology

CR Dhan 328, an NGR variety released and notified

CR Dhan 328, an NGR variety was released and notified for cultivation in Odisha (Fig. 1.28). This is high yielding with average yield of 6.68 t ha^{-1}. It matures in 145 days. This high yield has been achieved by incorporating genes from *tropical japonicas* with ideal plant architecture, along with excellent grain quality traits. It has excellent response to higher dose of fertilizer as tested in agronomy trials. The genotype is a kind of modified New Plant Type with semi-dwarf plant and slightly increased height (115cm) but non-lodging due to strong culm. It has moderately long and heavy panicle, moderately high grain number with long bold grains and high fertility. It is suitable for irrigated late and particularly favorable shallow lowlands of eastern region particularly in Odisha. It possesses moderate panicles m$^{2-1}$ (avg 270) with 118 days to 50% flowering, little shy tillering, moderately long and dense panicle with relatively high-test weight. It is highly resistant to leaf folder, stem borer (% dead heart incidence). It has good hulling, milling and head rice recovery. It possesses intermediate amylose content, long bold grains and other desirable grain quality parameters.

Fig. 1. 28. Field view of CR Dhan 328 (IET 26420).

Developing NGR breeding lines with high yielding ability and biotic stress tolerance

Few NGR lines were evaluated during 2022-23 (DS). Among them C 1407-5-1-1-1-2-1 yielded (8.33 t ha^{-1}), C 1407-3-2-1-1-1-1 (8.17 t ha^{-1}), C 1399-14-1-1-1-2-1-1-1 (8.13 t ha^{-1}), C 1440-9-1-1-1-1-1-2 (8.04 t ha^{-1}) and C 1908-14-1-1-1-1 (8.01 t ha^{-1}) and they were found promising with yield advantage over the best check Naveen (5.90 t ha^{-1}) and MTU 1010 (6.12 t ha^{-1}). Similarly, in favourable late situation out of six best entries tested two promising entries i.e. C 1867-3-1-1-1 (8.15 t ha^{-1}) and C 1643-1-1-5-1-1 (8.03 t ha^{-1}) yielded higher than control check Swarna (6.34 t ha^{-1}). In a new strategy, improvement of tiller was focused with compromising the panicle size resulting in improvement of grain yield. The identified NGR lines showed stable performance for yield and the lines C 1407-5-1-1-1-2-1, C 1407-3-2-1-1-1-1, C 1399-14-1-1-1-2-1-1-1, C 1440-9-1-1-1-1-1-2 and C 1908-14-1-1-1-1 were identified for high yield potential of >8.0 t ha^{-1}.

Genotyping of NGR lines

Forty-three entries were genotyped using 56 Indel and SSR markers for marker-trait association analysis using MLM model by GAPIT package of R software. Ten markers were found to be significantly associated with different morphological traits viz., GS-5 indel1 (tiller No), Sub1BC2 (panicle length), SCM2-indel 1(flag leaf width), RM25 (root length), RM19 (No. of fertile grains), GS5- indel-1and SUB1BC2 (No. of sterile spikelets), Gn1A-17 SNP, RM19 and Sub1BC2 (grain yield). The study validated two SSR markers, RM168 and RM 5711 those were linked with grain yield and flag leaf width, respectively. Moreover, these genotypes were clustered into different groups and could be good indicator for selecting diverse parents for hybridization. NGR lines have been genotyped for *IPA1*, *Gn1a*, and *GRF4* gene in rice. IPA1-Promoter, Gn1a-Indel03, and GRF4-Indel was found to be highly polymorphic and could be associated with the yield related traits. OsSPL14-Promoter polymorphism and Gn1a-3'UTR polymorphism are associated with the yield. MiR156 allele of SPL14 is common in all the NGR lines (Fig. 1.29).

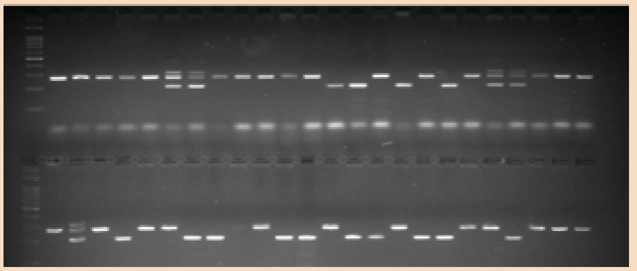


Fig. 1.29. NGR lines showing polymorphism for Gn1a-Indel03.

Mapping for spikelet branching

F_3 generation of Nadiaphula x Swarna and Nadiaphula x Naveen were raised. The population showed good variability for clustered spikelet trait.The phenotyping process for the clustered spikelet is to be standardized using image analysis (Fig. 1.30) for Mapping of QTLs/genes in multi-branched panicle.

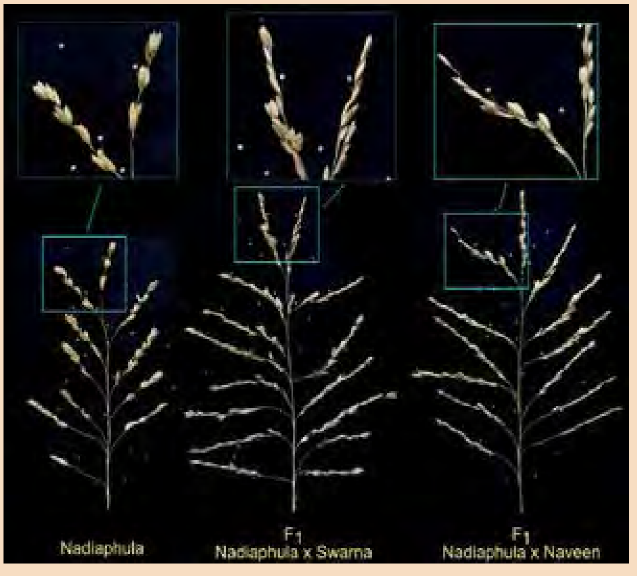


Fig. 1.30. Multi-branched panicle in population derived from Nadiaphul.

Utilization of genome editing, *in vitro* mutagenesis, transgenics and doubled haploid technologies for rice improvement

Efficiency of developed androgenic protocol for the generation of DHs

The potentiality of the androgenic protocol was proven by producing a significant number of DHs from intervarietal crosses (SP49 x MBR4, SP49 x MBR1, SP49 x MBR7, Ratna x Chakhao and G x PR6) showing callus induction from 25.3-34.5% and regeneration of 29-71%. A total of 196 DHs were developed from intervarietal crosses (Fig. 1.31).

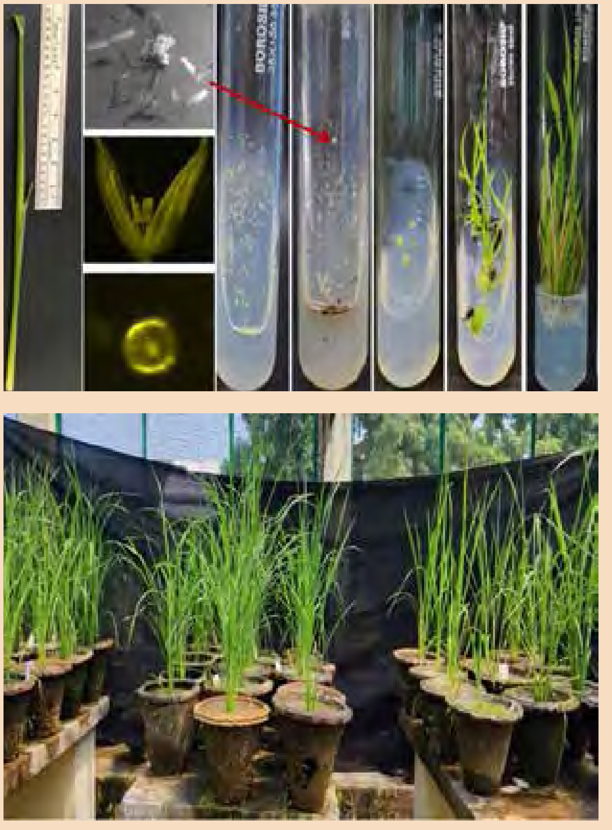


Fig. 1.31. a. Androgenesis in the generation of DHs from Arize 8433DT. b. DHs of Arize 8433DT at net house.

Utilization of DH technology in rice improvement

Development of DHs from BxR and AxR : The anther culture response of the CMS line-based hybrid (A x R) with that of its corresponding iso-nuclear male fertile maintainer line-based hybrid (B x R) was conducted. The hybrid chosen was CR Dhan 704.

A total of 200 DHs were developed following the standardized androgenic protocol. The callusing response was 34.47% for B x R whereas 47.63% for A x R. The regeneration frequency ranged from 35.2% to 70.13% when supplemented with proline (5mg L^{-1}) for B x R and 80.34% in A x R in only MS medium without proline.

Parental Line Improvement: The utilization of DH breeding has proven its efficiency in development of climate resilient restorer lines that exhibited tolerance to Drought (*qDTY1.1*), Heat (*qHTSF4.1*), and resistance to BB (*xa 5*, *xa 13*, and *Xa21*) which was also evident by Marker Assisted Selection (MAS) (Fig. 1.32**).**

Multiple stress tolerance in DHs (Savitri x Pokkali): Identified a DH (Savitri x Pokkali) for multiple stress tolerance (Anaerobic germination+ salinity stress+ osmotic stress) and

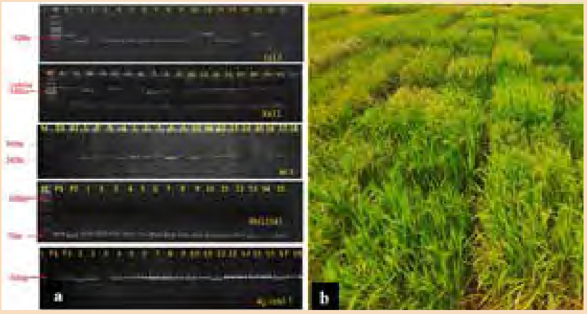


Fig. 1.32. a. Molecular validation of DHs carrying targeted genes/ QTLs (Xa21, qHtsf 4.1, xa 13 and qDTY1.1) in R line. b. Variation among DHs possessing targeted genes/QTLs (Xa21, qHtsf 4.1, xa 13 and qDTY1.1) in the field.

4 DHs (Savitri x Pokkali) for salinity stress through 8 multi-location trials across India (Cuttack, Coimbatore, Maruteru, Pattambi, Karaikal, Kaul, Karjat, Titabar). CR4423-17 was identified with multiple stress tolerance having anaerobic germination ability, salinity and osmotic stress tolerance. Another four genotypes, CR4423-8, CR4423-17, CR4423-101, CR4423-111 were tolerant to salinity stress at seedling stage.

Yield evaluation of DHs under station trial

A total of eight DHs derived from the hybrids 27P63, BS6444G and CR Dhan 701 were evaluated under replicated trial with their respective parents and checks, Naveen and BPT 5204. Out of which, CRAC 3998-43-1 recorded the highest yield (6.62 t ha^{-1}) followed by CRAC3998-325-2 (6.42 t ha^{-1}), CRAC3994-9-1 (6.38 t ha^{-1}) and CRAC3995-48 (6.29 t ha^{-1}) which showed at par yield with the parent hybrids 27P63 (6.30 t ha^{-1}), BS6444G (6.17 t ha^{-1}) and CR Dhan 701 (6.22 t ha^{-1}). Besides, 10 DHs, CRAC 3994-2-1, CRAC 3994-2-5, CRAC 3995-27-1, CRAC 3998-325-3, CRAC 3998-128-2, CRAC 3998-247-2, CRAC 3998-221-2, CRAC 3998-233, CRAC 3998-122-2 and CRAC 3998-114-1 were also evaluated under multilocation trials at two research stations of OUAT, at Ranital and Jeypore.

Notably, DH line CRR DH64 (Parentage -Savitri x Pokkali -IET30687) evaluated under IVT-ETP was promoted to AVT1-ETP. Furthermore, five promising DHs; CRAC 3994-2-2, CRAC 3998-221, CRAC 3998-325-2, CRAC 3998-128-1, CRAC 3998-247 and nine DHs; CRAC 3998-154-2. CRAC 3998- 324-2, CRAC 3998-325-2, CRAC 124-2, CRAC 101-1, CRAC 94-1, CRAC 3998-43-2, CRAC 4424-118-1, CRAC 4424-6A-17 were nominated for AICRIP Kharif -2023 and AICRIP Boro -2023, respectively.

Rice varieties developed through DH approach

A total of 3 DH varieties were released and notified through SVRC out of which one is nutri dense CR Dhan 324 with high protein, and moderate zinc, iron) and another is aromatic (CR Dhan 911) while CR Dhan 323 is high yielding with moderate tolerance and resistance to different pests and diseases (Table 1.3; Fig. 1.33). Further, 6 DHs (CR Dhan 325, CR Dhan 212, CR Dhan 334, CR Dhan 335, CR Dhan 336 and CR Dhan 912) are recently been nominated in SVRC-2023.

Fig. 1.33a. Morphology of DH variety -CR Dhan 323 in field.

Fig. 1.33b. Morphology of DH variety -CR Dhan 911 in field.

Fig. 1.33c. Morphology of DH variety -CR Dhan 324 in field.

Table 1.3. List of released DH varieties in 2023.

Variety	CR Dhan 323	CR Dhan 324	CR Dhan 911
Parentage	CR Dhan 701	CR Dhan 701	BS 6444G
Breeding Method	Doubled Haploid breeding through androgenesis	Doubled Haploid breeding through androgenesis	Doubled Haploid breeding through androgenesis
Recommended Ecology	Irrigated and shallow lowland - both Kharif & Rabi	Irrigated - both Kharif & Rabi	Irrigated - both Kharif & Rabi
Plant Height	115-120cm	105-110cm	95-105cm
Duration	135-140 days	115-120 days	120-125 days
Grain type	Short Bold; HRR-65.2%; AC-23.97%	Long Slender; HRR-67.9%; AC-25.66%	Long Slender (Aromatic); HRR-68.2%; AC-21.03%
Grain yield	5.0-6.0 t ha^{-1}	4.5-5.5 t ha^{-1}	4.5-5.5 t ha^{-1}
Special Traits	Moderate Resistance to leaf blast, neck blast, bacterial blight, grain discoloration, RTD and resistant to false smut; moderate resistance to gall midge.	Moderate Resistance to leaf blast, neck blast, brown spot, grain discoloration and false smut; moderate resistance to leaf folder and gall midge	Moderate Resistance to leaf blast, neck blast, bacterial blight, grain discoloration, RTD and resistant to false smut; moderate resistance to gall midge.

In vitro mutagenesis for *indica* rice improvement

Mutants of Acharmati and Kalajeera (landrace) developed through EMS-based mutagenesis in *vitro* showed 29.3% and 28.06% height reduction from the parent respectively. (Fig. 1.34a.). Variation among the seed kernels of mutants derived from Kalajeera was observed. (Fig. 1.34b.).

Fig. 1.34a. Height reduction in Kalajeera and Acahrmati mutant.

Fig. 1.34b. Variation among the seed kernels of mutants derived from Kalajeera.

Editing *TMS5, Sd1 and Growth Regulating Factor 4* (*GRF4*) for improving yield and nitrogen use efficiency (NUE) in rice through CRISPR/*Cas9*

A total of two homozygous CRISPR/Cas9 edited plants were developed for thermo-sensitive genic male sterile lines (tms5) in Lalat and MTU1010 (Fig. 1.35).

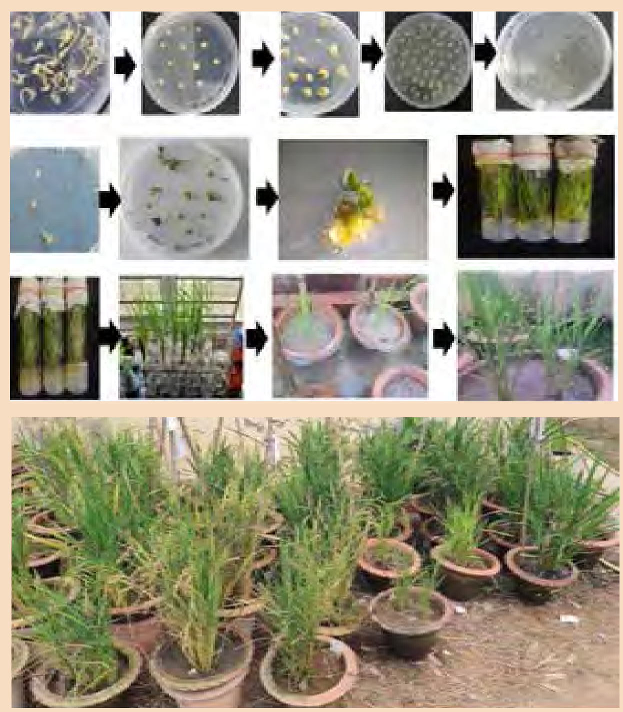


Fig. 1.35. Development of thermo-sensitive genic male sterile lines in elite rice cultivars using CRISPR/*Cas9*.

OsSD1 (semi dwarf) gene was targeted to reduce the height and develop lodging tolerance in Gobindabhog and Nua Kalajeera using CRISPR-*Cas9*. We have constructed a vector with two guide RNAs (gRNA) and used it for genetic transformation. Regenerated T0 plants exhibited monoallelic mutation with a deletion of 620 bp in the *SD1* locus. The deletion resulted in reduced height in the first generation (Fig. 1.36). It is expected to obtain homozygous biallelic mutants in the T1 generation with further reduced height.

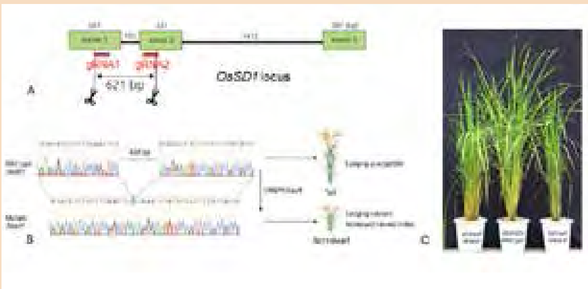


Fig. 1.36. Development of lodging tolerant Gobhindobhog and Nuakalajeera using CRISPR/*Cas9*.

Two edited lines of the *GRF4* gene in Swarna for enhancing NUE and yield were detected (Fig. 1.37). The ideal Plant Architecture 1(*IPA1*) gene which was edited in the popular rice variety, Swarna (T2-4-7-1) showed a 23% yield enhancement. The IBSC clearance was obtained on October 2023. Further, it was submitted to RCGM following SoP of DBT, GoI subsequently it will be nominated in AICRIP trial 2024. (Fig. 1.38).

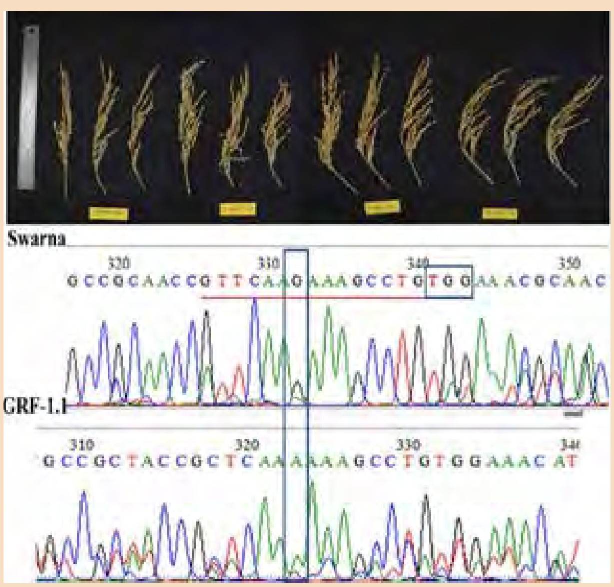


Fig. 1.37. Edited lines for Growth Regulating Factor 4 (GRF4) in Swarna for enhancement in Yield and NUE.

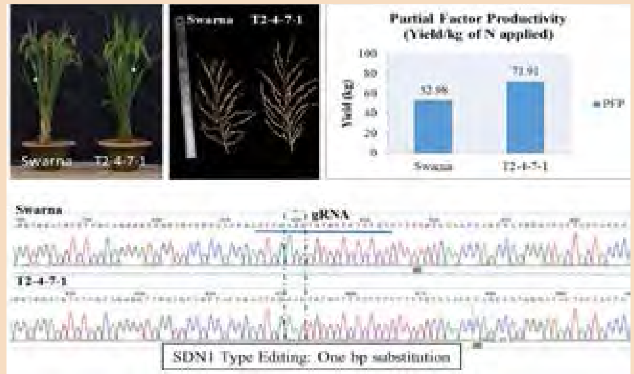


Fig. 1.38. Ideal Plant Architecture 1 (IPA1) gene edited by SDN1 type editing in popular rice variety Swarna.

Genome-wide analysis and haplotype gene analysis for vegetative stage drought tolerance in rice.

The phenotyping of vegetative stage drought stress was carried out in 329 genotypes (320 genotypes and 6 checks of 3K Rice Genome Project panel along with Mahulata, CR143-2-2 and IR20) in summer 2023 using augmented RCBD at two different locations; drought experimental field of ICAR-NRRI, Cuttack and research cum experimental farm, IGKV, Raipur (under rain out shelter condition). Genome-Wide Association Studies (GWAS) analysis identified 12 major QTLs for six different traits such as leaf rolling, relative water content, plant height, leaf area, tiller number and leaf number. The two *indica* genotypes; TSAO SHENG LI 1 and PODIWEE were considered superior based on their representation in the superior haplotypes of the studied traits which can be utilized in the breeding programs for the development of ideal varieties with vegetative stage drought tolerance.

Phenotyping and genotyping of mapping populations for identification of 21 days submergence stress tolerance genes

Phenotyping of 120 Recombinant Inbred Lines (F_{10}) derived from Swarna-*Sub 1* x AC 20431B and 15 Backcross Inbred Lines (Swarna-*Sub1**2 x AC 20431B) was carried out in three replications for identification of 21 days submergence tolerant genes in *kharif* 2023. Twenty-eight days old seedlings were completely inundated with water in the submergence tanks for 21 days. The plants were de-submerged after 21 days and after a recovery period of seven days; survival percentage, total shoot elongation and chlorophyll content were recorded. It was found that 18 RILs and one BIL showed mean survival rate of above 70%. Further, genotyping of the mapping populations were carried out using 1k-RiCA SNP genotyping. A total of 353 SNPs marker were identified as informative, which will be used for construction of linkage map and identification of QTLs/Genes.

Development of Novel Genomic Resources for Rice improvement

Identification and mapping of QTLs/ genes associated with resistance/ tolerance to biotic and abiotic stresses, and straw quality

An association panel containing 210 cultivars (varieties and land races) was genotyped with 300 SSR markers and phenotyped in controlled and field conditions. Genotypic data were used to delineate PCA, phylogenetic relationship and population structure among genotypes **(Fig. 1.39 a, b, c).** Two subpopulations were identified.

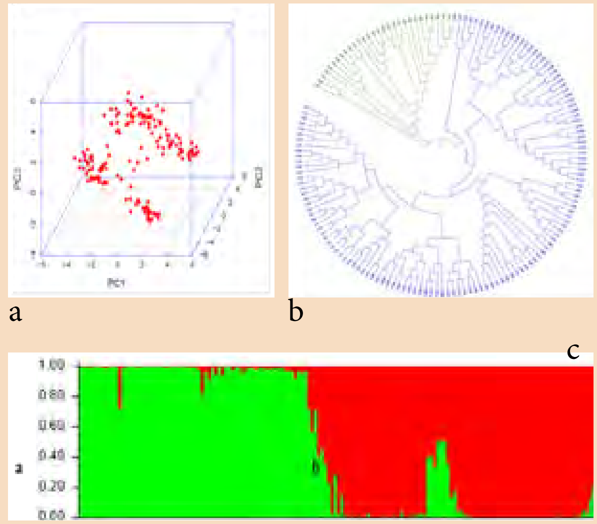


Fig. 1.39. PCA (a), phylogenetic relationship (b), and population structure (c) among genotypes of association of mapping panel based on the genotypic data.

An association mapping panel consisting 133 rice cultivars was evaluated for straw qualities like dry matter, ash, silica, nitrogen content, lignin, cellulose, hemicellulose, and digestibility. These traits showed wide variations and normal distribution. The association mapping panel was genotyped with 133 SSR markers and was used to delineate the phylogenetic relationship and population structure among genotypes **(**Fig. 1.40 a, b, c**).** Two subpopulations were identified. 1%, 95%, and 4% AMOVA were explained within individual genotype, among individual genotypes, and among populations, respectively (Fig. 1.40 d)**.** Marker-trait association analysis identified 8 markers associated with multiple traits (Table 1.4)**.** Three putative candidate genes, *OsSND2 (LOC_Os05g48850), OsNADH-GOGAT2 (LOC_Os05g48200,* and *OsMYB55 or OsPL(LOC_Os05g48010*) were identified for dry matter, nitrogen, and cellulose content using annotation and enrichment analysis.

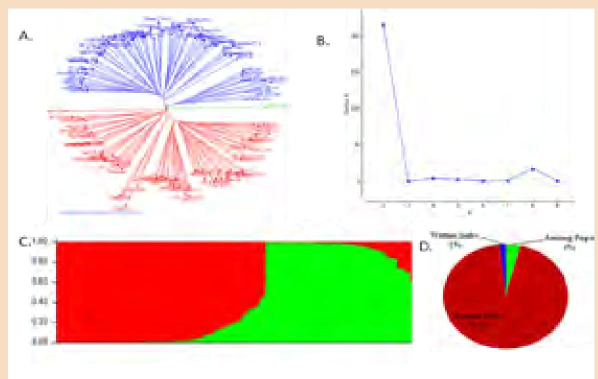


Fig. 1.40. Phylogenetic relationship (a), Delta K value to know number of subpopulations, (b) population structure (c), and AMOVA (d) among genotypes of association mapping panel based on the genotypic data.

Gene prospecting and epigenetics for tolerance to abiotic stresses

One highly stable line (F_7) having more than 95% grain filling was identified from a cross between N22 X Bhalum2. The booting stage epigenome of this line will be studied under control condition for high temperature stress.

Functional validation of putative candidate genes for resistance to biotic stresses

Expression analysis of 10 putative genes associated with BPH resistance was carried out in resistant parents (Salkathi and CR3006-8-2(Pusa44/Salkathi) and susceptible parents (TN1 and Naveen) and 14 BILs. Three genes, *LOC_Os04g02920* (NBS-LRR) (Fig. 1.41)**,** *LOC_Os04g02920* (Leucine rich repeat family protein), and *LOC_Os04g34250* (Serine/ threonine-protein kinase receptor) were found to be potential candidate genes. Functional markers will be developed for these candidate genes using whole-genome sequence of TN1 and Salkathi, and validated in alternative $IC_1F_{4/5}$ population (developed from CR 3006-8-2 and Naveen) for use in MAS breeding program.

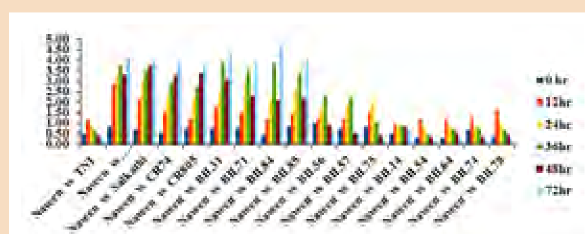


Fig. 1.41. Comparison of expression of prospective candidate gene, LOC_Os04g02040 (NBS-LRR) from BPH resistance QTL, qBph4.3 regions of Salkathi between highly resistant, resistant, moderately resistant, susceptible and highly susceptible genotypes with respect to highly susceptible parent, Naveen.

Table 1.4. Significant marker trait associations identified using GLM and MLM approaches for straw quality traits in rice.

Sl No	Trait	Marker	Position (cM)	QTL	Chr	GLM		MLM (Q+K)	
						***p* value**	R^2	***p* value**	R^2
1	Dry Matter Content	RM5784	110.51	qdm5.1	5	0.023	0.073	0.04	0.072
2	Ash Content	RM22	6	qac3.1	3	0.012	0.051	0	0.053
3	Nitrogen Content	RM5784	110.51	qni5.2	5	0.006	0.1	-	-
4	Lignin	RM334	112.61	qli5.1	5	-	-	0.004	0.069
5	Cellulose	RM334	112.61	qcl5.3	5	0.041	0.08	0.001	0.08
6		RM5784	110.51	qcl5.4	5	0.021	0.069	-	-
7	Hemicellulose	RM22	6	qhc3.1	3	0.001	0.089	0	0.089
8	Digestibility	RM334	112.61	qdi5.1	5	0.002	0.178	0.032	0.178

Conclusion

Considering the present scenario of climate change, malnutrition, changing food habit and shortage in agricultural laborers, Crop Improvement Division has undertaken research on varietal development using both traditional breeding and modern biotechnological approaches to achieve sustainable developmental goals. Crop improvement division also plays a significant role in rice breeding by releasing varieties through Doubled Haploid and marker-assisted selection techniques which are cost effective mainly by shortening the breeding cycle. In one hand, hybrids and new generation rice varieties with very high yielding potentiality will elevate the productivity. On the other hand, multiple biotic and abiotic stress tolerant varieties can also ensure the sustainable production under changing climatic scenarios. Genotypes high with multiple nutritional traits are being developed which can complement significantly in the nutritional security of rice consumers. Aerobic and direct seeded rice varieties can also ensure the economic and environmental friendly use of available inputs. New insight into genomics along with the usages of genome editing tools facilitate in the development of novel products. All these outcomes will certainly help our stakeholders directly or indirectly and also facilitate to modify or frame new policy in agricultural planning and development.

PROGRAMME

02

Enhancing Productivity, Sustainability and Resilience of Rice Based Production System

The sustainable rice production primarily depends on four major components *viz.*, productivity, profitability, resource use efficiency and climate change resilience. In this context, the programme has been planned to develop, validate and disseminate innovative cutting-edge technologies for enhancing productivity, sustainability and resilience of rice-based production systems. The main objectives of the programme are to: (i) develop precision nutrient and water management framework using advanced digital sensors, delivery protocols and nano technology for enhancing resource use efficiencies in rice, (ii) site-specific planning and development of cropping and farming system models and weed management strategies for enhanced productivity and profitability, (iii) economic and environmental friendly utilization of rice residues by resource conservation technologies and microbial intervention, (iv) customize new prototypes and improvement of identified machineries for small farm mechanization, (v) development and evaluation of rice-specific microbial formulation for nutrient, pest and residue management, (vi) impact assessment of land use and land cover change on ecosystem services from rice based cropping systems, and (vii) vulnerability analysis and prioritization of climate-smart agricultural technologies for enhancing resilience in stress-prone rice ecologies.

Enhancing nutrient use efficiency in rice through advance agronomy using smart sensors, models and nano fertilizers

Calibration and validation of Greenseeker for in-season N application in rice

Greenseeker optical sensor is a recent tool in precision nutrient management which senses the wavelengths of reflected lights from the crop canopy and produce a normalized difference vegetation index (NDVI). The NDVI correlates well with the leaf chlorophyll content, and based on the relation, topdressing of nitrogen could be done by synchronizing site-specific crop demands. However, there is a need for site-specific calibration of Greenseeker for generating the recommendation for a group of cultivars. Field experiment was conducted during the *rabi* season of 2022-23 with six rice varieties (CR Dhan 312, CR Dhan 310, Lalat, Shatabdi, Swarna shreya and CR Dhan 206) and six nitrogen (N) levels (0, 40, 60, 80, 100, 120 kg N ha^{-1}). The NDVI measurements were recorded at 22 and 45 DAT. The in-season-estimation-yield (INSEY) was calculated by dividing NDVI of sensed date with the number of days with GDD>0. The yield potential with no additional fertilization (YP0) was calculated using an empirically-derived function YP0= a * $(INSEY)^b$. The relationship between INSEY and yield showed best fit to power function equation at 45 DAT for both the varieties, hence used to calculate the Greenseeker based fertilizer recommendation for PI stage using the following equation.

Fertilizer N dose (kg ha^{-1}) = (YPN-YP0) *1.2 /(0.5*100).

The validation trial of Greenseeker guided dose was conducted during the *kharif* season of 2022-23 at Badakusunpur village, Tangi Block, Cuttack with Naveen variety. Results revealed that depending on the initial level of N application the Greenseeker recommendation for 2^{nd} top dressing varied from 13.6 to 23.5 kg ha^{-1}. The highest yield of 4.77 t ha^{-1} was recorded in the treatment comprising application of 33 kg N ha^{-1} each at basal and MT stage followed by Greenseeker guided dose of 23.5 kg ha^{-1} (Table 2.1).

Estimation of N footprint of rice production in India using partial LCA (gate to gate) approach

Life cycle impact assessment (LCIA), connects the different emissions to the corresponding environmental impacts e.g. global warming potential (GWP), eutrophication potential (EP), acidification potential (AP), photochemical ozone creation potential (POCP) and ozone depletion potential (ODP). Attempt was made to estimate N footprint (NF) of rice production in India using partial LCA (gate-to-gate) approach. Partial LCA (gate-to-gate) method evaluates the production process i.e. takes into consideration the processing of raw materials into harvested product and release of reactive N species (Nr: N_2O, NH_3, NO_3) in this processes. For this inventories of state-wise rice area, state-wise rice production, state-wise N fertilizer consumption in rice, emission factors for all Nr were prepared. The N footprint was measured in terms of eutrophication potential. Using the formula given by ISO 14044, 2006 (Environmental Management Life Cycle Assessment – Requirements and Guidelines, International Organization for Standardization).

Table 2.1. Greenseeker based N recommendation and grain yield (Var: Naveen) at Badakusunpur, Cuttack.

Conventional N Dose	Fertilizer applied (kg ha^{-1})	Split ratio	GSRecommended N dose (2^{nd} TD) (kg ha^{-1})	Total fertilizer applied (kg ha^{-1})	Grain Yield (t ha^{-1})	AE	HI
80 kg N ha^{-1}	40:20:20	50:25:25		80.0	4.20	25.00	0.45
	40:20:GS	50:25:GS	13.6	73.6	4.27	28.06	0.45
	26.6:26.6:26.6	33:33:33		80.0	4.13	24.41	0.43
	26.6:26.6:GS	33:33:GS	18.8	71.6	4.50	32.09	0.45
100 kg N ha^{-1}	50:25:25	50:25:25		100.0	4.13	21.00	0.46
	50:25:GS	50:25:GS	20.2	95.2	4.50	25.21	0.44
	33:33:33	33:33:33		100.0	4.33	21.21	0.45
	33:33:GS	33:33:GS	23.5	89.5	4.77	29.04	0.47

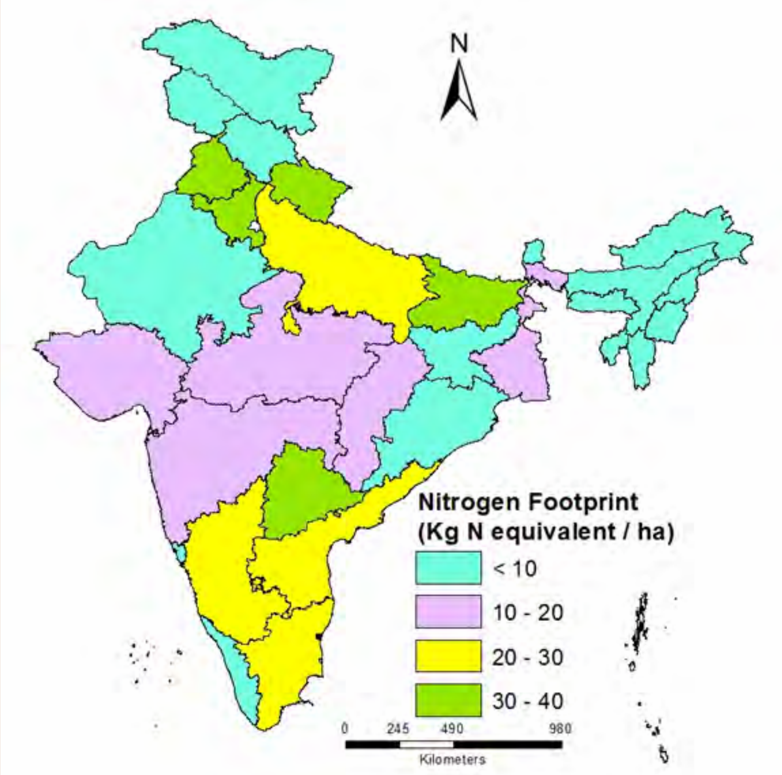


Fig. 2.1. State wise estimated N footprint in rice production

The NF ranged from 2.7 -38.5 kg N equivalent ha^{-1}. The lowest value was recorded in Mizoram. The highest was in Telangana. The NF (per unit produce) ranged from 1.08-16.56 kg N equivalent t^{-1}. Haryana, Uttar Pradesh, Uttarakhand and Telangana states have the NF per ton yield in the range of 10-15 kg N equivalent.

Evaluations of organic nutrient management options in relation to N uptake and microbial activities in rice-pulse system

The experiment under long-term organic nutrient management is being maintained in rice-based system at Institute-farm. The eight distinct organic nutrient treatments for *kharif* rice were as follows: T1-absolute control; T2-FYM; T3-Azolla; T4-Green manure; T5- Vermicompost; T6- FYM + Azolla; T7- FYM + Green manure; T8- FYM + Vermicompost to replace the dose of 60 kg N ha^{-1} either 100% or 50% combinations. Three N-responsive varieties (Naveen, CR Dhan 411, Genotype IET 28084) were evaluated under long-term organic nutrient management (ONM). The N uptake of different N-responsive cultivars was estimated. Among the eight ONM treatments, significantly higher grain yield was obtained in the treatments like FYM + Azolla, FYM + Green manure (Naveen), Azolla (CR Dhan 411), Azolla and Vermicompost (IET 28084). The mean grain yield was highest in Naveen (4.3 t ha^{-1}). Total N uptake across the varieties varied between 50-94 kg N ha^{-1}, where either FYM or Azolla treatments showed their dominance for three varieties tested. It was observed that due to more microbial activities in surface soil (0-15 cm) over sub-surface soil (15-30 cm) resulted in more C-mineralization. The maximum increment of Cmin observed between 20-D of incubation to 40-D of incubation for all treatments. Among the treatments, T7 and T8 showed less Cmin values as compared to T2, T3, T4 and control. Surface soil has more microbial activities measured in terms of dehydrogenase, urease, acid and alkaline phosphatases and FDA over sub-surface soil.

Functional and structural diversity of nitrifying bacteria under long-term organically managed rice soil

Organic nitrogen sources used in organic farming boost nitrogen utilization through symbiotic interactions like biological nitrogen fixation and nutrient recycling by encouraging the growth of soil biota, which contributes a significant amount of organic matter, enhances the microbial action on the substrate, and makes water and nutrients available to crops. The specific study was done with objectives: i) to evaluate the influence of long-term organic nutrient management on nitrifying bacterial diversity, and ii) to establish relationship of the functional and structural diversity of nitrifying bacteria with soil properties. Results showed that in structural diversity the highest populations of *Nitrosomonas* and *Nitrobacter* were observed in green manure treatment. However, the FYM + *Azolla* had the highest copy number of the *amoB* gene. McIntosh index suggested that heterogeneity level of microbial community was less in various organic application.

Nutrient cycling pathways analysis of microbial communities in long-term fertilizer experiment

De-novo whole metagenome sequencing has been done in 6 contrasting treatments of 52 years old LTFE paddy soil. Sequences were submitted in NCBI as SRA accession no. (Table 2.2). Nutrient cycling pathway was analyzed through Kyoto Encyclopedia Genes and Genomes (KEGG). Contrasting metabolic pathways were reported in the six defined treatments of 52 years old LTFE. Less frequency of pathways was observed in control whereas higher frequency in NPK followed by FYM+N, FYM, FYM+NPK and N. Carbon metabolism pathways were observed higher in NPK followed by FYM+N and FYM but the abundance of organism-specific metabolic pathway observed very less in control treatment. The work related to elucidation of specific gene encoding specific enzymes to differentiate nutrient cycling pathways under different LTFE would be studied.

Table 2.2. Sequence read achieves (SRA) number of six treatments under 52 years' old LTFE paddy soil.

Treatment	SRA NCBI Accession no. (https://www.ncbi.nlm.nih.gov/)
Control (C0N0)	R1:SRR24356811 R2:SRR24350682
N (C0N)	R1:SRR24356810 R2:SRR24350681
NPK (C0NPK)	R1:SRR24356809 R2:SRR24350680
FYM (C1)	R1:SRR24356808 R2:SRR24350679
FYM+N (C1N)	R1:SRR24356807 R2:SRR24350678
FYM+NPK (C1NPK)	R1:SRR24356806 R2:SRR24350677

Smart delivery of phosphate fertilizers through nanoclay polymer composites (NCPC) loaded with low molecular weight organic acids and phosphorus

An experiment was conducted with this innovative technology at ICAR-NRRI in Cuttack (2021-2023) where three low molecular weight organic acids (LMWOA) (citric acid (CA), malic acid (MA) and tartaric acid (TA)) and three phosphorus (P) sources (diammonium phosphate, DAP; simple superphosphate, SSP and rock phosphate, RP) making nine combinations. In the laboratory experiment, the procedure was modified by adding DAP and citric acid between the process of polymer formation. In this way five variants: NCPC (pure NCPC), NDR (addition of DAP after the synthesis of NCPC), NDCAR (addition of DAP and citric acid after the synthesis of NCPC), ND (addition of DAP between the process of polymer formation), NDCA (addition of DAP and citric acid between the process of polymer formation) were obtained. It was found that the application of DAP using NCPC as a smart delivery system slows down its release as compared to crude DAP. However, in the later stages (240 hours), the P concentration decreases, which is probably due to the P-fixation. The simultaneous application of DAP and CA resulted in a higher P concentration, probably due to the chelation of reactive Fe and Al sites by CA. Further, it was observed that DAP, SSP and RP can be loaded up to a maximum of 10% w/w, 20% w/w and 10% w/w, respectively. The release pattern of P from loaded NCPC in water and soil was studied for both SSP and RP variants; only 34% of applied P is released in 10 days, whereas in the presence of acid, 84-87% of P is released in water. In terms of P release in soil, NCPC+SSP (20%) +TA and NCPC+RP (10%) +TA had the highest levels. Fourier transform infrared spectroscopy (FTIR) and scanning electron microscope (SEM) were used to characterize the polymer.

In the pot experiment, 11 treatments and three replications were used with the combinations of Control, NCPC+TA, NCPC+DAP, NCPC+SSP, NCPC+RP, NCPC+DAP+TA, NCPC+SSP+TA, NCPC+RP+TA, NCPC+RP+TA, NCPC+DAP+TA (75%), NCPC+SSP+TA (75%), NCPC+RP+TA (75%) with rice var. Sahabhagidhan. Results showed that NCPC+DAP+TA produced the highest yield (19 g pot^{-1}) and yield attributes. Further, the micro-plot experiment included 8 treatments (Control, NCPC+TA, NCPC+DAP, NCPC+SSP, NCPC+RP, NCPC+DAP+TA, NCPC+SSP+TA, NCPC+RP+TA, NCPC+RP+TA, NCPC+RP+TA, NCPC+RP+TA, DAP), in three replications, with rice var. Sahabhagidhan, where NCPC+DAP+TA produced the highest yield (4 g pot^{-1}) and yield attributes of all the treatments.

National level zonation of rice ecologies, site specific planning and development of cropping and farming system models

Studies of the micro-climate interactions among the enterprises components under integrated system

Experiment was conducted during *kharif* 2023 to evaluate the varieties under rice-fish and rice alone for yield, yield parameters and nutrient uptake. Results revealed that mean grain yield was significantly higher with the varieties taken under rice-fish and it was 16% higher over rice alone. During the year, among the varieties Mahamani significantly gave higher grain yield followed by variety CR Dhan 506. No significant difference was found for nutrient uptake with Rice-fish and rice alone treatments. Varieties like CR Dhan 500 and Prashant Dhan exhibited better nutrient uptake under Rice-fish (Table 2.3).

Table 2.3. Varietal performance for grain yield (t ha^{-1}), straw yield (t ha^{-1}) harvest index (HI) and plant height (cm).

Varieties	Grain Yield (t ha^{-1})		Straw Yield (t ha^{-1})		Harvest Index		Plant Height (cm)	
	R- F	R A	R- F	R A	R- F	R A	R- F	R A
V_1	8.43	6.91	12.53	13.41	0.40	0.31	158	160
V_2	4.66	4.29	7.89	8.02	0.37	0.29	122	144
V_3	6.43	6.71	11.17	8.1	0.36	0.45	164	174
V_4	7.24	5.86	12.27	7.81	0.36	0.39	159	176
V_5	7.50	5.97	11.33	9.07	0.38	0.35	150	171
V_6	6.86	4.95	11.33	7.25	0.38	0.35	161	165
V_7	7.12	5.53	12.60	8.70	0.36	0.34	158	167
V_8	6.01	5.71	10.05	8.90	0.38	0.34	157	183
Mean	**6.78a**	**5.87b**	**11.15a**	**8.91b**	**0.37**	**0.35**	**154b**	**168a**

Rice-Fish(R-F), Rice alone (RA): V_1-Mahamani, V_2-Pradhan Dhan (CR Dhan 409) V_3 -CR- Dhan 500, V_4-CR- Dhan 505, V_5-CR-Dhan 506, V_6-CR Dhan 508, V_7-Prashant Dhan (CR Dhan 509), V_8-Varshadhan

Sustainability and profitability of different production systems under various rice-based cropping systems (Natural Farming and Organic Farming)

The experiment was initiated in the *rabi* season of 2022-23 to study the sustainability and profitability of organic and natural farming systems in various rice-based cropping systems: Rice-Rice, Rice-Green gram, and Rice-Groundnut. The treatments were laid out in split plot design. Under organic farming system, varying doses of FYM was applied as per the requirement of crops. Seeds were treated with biofertilizers and trichoderma. Under natural farming system, seeds were treated with Beejamrita, Jeevamrita (as foliar spray @500 L ha^{-1} at 15-days interval) and straw mulching (Achhadana) in crop rows was practiced. Neemastra, Bramhastra, and Agniastra were applied to all the crop for management of disease and pest. During the year, a higher rice equivalent yield (REY) was observed in the groundnut crop under organic farming system (9.64 t ha^{-1}), which was at par with the groundnut crop under natural farming system (7.88 t ha^{-1}), followed by green gram in organic farming (2.77 t ha^{-1}) and green gram in natural farming (2.05 t ha^{-1}) (REY of green gram was at par in both systems). Higher B:C ratio was observed with groundnut crop under organic farming (0.79). Biodiversity in the field was promoted by growing plantation crops like coconut, arecanut. The pulse crop (Arhar) was grown on bunds and straw bundles were erected to improve the spider population in the system.

Vulnerability analysis and assessment of climate smart agricultural technologies for enhancing resilience in stress prone rice ecologies

Development of block-wise drought vulnerability index for Balangir district

Drought is recurring natural disaster that have significant socio-economic and environmental impacts. Balangir, a drought-prone district in Odisha, is often facing drought events that affect its farming communities and agricultural productivity as a whole. To better understand and address the vulnerability of different blocks within Balangir district to droughts, a comprehensive drought Vulnerability Index (VI) was calculated. The results of the Drought Vulnerability Index (VI) for the different blocks in Balangir district revealed a varying levels of vulnerability. Titilagarh and Bangomunda blocks stand out with very high vulnerability scores (combining high exposure, sensitivity, and relatively lower adaptive capacity), indicating their increased susceptibility to drought events, highlighting the need for targeted interventions to enhance resilience in these specific areas. Similarly, Belpada, Tureikela, and Muribahal have high vulnerability scores, falling into the "High" vulnerability category. On the other hand, Balangir, Puintala, Gudvella, Loisingha, Patnagarh, Khaprakhol and Saintala all fall into the "Medium" vulnerability category. Agalpur and Deogaon are found to be the least vulnerable blocks in the district, categorized as "Low" vulnerability, as these blocks have comparatively lower exposure and sensitivity to drought events and relatively higher adaptive capacity. Based on the vulnerability index, block-wise map is prepared (Fig. 2.2).

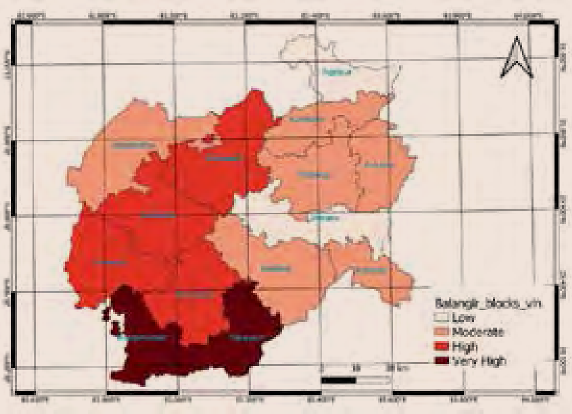


Fig. 2.2. Drought Vulnerability map of different blocks of Balangir district, Odisha.

Standardized Precipitation Index of different blocks of Dhenkanal district

Standardized Precipitation Index (SPI) is a widely used as meteorological tool that quantifies and categorizes precipitation anomalies. It standardizes precipitation data to allow for the comparison of drought or wetness conditions across the different time scales, providing valuable insights into the severity and duration of climatic variations. Using a series of precipitation records in the growing periods of 1990-2021 the standardized precipitation index (SPI) have been calculated from Balangir, Puintala, Gudvella, Agalpur, Deogaon, Loisingha, Patnagarh, Belpada, Khaparakhol, Titilagarh, Tureikela, Bangomunda, Muribahal and Saintala blocks of Balangir districts. Standardized Precipitation Index (SPI) for all the blocks of the Balangir district are under the mild drought category. The SPI for the Loisingha block during July and August have a significantly negative trend which indicates that total rainfall during these months is decreasing in this block. The SPI for the Gudvella and Patnagarh blocks during September have a significantly positive trend which indicates that total rainfall during that month is increasing in these blocks.

Arsenic speciation in grain of rice genotypes grown in arsenic contaminated soil

Arsenic is a naturally occurring element in the environment and can be found in various forms, such as arsenite (AsIII), arsenate (AsV), dimethylarsenic acid (DMA), monomethylarsonic acid (MMA) etc. The accumulation of arsenic in rice grains is a major concern due to its potential health risks to consumers. Different rice varieties have varying abilities to accumulate and convert arsenic species, making it essential to assess their levels to ensure food safety. We analyzed the concentrations of AsIII, AcV, DMA, and MMA in twenty-one rice genotypes, and the results are presented in fig. 2.3. Among the analyzed rice genotypes,

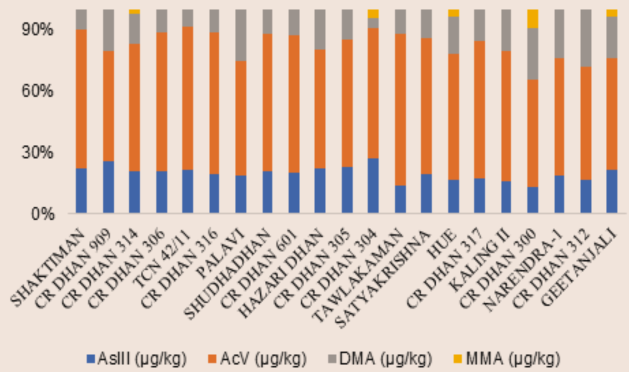


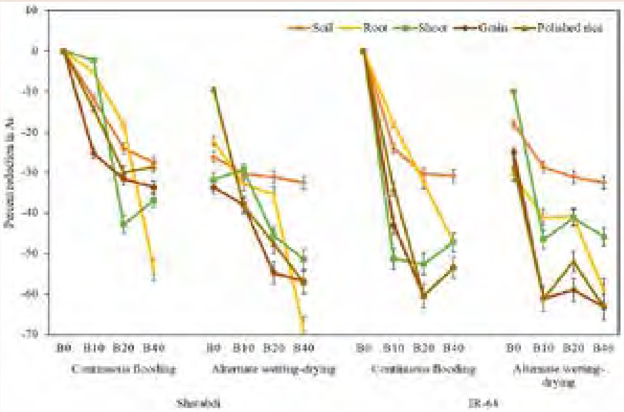
Fig. 2.3. Arsenic speciation in grain of different rice varieties.

CR 4389-RGA-11 showed the highest concentration of AsIII (79.05 μg kg^{-1}) and AsV (286.50 μg kg^{-1}), while Kalinga II exhibited the lowest concentration of AcIII (28.97 μg kg^{-1}) and Pallavi exhibited the lowest concentration of AcV (90.49 μg kg^{-1}). With regard to the organic species of As, highest concentration of DMA was observed in CR Dhan 300 (58.87 μg kg^{-1}) and lowest was observed in CR Dhan 304 (7.33 μg kg^{-1}). Notably, MMA was either absent or present in very low quantity in most of the grain samples. The total arsenic content in rice grains ranged between 0.20 mg $kg^{-1}$to 0.54 mg kg^{-1}across the varieties. CR 4389-RGA-11 had the highest total arsenic content (0.54 mg kg^{-1}), while CR Dhan 304 had the lowest (0.20 mg kg^{-1}).

Effect of rice husk biochar and water management strategies to restrict Arsenic loading in rice

We assessed the role of biochar and water regimes, on arsenic (As) contamination of rice for making high As accumulating rice cultivars. Essentially, the changes in molecular expressions of As transporters in rice as a function of bio-availability of As, Si, P and S in soil and plant. The formation of Fe plaques under two distinct water regimes: alternate wetting and drying (AWD) and continuous flooding (CF) with varying levels of biochar using two cultivars (Shatabdi and IR 64) were studied. Practice of AWD with biochar (B_{40}AWD) enhances the competitive interactions between As, Si, and P for uptake, with a concomitant downregulation of Si (*OsLSi1* and *OsLsi2*) and phosphate (*OsPT1* and *OsPT2*) co-transporters of As in both Shatabdi (34.6 and 83.4%, and 66 and 25%, respectively) and IR 64 (83.4 and 99%, and

92.5 and 49%, respectively) (Fig. 2.4). Improving S nutrition (37.1%) under AWD-biochar promotes biosynthesis of phytochelatins (PCs) and upregulation of OsABCC1 (99.1%) ensuring increased sequestration of As-PC complexes in shoots. These alterations of the nutritional balance of soil-plant system and modifications of the expressions of As transporters under AWD-biochar declined 56.8-63.1% As concentrations in grains in popular cultivars and made them As benign for unrestricted use in As contaminated areas.



B0: No biochar added, B10: 10 g biochar kg^{-1} soil, B20: 20 g biochar kg^{-1} soil, B40: 40 g biochar kg^{-1} soil

Fig. 2.4. The concentration of arsenic the in soil, root, shoot, grain and polished rice at maturity under different treatments in Shatabdi and IR 64.

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

An experiment was conducted to study the effect of stand-establishment methods, varieties and agroecological intensification on productivity of rice-based cropping system. The experiment was laid out in a split plot design with two production systems i.e. conventional (DSR) and conservation agriculture (CA) in main plots, two varieties i.e. CR Dhan 314 (NGR) and Swarna in sub-plot, and three agro-ecological intensifications i.e. maize+ groundnut, maize + cowpea and maize in sub-sub plots and replicated thrice. In the wet season, DSR(C) recorded significantly higher grain and straw yields of rice as compared to ZTR. Yield reduction with ZTR as compared to DSR was lower in CR Dhan 314 (7.4%) than that of Swarna (16.7%). Grain yield of CR Dhan 314 was at par with Swarna. In the dry season, REY of dry crops decreased after Swarna, whereas increased after CR Dhan 314. Highest REY was recorded with maize + groundnut intercropping which was significantly higher than maize + cowpea intercropping or sole cropping of maize. The system productivity of intensive rice – maize cropping system under CA (12.58 t REY ha^{-1}) was at par with conventional agriculture (13.09 t REY ha^{-1}). The highest system productivity was recorded with rice – maize + groundnut cropping system (14.21 t REY ha^{-1}) though comparable to rice - maize + cowpea cropping system, which was significantly higher than sole rice – maize cropping system (10.89 t REY ha^{-1}) (Fig. 2.5).

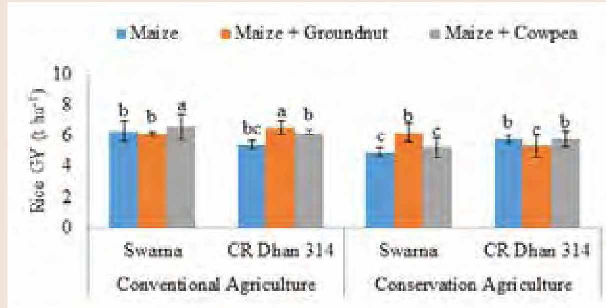


Fig. 2.5. Productivity of agro-ecologically intensified rice-maize cropping system with new generation rice varieties and conservation agriculture.

Effect of nitrogen and phosphorus nutrition on NPT based rice cultivars

A field experiment was conducted to study the effect of nitrogen (N) and phosphorous (P) nutrition on the productivity of new plant type (NPT) based rice cultivars. The experiment was laid out in a split plot design with five nitrogen levels (Control, 40, 80, 120, 160 kg ha^{-1}) and four phosphorus levels (Control, 20, 40, 60 kg P_2O_5 ha^{-1}), replicated thrice. The grain and straw yield of NPT based variety CR Dhan 314 increased progressively up to 120 kg N ha^{-1} (6.13 t ha^{-1}) and declined significantly thereafter. The harvest index did not differ significantly up to 120 kg N ha^{-1} but reduced significantly with the application of 160 kg N ha^{-1}. Similarly, the grain and straw yields increased progressively up to 40 kg P_2O_5 ha^{-1} while the grain yield obtained at 60 kg P_2O_5 ha^{-1} was significantly at par with that of 40 kg P_2O_5 ha^{-1}.

Assessment of ecosystem services of different districts rice farms in coastal plain eastern Odisha

Rice farming provides both tangible and non-tangible benefits to ecosystems which need to be maintained and enhanced. These benefits are provided through ecosystem services (ES) that include both marketable and non-marketable ES. In this study, the ES of rice farms from four different districts (Cuttack, Jajpur, Bhadrak, Ganjam) comprising of sixteen villages and 400 households representing four agroclimatic zones of Odisha (Fig. 2.6) were valued by quantifying the economic value of the services under conventional rice cultivation; and the gap of ecosystem services value and farm income per unit area were assessed. A stratified random sampling technique was used to select the study districts from four ACZs.

The ES assessment for rice farms followed the method described by Sandhu et al. (2008), which summed the individual ES values.

The total marketed value for food and by products (raw materials) ranged from US$ 1699 ha^{-1} y^{-1} (MCTL) to US$ 2736 ha^{-1} y^{-1} (ESCP) with mean value of US$ 2187 ha^{-1} y^{-1}. The non-marketed ES were valued, which constitute ~61% of the total ES from rice field, in which gas regulation service through O_2 evolution was a major part (~55%) (Table 2.4). Valuation of some of the ecosystem services such as cultural services, biodiversity, gas regulation, and soil fertility ES that also forms a considerable part in non-marketable ES valuation which may contribute a significant role in total ES have not been made due to non-availability of data and appropriate methodology for rice ecosystem. Different values of ES parameters can explain the variability in ecosystem services among the agro climatic zones (ACZs) in eastern Odisha. The clustering of sites and particular ecosystem services aids in finding specific points for intervention to sustain and enhance ecosystem services, while also allowing for sustainable agro-ecological intensification.

The maximum economic gap of ES for rice farming (i.e. Maximum economic gap = Total ES - farmer income; Minimum economic gap = Marketable ES - farmer income) was higher in Cuttack (US$ 6431 ha^{-1} y^{-1}) due to higher total ES value. Similarly, the minimum economic gap was highest for Cuttack (US$ 2059 ha^{-1} y^{-1}) and lowest for Jajpur (US$ 992 ha^{-1} y^{-1}) (Fig. 2.6). We propose implementing a range of strategies to narrow down the economic disparity, such as the implementation of payments for ecosystem services (PES) specifically for rice cultivation. This approach aims to promote the long-term sustainability of the ecosystem and agricultural progress, while also guaranteeing a stable and dependable income for farmers.

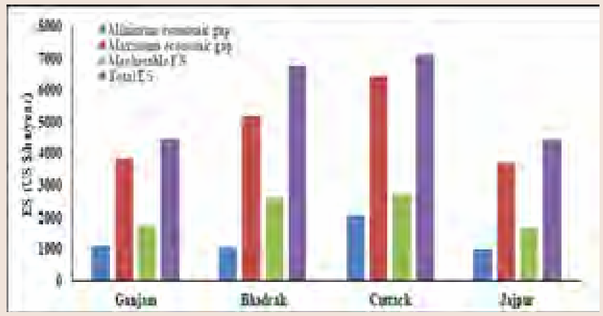


Fig. 2.6. Economic gap between total and marketed ES.

Table 2.4. Ecosystem services from rice farms in four agroclimatic zones of eastern India.

Ecosystem services	NECP (Bhadark)	ESCP (Cuttack)	NEG (Ganjam)	MCTL (Jajpur)	Mean
Food	2421.42 ± 217.3	2548.86 ± 175.6	1597.87 ± 270.6	1583.11 ± 66.9	2037.81
Raw materials	178.05±16.0	187.42±12.9	117.49±19.9	116.41±4.9	149.84
Market value of ES	2599.46	2736.28	1715.36	1699.51	2187.65
Bio control of pest ($/ha)	0.27±0.1	0.15±0.1	0.33±0.4	0.29±0.2	0.26
Soil Formation	5.59±0.0	3.75±0.0	5.60±0.0	1.87±0.0	4.20
Mineralisation of plant nutrients	56.49±5.3	48.77±4.7	49.46±2.2	41.48±2.2	49.05
Carbon accumulation	23.74±2.1	25.52±1.8	16.76±2.8	17.05±0.7	20.77
Nitrogen fixation	1.21±0.1	1.11±0.0	0.86±0.1	1.02±0.1	1.05
Soil fertility	297.75±30.3	319.11 ±23.5	193.22±34.2	185.94±9.5	249.01
Hydrological flow	9.63±0.0	9.61±0.0	8.61±0.0	10.52±0.0	9.60
Erosion	7.21±1.1	6.28±1.4	9.07±0.7	6.28±0.7	7.21
O_2 value	3763.44±337.7	3961.51±272.9	2483.45±420.6	2460.51±107.0	3167.23
Non-market value of ES	4159.74	4372.06	2761.77	2723.10	3504.17
Total economic value of ES	6759.20	7108.34	4477.13	4422.61	5691.82

Environment friendly management of rice straw and value addition for income generation to rice-farmers

In-situ rice straw decomposition

In India, rice straw production is around 126.6 million tonnes. The burning of straw primarily causes the emission of harmful gases and particulate matter which increases air pollution and greenhouse gas/ carbon footprint significantly. So, we need to find out economically viable, socially acceptable, and eco-friendly solutions for the alternative uses of rice straw. *In-situ* management is one of the viable options of straw management. A field experiment was conducted at ICAR-NRRI experimental fields (B13, 14ab Block) during *rabi* season 2023 for *in-situ* management of rice straw. The treatment details (Table 2.5) and different methods of treatment imposition (Fig. 2.7) are given below.

Table 2.5. Treatment details.

T1- Immediate incorporation of rice straw after harvesting (**IIRS**)
T2- Zero Tillage + Glyphosate Spray (**ZT**)
T3- Spreading of rice straw over the field (Simulated as combined harvester) (**SRS**)
T4- Straw Retention + Zero Tillage (**ZT+SR**)

Fig. 2.7. Treatment imposition after harvesting the paddy.

It was observed that among the treatments the methane (CH_4) emission was higher in IIRS followed by SRS, ZT and ZT+SR. Both the CH_4 and nitrous oxide (N_2O) emissions were increased from 3 to 18 days of treatment imposition and then decreased gradually up to 38 days. The N_2O emissions also followed the same trend. However, in the treatment of IIRS, the CH_4 emission was higher than that of SRS. All the GHGs emissions were relatively less in zero tillage (ZT). The emissions and yield were also studied in subsequent crop growing season including fallow period. Among all those period the higher GHGs emissions were observed during the crop growing period > decomposition period > fallow period (Fig. 2.8). Crop yield was higher in IIRS (5.64 kg ha^{-1}) followed by SRS (5.19 kg ha^{-1}) as compared to other treatments (Table 2.6).

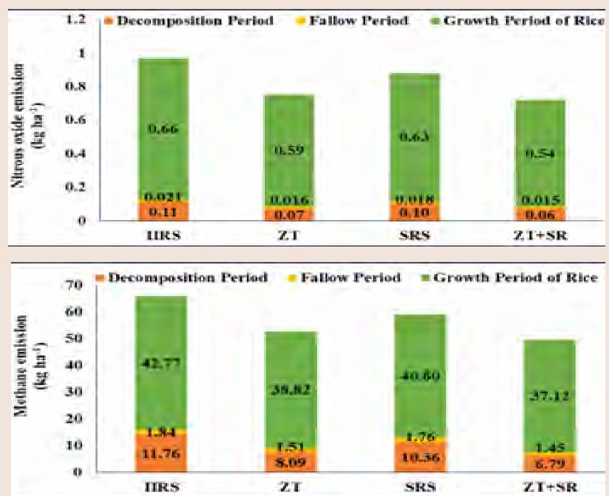


Fig. 2.8. Seasonal CH_4 and N_2O emission (both decomposition and crop growth period).

Status of rice straw burning scenario in Odisha

In a study continuing from last three years, it was observed that rice straw burning events occurred in between the months of December-March as per the base data of Terra and Aqua satellites, MODIS sensor. During 2022-2023, total burning events occurred in different districts of Odisha were 2675, which contributed about 2% of the country's straw

Table 2.6. Grain yield and seasonal methane and nitrous oxide emission from rice under different in-situ rice straw management practices.

Treatments	Grain yield (t ha^{-1})	Straw yield (t ha^{-1})	CH_4 (Kg ha^{-1})	N_2O (Kg ha^{-1})	GWP
IIRS	5.64 ± 0.31	9.83 ± 0.23	42.77 ± 1.6	0.66 ± 0.03	1349.90
ZT	5.10 ± 0.26	7.29 ± 0.28	38.82 ± 2.4	0.59 ± 0.03	1264.00
SRS	5.19 ± 0.24	7.86 ± 0.22	40.60 ± 3.1	0.63 ± 0.02	1325.10
ZT+SR	5.07 ± 0.21	7.71 ± 0.23	37.12 ± 2.3	0.54 ± 0.05	1201.00

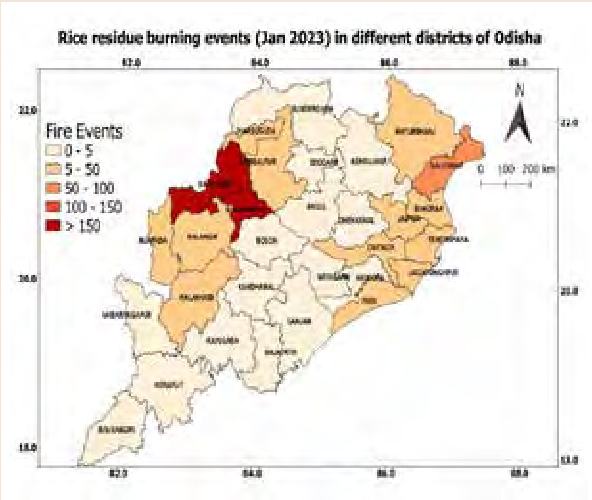


Fig. 2.9. Rice residue burning events in different districts of Odisha in January, 2023.

burning scenario. In between December, 2022 and March, 2023, frequent burning events were observed in Baragarh (270, peak in January) and Subarnapur (154; peak in January), and Baleswar (149, peak in December). Total burning events as well as month-wise burning events were more in the last year as compared to previous year (2021-2022) (Fig. 2.9).

Carbon enrichment in soil and plant governed by rice straw biochar under elevated and ambient CO_2 conditions

Biochar is a potential soil amendment for improving soil physical-chemical-biological properties with a proven role in enhancing soil C-dynamics and to increase vegetative growth and yield of crop plant. However, there is a research gap that how a biochar can regulate the carbon flow simultaneously in soil and plants under elevated CO_2 conditions. To investigate further one pot experiment was conducted in Open Top Chamber facility at Institute farm, comprising two rice varieties – V1 (Abhishek) and V2 (Satabdi), with two biochar treatments – BC_0 (Control) and BC_1 (1% BC: w/w ratio) at two chamber conditions i.e. ambient ($aCO_{2;}$ 400 ppm) and elevated ($eCO_{2;}$ 550±25 ppm) CO_2 conditions. Biochar was prepared using rice straw under anaerobic chamber of muffle furnace (300°C). At eCO_2 condition the effect of biochar was prominent for majority of the carbon fractions (WSC, RMC and SOC). Among the labile C-fractions very labile, labile and less labile C fractions was found to be enriched with influence of biochar, this emphasizes the better C-dynamics under changing climate at the rhizosphere of both the varieties. However, the effect was not so distinct at aCO_2 condition with biochar addition. Interestingly, total starch and sugar analysed at leaf and grain tissues from both varieties, and showed a good response of biochar addition under eCO_2 condition. Soil microbial activities also varied under biochar treatment hence soil enzymes like alkaline phosphatase, dehydrogenase, FDA were found to be better responsive. Plant height, panicle weight, fresh straw yield and grain yield were revealed as the biochar-responsive agronomic traits under eCO_2 condition. This study indicates a synergistic effect of elevated CO_2 × biochar might be an important management practice for better C-dynamics in soil, carbon reserve in different plant tissues, and agronomic benefit.

Harnessing microbiome for enhancing rice productivity and improving soil health

Standardizing the mass production of biocontrol agents and validation of its efficacy against rice leaf folder

B. thuringiensis strains (BT1, BT2, and BT3) and *Skermanella* sp (SKM) were used to prepare talc, liquid, capsule, and oil-based formulations. An evaluation of their shelf-life under room conditions revealed that liquid, capsule, and oil-based formulations can be stored up to one year with a cell load of 10^8 cfu mL^{-1}. The liquid formulation of *B. thuringiensis* (NRRI-CPD-BIOCB7) is currently undergoing validation for managing leaf folder as part of the AICRP-Biocontrol at NBAII, Bengaluru. The results demonstrate that the efficacy of this formulation was significantly comparable to that of an insecticide (thiamethoxam 0.2 g L^{-1}) spray.

Characterization Azolla sp and BGA to identify efficient nitrogen fixer

The growth of *A. microphylla* (AM) and *A. rubra* (AR) under salt stress conditions revealed a reduction in pigments such as Chl a/b ratio, carotenoids, and anthocyanin as compared to controls. Antioxidant enzyme activities, including SOD, APX, proline, and electrolyte leakage, were higher under salt stress in both Azolla species as compared to the control. However, *A. microphylla* exhibited higher activity than *A. rubra*. The diversity of cyanobionts in two distinct Azolla species, namely A. *microphylla* and *A. pinnata,* suggests that there was not significant variation in cyanobacterial diversity between these two distinct genera of Azolla.

Dissimilatory Nitrate Reduction to Ammonia (DNRA) under rice ecosystem.

The DNRA activity was evaluated in various paddy soil types, i.e. irrigated (IR) and shallow (SL) at 0-30 cm depth, intermediate (IL) at 30-50 cm depth, semi-deep (SD) at 50-100 cm depth, and aerobic (AR). The Q-RT PCR results indicated that the more abundance of the nrfA gene was found in the semi-deep (SD) rice ecology, followed by AR, IR, and SL. On the other hand, the nirK gene was more abundant in irrigated (IR) soil, followed by SL, IL, AR, and SD, respectively. Additionally, there was a positive correlation between the DNRA microbial population and the semi-deep (SD) rice ecology.

Evaluation of Arbuscular Mycorrhizal fungi (AMF) potential in different rice varieties

The combined application of arbuscular mycorrhizal fungi (AMF), specifically *Glomus* sp. (NRRI-CPD-AMF3), *Funneliformis* sp. (NRRI-CPD-AMF1), *Rhizophagus* sp. (NRRI-CPD-AMF6), and *Acaulospora* sp. (NRRI-CPD-AMF7), resulted in a significant increase in both plant phosphorus (P) uptake and yield in direct-seeded rice (CR Dhan 312) compared to the uninoculated control. In a study on phosphate transporter gene expression (OsPht1 to OsPht13), and Pstol, in relation to AMF inoculation across four different aerobic rice varieties (CR Dhan 201, CR Dhan 204, CR Dhan 205 and CR Dhan 207), there was 33-55% enhancement of root architecture in AMF-inoculated plants in all varieties under low and medium soil P conditions as compared to the uninoculated control. Notably, CR Dhan 207 exhibited the highest expression of most phosphate transporter genes (10 genes) under low available soil P conditions among all the varieties.

Popularization and demonstration of microbial inoculants

The liquid formulation of *Azotobacter chroococcum* Avi2, known as NRRI EndoN^{Tech}, was tested in 18 rice farmer fields in Ganjam and Bhadrak districts in Odisha. The results indicated that the application of NRRI EndoN^{Tech} could lead to approximately 25% savings in nitrogen (N) fertilizer without compromising the grain yield. Similarly, the application of Tech NRRI Decomposer was demonstrated in two distinct agro-ecological regions of Sikkim and Mandya, Karnataka. The study revealed that the application of 1.0 kg inoculum along with 0.5% urea and 1.0% cow dung, or alternatively, 1.0 kg inoculum with 5.0% cow dung for one tonne of agricultural wastes, could facilitate decomposition within a span of 60 days.

Development of weed management strategies assessing the risk of herbicide resistance in rice weeds

Integration of chemical and mechanical approaches of weed control for enhancing the productivity and profitability of dry direct seeded rice

Targeting two questions: i) whether the mechanical weeding is (MW) better than chemical weeding (CW) in Dry-DSR, and ii) can MW replace herbicide in integrated weed management packages in Dry-DSR? The experiment was designed with 10 treatments: two integrated methods (PDM followed by (*fb)* MW and, BPS *fb* MW), one chemical method (CW i.e. PDM *fb* BPS) and one mechanical method (MW by motorized weeder twice at 20 and 40 days after emergence (DAE). The two integrated methods were tested with 20 and 25 cm row spacing to assess whether modification in row spacing is necessary while using power weeder. Sequential

Table 2.7. Weed control efficiency, yield and B:C ratio as influenced by different treatments.

Treatment	Total weed density (No. m^{-2})	Total weed dry weight (g m^{-2})	Weed control efficiency (%)	Grain yield (t ha^{-1})	Straw yield (t ha^{-1})	B:C ratio
PDM *fb* MW30 + 25 cm	45.70 (6.79)B	5.69 (2.49)C	57.84E	4.82A	5.92A	1.86B
PDM *fb* MW30 + 20 cm	38.40 (6.23)B	4.78 (2.30)D	61.05D	4.86A	6.01A	1.84B
BPS *fb* MW30 + 25 cm	28.20 (5.35)C	3.51 (2.00)E	73.99C	5.27A	6.28A	1.97A
BPS *fb* MW30 + 20 cm	20.50 (4.56)D	2.55 (1.74)G	79.21B	5.32A	6.34A	1.95A
MW 20 + MW 40 + 25 cm	22.60 (4.80)CD	2.81 (1.82)EFG	79.15B	4.86A	5.88A	1.77C
PDM *fb* BPS + 20 cm	26.80 (5.22)CD	3.34 (1.96)EF	72.82C	4.66AB	6.12A	1.74D
Weed free check + 25 cm	0 (0.71)E	0 (0.71)H	100.00A	5.41A	6.03A	1.49E
Weed free check + 20 cm	0 (0.71)E	0 (0.71)H	100.00A	5.49A	6.02A	1.49E
Weedy check + 25 cm	108.40 (9.95)A	13.50 (3.74)A	-	3.13C	4.15B	1.35F
Weedy check + 20 cm	98.60 (10.42)A	12.28 (3.58)B	-	3.26BC	4.28B	1.37F
Tukey's HSD	0.67	0.17	0.20	1.41	0.47	0.02

PDM *fb* MW: Pendimethalin follwed by mechanical weeding; BPS *fb* MW: Bispyribac sodium followed by mechanical weeding; BPS: Bispyribac sodium; PDM: Pendimethalin application of herbicide was done in standard spacing (20 cm), and mechanical weeding (twice) was done in standard spacing (25 cm), considering the second weeding at 40 DAE. Sequential mechanical weeding i.e. MW 20 *fb* MW 40 recorded significantly higher weed control efficiency i.e. WCE (79.15) at 30 DAE compared to sequential application of herbicides (CM) i.e. PDM *fb* BPS (72.82). Among the four IWM practices tested in the experiment, only BPS *fb* MW30 + 20 cm recorded WCE at par with sequential mechanical weeding. It was also notable that under IWM practices, 20 cm spacing recorded higher WCE than 25 cm row spacing at 30 DAE (Table 2.7).

Statistically, all the weed management treatments recorded yield at par with weed free plots, however, the values differed substantially in following the order: Weed free check >BPS *fb* MW >MW >PDM *fb* MW >CW >weedy check. MW gives an alternative option to herbicide usage which is not only environment friendly, but also promotes soil aeration leading to plant growth and development. Though non-significant, 20 cm row spacing recorded slightly better grain yields than 25 cm row spacing. This could be due to higher plant population with closer spacing. However, B:C ratio followed a different order i.e., BPS *fb* MW >PDM *fb* MW >MW >CW. The IWM either with BPS or PDM recorded significantly higher B:C ratio than CW and MW. Even the cost of fuel and weeder hiring charges could not negatively impact the net returns and B:C ratio as compared to CW (Table 2.7).

Another experiment was conducted to identify and evaluate the premix herbicide and dosage of application to achieve optimum weed management and rice grain yield in wet DSR. The test variety '*Naveen*' was sown 20 cm apart using 40 kg seed rate. Application of Florpyrauxifen- benzyl alone and its combination with Cyhalofop-butyl were tested and compared for their weed control efficacy in wet- DSR. Application of Florpyrauxifen- benzyl + Cyhalofop-butyl 12% EC (w/v) @150 g ha^{-1} recorded at par grain yield and weed control indices to the standard check (Bispyribac sodium @ 30 g ha^{-1}). Values of weed control indices *viz*., Weed Control Efficiency, Weed Control Index, Weed Persistence Index, Crop Resistance Index, Treatment Efficacy Index, Weed management Index, enhanced with Florpyrauxifen- benzyl + Cyhalofop-butyl 12% EC (w/v) @150 g ha^{-1} compared to standard check (Table 2.8).

Development and refinement of farm implements, post-harvest and value addition technologies for small farm mechanization

Optimization of extrusion process parameters for obtaining extruded product with maximum nutrient retention and acceptable sensory and functional properties

A twin-screw extruder was utilized for developing a fortified rice-based ready-to-eat (RTE) extrudate, incorporating

Table 2.8. Effect of treatments on different crop and weed indices at 30 and 60 DAS in wet-DSR.

	Weed Control Efficiency		Weed Control Index		Weed Persistence Index		Crop Resistance Index		Treatment Efficacy Index		Weed management Index	
	30 DAS	60 DAS	30 DAS	60 DAS	30 DAS	60 DAS	30 DAS	60 DAS	30 DAS	60 DAS	30 DAS	60 DAS
FPB+CFB 120 g/ha	68.6	67.2	50.5	33.8	0.63	0.49	4.5	4.2	1.5	1.5	0.71	0.73
FPB+CFB 150 g/ha	77.9	74.8	64.6	54.0	0.62	0.55	7.7	6.9	2.5	2.2	0.72	0.75
FPB+CFB 180 g/ha	75.6	61.6	75.5	33.3	1.00	0.58	4.0	2.8	1.3	0.8	0.43	0.53
FPB+CFB 360 g/ha	84.4	65.5	85.9	46.8	1.11	0.65	5.1	2.8	1.1	0.5	0.22	0.28
FPB 25 g/ha	58.4	63.4	41.5	26.3	0.71	0.50	2.9	3.3	1.0	1.1	0.72	0.66
FPB 30 g/ha	57.9	61.4	43.1	20.1	0.74	0.48	2.5	2.9	0.9	1.0	0.67	0.63
BPS 30 g/ha	68.6	70.3	54.4	43.5	0.69	0.52	4.8	5.2	1.6	1.7	0.74	0.72
Weed free	100	100	100	100	-	-	-	-	-	-	0.68	0.68
Unweeded control	0.0	0.0	0.0	0.0	1.00	1.00	1.0	1.0	0.0	0.00	-	-

[FPB: Florpyrauxifen- benzyl; CFB: Cyhalofop-butyl; BPS: Bispyribac sodium] black rice, millet, pulses, and green leafy vegetables to enhance nutritional and functional aspects. The impact of extrusion parameters (Barrel temperature, Screw Speed, and Feed Moisture content) on the quality of the fortified rice extrudates was investigated. Variations in nutritional factors (anthocyanin) and specific textural/sensory attributes such as hardness and colour were notable, however no significant differences were found in physical and functional parameters. Numerical optimization was employed to improve process parameters, resulting in a fortified rice extrudate with increased protein and anthocyanin levels, achieving enhanced functional and textural properties (Fig. 2.10).

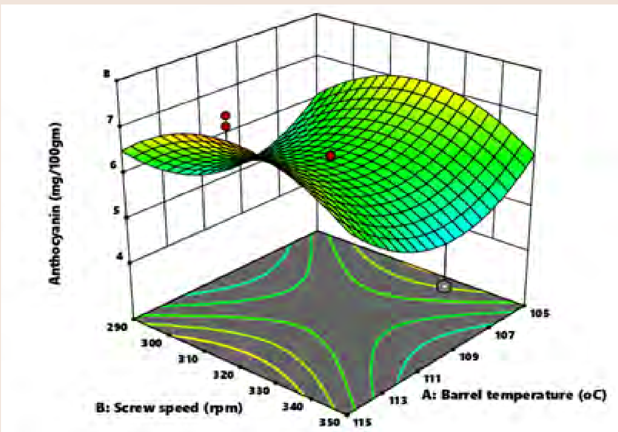


Fig. 2.10. Response surface plots showing the interaction effect of extrusion processing parameters on Anthocyanin Content (Screw speed vs Barrel temperature)

[$\text{Anthocyanin} = 6.17 + 0.1830\,A + 0.0190\,B - 1.13\,C - 0.0200\,AB - 0.2175\,AC + 0.0575\,BC + 1.14\,A^2 - 0.9736\,B^2 - 0.2236\,C^2$

(A= Barrel Temperature (°C); B= Screw Speed (rpm); C= Feed Moisture (%))]

Fig. 2.11. Fortified Rice Extrudates.

Formulation and standardization of nutritionally rich fortified rice cookies from specialty rice varieties like CR-Dhan 311 and CR-Dhan 315 and Black rice to combat malnutrition

This study aimed to develop fortified rice cookies enriched with functional ingredients and minerals, incorporating high protein, high zinc, and anthocyanin-rich black rice varieties, along with millets. The formulation featuring high protein rice, high zinc rice, and black rice at different percentages received the highest preference on a 9-point hedonic scale. While all formulations scored moderately above 7.0 on organoleptic assessment, those with increased black rice content showed slightly higher scores, attributed to superior sensory parameters like color, flavor, and texture. The inclusion of specialty rice varieties significantly enhanced product acceptability as compared to the control (only wheat flour) (Fig. 2.11 and 2.12).

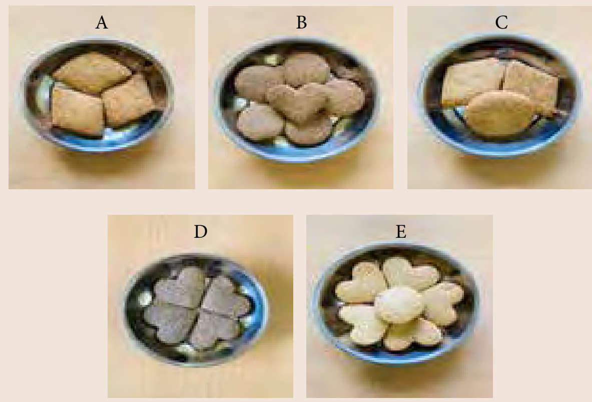


Fig. 2.12. Fortified Rice Cookies A. High Zinc, B. Anthocyanin rich, C. High protein, D. anthocyanin rich and E. control sample (only wheat).

Effect of fermentation on physico-chemical properties of rice water and its suitability as health drink

Two rice varieties (Pooja and Geetanjali) were separately dish-cooked and pressure-cooked until mushy, and the resultant rice water underwent fermentation at 37°C. Initial pH, slightly alkaline at 7.41-7.98, decreased to 3.41-4.01 after 36 hours, indicating acidity. Electrical conductivity (EC) increased to 0.404-0.432 µS cm^{-1}. Total flavonoid content (TFC) increased from 12.7 to 14.1 mg100 g^{-1}, and total sugars increased from 19.1 to 51.6 g g^{-1} at 36 hours, suggesting increased antioxidant compounds (Table 2.9). Dish cooking produced superior-quality fermented water with a sweet aroma, highlighting the potential health benefits from increased flavonoids and phenols. The findings underscore the promise of rice-based drinks as potential antioxidant-rich health beverages. Thus, rice-based drink can act as a health drink.

Development and performance evaluation of IoT based smart real-time irrigation Scheduling system for Rice

Development and performance evaluation of IoT based smart real-time irrigation for rice was conducted, using the

Table. 2.9. Physicochemical properties of rice samples at different time intervals.

Parameters		Geetanjali		Pooja	
		D. C	P. C	D. C	P. C
pH	0 hr	7.41	7.98	7.7	7.86
	12hr	6.9	7.69	5.35	5.12
	24hr	4.35	4.72	3.89	3.55
	36hr	3.92	4.01	3.5	3.41
Temp.	0hr	37.1	36.9	36.25	37.2
	12hr	37.5	37.6	36.9	37.5
	24hr	37.5	37.5	37	37.9
	36hr	37.7	37.4	37.5	37.6
EC (µS)	0hr	0.361	0.343	0.389	0.376
	12hr	0.367	0.361	0.401	0.385
	24hr	0.392	0.379	0.457	0.392
	36hr	0.401	0.396	0.432	0.404
Flavonoids (mg/100g)	0hr	12.756	14.089	12.689	13.756
	12hr	15.24	16.251	17.222	15.462
	24hr	31.533	23.489	21.411	16.311
	36hr	45.222	18.378	28.953	20.364
Total phenols (mg/100g)	0hr	10.97	12.73	18.24	30.45
	12hr	15.12	13.12	20.56	32.54
	24hr	38.68	20.97	26.53	33.01
	36hr	42.16	19.91	32.15	34.11
Total sugars (mg/g)	0hr	16.8	28.4	15.5	24.6
	12hr	21.2	31.5	19.1	26.5
	24hr	28.8	45.7	22.3	33.6
	36hr	31.2	51.6	27.1	46.7

[*D.C: Dish-cooked; *P.C: Pressure-cooked]

Microcontroller circuitry to sense the real-time field soil moisture content for targeted automated pipe irrigation system. The system detects both the real-time outputs of soil moisture sensor and the rainfall detector. In case any rainfall is detected during the pump operation time, the circuitry is able to stop the irrigation pump, and send a signal to stop the solenoid valve at a time to avoid wastage of irrigation water.

Enhancing water use efficiency in rice-based cropping system

Drought-resistance rice variety with water-saving irrigation scheduling method reduces greenhouse gas emissions while enhances water productivity

To examine the effect of rice varieties with drought QTLs and water saving management practices on water productivity and greenhouse gas emission, a field experiment was conducted during *rabi* season in split plot design. The main plot consisted of six irrigation treatments: (a) Fully irrigated condition as the control, (b) Re- irrigation at -20 kPa soil water potential (SWP), (c) Re- irrigation at -30 kPa SWP, (d) Re- irrigation at -40 kPa SWP (e) Re- irrigation at -50 kPa SWP, (f) Re- irrigation at -60 kPa SWP, whereas the subplot consisted of five rice varieties: V1 = DRR Dhan 44, V2 = Swarna Shreya, V3 = CR Dhan 801, V4 = CR Dhan 802, V5 = IR 64. Greenhouse gases were collected from the differentially irrigated plots and samples were analysed in Gas Chromatograph. For all the varieties, exposure of different levels of soil moisture deficit stress resulted in decline in grain yield as compared to the continuous flooded condition, however, the quantum of decrease varied. When the varieties having drought QTLs were subjected to mild water deficit stress (up to -30 kPa), the decrease in grain yield varied from 9-12%, whereas the exposure to moderate water deficit stress (up to -40 kPa) resulted in decline in grain yield up to 12-21%. The exposure to severe water deficit stress (up to -60 kPa) resulted in yield decline up to 46-56%. Contrary to this, the exposure of different levels of water deficit stress to drought-sensitive varieties resulted in yield decline by 33% under mild water deficit stress, by 50% under moderate water deficit stress and by 69% under severe water deficit stress. Water productivity (Wp) varied between 0.29 to 0.65 g grain kg^{-1} water, and the highest value was observed under -40 kPa for all the QTL containing varieties, however, for IR 64, highest Wp was observed at -20 kPa. Seasonal cumulative CH_4 emission was depended on soil water regime during the rice-growing season, while it followed the order: Continuously flooded > -20 kPa > -30 kPa > -40 kPa > -50 kPa = -60 kPa. Compared to the continuously flooded treatment, the global warming potential declined under different levels of water deficit stress (Fig 2.13).

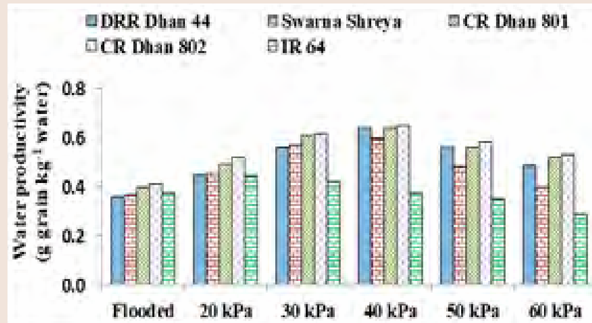


Fig. 2.13. Water productivity of different varieties under different levels of water deficit stress.

Conclusion

The Crop Production Division has engaged in various research activities, resulting in the standardization of precision nitrogen application using optical sensors and the creation of an IoT-based real-time irrigation scheduling system for rice production. A cost-effective strategy for weed management in dry direct-seeded rice cultivation has been developed. Research on organic farming has been adopted with respect to N uptake of different varieties, soil microbial functions and diversity along with performance of rice-based cropping system, advocating scientific practice of natural farming. Furthermore, a block-wise assessment of drought vulnerability and precipitation index has been established for selected districts in Odisha. Rice straw burning scenario in Odisha was assessed over a period of time and most sensitive districts were identified. In the realm of rice straw management, an innovative patented technology involving microbial-mediated rice straw pulp preparation has been devised, having the potential to reduce energy consumption by 65-70%, thereby contributing to a decrease in carbon footprint in the production of pulp plates from rice straw. The microbial-mediated technology has been standardized for both in-situ and ex-situ management of paddy straw residues. Additionally, nutritionally enriched fortified rice cookies, boasting high protein, zinc, and anthocyanin content, have been formulated and standardized using specialty rice varieties such as CR-Dhan 311 and CR-Dhan 315, along with black rice.

PROGRAMME

03

Biotic Stress Management in Rice

The Crop Protection Division conducts research to develop safe and sustainable technologies against insect pests, diseases, nematodes and other non-insect pests in rice. The division currently focuses on understanding key chemicals and mechanism in the interactions between host, pest-pathogen and natural enemies while uncovering donors for multiple pest resistance and comprehending the dynamics of insect, pathogen population under changing climate scenarios. Studies are undertaken to develop smart pest management techniques and make use of naturally occurring resources and new pesticide molecules. Integrated pest management strategies are also employed in the farmers' fields for sustainable management in different rice ecologies.

Identification and characterization of donors against biotic stresses

New sources of resistant donor against Brown Plant hopper (BPH) and White Backed Plant hopper (WBPH)

Out of 100 germplasms screened against BPH and WBPH in control condition, only IC 298361 and IC 316446 were found moderately resistant to BPH having damage score 3. The germplasm IC 316446 was moderately resistant to WBPH having damage score three.

Morpho-Biochemical factors governing resistance to Asian rice gall midge, *Orseolia oryzae* (Wood-Mason)

Altogether 202 rice genotypes were phenotyped against Asian rice gall midge, *Orseolia oryzae* (Wood-Mason) and the mechanism of resistance was studied. Morphological factors of rice plant for adult settlement and egg laying indicated that the susceptible genotypes were preferred more than the resistant genotypes in a free choice test. First instar maggots were found and did not continue their growth on resistant genotypes further. However, in susceptible genotypes, they molted successfully and emerged as adults. No choice tests revealed that the emergence of adults in susceptible genotypes took lesser duration than in resistant genotypes. Higher adult sex ratio was found in susceptible genotypes. Estimation of biochemical components in rice shoot apices of selected genotypes revealed that higher levels of total phenols, wax content, total flavonoids and total free amino acids were present in the resistant genotypes. Still, the number of total sugars, reducing sugars and total protein contents were significantly higher in the susceptible genotypes.

Identification of resistant donors to rice leaf folder, *Cnaphalocrocis medinalis*

Field and net house screening of 94 Odisha landraces with two standard checks TKM6 and TN1 against leaf folder revealed significant variation. The trusted genotypes were classified into different responsive groups. 32 genotypes (33.33%) were found resistant (scored 1-3) with ADLR ranging from 7.16% to 28.46% and ADAR ranging from 8.71% to 29.56% along with the resistant check, TKM6. Likewise, 26 genotypes (27.08%) were classified as moderately resistant (score 5) in both field and net house screening with ADLR range from 40.30% to 59.80% and ADAR range from 31.30% to 49.09%. Nineteen genotypes (19.79%) fell under susceptible category (score 7-9) in both the screening techniques with ADLR between 61.06%-111.57% and ADAR range between 54.21%-102.58%. Landraces like Manipuri (black), Mahasuri, Jangalijata, Pahadiabanki, Kalajeera (I), Benabahar, Biradiabankoi, Chamarmani, Balibhuta, Basudha, Bayabhanda, Bhalunki, Bhatta, Champasola, Kadalikenda, Kalakusuma, Kaliasaru, Kanakachampa, Kanhav, Kansapurimajhijhuli, Karpuramoti, Makadhan, Makarkand, Malata, Menaka, Mogra, Nagara, Padmakesari, Pandukalyan, Saraswati and Radhajugal were found resistant to leaf folder.

Morpho-biochemical characterization of Odisha landraces against rice leaf folder

Based on the screening result from all the categories certain genotypes were selected for morpho biochemical analysis. Resistant genotypes *viz.*, Benabahar, Kalajeera(I), Basudha, Baya Bhanda, Bhalunki, Bhatta, Manipuri(black), Mahasuri, Jangalijata, Pahadiabanki, Kalakusuma, Kaliasaru, Kanhav, Kansapuri majhijhuli, Menaka, Mogra, Nagara, Padmakesari, Radhajugal; moderately resistant genotypes *viz.*, Agnisar, Ankul, Chinamali-k, Maguramanji, Maharaji, Mahipal-B, Majhalijhuli, Mayurkantha-k, Motahalkal, Nadalghanta and susceptible genotypes *viz.,* Ganjam Ratnachudi, Nimei, Kathidhan, N.umerchudi, Safari, Ramkrushna bilasha were chosen for morph biochemical studies.

The morpho biochemical study showed that leaf folder damage has significant negative correlation with plant height and leaf length ($r = -0.903$ and -0.862, $P<0.001$, respectively) while leaf width association has significant positive reaction ($r = 0.773$, $P<0.001$). Among the different plant metabolites analyzed, total soluble sugar and soluble protein showed significantly positive correlation ($r = 0.778$ and 0.788, $P<0.001$, respectively) with leaf folder damage, conversely phenol ($r = -0.651$, $P<0.001$) and antioxidative enzymes showed significantly negative correlation. When these rice genotypes were exposed to leaf folder larval feeding, they exhibited defense responses characterized by reduction in the level of sugars and proteins, accumulation of phenolic compounds and upregulation of antioxidative enzymes.

Molecular characterization of Odisha landraces against rice leaf folder

Molecular characterization of 94 Odisha landraces was conducted in this study where the different landraces were grouped into three major clusters. Cluster I(SG1) included most of the resistant cultivars, whereas Cluster II (SG2) had mostly susceptible types. Likewise, cluster III(SG3) contained mostly moderately resistant genotypes (Fig. 3.1).

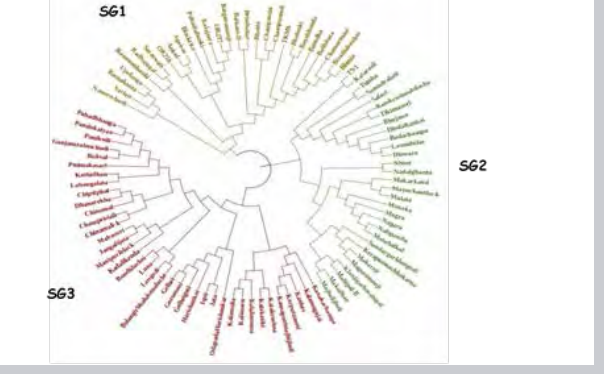


Fig. 3.1. Clustering pattern of land races along with standard checks.

Analysis of molecular variance revealed 12% variation among populations and 88% variation within the population of tested genotypes. The marker-trait association analysis using simple linear regression showed that the markers RM 162 and RM 284, located on chromosomes 6 and 8, respectively, were found to be significantly associated with leaf folder resistance (Fig. 3.2).

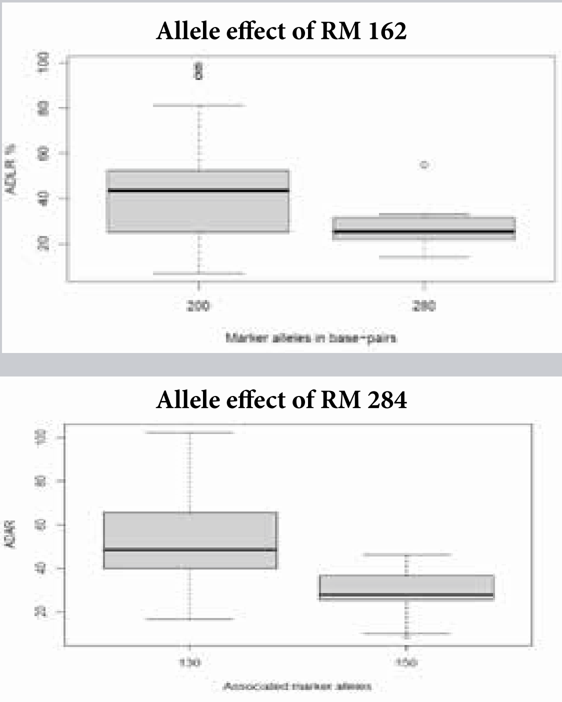


Fig. 3.2. The allelic effect of Marker RM 162 and RM 284 associated with ADLR and ADAR, respectively.

Phenotyping of rice varieties against Angoumois grain moth (*Sitotroga ceralella*)

About 80 popular rice varieties were evaluated for assessing the extent of damage caused by *Sitotroga cerealella*. Among them 38 varieties showed moderate resistance, 37 susceptible and 5 highly susceptible responses. It was observed that all the susceptible varieties had higher adult emergence and per cent weight loss of grain content compared to the moderately resistant ones. Some varieties *viz.,* CR Dhan 1014, CR Dhan 300, Phalguni, Jayanti Dhan and Padmini showed highest weight loss, indicating that they are highly susceptible to *S. cerealella* attack.

Phenotyping for bacterial blight disease resistance

Altogether 81 lines, comprising 27 recently released NRRI varieties and 54 ARC collections were phenotyped against *X. oryzae pv oryzae*. Out of 27 NRRI varieties, three varieties namely CR Dhan 800, CR Dhan 326 and CR Dhan 412 showed resistance and rest showed susceptible reaction. Out of 54 ARC lines, five showed moderate resistance; CR-18, ARC 55758, CR-29, SB-53, SB-27 and the rest of the genotypes showed moderate to high degrees of susceptibility.

Phenotyping for sheath blight disease resistance

Out of 76 NRRI released varieties, 53 Assam Rice Collections, 12 New Generation Rice lines and 40 OUAT released varieties screened for resistance against sheath blight disease under artificial inoculation; 7, 5, 2 and 4 entries, respectively were found moderately resistant against sheath blight fungus.

Screening for resistant donor to False Smut (FSm) (*Ustilaginoidea virens*) pathogen

Out of 179 Assam rice collections (ARC), 48 were short listed after repeated screening under natural field condition during the previous years (2018-22). These 48 ARC were screened both at field under artificial inoculation condition and 19 found non-infected to FSm. These 19 ARC were further tested under artificial inoculation condition in net house. The promising ARC resistant to FSm are ARC-5769, 5842, 5940, 5982, 6605, 6606, 6628, 7009, 7038 and 7085.

Screening of rice germplasm against sheath rot disease

A total of 278 landraces from Manipur collection were screened for resistance to sheath rot disease under field conditions. The results showed that 16 were resistant, 114 were susceptible, 101 were moderately susceptible, and 47 exhibited moderate resistance to the disease. The resistant genotypes included AC 9002, AC 9004, AC 9038, AC 9044, AC 9052, AC 9058, AC 9064, AC 9067, AC 9074, AC 9076, AC 9070, AC 9086, AC 9102, AC 9118, AC 9119 and AC 9136.

Evaluation of rice germplasms against grain discoloration disease and identification of resistant genotypes

A set of 160 rice accessions were evaluated for their reactivity against grain discoloration disease following (0–9) scale of

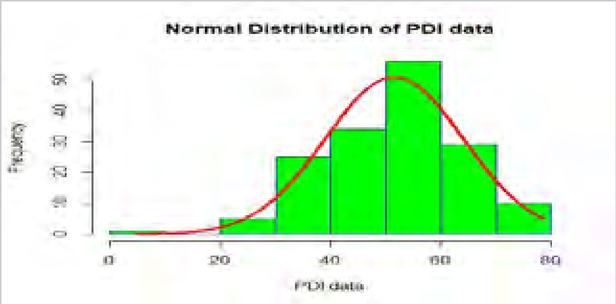


Fig. 3.3. Frequency distribution of grain discolouration among diverse rice accessions.

Fig. 3.4. Resistant and susceptible rice accessions for grain discolouration disease.

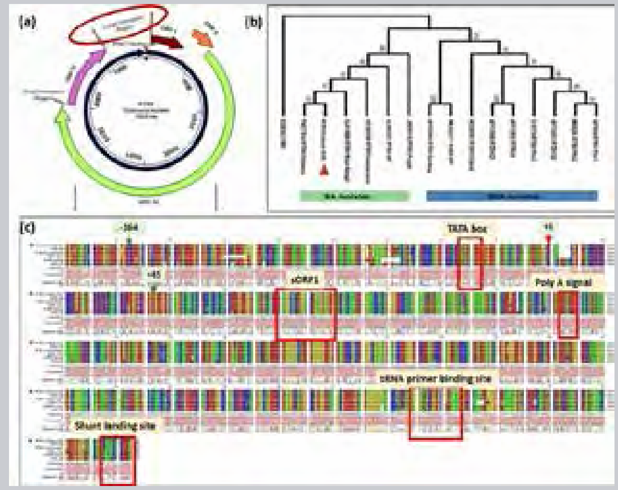


Fig. 3.5. Molecular characterization of RTBV-Cuttack-2020 isolate based on complete large intergenic region (LIGR). (a) Indicates the position of LIGR in RTBV genome. RTBV isolate Chinsura, WB (NCBI # FN377814) was used as reference genome. (b) Phylogenetic analysis of nucleotide sequences of complete LIGR of RTBV-Cuttack-2020 along with previously reported SA and SEA isolates. The present isolate is indicated by red arrow. (c) Nucleotide sequence alignment of LIGR of RTBV-Cuttack-2020 with previously reported Indian RTBV isolates. The present isolate RTBV-Cuttack-2020 is indicated by * mark.

IRRI, Philippines. Out of 172 rice genotypes, none of the accessions showed either 0 or 1 score. Disease percentage varied from 4.58% to 78.35 %. The normality of distribution of genotypes in the population was tested using Shapiro Wilks' test and 'p' value indicated the normal distribution of disease response within the population (Fig. 3.3). The variety CR Dhan 303 was found to be promising with the least disease incidence (4.58%) (Fig. 3.4). 64 accessions showed the percent disease index between 26 – 50 %. The composition of the population included a range of genotypes from highly susceptible to highly resistant responses to grain discoloration.

Monitoring of viral diseases in rice germplasms

Total 71 germplasms procured from NRRI Gene Bank were transplanted for monitoring virus diseases (e.g., Tungro) of rice. None of the symptoms of Tungro disease was found on the germplasms. No other virus diseases were also observed. However, incidence of other diseases and pests was recorded meticulously. Comprehensive phenotyping of all germplasms was also done in respect to plant height, number of tillers, panicle length, panicle weight, total number of spikelets, number of filled grain, number of chaffy grain.

Evolutionary dynamics of rice tungro disease (RTD) causing virus

The RTBV isolate collected from the experimental farm of ICAR-NRRI, Cuttack (RTBV-Cuttack-2020) was characterized based on the complete large intergenic region (LIGR) following PCR-based fragment amplification, cloning, and sequencing. The DNA sequence data of RTBV-LIGR of the Cuttack-2020 isolate was compared with the LIGR of previously reported isolates available in the NCBI database (Fig. 3.5a). The nucleotide sequence of complete LIGR (819 nucleotides) of RTBV-Cuttack-2020 showed 95.42-97.23% identity with SA isolates, while only79.40-80.19% identity with SEA isolates**.** The phylogenetic analyses also revealed the grouping of present isolate (RTBV-Cuttack-2020) within SA cluster having previously reported Indian isolates (Fig. 3.5b). The multiple alignments of LIGR of RTBV-Cuttack-2020 with SA isolates (Fig. 3.5c) revealed that TATA box consensus, small ORF1 (sORF1), poly A signal, tRNA primer binding site and shunt landing site of LIGR remained conserved in the present isolate including other RTBV isolates reported from India. Overall, the molecular characterization of the new RTBV isolate (Cuttack-2020) from eastern India confirmed its homology with previously reported Indian isolates. This in turn confirmed that the genomic features of the isolates remain conserved over more than ten years. However, full genome characterization is in progress to know the actual status.

Identification and characterization of donors against rice root knot nematode

A total of 99 accessions which included breeding lines, land races and improved varieties were screened against the rice root knot nematode (*M. graminicola*) by artificial inoculation @ 1J2 gm^{-1} of soil under biotic stress screening in the net house conditions. Out of the 99 accessions 33 were highly susceptible, 39 susceptible, 24 moderately susceptible and 3 moderately resistant to *M. graminicola* infection. Lines NEH5, TRB406, TRB438 i.e. (Abor Red-4, IR 09A228 and IR

122310:7-2-2) exhibited moderately resistant reaction to the rice root knot nematode (Fig. 3.6).

Fig. 3.6. Screened susceptible rice varieties exhibiting high galling percentage.

Ecology, diversity and interaction of plant, pests & natural enemies in rice

Community structure of hymenopteran parasitoids associated with upland and low land paddy

During *kharif* 2022, a survey was carried out for parasitoids associated with major pests of rice at various plant stages from KVK, Santapur, an upland rice station and in lowland fields of ICAR-NRRI. Altogether 21 species of parasitoids belonging to 11 Hymenopteran families *viz.*, Ichneumonidae, Braconidae, Chalcididae, Eurytomidae, Eulophidae, Trichogrammatidae, Elasmidae, Scelionidae, Mymaridae, Bethylidae, Dryinidae under four super families, Ichneumonoidea, Chalcidoidea, Chrysidoidea and Bethyloidea were observed in both ecologies. Results indicated that overall abundance of parasitoids was higher for upland rice compared to lowland rice. Certain parasitoids like *Tetrastichus howardi, Tetrastichus schoenobii Telenomus dingus, Trichogramma japonicum, Amauromorpha accepta, Charops bicolor, Apanteles flavipes, Cardiochiles* sp., *Stenobracon nicevielli* and *Chelonus insularis* are more abundant in upland rice compared to lowland rice (Fig. 3.7). Whereas, *Goniozus* sp., *Brachymeria excarinata, Pseudogonatopus* sp., *Haplogonatopus* sp., *Eurytoma setitibia, Elasmus albotibialis, Anagrus* sp., *Isotima javensis, Temelucha phillippinensis, Xanthopimpla flavolineata, Macrocentrus phillippinensis* are the parasitoids which are more abundant in lowland rice compared to upland rice.

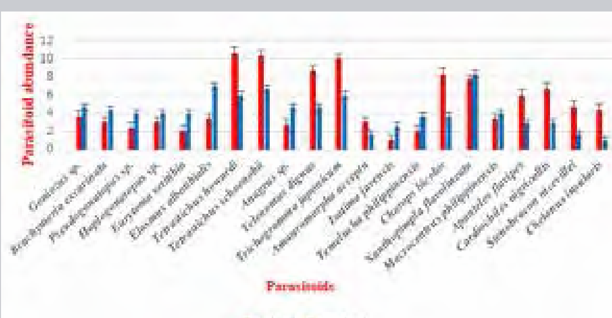


Fig. 3.7. Abundance of parasitoids associated with paddy in upland and lowland rice.

Exploring host preference and ovipositional patterns of *Goniozus triangulifer* Kieffer (Hymenoptera: Bethylidae) on rice leaf folder, *Cnaphalocrocis medinalis*

The host stage preferences, ovipositional behaviour, and the sex ratio of *Goniozus triangulifer* on paddy leaf folder was studied. Choice and no-choice tests utilizing various leaf folder larval instars revealed a pronounced affinity for 4th instar leaf folder larvae, followed closely by 3rd instars, while 1st and 2nd instars were disregarded due to their diminutive size. In the choice experiment, the findings indicated that 4th instar larvae were the most preferred stage for *G. triangulifer*, with a parasitization rate of 40.31 ± 1.69 per cent and 47.31 ± 1.55 in the no-choice experiment (Fig. 3.8). Male took 11.50 ± 0.22 days to develop from egg to adult, which was less than the female developmental period of 13.40 ± 0.16 days in choice test. Similarly, In the no-choice experiment, the mean developmental durations of each pre-adult stage were 11.60 ± 0.30 days for males and 13.90 ± 0.27 days for females. The adult longevities of males and females were 4.30±0.15 and 6.30 ± 0.15 days, respectively. Oviposition preference tests underscored the parasitoid's affinity for 4th instar leaf folder larvae, attributed to their substantial size. Additionally, a female-biased sex ratio (1:3.8) among the parasitoid's offspring was identified. Understanding the host preference and oviposition behavior of this parasitoid is pivotal in the development of effective biological control strategies, promoting sustainable pest management practices in rice agriculture while reducing reliance on synthetic chemicals.

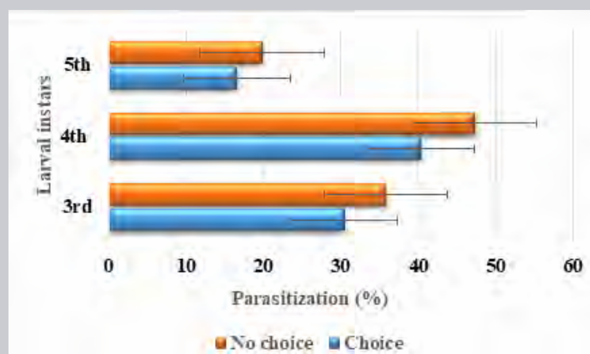


Fig. 3.8. Parasitization per cent of leaf folder larval instars by *G. triangulifer* in no-choice and choice experiments.

Molecular diversity of *Ustilaginoidea virens* in agro-ecological zone of north, east and north-eastern India

Moderate level of genetic diversity was observed among 112 *U. virens* isolates collected from eight agro-ecological region covering states of North, East and North-eastern of India. Allele frequency was in the range of 0.598 to 0.748. Genetic diversity was highest (0.493) among the isolates belonging to eastern coastal plains while it was lowest (0.311) in North-eastern hills. The dendogram analysis have shown three main clusters (Fig. 3.9). Cluster I comprised almost all isolates from one region i.e. Northern plains (NP) includes isolates mostly from UP while Cluster II formed the highest group

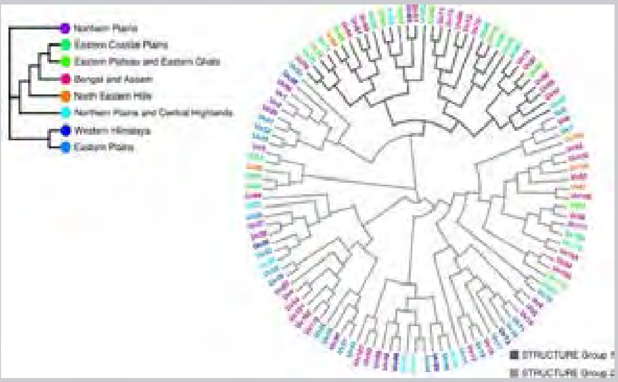


Fig. 3.9. Neighbor-joining tree constructed based on Rogers 1972 distance measures.

and isolates are included from five agro-eco regions *viz.*, Eastern coastal plains (ECP), Eastern plateau and eastern ghats (EP & EG), Bengal and Assam zone (BAZ), North eastern hills (NEH), Northern plains and central highlands (NP & CH). These group accumulated isolates from almost all the eastern (WB, Odisha, few eastern UP), north-eastern (Assam, Meghalaya) and central (MP) states. The Cluster III mainly grouped isolates from two agro-eco regions i.e. Western Himalayan region (WHR) (isolates of Himachal Pradesh, Uttarakhand) and Eastern plain region (EPR) (isolates from parts of UP). Structure analysis grouped mainly two clusters. Analysis of molecular variation showed more genetic variation within populations (92%) and less among populations (8%). Highest genetic differentiation (0.24) was found between population of Eastern plateau eastern ghats and Eastern plains whereas lowest differentiation (0.03) was observed among the population of Eastern Plain and Northern Plains & Central highlands. But no differentiation was observed between populations of BAZ and NEH; populations of Northern plains and Western Himalaya & Eastern plains. The study will help in agro-eco region based management strategy of false smut disease of rice.

Analysis of mating type of Indian isolates of false smut pathogen

Sexual reproduction and development in ascomycetous fungus is controlled by a single locus called mating-type locus 1 (MAT1), which has two idiomorphs, MAT1-1 and MAT1-2 (Fig. 3.10). At the MAT1 locus, heterothallic strains have either MAT1-1 or MAT1-2, whereas homothallic strains have both idiomorphs. Two sets of primers (MAT1-F1/MAT1-R1, MAT2-F1/MAT2-R1; were used to analyze 74 isolates collected from north, east and north-eastern India. Mating type analysis was done of 74 isolates collected from different states of north, east and north-eastern India. Out of 74 isolates, 42 were found as homothallic and 32 were found as heterothallic.

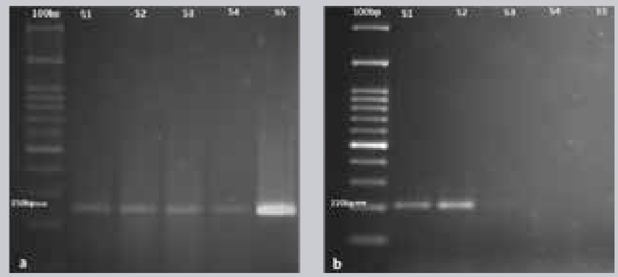


Fig. 3.10. PCR amplification of mating-type gene fragments in 51 to 55 *U. virens* isolates (a) MAT1-1 gene (b) MAT1-2 gene.

Use of Precision Tools and Techniques in Rice Insect Pest and Disease Management

Classification of rice false smut severity using hyperspectral spectrometry

Rice false smut (RFS) caused by *Ustilaginoidea virens* has emerged as a serious grain disease in rice production. The disease is characterized by the transformation of individual rice florets into false smut balls. In current research work, the purpose is to characterize the RFS's spectral reflectance in order to identify its sensitive spectral region. The RFS damage was classified based on the Disease Severity (DS) percent of RFS samples and the damage scale of RFS (Scale 7 and 9). Result shows that the healthy sample has higher reflectance value than the RFS samples in all the spectral regions (Fig 3.11). Change in the reflectance for the infected RFS sample as compare to the healthy plant was more pronounced in the 500-552, 677-774, and 800-834 nm (common spectral region identified after performing spectral derivative analysis (SDA)) having correlation coefficient 'r' above 0.6. The analysis of the reflectance change as a function of wavelength (1^{st} derivative) showed that the Visible (VIS) and Near Infrared region (NIR) have high correlation with the DS. The Sensitivity Analysis (SA) was also done to identify the sensitive spectral regions (506-580 and 646-693) nm based on band depth (BD). Identifying the spectral sensitive regions using SA, the Continuum Removal Analysis (CRA) was done to identify the absorption dips (512 and 684) nm. Finally, seven bands (512, 522, 545, 684, 730, 756 and 812) nm were identified as sensitive bands for RFS infection. But, as the bands were in close proximity to each other and to reduce data redundancy, the RELIEFF algorithm was used to solve the issue based on accuracy model. The combination of identified sensitive bands from all the methods (SDA, CR and SA) were done and it was found that the combination of bands 522, 684 and 730 nm gave us maximum accuracy of 78.3 per cent.

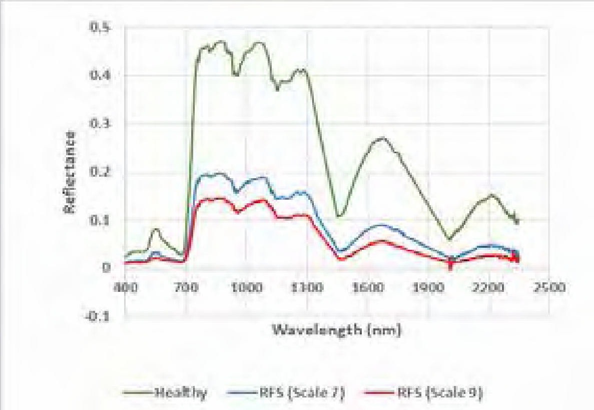


Fig. 3.11. Spectral signature of Healthy vs RFS infestation at different damage level.

Search for novel mediators in plant defense response to pathogenic infections in rice through molecular techniques

Transcriptome analysis of Rice-*Fusarium proliferatum* interaction

The pathogen *F. proliferatum* was inoculated on Tapaswini variety and the sheath samples were collected from 0 h, 24 h, 48 h and 72 h after pathogen inoculation. Differential expression analysis for the sample comparisons are performed using cuffdiff program of cufflinks package. Absolute (Log2 fold change) ≥ 2 along with p-value ≤ 0.01 and p-value ≤ 0.05 separately were used as cutoffs for identifying up and down regulated genes and isoforms. Total reads are around 20 million, mean phred score is > 35, raw read length is 150 bp, aligned read percentage is > 90.

Comparison (A vs B)	Up-regulated in 'B' compared to 'A'	Down-regulated in 'B' compared to 'A'
0HR vs 24HR	488	348
0HR vs 48HR	446	299
0HR vs 72HR	748	525
24HR vs 48HR	93	47
24HR vs 72HR	314	172
48HR vs 72HR	301	172

During the 0H vs 24H interval, Tyrosine aminotransferase (Os02g0306401), Flavonol sulfotransferase (Os08g0239900), and Transmembrane amino acid transporter protein (Os06g0228500) exhibited upregulations of 8.11-fold, 7.9-fold, and 7.6-fold, respectively. In contrast, during the 0H vs 24H interval, Ossub38 - putative subtilisin homologue (Os04g0127300), Heavy metal-associated domain containing protein (Os05g0534500), and Ltpl159 - protease inhibitor/seed storage/ltp family protein (Os10g0505500) exhibited downregulations of 7.00-fold, 5.06-fold, and 4.88-fold, respectively. Similarly, during the 0H vs 48H interval, Circumsporozoite protein (Os04g0478000), Retrotransposon protein (Os08g0170700), and Tyrosine aminotransferase (Os02g0306401) exhibited high expression levels. Differentially expressed genes were identified in other comparison intervals. Selected genes will be validated further using RT-PCR for confirmation of transcriptomic data.

Elucidation of reactive oxygen species (ROS) signaling during *Oryza sativa-Xanthomonas oryzae* pv. *oryzae* interaction:

Oxidative burst, a first line plant defense against pathogen attack, has been characterized during interaction of *Xanthomonas oryzae* pv. *oryzae* (Xoo)/elicitors and *Oryzae sativa* in three resistant (Ratna, CR Dhan 311 and Improved Tapaswini) and three susceptible (TN1, Naveen and Annapurna) varieties. Overall, resistant varieties showed higher hydrogen peroxide (H_2O_2) production compared to susceptible varieties. Superoxide anions were found in higher concentration in plants inoculated with Xoo in comparison to plants sprayed with elicitors viz., Chitosan or Salicylic acid. Resistant varieties showed higher superoxide anions compared to susceptible varieties. Susceptible varieties had comparatively lower hydroxyl radical production at all-time intervals. Superoxide dismutase (SOD) activity was comparatively higher in Xoo treated plants upto 48 hpi. Improved Tapaswini had consistently high SOD activity among all the varieties tested. It was observed that Ratna, CR Dhan 311 and Improved Tapaswini had highest Catalase (CAT) activity attaining peak at 48 hpi while susceptible varieties had slower CAT acivity. Ratna had highest Guaicol peroxidase (GPX) activity upto 72 hpi. CR Dhan 311 and Improved Tapaswini also had similar higher GPX activity while all three susceptible varieties showed lower GPX activity. Both Ratna and Improved Tapaswini had higher Ascorbate peroxidase (APX) activity upto 48 hpi, while CR Dhan 311 had slightly lower value. Susceptible varieties had lower APX activity which is linked to lower production of oxidative burst radicals against which these anti-oxidative enzymes are activated. The oxidative burst generated during the interaction of rice with Xoo and elicitors was host's first line of defense against the invading pathogen. The two elicitors Chitosan and Salicylic acid acting as mimics of the pathogen could also induce ROS generation and antioxidative mechanism (higher in resistant varieties).

Mechanism of biocontrol and growth promotion by *Trichoderma*: Role of Volatile organic compounds

The effect of Volatile Organic Compounds (VOCs) released by *Trichoderma* for stimulation of plant growth, inhibition of pathogen and induction of resistance were studied and interestingly observed that different *Trichoderma* species behaving differently against different pathogens for example *Trichoderma erinaceum* could inhibit the growth of all four pathogens whereas, *Trichoderma pleuroticola* could supress the growth of *Bipolaris oryzae* only. In a closed chamber it was observed that the volatiles were effective to promote growth in Karuna and Sahbhagidhan seedlings. Identification of the VOCs were made using GC-MS and was observed that *Trichoderma erinaceum* is emitting 6-Pentyl-2H-pyran-2-one (6-PP) as the major volatile (84.10%). Interestingly, this VOC is already reported to have growth-promoting action, antimicrobial property and involvement in the over-expression of defence-associated proteins. *T. pleuroticola* and *T. erinaceum* were found to contain the compounds 1-Octen-3-ol and 3-Octanone, both exhibiting growth-promoting and antifungal activities. Besides, 3-Octanone comprised the major portion (15.83 %) of the VOCs produced by *T. pleuroticola.* The antifungal compounds, (Z) - Ocimene and 1, 3-Octadiene were detected in both the species. Dodecane & Tetradecahydro-anthracene from CRRI-TS-1; Propanoic acid, 2-pentyl-Furan, Acetophenone, Benzoic acid methyl ester, 2-heptyl-Furan, 2-chloro-Acetophenone & Neomethyl acetate & p-Menth-l-en-9-ol acetate from CRRI-TS-10 are some other compounds which have antimicrobial properties. Moreover, Dodecane and 2-pentylfuran also possess growth enhancing ability. N-Tridecane which is known to induce defense genes was identified from *T. pleuroticola.*

Molecular characterization of hymenopteran parasitoids associated with paddy Leaf folder

DNA barcodes of two species of parasitoids *Platyscelio* sp. and *Habrobracon syzygiumae* using mt COI were generated and submitted to NCBI to confirm their identity at molecular level under various taxonomic levels. The species are with fair distribution under two families *viz.,* Scelionidae and Braconidae of Hymenoptera. Generated sequences are deposited in the NCBI Database and the accession numbers are *Habrobracon syzygiumae* (OQ650010) and *Platyscelios* sp. (OQ685082).

DNA barcoding of *Platyscelio* sp. (Larval parasitoid of *Cnaphalocrocis medinalis*)

The nucleotide sequence of mitochondrial cytochrome oxidase I gene (mtCO1) of *Platyscelio* sp. (Fig. 3.12) was found to be of 595 bp. The blast analysis of the generated DNA sequence resulted in identifying the parasitoid to the family level Platygasteridae with 99.83 per cent sequence identity and query coverage of 99 per cent.

DNA barcoding of *Habrobracon* sp. (Larval parasitoid of *Cnaphalocrocis medinalis*)

The nucleotide sequence of mitochondrial cytochrome oxidase I gene (mtCO1) of *Habrobracon* sp. (Fig. 3.13) was found to be of 659 bp. The blast analysis of the generated DNA sequence resulted in identifying the parasitoid to the genus level *Habrobracon sp.* with 98.90 per cent sequence identity and query coverage of 96 per cent.

Fig. 3.12. *Platyscelio sp.*

Fig. 3.13. *Habrobracon sp.*

Plant protection molecules: efficacy, distribution, toxicity and remediation

Effectiveness of combination and new products in rice pest management

The combination insecticides (Chlorantraniliprole 20% SC 0.3 mL L^{-1} + Cartap hydrochloride 50% SC 2 mL L^{-1}+ Triflumezopyrim 10% SC 0.48 mL L^{-1}) at 25, 50 and 65 days after tillering (DAT) recorded highest grain yield (3.4 t ha^{-1}) followed by botanical and insecticide combination of (Neemazal 1% EC 2 mL L^{-1}+ Dhanuvit 2 mL L^{-1}+ Cartap hydrochloride 50% SC 2 mL L^{-1}) (3.2 t ha^{-1}). In control, the grain yield was 2.5 t ha^{-1}. These pesticide combinations were effective against stem borer and leaf folder during *kharif* 2022.

Uptake, translocation and partitioning of trifloxystrobin and tebuconazole in rice

Mobilisation of trifloxystrobin from shoot to root was slower. Results suggest tebuconazole may move faster within plant.

Exclusion of tebuconazole (1-14 ppb) to media was more in comparison to trifloxystrobin when sprayed on plants. Maximum quantity of trifloxystrobin and tebuconazole were fractioned in cell organelles. Higher affinity of trifloxystrobin was observed towards cell organelle and cell wall fractions of the rice plant as compared to tebuconazole.

Pesticide risk to the non-target organisms in small streams adjoining paddy fields

The risk assessment against the fishes, micro-invertebrates and algae were measured by risk quotient index (RQ) obtained by dividing the measured environmental concentration of pesticides and predicted no effect concentration values. Twenty-five pesticides out of the detected pesticides (n=55) had risk quotient values greater than 1. The highest RQ_{max} values were observed in case of fenpropathrin (1347) followed by cyfluthrin-3 (589). The highest RQ_{mean} value was observed in case of cyfluthrin, indicating higher toxicity to fishes, aquatic invertebrates and algae. The present study reveals that small streams were found to be polluted with pesticides and there is an urgent need to develop strategies for reducing the pesticide pollution in small streams and their harmful effects on non-target organisms (Fig. 3.14).

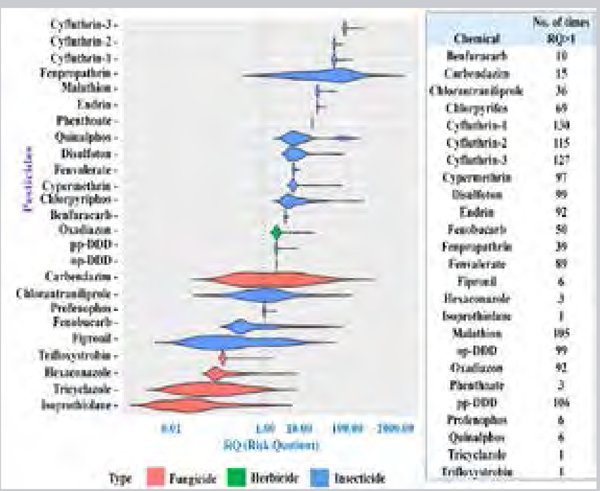


Fig. 3.14. Pesticide risk quotient of different pesticides measured in the small streams adjoining paddy fields.

Facile synthesis of novel magnesium oxide nanoparticles for pesticide sorption from water

The quantum of pesticides in surface as well as drinking water has become a serious health hazard. In this experiment, magnesium oxide nanoparticles (MgO NPs) were synthesized using leaves of purple coloured rice variety (Crossa) and utilized for simultaneous removal of three pesticides namely, thiamethoxam, chlorpyriphos and fenpropathrin from water. The biogenic MgO NPs were characterized using SEM-EDX, FTIR, XRD, DLS, etc. The optimum synthesis parameters (1M NaOH, 80^0C and 2h) resulted in maximum yield of MgO NPs (87.7 mg), minimum hydrodynamic diameter (35.12 nm), poly dispersity index (0.14) and mean zeta potential (-11 mV). Sorption data of the three pesticides fitted well with non-linear Langmuir and Freundlich isotherm models and non-linear pseudo second order kinetic model. The maximum adsorption capacity of MgO NPs for the three pesticides was 87.66 µg/mg, as obtained from the Langmuir isotherm model. Under optimum conditions (initial concentration: 40 mg/L, dose: 30 mg/30 mL and pH: 9), 60.13, 80.53 and 92.49% removal of thiamethoxam, chlorpyriphos and fenpropathrin was achieved with a 100 % desirability, respectively. Thus, the biogenic MgO NPs could be an efficient adsorbent of pesticides and could be recommended for pesticide decontamination in water treatment plants and domestic water purifier systems (Fig. 3.15).

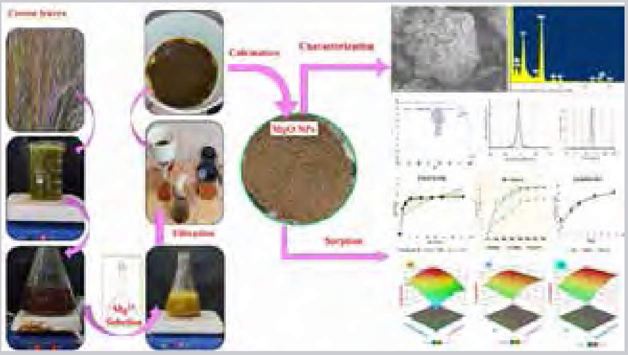


Fig. 3.15. Synthesis of novel magnesium oxide nanoparticles and their utilisation for pesticide sorption from water.

Biogenic magnesium oxide loaded rice husk biochar composite for pesticides sorption from water: Preparation and adsorption performance

The use of pesticides in agriculture results in-point and non-point pollution of ground and surface water bodies. A promising low–cost sorbent for removing xenobiotics from wastewater is rice husk biochar. Modifications of biochar to produce metal-biochar composites could exhibit high adsorption capacities. One pot synthesis of MgO doped rice husk biochar composite was done to harness the benefits of both biochar and magnesium. MgO nanoparticles were prepared from magnesium salts treated with leaf extracts of purple coloured rice variety (*Crossa*). The MgO doped rice husk biochar (MgO RHBC) were characterized using SEM-EDX, CHNS analysis, FTIR and XRD; was used for simultaneous removal of three pesticides from water. The combination of 5 g of magnesium nitrate hexahydrate ($Mg(NO_3)_2$. $6H_2O$, 0.2 M) salt, 10 g of rice husk powder and 200 mL of 5 % rice leaf extract were used to synthesize most efficient magnesium oxide biochar composite (MgO RHBC) for removal of three pesticides. The maximum adsorption capacity of MgO RHBC was 283.84 µg/mg, as obtained from the Sips isotherm model. Under optimum conditions (dose- 23.70 mg/ 30 mL, initial concentration- 75.00 mg/L and pH-7.0) resulted in 75.75, 79.65 and 77.66 % removal of thiamethoxam, chlorpyriphos and fenpropathrin, respectively with a desirability of 1.00. Thus, the novel MgO RHBC could be an efficient and eco-friendly adsorbent for decontamination of pesticides from water.

Sub-lethal imidacloprid exposure and its consequences on functional response of *Trichogramma chilonis* Ishii

The success of a biological control agent relies on the suppression potential of the intractable pests along with its compatibility with pesticides. Therefore, we reported multigenerational effect of commonly used insecticide, imidacloprid on the functional response of a widely acclaimed egg parasitoid, *Trichogramma chilonis* Ishii to different densities of host, *Corcyra cephalonica* Stainton eggs. The study investigated the outcomes of the lethal concentrations (LC_5, LC_{30} and LC_{50}) along with control for five continuous generations (F_1 to F_5). The outcomes revealed a type II functional response for the F_5 generation of LC_{30}, both the generations (F_1 and F_5) of LC_{50} and control. A type I functional response was exhibited for F_1 generation of LC_{30} and both the generations of LC_5. A shift in the type of functional response did not alter (decrease) the attack rate over the host eggs treated with LC_5 and LC_{30} in comparison to the control. A significant increase in the searching efficiency (*a*) was observed in the later generation (F_5) under the exposure of LC_5 and LC_{30} imidacloprid concentrations. A lower handling time (T_h) in both the generations of the LC_5 followed by LC_{30} treated individuals was observed juxtaposing the control and LC_{50} treatments. The per capita parasitization efficiency ($1/T_h$) along with rate of parasitization per handling time (a/T_h) were also considerably high in both the generations of LC_5 and LC_{30} than in the control and LC_{50}, thereby implying positive effects of imidacloprid on the parasitization potential of *T. chilonis*. Altogether, these multigenerational outcomes on the functional response of *T. chilonis* could be leveraged not only in the mass rearing of the parasitoid but also to annihilate the intractable lepidopteran pests under the mild exposure of imidacloprid in IPM programmes.

Relative toxicity of phosphine against *Tribolium castaneum* populations of Odisha

Twelve Odisha populations of red flour beetle (*Tribolium castaneum*) were assessed for their resistance to phosphine. After seven days of exposure to phosphine fumigation, all the assessed populations of *T. castaneum* (Herbst) from different regions of Odisha were found resistant to phosphine gas in comparison with the laboratory population except for Balangir (Madhiapali) population. Moreover, resistance to phosphine varied across populations tested. The results of Probit analysis indicated that the LC_{50} value of the location Madhiapali (Balangir) was 0.010 mg/L, which was similar to the susceptible/laboratory population. The phosphine resistance degrees varied from the LC_{50} values of 0.130 mg/L (Kendupali, Bargarh) to 0.011 mg/L (Durgapali, Sambalpur). The Bargarh population was 13.00 times more resistant than the laboratory-susceptible population.

Resistant status of insecticides against brown planthopper, *Nilaparvata lugens* (Stal.)

The susceptibility of the BPH population exhibited a declining trend through repeated exposure to median lethal concentrations of insecticides from F_0 to F_5. Notably, there were variations in the resistance patterns across different insecticide treatments. In the F_0 generation, pymetrozine displayed the highest LC_{50} value (0.963 mg/L), followed by imidacloprid (0.850 mg/L), dinotefuran (0.766 mg/L), and buprofezin (0.593 mg/L). Triflumezopyrim treatment registered the lowest LC_{50} value of 0.012 mg/L. As generations advanced to F_5, LC_{50} values increased for each insecticide. Imidacloprid exhibited the highest LC_{50} value of 2.896 mg/L, followed by pymetrozine (1.784 mg/L), dinotefuran (1.621 mg/L), and buprofezin (1.228 mg/L). Triflumezopyrim demonstrated the least resistance in the F_5 generation, with the lowest LC_{50} value of 0.018 mg/L and a resistance ratio (RR) of 1.404 compared to the F_0 generation. In contrast, the most substantial increase in resistance level in F_5 was observed in imidacloprid (Resistance ratio: 3.407).

Dissemination of integrated pest management strategies for insect pest, diseases and nematodes in rice

Evaluation of *Bacillus* sp. against sheath rot disease

Among the bioagents tested, the combined application of RBS-57 (*Bacillus cereus*) liquid formulation as a seed treatment + seedling dip + foliar spray (ST+ SD+FS) resulted in a lower sheath rot index of 21.33% in the pot experiment. The chemical treatment Carbendazim 12% + Mancozeb 63% WP had the lowest disease index, with 16.00% PDI. Maximum PDI of 83.70% was recorded in the control. Similarly, RBS-57 liquid formulation has recorded the lowest sheath rot disease index in field conditions (15.33% PDI in trial I and 12.42% PDI in trial II, respectively). Enzymatic activities such as PO, PPO, PAL, CAT and SOD were induced in the rice sheath by *B. cereus* (RBS-57) treatment. Real-time expression analysis was performed to validate the fold changes in defense enzymes and reactive oxygen species. The defense gene expression was up-regulated for PO, PPO, PAL, CAT and SOD in combined application of RBS-57 treatment which was followed by combined application of BS-5 (*Bacillus amyloliquefaciens*) treatment. Hydrogen peroxide (H_2O_2) and superoxide anion (O_2^-) genes were highly expressed and upregulated in only pathogen-inoculated control.

Evaluation of *Aspergillus* sp. and *Trichoderma harzianum* against rice diseases

Five fungal biocontrol agents (BCAs) were isolated from a contaminated and rotten 'ready-to-fruit' mushroom bag (with paddy straw) and they were tested against four rice pathogens for their biocontrol efficacy. Two of the five BCAs have been identified as *Aspergillus tubingensis* and *Trichoderma harzianum* based on nucleotide homology and phylogenetic analysis. For identification of the BCAs, fungal DNA was amplified with 18s rRNA Specific Primer (ITS1 and ITS4). A single discrete PCR amplicon band of ~600 bp was observed. The PCR amplicon was bead purified and further subjected to Sanger Sequencing. Bi-directional DNA sequencing reaction of PCR amplicon was carried out with ITS1 and ITS4 primers using BDT v3.1 Cycle sequencing kit on ABI 3500Dx Genetic Analyzer. Both *Aspergillus tubingensis* and *Trichoderma harzianum* have shown promising biocontrol properties against brown spot (*Bipolaris oryzae*) and sheath blight (*Rhizoctonia solani*) pathogens *in vitro* and *in vivo* (Fig. 3.16). Culture filtrates and fungal mat extracts were also prepared for product formulation.

Fig. 3.16. Dual culture plates of *Bipolaris oryzae* (brown spot) with biocontrol agents: Left – *Bipolaris oryzae* (Control), Middle – *B. oryzae* on left and *Trichoderma harzianum* on right side, Right – *B. oryzae* on left and *Aspergillus tubingensis* on right side.

Evaluation of botanicals against rice root-knot nematode

The formulations of Neemastra, Bhramastra and Agniastra were studied against J_2 (infective juveniles) of *M. graminicola* in *in vitro* conditions. The juveniles of *M. graminicola* were exposed to different doses of Neemastra, Bhramastra and Agniastra i.e. 1000 ppm, 5000 ppm, 10000 ppm and 50000 ppm. The dose of 50000 ppm of Bhramastra caused 100% mortality after 48 hrs. of exposure against nematode juveniles in lab conditions. The dose of 5000 and 10000 ppm of Brhamastra exhibited more than 80 per cent mortality after 48 hours of exposure. The neemastra also exhibited 100% mortality after 48 hours of exposure.

Dual role of potassium silicate and salicylic acid as plant growth promotor and immunity booster against Bakanae disease

The present study investigates the individual and combined effect of PS and SA seed priming for plant growth and defense responses against *Fusarium fujikuroi*. The seed priming combined with SA (100 mg/L) and PS (1.0%) effectively controlled the bakanae disease incidence. In addition, it was also effective on growth parameters like improved germination, root and shoot length, plant biomass, and seedling vigor. Accumulation of defense enzymes like phenylalanine ammonialyase (PAL), polyphenol oxidase (PPO), Peroxidase (POD), and phenol derivatives was significantly higher in the treated plants. The maximum activity of these defense enzymes was recorded in PS+SA-treated plants at 21 DAS. The plant treated with SA-100 mg/L+PS-1% showed the best response without any phytotoxic effect. The information gathered in the present study suggests that seed priming of SA-100 mg/L+PS-1% can promote plant growth and suppress bakanae disease in rice. This research demonstrates how PS and SA can be used to combat the *F. fujikuroi* in rice by activating key defense enzymes. Additionally, applying these substances to plants stimulates their antioxidant defenses, which indirectly prevents the spread of disease. In place of fungicides, the PS and SA treatment options are harmless for the environment and can be used to manage the bakanae disease.

Rhizosphere Bacteria Isolated from Medicinal Plants Improve Rice Growth and Induce Systemic Resistance in Host Against Pathogenic Fungus

Sheath blight (ShB) disease is a major biotic stress that causes significant yield loss in rice. Plant growth-promoting rhizobacteria (PGPRs) have been found to suppress the adverse effects of disease on plants. In the present investigation, an attempt has been made to evaluate the effect of PGPR strains isolated from the rhizosphere soil of medicinal plants on rice under stress conditions. We isolated 158 morphologically distinct bacterial strains and tested them against *R. solani* under *in-vitro* conditions and found 52 promising strains with more than 50% antifungal activity. These strains were examined for their physiological and biochemical characteristics and further confirmed with 16S rDNA gene-specific markers. Strains that inflicted >80% inhibition during *in-vitro* studies were selected for pot and field experiments. The results indicated that *Bacillus velezensis, B. megaterium*, and *B. toyonensis* registered significantly higher plant growth-promoting activities with enhanced germination, seedling vigor, and dry weight. In addition, applying these PGP strains exhibits the lowest disease incidence, relative lesion length, delayed sclerotia formation, and recorded maximum grain yield per pot. The field study further confirmed that *B. toyonensis* provided significant disease suppression with least disease incidence (PDI: 17.37 and 12.88), relative lesion length percent (27.71 and 12.88), area under disease progress curve (382.98 and 286.25) value (AUDPC), and highest grain yield (63.00

and 48 t ha^{-1}) in Tapaswini and CR Dhan 1014 varieties, respectively, followed by *B. megaterium* and *B. velezensis*. The PGPR-treated plants also showed enhanced activities of defense enzymes like polyphenol oxidase, superoxide dismutase, and catalase showing induced systemic resistance (ISR). Thus, these three PGPR strains from medicinal plants enhanced the tolerance of rice to ShB disease with improved crop growth.

Bacterial communities associated with *Scirpophaga incertulas* (Walker) (Lepidoptera: Crambidae), display high taxonomic and functional diversity

Next-generation sequencing technology was employed to investigate the gut microbiota of *S. incertulas*. Present study determined the taxonomic and functional characterization of the bacterial community associated with different developmental stages of the *S. incertulas* using 16S ribosomal RNA gene amplicons metagenomics. The highly variable V3-V4 region of the bacterial 16S rRNA gene sequencing's analysis revealed that the bacterial community associated with *S. incertulas* was taxonomically classified with 25 phyla which also includes unclassified and unassigned bacteria that comprised 46 classes, 101 orders, 197 families, 364 genera. Proteobacteria, Firmicutes, Actinobacteria, and Bacteroidetes were the major phyla, and Proteobacteria was the most predominant phylum in the *S. incertulas* in all the developmental stages except the larval stage, where Firmicutes found as predominant. Our findings shed light on the significant variance in *S. incertulas* microbiota across developmental stages and serve as the foundation for microbiota-based management techniques.

Alternative delivery mechanism for *Trichogramma*

A study was conducted to explore alternative methods of delivering *Trichogramma*, a parasitic wasp used widely as biocontrol agent. Material for alternate delivery of *Trichogramma* other than the paper cards was selected. High Impact Polystyrene (HIPS) and Low density polyethylene (LDPE) were selected based on their water proofing and floating ability. The material was used to customize the delivery technique in proper shape and size so as to accommodate parasitized *Trichogramma* safely without hampering the adult emergence. HIPS and LDPE along with conventional paper card and control (loose parasitized eggs) were compared for their adult emergence. Results indicated non-significant difference between treatments. HIPS and LDPE recorded 79.68% and 82.34% adult emergence, respectively.

Evaluation of *Melaleuca alternifolia* essential oil against stored grain moth

The essential oil of bottle brush tree, *Melaleuca alternifolia* exhibited both contact & fumigant toxicity against *Corcyra cephalonica*. The mortality rates were dose & time dependent. Highest toxicity was observed after seven days of exposure period. From GC-MS analysis, presence of 1,8-cineol (67.79%), α-pinene (16.73%), α-Terpineol (4.87%); p-cymene (4.48%) as major compounds were confirmed in the tested oil.

Validation and promotion of integrated pest management of rice module in farmer's fields under shallow low land ecosystem

Validation and promotion of IPM module under shallow lowland ecosystem in the farmer's fields were undertaken in Haripur of Derabis Block (Dist. Kendrapara) with Swarna and Pooja (21 acres) involving 27 farmers during *kharif* 2022. In IPM practice, seed treatment with *Trichoderma* formulation @ 10 g kg^{-1} seed before sowing and need based application of pesticides were undertaken by the farmers in the affected areas only. Carbendazim 50 WP @1.0 g liter^{-1} water against brown spot, sheath blight, sheath rot diseases; cartap hydrochloride @ 1kg ai ha^{-1} water against YSB, leaf folder, BPH and need based foliar application of chloropyriphos 20% EC @ 0.5 kg ai ha^{-1} against gundhi bug were applied. Also, sex pheromone traps @ 8 nos. ha^{-1} with lure and bio-control agent (*T. viride* and *Pseudomonas fluorescens*) formulations were provided to the farmers. In need based IPM practice in both the varieties less infestation of targeted diseases and insects were observed as compared to farmer's practice. Yield in need based IPM outperformed the farmer's practice with yield advantage of 1.8 t ha^{-1}.

Effectiveness of plant essential oil (PEO) on false smut pathogen (*U. virens*)

Altogether plant essential oil (PEO) *viz.,* Lemon oil (LO), Cinnamon oil (CO), Bottle brush oil (BBO), Orange oil (OO), and Eucalyptus oil (EO), are taken for study the effect on false smut pathogen *Ustilaginoidea virens* following food poison technique (Fig. 3.17). Out of these, lemon and cinnamon oil are found highly effective to *U. virens* both at100 (>60% growth inhibition) & 200 ppm (>85% growth inhibition) concentration whereas bottle brush, orange and eucalyptus oils are effective at 200 ppm (>50% growth inhibition) but not at 100 ppm (<40% growth inhibition). In present study, LO and CO were found to be much effective than BBO, OO, and EO at 100 ppm.

Effect of sheath blight pathogen infection at different rice growth stage on grain production

In order to assess the impact of sheath blight pathogen infection at different rice growth stage, artificial inoculation with *R. solani* was done on Tapaswini variety at four different stages *viz.,* Early tillering (ET), Maximum tillering (MT), 50% flowering (50F), and 100% flowering (100F) (Fig. 3.18).

Vertical expansion of the lesion (sheath blight lesion) was growing faster during first 15 days in ET & MT inoculated plant than 50F & 100F, but it was slower during last 15 days in ET & MT inoculated plant than 50F & 100F. Disease severity was much higher when inoculated during flowering stages. Seed weight was significantly lower ($p<0.001$) when inoculated at flowering stages than tillering stages. The primary studies revealed that flowering stage is more vulnerable to *R. solani* (sheath blight disease) infection than tillering stages under favorable condition.

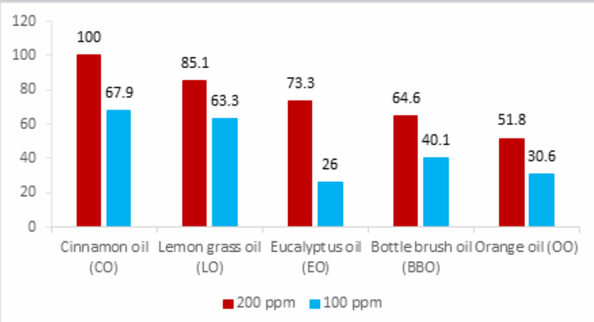


Fig. 3.17. Effect of Botanical oils on mycelial Growth of *U. virens*.

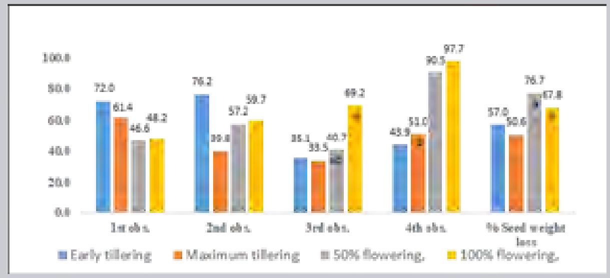


Fig. 3.18. Effect of sheath blight pathogen infection at different rice growth stage on grain yield.

Conclusion

The programme on biotic stress management in rice covers evaluation of more than 1400 rice entries against major rice insects, diseases, and nematodes to find out resistant donors which will help in biotic stress resistant varietal development programme. Identification of false smut disease damage and assessment in rice, hyperspectral imagery data were recorded through handheld spectro-radiometer. The bands at 522, 684 and 730 nm were observed to be the sensitive bands for rice false smut disease. Molecular studies were taken up to characterize different parasitoids of rice leaf folder, identify differentially expressed genes in rice plants-*Fusarium proliferatum* interaction, rice tungro disease evolutionary dynamics, and false smut disease genetic diversity. Volatile organic compounds contribution in biocontrol and growth promotion potential of *Trichoderma* were elucidated. Explored the pesticide risk to the non-target organisms in small streams adjoining to paddy fields. Synthesized novel magnesium oxide nanoparticles and magnesium oxide loaded rice husk biochar composite as an agent for pesticide removal from water. Detected hormesis effect of imidacloprid on egg parasitoid, *Trichogramma chilonis* Ishii for multiple generation. Enumerated the relative toxicity of phosphine against rice storage pest, *Tribolium castaneum* populations of Odisha. Computed resistant profile of brown planthopper against various insecticides. Evaluated various botanicals and biocontrol agents against different rice pests to develop an eco-friendly rice health management module. Validated and promoted rice IPM module in farmer's fields under shallow low land ecosystem.

PROGRAMME

04

Photosynthetic Enhancement, Abiotic Stress Tolerance and Grain Nutritional Quality in Rice

Rain-fed rice cultivation is associated with several environmental challenges which have aggravated in recent years due to changing climatic conditions. The broad genetic base and availability of huge germplasm resources of rice enable us to identify and understand cues of the unique tolerance mechanism of rice to numbers of abiotic stresses either coming individually or combined. These stresses are often found to limit crop growth and productivity by hampering photosynthesis and other key metabolic processes in rice. Besides, it also affects the grain and nutritional quality of rice. The quality of rice grains is a paramount consideration for evaluation from the perspectives of farmers, millers, and consumers. For this, the evaluation of physicochemical, nutritional, and sensory qualities along with various biochemical factors, such as resistant starch, amylose, and phytic acid is important. With an increasing diabetic population majorly consuming milled rice, it is high time to look into different factors contributing to the high Glycaemic Index value of rice. These challenges are being addressed through three institutional and five externally funded projects in our division. The division is actively engaging eight scientific and seven technical staffs in these efforts to find sustainable solutions.

Photosynthetic efficiency and productivity of rice under changing climate

Improvement of photosynthetic efficiency of rice through transgenic approaches

Transgenic lines were generated by cloning the *SiPEPC* fragment downstream of the *ZmPPDK* promoter and cassette of *ZmPPDK-SiPEPC-Nos,* abbreviated as *PPN* (Fig.1a) and the cassette was transformed into rice embryogenic calli of IR-64 rice variety using Agrobacterium-mediated transformation. To verify the stable integration and copy number, the PCR-positive plant lines were subjected to Southern blot analysis, and the hybridization profile showed positive signals in transgenic PEPC lines 2, 4, 7, and 8. No bands were detected in WT control plants (Fig. 4.1d). Quantitative real-time PCR (qRT-PCR) was conducted to measure the expression pattern of *SiPEPC*, and the results highlighted elevated expression of *SiPEPC* in the southern blot and PEPC positive lines concerning wild type. The maximum expression of *SiPEPC* was observed in P-7-3 (9.1-fold) followed by P-8-6 (7.8-fold) transgenic lines, whereas the P-2-5 line showed relatively lower expression concerning wild type (Fig. 4.1e). The activity of PEPC enzyme showed increased PEPC activity in three transgenic lines. It was found to significantly increase 2.2–6.4-fold ($P = 0.03$, $P < 0.0001$) in transgenic lines than control (Fig. 4.1f).

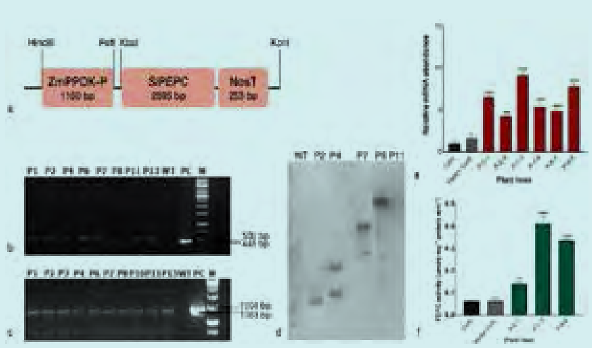


Fig. 4.1. Molecular evaluation of transgenic rice lines. (a) Schematic representation of the gene constructs PPN (*pZmPPDK-SiPEPC-nos*) (b, c) PCR amplification of putative PPN transgenic plants. (d) Integration SiPEPC in rice genome confirmed using Southern hybridization. (e) Quantitative real-time PCR (qRT-PCR) analysis of transgenic and control plants and (f) PEP carboxylase enzyme activity in control and transgenic lines.

Transgenic rice lines exhibited enhanced photosynthesis, yield and yield-attributing traits

Photosynthesis rate (A), stomatal conductance (g_s), transpiration rate (E), and instantaneous water use efficiency (iWUE) were measured in control and transgenic lines. The photosynthesis rate was significantly higher in PPN transgenic lines (15.9%, 20.06%, and 21.9% in P-2-1, P-7-3, and P-8-6 respectively) (Fig. 4.2). Based on stomatal conductance and transpiration rate, the instantaneous water use efficiency (iWUE) was calculated and it was found that PPN rice lines P-7-3 and P-8-6 exhibited higher iWUE than control plants, with 15.9–21.9% increment in PPN transgenic rice lines. Significant changes in plant height, tiller number, panicle weight, fertility %, yield/plant, and dry biomass were observed in PEPC transgenic lines compared to wild-type counterparts (Fig. 4.2e,f). Significant differences were observed between control and transformed rice lines for most of the traits studied.

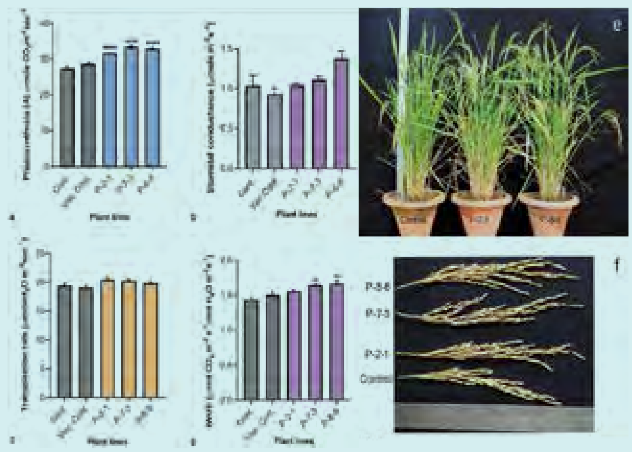


Fig. 4.2. Analysis of photosynthetic character between transgenic and wild-type plants at the flowering stage. (a) Net photosynthetic rate (b) stomatal conductance (c) transpiration rate (d) intrinsic water use efficiency. Evaluation of morphological characters between wild-type plants (WT) and transgenic plants. (e) The appearance of transgenic (P-7-3 and P-8-6) wild-type plants after 90 days of germination (f) Representative panicles from WT and transgenic plants.

Deciphering the role of endogenous *OsPEPC* & *OsME* genes using CRISPR-Cas9 multiplexing system

For the construction of multiplex sgRNA CRISPR/Cas9 vector, PTG (polycistronic tRNA-gRNA) cassette was designed with the two sgRNA targeting endogenous *OsPPDK*, *OsPEPC*, *OsNADP-ME*, and *OsCA* genes in rice. We have fused the tRNA sequence upstream for each sgRNA to enhance the editing efficiency. We combined a tRNA upstream of each guide RNA to improve the editing efficiency. We have assembled the tRNA-gRNAs for the four targets through a golden gate assembly reaction. Assembled fragments were amplified using Q5 polymerase (NEB) and ligated into a pGEMT-easy vector. The clone was confirmed through restriction digestion and sequencing. The cloned product was further sub-cloned into a binary vector. We have established a highly efficient protoplast isolation and PEG-mediated transfection study in our laboratory. With the help of this protocol, we have transfected all four constructs into rice protoplast.

Agrobacterium-mediated transformation and generation of stable mutant lines

Stable transgenic rice lines were generated using Agrobacterium-mediated transformation. Mature rice embryos were incubated in callus induction media supplemented with N6 basal salts and 2-4-D for 14 days at 30 °C under white cool light. The binary vector was transformed into Agrobacterium strain LBA4404 using the freeze-thaw method. These cultured cells were used to infect the 21-day-old rice embryogenic calli. After 72 hrs co-cultivation, the infected calli were washed with liquid CIM supplemented with Timentin 200mg/l and finally transferred into selection media containing 50 mg/l hygromycin and Timentin 200mg/l for three weeks (Fig.4.3A). The selected calli were placed into regeneration media (Fig.4.3B), and after regeneration, putative mutant plants were first placed into rooting media (Fig.4.3C) and then transferred to soil within a climate-controlled greenhouse (Fig. 4.3D).

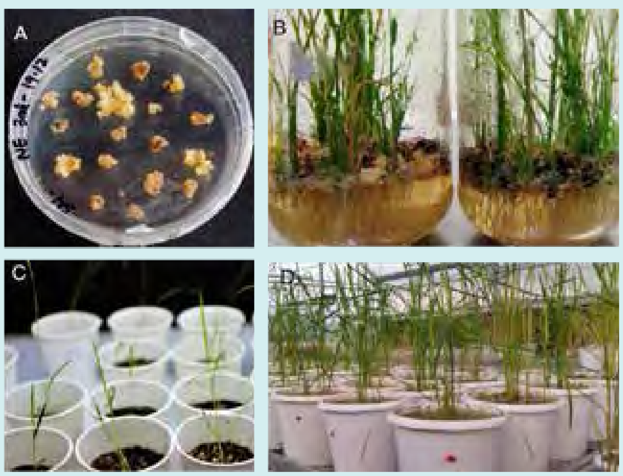


Fig. 4.3 Stable *Agrobacterium*-mediated rice transformation using embryogenic calli as explants. (A) Hygromycin-selected calli (B) Regenerated putative mutant rice plants in growth chamber. (C) Putative mutant plants in soil rite for hardening (D) Mutant plants in climate-controlled greenhouse.

Identification of elite rice accessions for high photosynthetic rate and superior physiological traits

High grain yield in rice is a cumulative contribution of different morphological and physiological traits. Rice grain yield strongly relies on the chlorophyll content as well as the photosynthetic efficiency of the flag leaf. Other important traits include transpiration rate and culm strength. An increase in transpiration rate is associated with an increase in photosynthetic rate. High culm strength is required to support heavy panicles thus highly contributing to grain yield in rice. However, the selection of high-yielding genotypes based on physiological traits is difficult where a large set of genotypes is used. Therefore, a study was carried out to assess the physiological efficiency of 211 elite rice genotypes having varying yield potential. We found 29, 41, 34, 49, 30, and 39 genotypes showing high values for flag leaf area, total chlorophyll content, photosynthetic rate, transpiration rate, culm strength, and grain yield respectively (Fig. 4.4a). Among them, 3 genotypes i.e. IG-020, IG-211, and IG-010 were identified to be highly efficient in 4 traits, 2 genotypes i.e., IG-044 and IG-186 in 5 traits, and 2 genotypes; IG-008 and IG-161 were found to be superior in 7 traits along with high grain yield (Fig. 4.4b).

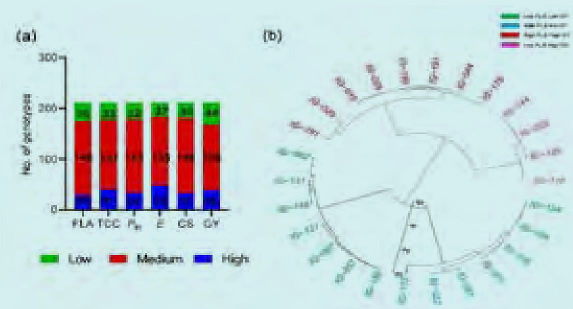


Fig. 4.4. (a) Distribution of genotypes in high, medium, and low categories based on morphophysiological and yield traits. FLA, flag leaf area (cm^2); TCC, total chlorophyll content (mg/g fresh weight); PN, photosynthetic rate (μmol CO_2 m^{-2} s^{-1}); E, transpiration rate (mmol H_2O m^{-2} s^{-1}); CS, culm strength (g $stem^{-1}$); GY, grain yield (t ha^{-1}) (b) Hierarchical cluster analysis of rice genotypes based on grain yield and photosynthetic rate, using Euclidean distance and Ward's algorithm.

Evaluation of rice genotypes for new sources of multiple abiotic stress tolerance and understanding the underlying mechanism

Evaluation of rice genotypes for drought and submergence stress tolerance

A total of 181 aus rice genotypes were evaluated under drought and submergence for multiple seasons. Besides many accessions performed superiorly over the check varieties under individual stress conditions, a few accessions such as Ratnagiri45-2, Rani bhog, ARC 12124, Sona aus, Sathi, Simulkhuri, and Lal Taura performed well under both drought and submergence. The drought score in these genotypes varied from 1.89 - 4.33 (average of four environments), while the survival rate under submergence varied from 54.1 – 90.65 (average of two seasons). Further multi-location evaluation of these accessions has been undertaken.

Screening rice genotypes for tolerance against stagnant flooding stress

Stagnant flooding (SF) or partial submergence is a major constraint for rice production particularly in lowland and deep-water ecology of rice. To identify new sources of SF tolerant rice accessions, 60 genotypes comprising landraces and cultivars of lowland ecology were tested against >60 days of SF stress (45 ± 5 cm) imposed from tillering to the maturity stage. Out of the studied genotypes, we found seven accessions tolerant to prolonged SF stress based on plant height, tiller number, and panicle length as compared to the tolerant (Varshadhan, Rahaspunjar, AC 39416A). Seven rice genotypes (Kalamota, Hanseswari, AC 85, Khoda, CSR27, Ravana, and JRS5) were found relatively tolerant in terms of least reduction in yield and yield-attributing traits. Among these, Kalamota and AC 85 were found to be the best having plant height of >190 cm and tiller number of >8 (per plant) with >28 cm of panicle length under stress conditions.

Evaluation of rice genotypes for high-temperature stress tolerance

About 200 rice genotypes (ARC and PB) were evaluated for high-temperature stress tolerance in field conditions using staggered sowing method. Phenology of rice genotypes was recorded so that flowering time coincides with high temperatures in the field conditions. From the panel, 10 genotypes were identified that had higher spikelet fertility than the tolerant check N22. From these 10 genotypes, 2 entries *viz*., IC 256508 and IC 256605 were found to maintain higher spikelet fertility under high-temperature stress conditions and were nominated for AICRIP multiple abiotic stress trials. IC 256508 was found to be tolerant to multiple abiotic stresses at multi-location trials. While IC 256605 besides having tolerance to high-temperature stress was also tolerant to salinity and osmotic stress.

Four unique rice accessions were identified and registered at PGRC, New Delhi as novel donors for different abiotic stress tolerance

AC 43012 (INGR22108): Tolerant to both vegetative and reproductive stage drought Stress. Possess low transpiration rate and high water use efficiency.

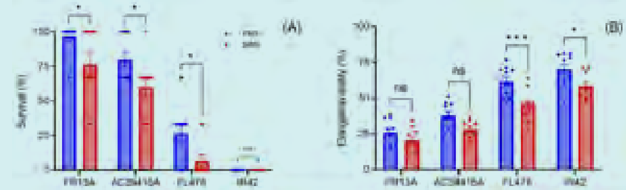
AC 43025 (INGR22109): Tolerant to vegetative stage drought stress with low transpiration rate and high WUE. Tolerant to submergence and salinity stress at the vegetative stage.

AC 43037 (INGR22110): Tolerant to vegetative stage drought stress with low stomatal density and high WUE. Tolerant to salinity and osmotic stress at the vegetative stage.

Black Gora (INGR23004): A unique multiple abiotic stress tolerant rice germplasm tolerant to drought, submergence (germination and seedling), and phosphorus starvation.

Mechanistic understandings of combined stresses of salinity and submergence in rice

Salinity and flooding are two major production impediments affecting rice cultivation in coastal agro-ecosystems. How rice plants adapt to two contrasting strategies energy conservation (for submergence tolerance) and energy expenditure (for ion exclusion) for tolerance to combined stresses of saline water (150 mM NaCl) submergence (SWS) was investigated. For this, four genotypes carrying *Sub1* and *Saltol* QTLs in their genetic background were taken and exposed to salinity and submergence stresses individually and combined. We found that *Sub1*-containing submergence-tolerant lines performed better under SWS while *Saltol*-containing Na^+-excluder couldn't (Fig. 4.5). Presence of thicker leaf gas film (LGF) and higher leaf wax helped longer underwater retention of LGF in *Sub1*-lines which helped them to survive under SWS. Thicker LGF significantly delayed Na^+ entry to the leaves under anoxic conditions, while the genotype having good Na^+-exclusion potential, but thinner LGF ultimately accumulated more Na^+ in the leaf tissue under SWS.



(C)

Genotype	Screening at 12 dS m⁻¹ NaCl SES score based on VSI	Dry Biomass (mg) under stress		Na^+/K^+ under stress		Presence of QTLs	
		Shoot	Root	Shoot	Root	SUB1A-1	SKC1
FR13A	7 (S)	20.16 ± 1.37	4.21 ± 0.56	1.63 ± 0.16	4.24 ± 0.59	+	−
AC39416A	5 (MT)	44.85 ± 3.18	12.08 ± 0.84	0.78 ± 0.12	2.67 ± 0.16	+	+
FL478	3 (T)	61.32 ± 2.47	15.84 ± 1.25	0.52 ± 0.07	2.84 ± 0.16	−	+
IR42	9 (HS)	19.59 ± 1.42	6.005 ± 1.53	2.19 ± 0.25	3.67 ± 0.23	−	−

Fig. 4.5. Survival rate (A) and elongation ability (B) of four rice genotypes under fresh water (FWS) and saline water submergence (SWS) were represented graphically for 4- different studied genotypes. (C) Screening and evaluation data of four rice genotypes for seedling stage salinity stress (12 dS m^{-1}) imposed hydroponically for seven days.

Understanding the dosage effect of the *SUB1* gene in submergence tolerance of rice

Submergence tolerance in rice is primarily attributed to *SUB1* gene action. Earlier research suggested that survival rates and *Sub1A* expression were significantly lower in heterozygotes compared with the homozygous tolerant parent. To test this, we made F_1s of the *Sub1A* gene from three different backgrounds i.e., Swarna, Pooja, and IR64 (Fig.4.6A). From the results obtained, it is clear that even a single favourable allele of *Sub1A-1* (heterozygous) can impart as good tolerance as double allelic form, although expression of *SUB1A* was almost half in the heterozygote (Fig.4.6B). However, the quiescence strategy i.e., restriction in internode elongation was not obtained fully in the heterozygote, which was evident from ethylene biosynthesis gene expression as well. Starch depletion and expression of α-amylase gene (*OsAmy3D*) followed a middle path in F_1 heterozygote, which suggests the influence of *SUB1A* gene on starch breakdown and internode

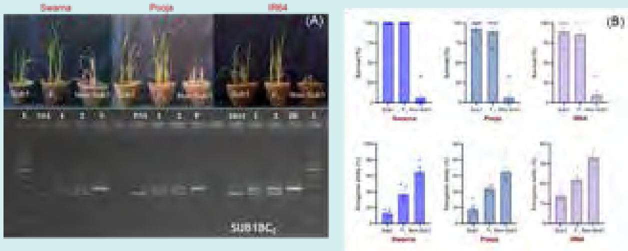


Fig. 4.6. Response of *Sub*1 and non-*Sub*1 homozygote and their F_1 heterozygote to 14 days of complete submergence (A) along with their post-submergence recovery and elongation ability under stress (B).

elongation is quantitative and dosage dependent, whereas for survival and LGF thickness, it shows dominant gene action.

Standardization of effective concentrations of Plant Bio-Regulators (PBRs) as seed priming agents to improve vegetative stage osmotic stress tolerance in Rice

The present study was conducted to standardize the effective concentrations of PBRs *viz*., salicylic acid (SA), Thiourea (TU), and potassium nitrate (KNO_3) as priming agents to improve the osmotic stress tolerance in rice. Different concentrations of Thiourea (0, 0.5, 1.0, 1.5, and 2.0 ppm), KNO_3 (0, 1, 1.5, 2, 2.5, 3, 3.5, 4, 4.5 and 5%) and SA (0, 1.0, 2.0, 3.0, 4.0 and 5.0 mM) along with absolute control were evaluated in osmotic stress susceptible genotype IR20 for seed germination and seedling emergence capacity under osmotic stress conditions. The seeds were soaked in respective concentrations of PBR solution for 8 hours and washed with distilled water before they were dried for 24 hours and put for germination in the Petri plates moistened with 20% PEG-6000 solution. The germination percentage, root and shoot lengths, seedling fresh and dry weights, and seedling vigour index were measured. After five days of the treatment, seedlings were sampled to measure various growth parameters like root and shoot length, and seedling fresh and dry weight to assess the impact of PBRs as seed priming agents in combating osmotic stress tolerance. From this study, we found that seed priming with 3% KNO_3, 150 ppm Thiourea, and 2 mM SA were more effective in improving seed germination and seedling growth under osmotic stress conditions (Fig 4.7).

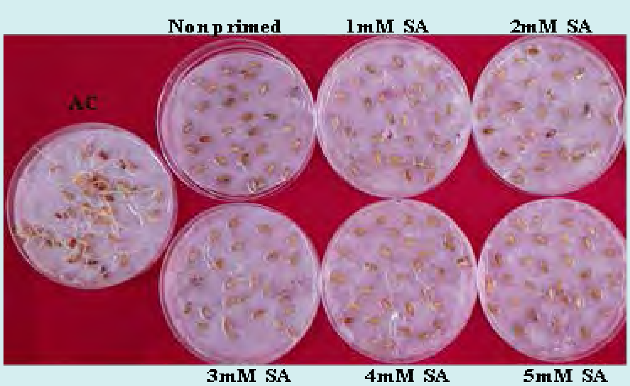


Fig. 4.7. Effect of different concentrations of Salicylic acid (SA) as seed priming agent on rice (IR20) seed germination under osmotic stress (20% PEG). AC: Absolute control, Non-primed: without SA + osmotic stress.

Deciphering the role of *OsCCA1* under low light stress using CRISPR-Cas9 multiplexing system

The design of the PTG cassette was performed with two sgRNA targeting the Exon 2 of *OsKitaake08g038000_OsCCA1* (Fig. 4.8C). We have fused the tRNA sequence upstream for each sgRNA to enhance the editing efficiency. Golden gate assembly was used to assemble three fragments [PS1 (128bp), PSII (195bp) and PSIII (138bp)] for two sgRNAs targets (Fig. 4.8D). Assembled fragments were amplified using Q5 polymerase (NEB), and ligated into a pGEMT-easy vector. The respective clone was confirmed using Sanger sequencing. Finally, the assembled fragment was digested with FokI restriction enzyme and cloned into the BsaI site within the pRGEB32 vector downstream of the OsU3 promoter.

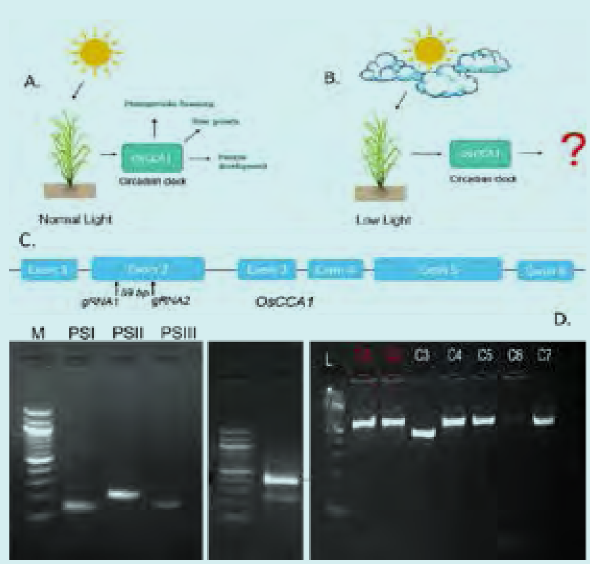


Fig. 4.8. Role of *OsCCA1* under normal light (A) and lowlight (B) conditions; (C) Schematic representation of the targeted gene and editing strategy. (D) PCR Amplification from pGTR plasmid GG Assembly product.

Identification of Pre-Harvest Sprouting resistant rice genotypes and understanding the underlying mechanism for developing climate-resilient rice varieties

Ninety-six diverse rice genotypes were evaluated for resistance to PHS in the field conditions and identified 12 PHS-resistant genotypes (Fig.4.9). The results revealed that resistant genotypes had 0% germination at all the flowering

Table 4.1. Classification of genotypes based on duration of dormancy. DAH: days after harvest.

Sl. No.	Weak (10 DAH)	Moderate (20 DAH)	Strong (30 DAH)	Very strong (40 DAH)
1	Budidhan	NHN-279	Mahulata	IC 256580
2		IC 256559	AC 34975	AC 35090
3		IC 256577	IC 256797	IC 256562
4		IC 256771		AC 35096

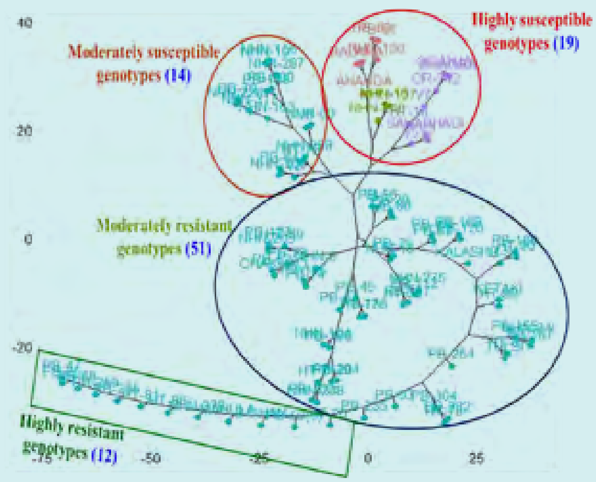
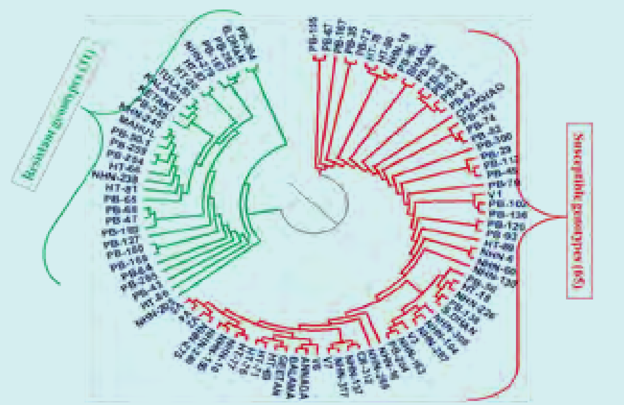


Fig. 4.9. Grouping of the rice genotypes based on phenotypic evaluation of PHS in the field condition at 20, 25, 30, 35, and 40 DAF

stages (20 to 40 DAF), while susceptible genotypes had 4 to 87.5% germination from 20 to 40 DAF. The 12 resistant genotypes were examined for germination to estimate the duration of dormancy. The duration of dormancy varied in these 12 resistant genotypes varying from 10 days up to 40 days after harvest. These findings suggest that these novel PHS-resistant genotypes (Table 4.1) may be exploited as donors in the crop improvement programmes to generate vivipary/PHS-resistant genotypes.

Molecular characterization of diverse rice germplasm for resistance to pre-harvest sprouting using twenty-four reported SSR markers

In the present study, a panel of 96 accessions having varied prominent physiological features was validated with the reported markers to observe the genotypic variation to vivipary/PHS. The marker data clustered the genotypes into resistant and susceptible groups (Fig. 4.10). The first cluster is divided into a small group of genotypes whereas the second cluster is divided into a large group of genotypes. In the first group, 31 genotypes (resistant genotypes) were clustered together while 65 genotypes (susceptible genotypes) were clustered together in the second group.



Genotypes were grouped in 2 groups based on genotypic variation and gene validation using 24 SSR markers

Fig. 4.10. Grouping of the genotypes based on genotypic validation by using power marker clustering analysis

Characterization of rice genotypes for improved Physico-chemical and Nutritional properties

Characterization of rice genotypes having diverse amylose content with similar starch digestibility

High resistant starch (RS) rice with low glycemic index (GI) exhibits slower starch digestion resulting in a slow rise of postprandial blood glucose level. In addition to amylose content (AC), linear chains of amylopectin also affect the rate of starch digestibility. After screening 110 rice genotypes for starch digestibility, genotypes IG 23, IG 40, and IG 72 were selected (based on contrasting AC, RS, and GI). Interestingly, it was found that IG 23 having lower AC (15.65%) had the lowest GI (52.49). In contrast, IG 40 with the highest AC (24.52%) showed intermediate GI (56.00). Genotypes IG 23 and IG 40 with contrasting AC indicated that amylose alone did not affect the digestion rate. To check the possible reasons behind that, these genotypes were analyzed for related starch biosynthesis enzymes (GBSS I, Pullulanase) activity and starch bio accessibility assay. Among the genotypes, the activity of GBSS I was 2.6-fold higher in IG 40 as compared to IG 23 and 2.8-fold higher as compared to IG 72 during grain development. The activity of Pullulanase in the rice genotypes increases during endosperm development. Among the genotypes, the activity of PUL was 1.3 fold higher in IG 23 as compared to IG 40 while 2.3 fold higher as compared to IG 72 during the grain development (Fig. 4.11). Starch debranching enzyme pullulanase assay indicated the role of linear amylopectin chain in crystallized RS formation within the grains. Therefore, the highest RS content in IG 23 (2.28%) could be due to the presence of a higher amount of linear

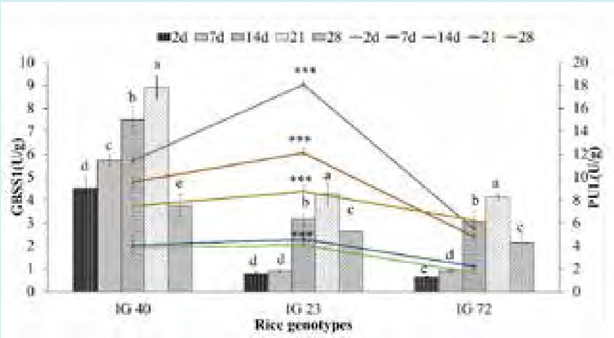


Fig. 4.11. Granule bound starch synthase I (GBSS I) and Pullulanase (PUL) activities in rice endosperm during different stages of grain development (2DAF, 7DAF, 14DAF, 21DAF and 28DAF).

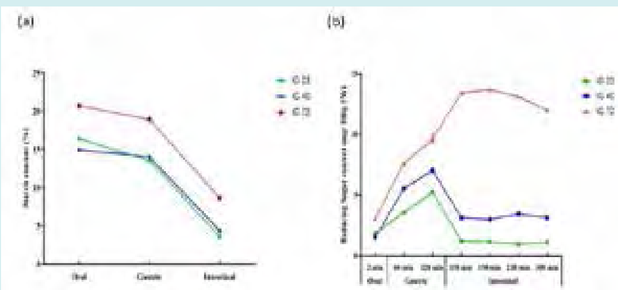


Fig. 4.12. (a) Starch bio-accessibility of rice genotypes with contrasting amylose content, resistant starch, and glycemic index. (b) Reducing sugar content (mg/100 g FW) during in vitro digestion.

amylopectin formed by trimming its branches, mimicking amylose-like function and lowering starch digestibility. In the starch bio-accessibility assay, a significant decrease in starch content was observed in the selected three genotypes across the oral, gastric, and intestinal phases. Genotype IG 72 released the highest sugar content during the intestinal phase (130-300 min) while IG 23 and IG 40 released the maximum sugar content at the end of the gastric phase (120 min) (Fig. 4.12). The higher sugar content released during the digestive phase in IG 72 may be attributed to its higher GI, resulting in higher glycemic responses. The development of rice-based food with low GI and high RS could be a promising strategy for lowering the prevalence of type-II diabetes.

Impact of grain processing (cooking, parboiling, and fermentation) on nutritional components, glycemic index, and pasting properties of rice

Different methods of rice grain processing *viz.*, cooking, parboiling, and fermentation significantly increased the DPPH and FRAP antioxidant activity, soluble sugars (TSS), Phenolics, flavonoids, and zinc (Zn) content, while protein, amylose, iron (Fe) content, and ABTS antioxidant activity decreased as compared to raw unprocessed rice. The reduction percentage of these components was minimal in the case of parboiling as compared to raw rice. The percent increase of TSS was highest in raw fermented rice while lowest in parboiled fermented rice. The processing significantly decreased the pasting viscosity as compared to raw rice. The average GI value of parboiled cooked rice (PCR) was the lowest while the raw fermented (FR) rice showed the highest value. PCR of Naveen showed the highest resistant starch (2.7%) whereas, fermented rice of Manipuri black showed the lowest content (0.31%). This finding will help rice consumers select appropriately processed rice for maximum nutritional quality.

Different milling times of rice influence the iron and zinc content in grain

Six ICAR-NRRI released rice varieties were evaluated for their Fe and Zn content after 30, 60, and 90 seconds of milling as compared to brown rice. The mineral content was estimated through a microwave digestion system followed by an atomic absorption spectrophotometer. The brown rice of CR Dhan 310 and CR Dhan 802 possess higher Fe content (26.82 ppm and 29.29 ppm respectively) but after 30s milling, a 50% reduction was observed whereas in the case of 60 s and 90 s milling 60% and 65% reduction was found. In case of Zn, the highest content was observed in CR Dhan310. In brown rice, 23.88 ppm Zn was found while an 18-20% reduction was observed in 30 s of milling whereas 60 s and 90 s milling reduced 23 to 25% Zn content. Relatively less reduction of Zn content was observed than Fe after different degrees of milling and there was no significant difference found in Zn content at 60 s and 90 s milling.

Screening of rice with high iron content

Thirty rice genotypes of Odisha, collected from OUAT, Bhubaneswar were evaluated for their Fe content. Among genotypes, Kalinga Dhan 1202 and Govinda showed the highest Fe content (77.75 and 75.45 ppm, respectively) whereas after milling (60 s) its content was reduced by around 50% and found to be 35.7 and 33.8 ppm, respectively (Fig. 4.13).

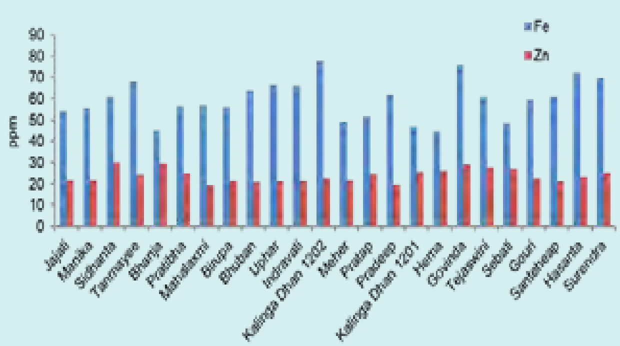


Fig. 4.13. Twenty-four rice varieties were evaluated for Fe and Zn content (brown rice).

Evaluation of rice genotypes for antioxidant content/ medicinal value

The Northeastern states of India harbor the richest genetic diversity reservoir for crops. Systematic nutritional profiling though is largely lacking for these germplasms. Around 100 germplasms of Arunachal Pradesh were analyzed for their bioactive compounds (Total Phenol Content, Total Flavonoid Content and Total Antioxidant Activity). Germplasm AC-9135 and AC-9102 were found to have high antioxidative potential (86.9% and 74.9% DPPH inhibition respectively), AC-9258 was found to be high in phenol (47.83 mg Catechin/100g) and AC-9257 was found to have high flavonoid content (7.31 mg Quercetin/100g). About 70 rice germplasm were screened from Assam for its nutritional properties. Boga Bao showed the highest content of phenol (78.53 mg Catechin/100g), while Kala Bao possessed the highest flavonoid content (28.2 mg Quercetin/100g). Total antioxidant activity was observed to be highest in Ulpi Bao and Bironi Sali (68% and 66% DPPH inhibition respectively). Kala Bora and Dentul Bao had the highest Fe and Zn content (14% and 40% respectively) while Rangali Bao was found to be rich in protein (10.7 % in milled rice). About 70 germplasms of Nagaland have been quantified for their grain physico-chemical characteristics. PRN16 (Rshuo) [alkali spreading value (ASV)-3, AC-21.53%, gel consistency (GC)-56mm] and PRN19 (Tsome) (ASV-4, AC-22.05%, GC-52mm) were found to have desirable cooking and eating quality. These indigenous rice varieties have unique properties and are cultivated by the local farmers and are mainly used for the preparation of traditional cuisine. Additionally, biochemical characterization of about 100 rice genotypes (IG: landraces, pigmented and aromatic rice; ICP: a core set of irrigated rice) was done for total antioxidant activity and protein content. IG-27, IG-5, and IG-3[A] were found to be high in antioxidant activity (57.9%, 52.1%, and 57.3% DPPH inhibition respectively). Genotypes IG-3[A] was found to contain the highest amount of phenol and flavonoid (72.14 mg Catechin/100g and 8.49 mg Quercetin/100g respectively). The highest protein content was found in IG-20 (11% in white rice) (Table 4.2). Characterization of these germplasms and genotypes is essential to identify desirable traits, effective utilization of genetic resources, and for its use in breeding programmes.

Table 4.2. List of promising varieties for biofortification.

Important Trait	Superior Genotype Identified
Total Antioxidant Activity	AC 9135, AC 9175, IG 27, IG 58 and IG 3[A], Ulpi Bao and Bironi Sali
Phenol Content	AC 9258, IG 3[A], Boga Bao
Flavonoid content	AC 9257, IG 3[A], Kala bao
Iron and Zinc Content	Kala Bora and Dentul Bao
Protein Content	IG 20, Rangali Bao

Conclusion

For improvement of photosynthetic efficiency in rice, a two-way approach was followed – (i) identification of rice genotypes having superior photosynthetic rate and improved physiological traits; (ii) transgenic rice plants were developed using *SiPEPC* and *ZmPPDK* genes/promoter elements. Besides several rice germplasms were screened for drought, submergence, and stagnant flooding stresses. Some new insight into mechanistic details for tolerance to combined stresses of saline water submergence was revealed. An attempt was made to understand the dosage effect of the *SUB1* gene in different genetic backgrounds of rice. In this process, we have identified and registered four unique genetic stocks of rice that can serve as novel donors for different abiotic stresses. Pre-harvest sprouting (PHS) or vivipary is another important area of our research, where we identified genotypes tolerant to PHS and also identified various factors regulating PSH in rice through physiological and molecular characterization. Several rice accessions were tested for grain mineral (Fe and Zn) availability; besides effect of milling time affecting availability of these minerals was also studied. In our quest to develop low GI rice, many genotypes were characterized for having diverse amylose content with similar starch digestibility. The total antioxidant contents of a hundred rice accessions collected from Arunachal Pradesh were also evaluated to explore the medicinal properties associated with these landraces.

PROGRAMME

05

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

Introduction

Social Sciences Division is engaged in technology dissemination and socioeconomic research by developing and testing new extension models, approaches, and strategies. Its primary focus is on outreach activities and disseminate recent technologies to end users, providing valuable feedback to the technologists. With a total staff strength of six scientists, eleven technical staff, and one administrative staff member, the division fulfills its research mandates through two institute research projects and ten externally aided projects. In the year 2023, the institute demonstrated 19 newly released rice varieties in eight states with collaboration of both state government and non-government stakeholders, along with participating farmers through INSPIRE 1.0 and INSPIRE 2.0 models. The division organized 88 training programs of varying durations, benefiting 3835 participants, including farmers, extension officials, administrative personnel, and other rice stakeholders. A rice value chain model, arORIce was designed with the objective of producing quality seeds of aromatic rice contributing to export quality non-basmati aromatic rice production. The Division assessed the share of NRRI varieties in overall varietal replacement by the states, identified of problems faced by farmers in rice farming, and estimated the economic value of NRRI varieties, specialty rice, and premium seed varieties. Furthermore, the division analyzed consumer preferences in rice consumption, trends in rice production, and the impact of minimum support prices. The division showcased NRRI technologies in exhibitions across the country, offering advisory services to visitors and providing agro-advisory services through various channels. Efficient rice database management, ensuring timely generation and submission of reports, is a key responsibility of the division. Moreover, the division plays a crucial role in disbursing various benefits, especially to marginalized beneficiaries, through programs such as the Scheduled Caste Sub-Plan (SCSP), Tribal Sub-Plan (TSP), NEH, Farmer FIRST Programme, and Mera Gaon Mera Gaurav (MGMG) Programme.

Reaching stakeholders to Enhance their socio-economic CAPacities (RECAP) through rice technologies

Minikit demonstration of improved NRRI varieties under INSPIRE model

Improved rice varieties of the institute were demonstrated in largescale under INSPIRE extension model developed under the project. Nineteen recently released varieties by the institute were demonstrated in the farmers' fields covering 193.01 acre area. The demonstrations covered thirty-one districts from eight states – Bihar, Chhattisgarh, Jharkhand, Madhya Pradesh, Maharastra, Odisha, Uttar Pradesh and West Bengal. Altogether 3125 kg. of quality seeds in minikits (5 kg.) were used in these demonstrations (Fig. 5.1).

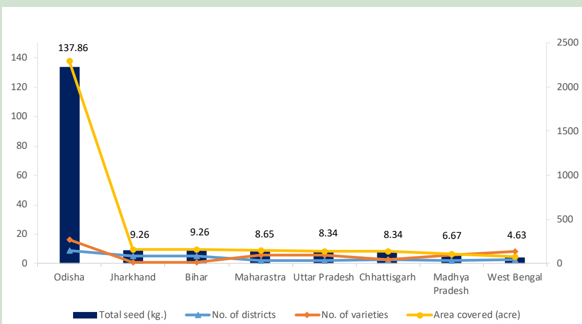


Fig. 5.1. State wise seed distribution and area covered under minikit demonstrations (INSPIRE model).

The demonstrations were conducted in close collaboration with *Krishi Vigyan Kendras* (KVKs), state agriculture departments, and NGOs.Technical guidance, follow up visits, relevant literatures, mobile calls and other digital modes, and crop cutting experiments-cum-field days ensured credible results. Among the key performance indicators (KPIs), yield and crop growth parameters were focussed. Majority of the demonstrated varieties outperformed the existing popular varieties as depicted in fig. 5.2.

Fig. 5.2. Five best performing NRRI varieties under farmers field condition.

Farmers field-level performance of NRRI varieties with farmers practice

A PPS sampling technique was followed to draw a sample of 415 farmers from 10 districts, 20 blocks, and 40 villages of Odisha with the purpose of estimating farmers field-level yield of NRRI varieties under farmers' practice (n=415). The NEMA dataset developed under the network project led by the Division of Agricultural Extension, ICAR was used in the study. The farmers field-level average yield was the highest for the irrigated varieties (3.95 t ha^{-1}), followed by rainfed upland (3.91 t ha^{-1}), rainfed shallow lowland (3.73 t ha^{-1}), medium deep water (3.66 t ha^{-1}), semi-deep water (3.54 t ha^{-1}), and coastal saline varieties (3.46 t ha^{-1}) (Table 5.1).

Table 5.1. Unit level varietal performances aggregated ecology-wise.

Ecology	Mean Yield (t ha^{-1})	Mean Acreage (in acre)	Average return (₹/ha)
Rainfed Upland (RUP)	3.91	2.27	44,235
Rainfed Shallow Low-land (RSL)	3.73	2.29	48,787
Semi-deep Water (SDW)	3.54	1.33	40,179
Medium Deep Water (MDW)	3.66	2.98	46,891
Irrigated (IR)	3.95	3.47	48,083
Coastal Saline (CS)	3.46	2.75	38,038

The mean acreage was the highest for irrigated varieties (3.47 acre), followed by medium deepwater (2.98 acre), coastal saline (2.75 t ha^{-1}), rainfed shallow lowland (2.29 acre), rainfed upland (2.27 t ha^{-1}), and semi-deep water varieties (1.33 t ha^{-1}). The average return from the varieties was the highest for rainfed shallow lowland varieties (₹48,787/ ha) followed by irrigated (₹48,083/ ha), medium deep water (₹46,891/ ha), rainfed upland (₹44,235/ ha), semi-deep water (₹40,179/ ha) and coastal saline varieties (₹38,038/ha).

Synthesis of Rice Value Chain (RVC) model from existing models

An RVC model, arORIce was designed with the objective of producing quality seeds of aromatic rice contributing to export quality non-basmati aromatic rice production. The model engaged 636 farmers from five districts of Odisha – Koraput (54), Kalahandi (83), Nayagarh (318), Kandhamal (115), and Cuttack (66) covering 1118 acre land. Production of 79.7 q quality seeds of different non-basmati aromatic varieties was done during the period under report.

Problem identification in rice farming

A survey was conducted with a sample size of 239 rice farmers from the state of Odisha to identify the major problems in rice farming. Increased pest and disease incidence (41%), timely availability of quality seed (38%), increased cost of cultivation (18%), increased fertilizer price (16%), and marketing issues (13%) emerged to be the five major problems.

Analysis of consumer preference of rice

A study was conducted in Jharkhand and Bihar to understand the relative priorities of different traits involved in determining consumption preference. The RBQ values suggest that taste (85.28), followed by price (68.33), grain quality (67.50), cooking quality (48.61), and aroma (48.06) dictate the consumer preferences (Table 5.2).

Table 5.2. Analysis of consumer preference of rice in Jharkhand & Bihar.

Consumption preference	Bihar		Jharkhand		Pooled	
	RBQ	Rank	RBQ	Rank	RBQ	Rank
Taste	88.10	1	82.81	1	85.28	1
Price	72.02	2	65.10	3	68.33	2
Grain Quality	63.69	3	70.83	2	67.50	3
Aroma	46.43	4	49.48	5	48.06	5
Cooking Quality	44.64	5	52.08	4	48.61	4

Designing a prototype of Training Management System (TMS)

A unified portal has been designed to manage the training programmes conducted in the institute, and for keeping records of training details conducted by the scientists of the institute. This is a systematic approach of maintaining the database incorporating details of all training programmes organized by the institute for ready access.

Working to Increase farm Net Gain through Socioeconomic research (WINGS)

Estimation of socioeconomic contribution of NRRI varieties

Attempting to quantify the societal value of rice varieties developed by the institute, we employed the economic surplus approach to measure the aggregated economic benefits. Economic surplus encompasses the incremental returns resulting from technological advancements originating from research, including both producer and consumer surplus. These aspects are typically overlooked in standard estimation procedures. In the previous year, our estimation process focused on two varieties, whereas this year, we expanded our scope to encompass 14 varieties. The calculated economic surplus ranged from 4 to 33 crores (Fig. 5.3). Categorizing the varieties based on their release year revealed a notable trend: the earlier the variety's release, the larger the economic surplus, attributed to an extended life period (Fig. 5.4).

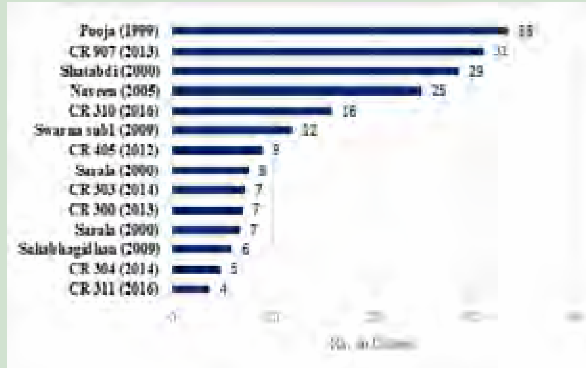


Fig. 5.3. Total economic surplus from popular NRRI varieties.

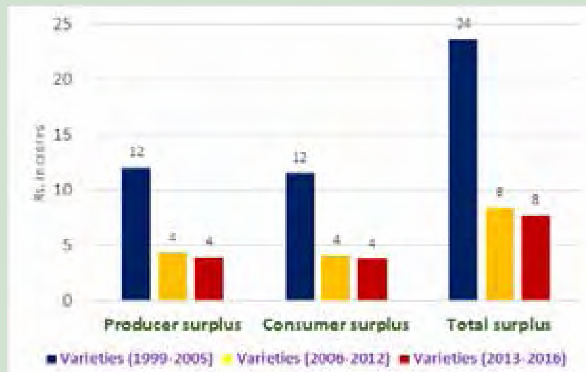


Fig. 5.4. Economic surplus from different groups of varieties.

Working to Increase farm Net Gain through Socioeconomic research (WINGS)

Estimation of economic value of specialty rice and premium seed varieties

Specialty rice and premium seed varieties, despite exhibiting price variations at market outlets, failed to yield significant financial returns to the farmers. Moreover, markets for high-protein rice and other specialty rice types are not well-established. In an effort to rationalize market prices and enhance returns for farmers, we shifted our focus from the actual prices paid by people to measuring their willingness to pay (WTP). Employing the contingent valuation method, we conducted a field survey in the states of Bihar and Jharkhand, utilizing choice cards to gather responses from various respondent categories. The analysis of the collected data revealed that people express a willingness to pay extra for specialty rice and premium seeds. The maximum increment in WTP was observed to be Rs. 10, 12, and 20 for high-protein rice, scented non-basmati rice, and premium seeds, respectively, compared to the rates of similar products within the same category (Table 5.3).

Table 5.3. Measurement of Willingness to pay (WTP) for high protein rice, non-basmati scented rice and premium seeds.

Variables	Mean	Median	Mode	Maximum	Minimum	Std. Dev.
$WTP_{Protein}$	5.20	5.00	5.00	10.00	1.00	1.53
$WTP_{Scented}$	5.90	5.00	5.00	12.00	2.00	2.01
$WTP_{Prem. seed}$	8.18	8.00	8.00	20.00	5.00	2.88

Projection of demand and supply of rice in India

To project future outlook of demand and supply of rice in the country, a partial equilibrium modelling framework was used, which is linear and recursive dynamic in nature and endogenously takes socioeconomic and policy changes. The model has three cores namely producer core, consumer core and trade core representing various stakeholders in rice value chain and links these cores through the price equations. The model used set of few structural equations following the commodity outlook model developed by ICAR-NIAP, New Delhi.

The national outlook of rice indicates surplus position of India in rice supply to the tune of 58 million tonnes by the year 2030-31 (Table 5.4). The area under the rice crop would increase in the years to come but that would be marginal than that of other cereals. The marginal increase in area would come from the summer cultivation of rice as witnessed by the country in recent years. Assuming the constant technical progress, the crop yield is expected to reach close to 3.0 tonnes per hectare by the year 2030-31. Subsequently the production is predicted to increase from 106 million metric tonnes in the base year 2017-18 to 123.84 million metric tonnes by the end of the decade. Similarly, the market stocks of the commodity (including both the public and private stocks) is also projected to follow the similar linear path in the near future which necessitates the need to strengthen the capacity of warehousing and storage infrastructure and to enhance the utilization of existing capacity of such infrastructure. On the demand side, the food demand of rice is predicted to increase by about 13 million metric tonnes and other demand including seed, wastage and industrial demand is projected to increase by about two million tonnes during the projection period. Although the net trade projections are underestimation from the actual figures acknowledging the difficulty in modelling the most dynamic component of food commodity market, the projected figures are sufficient enough to provide a clear direction of flow. The supply and demand balance would remain positive and is projected to follow an increasing trajectory indicating India's surplus position in the rice market.

Table 5.4. National Rice Market outlook during different periods.

	2017-18	**2023-24**	**2024-25**	**2026-27**	**2028-29**	**2030-31**
Area	41.69	42.01	42.05	42.17	42.09	42.29
Yield	2.55	2.70	2.73	2.80	2.86	2.93
Production	106.22	113.50	114.89	117.90	120.40	123.84
Ending stocks	24.50	26.30	26.90	28.27	29.37	31.26
Net trade	12.04	11.83	11.89	12.00	12.13	12.27
Aggregate supply	142.76	151.63	153.68	158.17	161.90	167.37
Seed & other demand	13.28	14.19	14.36	14.74	15.05	15.48
Food demand	78.85	88.27	89.08	90.68	92.07	93.36
Feed demand	0.00	0.00	0.00	0.00	0.00	0.00
Aggregate demand	92.13	102.46	103.44	105.42	107.12	108.84
Balance	50.63	49.17	50.24	52.75	54.78	58.53

Decade wise trend of rice area, yield and production estimated for two states

Decade wise compound annual growth rate (CAGR) for area, production, and yield (APY) of rice was calculated for Madhya Pradesh, Maharashtra, and Chhattisgarh state. The analysis revealed an increase in the area under rice cultivation in Madhya Pradesh, while it remained stagnant in Maharashtra and Chhattisgarh. Additionally, the growth rates for yield and production were higher in Madhya Pradesh compared to Maharashtra and Chhattisgarh (Table 5.5). Examining instability, it was found that both yield and production instability surpassed area instability. Moreover, Madhya Pradesh exhibited higher yield and production instability than Maharashtra and Chhattisgarh. Breaking down production growth into area and yield effects showed a positive contribution from the area effect for all states, with Madhya Pradesh and Maharashtra displaying positive yield effects.

Table 5.5. Growth and instability in area, yield and production of rice in Uttar Pradesh and Bihar.

Particulars	CAGR (%)	Instability index	Particulars	Decomposition of production growth (%)
Madhya Pradesh (1992-93 to 2019-20)				
Area	1.31	9.00	Area effect	65.16
Yield	5.03	30.70	Yield effect	10.80
Production	3.67	22.57	Interaction effect	24.03
Maharashtra (1983-84 to 2019-20)				
Area	0.01	2.70	Area effect	86.36
Yield	0.91	11.60	Yield effect	11.81
Production	0.90	10.47	Interaction effect	1.83
Chhattisgarh (2000-2001 to 2019-20)				
Area	0.00	1.56	Area effect	104.36
Yield	3.32	18.09	Yield effect	-1.48
Production	3.32	17.47	Interaction effect	-2.88

Impact of MSP on Rice Farmers' Socioeconomic Wellbeing

During previous year, we have made exercise to study the impact of minimum support price (MSP) for rice on socioeconomic wellbeing of farmers and observed that the MSP has significant impact on market price and help to ensure higher marketed surplus, higher acreage under crop, and (little) higher yield. Efforts have been made this year to identify the interfering factors in availing MSP through Analytical Hierarchical Process (AHP). The results indicated that convenience of disposal of produce and lack of awareness are the main impediment in availing MSP by farmers (Fig. 5.5).

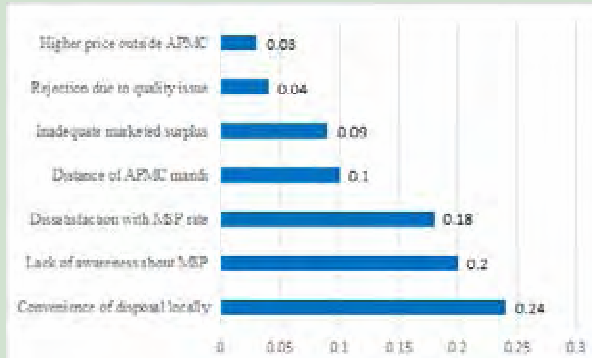


Fig. 5.5. Factors influencing availment of MSP by farmers.

Conclusion

The program envisions the rapid dissemination of NRRI varieties and technologies, primarily through demonstrations, awareness initiatives, and capacity-building efforts, etc. Its overarching goal is to influence policies that cater to diverse groups of rice stakeholders. In addition to governmental involvement, the program has provided orientation and empowerment to private institutions such as NGOs, CSR Units, and FPOs, promoting profitable and sustainable rice-based cropping systems. An assessment of the economic value contributed by the institute's developed varieties and technologies, along with the economic value of specialty rice and premium seed varieties, will serve as a guide for future research directions and crucial decision-making in the development of the rice sector. Analyzing trends in rice consumption, as well as examining the growth and instability in the areas of rice cultivation, yield, and production, the cost of paddy cultivation, and rice exports will offer essential policy guidance. This guidance will be instrumental in allocating areas for rice cultivation, promoting crop diversity, and ensuring the sustainability of rice production.

PROGRAMME

06

Development of Climate Resilient Rice Technologies for Rainfed Upland, Rainfed Lowland and Coastal Saline Ecologies

Climate change is predicted to increase the frequency and intensity of abiotic and biotic stress combinations that adversely impact crop yield and food supply in rainfed ecologies. Hence, development of improved climate resilient technologies is essential to safeguard the resource poor farming communities. Similarly, continuous efforts need to be devoted in characterizing and identifying novel donors for stress-resilient traits. During 2023 NRRI-CRURRS, Hazaribag has released three varieties suitable for diverse ecologies ranging from rainfed DSR to drought-prone shallow lowlands. Germplasm resources have been characterized for early vigour and tolerance to abiotic and biotic stresses. Promising accessions have been registered as genetic stocks for better utilization. Simultaneously, integrated production technologies have been assessed to improve and stabilize rice yield under drought-prone conditions. Advanced diagnostics for rice pathogens like rice tungro bacilliform virus have been standardized. Demonstrations of high-yielding climate-resilient varieties and production technologies has been undertaken along with organizing various training and workshops to improve the livelihood of farmers in rainfed drought-prone ecologies. Rice is cultivated widely under rainfed lowland and productivity in the rainfed lowland is less than national average. Low temperature at seedling stage in *boro* season prolongs the crop harvest and recurrent pre-monsoon flood cause heavy crop loss to *boro* and early *ahu* paddy cultivated in lowlands of Assam. Developing thermo-insensitive *boro*, photo-insensitive *sali* and short duration *ahu* rice varieties, coupled with pest management tactics and dissemination of rice-based technologies can improve the production and productivity of rice in rainfed lowland.

Rainfed Upland

Development of resilient production technologies for rice under rainfed drought-prone agro-ecosystems

Climate resilient varieties

Three rice varieties namely CR Dhan 804, CR Dhan 808 and CR Dhan 214 (Table 6.1) were released for drought-prone ecologies through CVRC (Fig. 6.1). Among these, CR Dhan 804 and CR Dhan 808 were developed through marker-assisted breeding (MAB).

Multiple stress tolerant genetic stocks

Two multiple stress tolerant genetic stocks have been registered with the Plant Germplasm Registration Committee, ICAR, New Delhi INGR22107 and INGR23004.

Evaluation of *aus* rice germplasm for agronomic features and stress tolerance

A total of 181 *aus* rice accessions from the 3000 Rice Genome Project (3K-RGP) were characterized for early vigour, low-P tolerance and brown spot resistance. Significant variation was noted for five early vigour traits, vegetative vigour (Vg), chlorophyll content index (CCI), seedling biomass, seedling height and average growth rate (AGR), were evaluated (Fig. 6.1-A). Vg, CCI and AGR were positively correlated with grain yield. GWAS analysis using 918K SNP markers revealed 25 loci for seeding vigour traits, and QTLs governing relative germination vigour, coleoptile length, shoot dry weight, plant height, and chlorophyll content were detected (Fig. 6.1-B).

Six *aus* accessions were resistant (SES score 0-3) and 57 were moderately resistant (SES score 3-6) to brown spot. GWAS identified SNP_13557242 on chromosome 4 explaining 32%

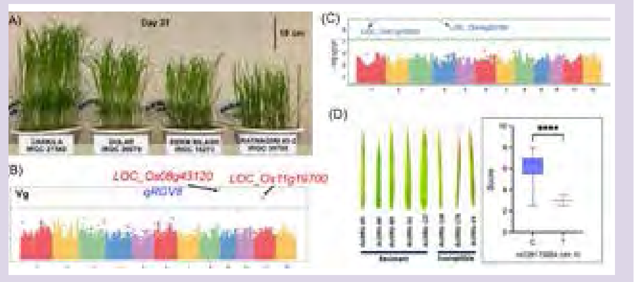


Fig. 6.1. Characterization of *aus* germplasm. (A) Variation in early vigour, (B) Manhattan plot showing significant associations for mean Vg. qRGV8.0 explained 70% of phenotypic variance (PVE), (C) Manhattan plot for brown spot scores showing LOC_Os04g23700 explaining 30% of PVE, (D) Significant allelic differences brown spot resistance.

Table 6.1. Salient features of rice varieties.

Variety	Ecology & States	Features
	Drought-prone rainfed shallow lowlands/irrigated conditions **States** Jharkhand, Uttar Pradesh, Tamil Nadu, Madhya Pradesh, Chhattisgarh, Andhra Pradesh and Telangana	Yield: 4.8 t ha^{-1} under normal condition; 1.9 t ha^{-1} under drought. Duration: 115-120 days Grain type: LS Tolerant to submergence and drought (introgressed with *qDTY2.2* & *Sub1*).
	Drought-prone rainfed DSR **States** Bihar and Jharkhand	Yield: 3.0 t ha^{-1} under normal rainfall and 2.2 t ha^{-1} under drought. Duration: 90-95 days Grain type: SB Tolerant to drought (introgressed with *qDTY12.1* & *3.1*)
	Aerobic **States** Odisha and Bihar	Yield: 4.2 t ha^{-1} Duration: 115-120 days Grain type: LS

of phenotypic variance, and a significant allelic differences between susceptible and resistant accessions were noted (Fig. 6.2.C-D). The closest gene was SDRLK-24 (lectin protein kinase family protein, *LOC_Os04g23700*) which has crucial roles in plant development and responses to abiotic and biotic stresses. Further validation of this locus has been undertaken through gene expression analysis.

Evaluation of *aus* accessions under low-P (8-10 mg kg^{-1}) conditions revealed that *PSTOL1* positive accessions were significantly more tolerant to low-P stress. Notably, a few *aus* accessions like Devarasi, ARC 11959, ARC 12067, ARC 12079, ARC 12101, and Kada Chopa were highly tolerant to low-P, but did not carry the *PSTOL1,* indicating existence of novel tolerance mechanism(s) in these *aus* accessions.

Screening germplasm for multiple stress tolerance

A total of 57 drought tolerant accessions were screened for genes/QTLs for drought, BPH, blast and low phosphorus tolerance. Seventeen accessions carried one or multiple DTY QTLs (*qDTY 1.1, 1.2, 2.2, 3.1, 2.3, 3.2, 12.1*), BPH QTL (*qBph 4.3*), Blast genes (*Pi9* and *Pita 2*) and low phosphorus tolerance gene (*pstol1*) (Table 6.2). The phenotypic screening of the germplasm for the said stresses is going on.

Table 6.2. Potential genotypes with multiple stress tolerance genes/QTLs

Stress	Genotypes carrying stress tolerant gene(s)/QTL(s)
Drought, Blast, Low-P	RSR/JLM-9, RSR2/JLM-40, RSR/SKY-22
Drought, Blast	IC 419206, IC 568223, DT14
Drought, BPH, Low-P	RSR2/JLM-34, SKSS05, SKSS-12, NR-25, NR-26, NR-31, IC 264006, IC 454372, IC 459347, IC 515116

Nutrient Management options for sustainable rice production under direct seeded rainfed ecology

Estimation of soil organic carbon pools as affected by nutrient management practices

Soil organic carbon pools (very labile, labile, less labile and non-labile carbon) were estimated in rice sole and rice pigeon-pea intercropping system under different nutrient management practices. The active carbon pools (very labile and labile) was higher in integrated nutrient management practices which comprised of about more than 50% of soil organic carbon. Among the integrated nutrient management treatment consisting of 50% RDF +FYM @ 5 t ha^{-1} + VAM 1.5 q ha^{-1}+ PSB 4 kg ha^{-1} is superior in maintaining the balance

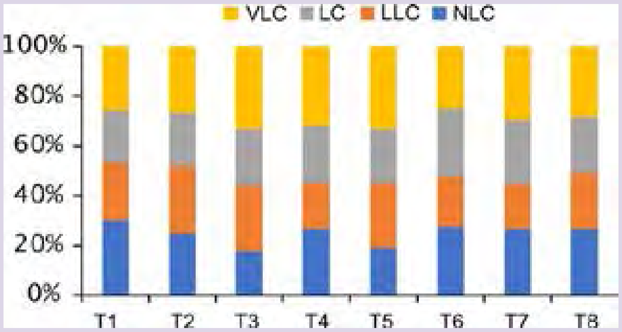


Fig. 6.2. Proportion of soil organic carbon pools as affected by nutrient management practices in rice. T1 Control ; T2 100% RDF (60:30:30) and (40:30:30); T3 50% RDF +FYM @ 5 t ha^{-1}; T4 50% RDF +FYM @ 5 t ha^{-1} +VAM 1.5 q ha^{-1} + PSB 4 kg ha^{-1}; T5 50% RDF +RI; T6 100% FYM @ 10 t/ ha; T7 100% FYM @ 10 t ha^{-1} + VAM 1.5 q ha^{-1} + PSB 4 kg ha^{-1}; T8 100% FYM @ 10 t ha^{-1} +RI.

between active and passive pools of soil organic carbon (Fig. 6.2).

Mineralization of carbon under different organic amendments

Incubation study was conducted to assess the carbon mineralization from rice residue in comparison with FYM and *Dhaincha*. The highest carbon mineralization was recorded in rice residue followed by *Dhaincha*, and FYM. Across the treatments and incubation periods, around 28.6 % increase in CO_2 evolution was observed as the temperature was increased from 20 ^{0}C to 30 ^{0}C, while (+) nitrogen treatments recorded 9 % more CO_2 evolution than (-) nitrogen treatments (Table 6.3).

Table 6.3. Interactive effects of nitrogen addition and temperature on carbon mineralization (mg CO_2/100 g soil).

Amendments (A)	Temperature (T)				Mean
	20 ^{0}C		30 ^{0}C		
	Nitrogen (N)		Nitrogen (N)		
	N (-)	N (+)	N (-)	N (+)	
Soil	56.8	60.4	75.7	87.4	70.1
Soil +FYM	69.1	74.1	82.5	90.3	79.0
Soil + *Dhaincha*	102.3	117	141.3	138.5	124.8
Soil + Rice Residues	108.2	122.5	145.5	158	133.5
Mean	80.8	89.8	105.7	113.7	
CD (P= 0.05)	A = 4.04; T = 2.56; N = 2.56; AxT = 5.72; TxN = 3.61; AxN = 5.72; AxTxN = 8.08				

Rain water use efficiency of red soil and clay soil in terms of water productivity and water used to produce per kg grain was worked out under rainfed rice. Rain water productivity of rainfed rice grown on clay soil using drum seeder was 57% than that of rice cultivated on red soil sown using seed drill.

Table 6.4. Rain water use efficiency in different soil under rainfed drought prone condition.

Soil type (Establish-ment)	Grain yield (t/ha)	Rainwater produc-tivity (kg/ha-mm)	Rainwater used per kg grain (L water/kg grain)	Effective Rainfall (mm)
Red soil (Seed Drill)	2.18	2.55	4088	856.2
Clay loam soil (Drum seed-ing)	2.77	4.01	2530	691.5
More/less (%)	27.1	57.3	-38.1	-19.2

Biotic stress management strategies for rainfed drought-prone ecologies

Advanced diagnostics for rice tungro bacilliform virus

A recombinase polymerase amplification (RPA) assay was developed using RTBV RT/RNaseH gene-based primers to detect viral titre from both genomic DNA and leaf sap of symptomatic plants. The RPA assay effectively detected RTBV following incubation at an isothermal condition of 39°C for 30 min. Among the three primer designed, RTBV-RPA F3/R3 was found to be most sensitive. Further validation of the assay on field samples from Cuttack and Hyderabad has been done.

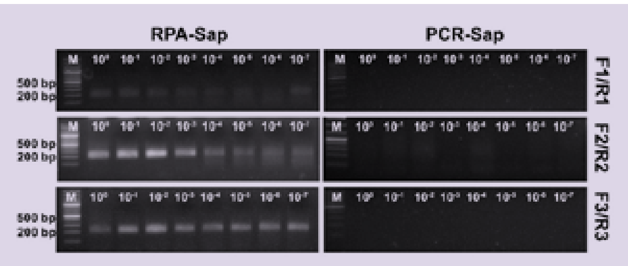


Fig. 6.3. Sensitivity of RPA in comparison to PCR for detecting RTBV in leaf crude sap. Lane 10^0-10^{-7}: Detection of a serially diluted crude extract (10^0-10^{-7}) on 2% agarose gel. Lane M: 100 bp plus DNA ladder (Thermo Scientific, USA)

Integrated disease management

On-farm trial conducted in collaboration with KVK, Lohardaga revealed that Bioinoculant based IDM module (seed treatment with *Trchoderma asperellum*, KP763500 (1 x 10^8cfu) @ 10 g kg^{-1} seed + soil application of *T. asperellum* enriched FYM (1 x 10^8cfu) (@ 5 kg m^{-2} in nursery bed + seedling dip treatment with *T. asperellum*, KP763500 (1 x 10^8 cfu) @ 10 g l^{-1} + need based application of Nativo) was significantly superior over non-IDM farmers practice in percent reduction of leaf blast, brown spot and false smut disease in rice variety Sahabhagidhan. The *T. asperellum* population in rhizosphere in IDM fields was significantly higher than non-IDM fields.

Breeder seed production

Produced 50.62 q of breeder seeds of 8 notified varieties namely Anjali, CR Dhan 320, CR Dhan 103, CR Dhan 107, CR Dhan 415, Sahbhagidhan, Vandana, Virendra, etc.to fulfil the indents by DAC and supplying to the farmers.

Rainfed Lowland

Rice production and productivity improvement in Rainfed lowland ecosystem

The Regional Rainfed Lowland Rice Research Station (RRLRRS) has systematically undertaken Front Line Demonstrations (FLDs) focused on climate-smart rice varieties characterized by resilience to both flooding and drought conditions. Simultaneously, efforts have been directed towards the evaluation of high-yielding rice varieties. The objective is to disseminate advanced rice production technologies among rainfed farmers, thereby contributing to the augmentation of rice productivity in the state of Assam. This station has collected and maintained rice germplasm suitable for this region for further breeding programme. Numerable numbers of entries were evaluated under AICRIP on Rice for varietal recommendation and release at National level. Research has been conducted on emerging pest management of rice at Gerua. Under the North Eastern Hill (NEH) Component, the distribution of crucial agricultural inputs, including seeds, fertilizers and Leaf Coloured Charts, has been executed to assist beneficiaries in need. This initiative aligns with the broader objective of promoting sustainable and resilient agricultural practices in the region.

Maintenance of rice germplasm

In the *kharif* season of 2023, a total of 758 rice germplasms were systematically maintained at RRLRRS, Gerua. Comprehensive assessments were conducted, focusing on key agronomic parameters, including plant height, days to 50% flowering, number of panicles per square meter and yield measured in tons per hectare.

The *Bora* rice germplasms exhibited a considerable range in plant height, spanning from 84.4 cm to 122.4 cm. The recorded number of panicles per square meter ranged from 231 to 257, with 50% of the plants reaching flowering stage between 94 to 95 days. Among the five *Bora* rice germplasms assessed, Nal Bora demonstrated the highest yield at 3.5 t ha^{-1}, while Aghoni Bora exhibited the lowest yield at 2.6 t ha^{-1}.

The Joha germplasms maintained at the Gerua station displayed a variation in plant height, ranging from 137.6 cm to 177.6 cm. The duration for 50% flowering ranged from 120 to 145 days. The yield of Joha rice germplasms showed a range from 2.2 t ha^{-1} to 3.6 t ha^{-1}, with Bakul Joha recording the highest observed yield.

Table 6.5. Performance of Bora rice germplasm of Assam

Sl. No.	Variety	Plant height (cm)	Days to 50% flowering	No. of pani-cle/sqm	Yield (t ha^{-1})
1.	Nal Bora	122.4	94	256	3.5
2.	Assam Biroin	120.2	95	250	3.2
3.	Bhogali Bora	86.8	94	231	3.0
4.	Ghiu Bora	120.6	94	237	2.7
5.	Aghoni Bora	84.4	95	257	2.6

Table 6.6. Performance of Joha rice germplasm of Assam.

Sl. No.	Variety	Plant height (cm)	Days to 50% flower-ing	No. of panicle/ sqm	Yield (t ha^{-1})
1.	Bakul Joha	177.6	135	303	3.6
2.	Mem Joha	154.6	140-145	187	3.5
3.	Kola Joha	167.8	145	297	3.3
4.	Tulsi Joha	154.8	140	363	3.2
5.	Tulsi Amrit	153.8	135	314	3.2
6.	Tulsi Prasad	149.8	140	241	3.2
7.	Keteki Joha	156.4	135	264	3.1
8.	Kon Joha	173.2	125-130	204	3.0
9.	Chini Kamini	144.2	145	274	3.0
10.	Maniki Mad-huri	171.8	125-130	283	2.9
11.	Bhabali Joha	137.6	135	199	2.8
12.	Atma Shital	160.2	140-145	247	2.8
13.	Gopal Bhog	153.0	145	308	2.5
14.	Kinkuni Joha	166.2	120	290	2.4
15.	Cona Chur	148.8	135	273	2.4
16.	Pimpudi Basa	152.2	145	135	2.3
17.	Adam-chini	146.6	135	297	2.3
18.	Pilpilia Joha	139.6	120	277	2.2
19.	Bhog	157.0	130	298	2.0
20.	Kharika Joha	144.6	145	300	2.0

Seed production and distribution

In the *Boro* season of 2022-23, a total of 365 kg of Truthful labelled Seeds (TL seed) for the Naveen variety and 96 kg for CR Dhan 315 were produced. Concurrently, in the subsequent *kharif* season of 2023, an area of 2.91 hectares was dedicated to the cultivation of CR Dhan 310, 311, 307, 801, 802, 909 and Chandrama varieties for seed production purposes.

Throughout the year, the research station contributed to the dissemination of seeds by supplying 7300 kg of breeder seeds and 1751 kg of TL seeds. This initiative is part of the ongoing efforts to support agricultural practices and enhance seed availability for farmers.

Frontline Demonstrations

Climate-smart rice varieties, specifically CR Dhan 801 and 802, characterized by tolerance to both flood and drought conditions, along with the high-yielding CR Dhan 307 variety, were subjected to field demonstrations during the *kharif* season of 2023. The demonstrations were conducted across a total area of 22 hectares in Baksa, Kamrup, Nalbari, and Darrang districts of Assam (Fig. 6.4).

Fig. 6.4. FLDs on CR Dhan 307, 801 and 802 in Assam.

The observed yields for CR Dhan 801 ranged from 5.08 to 5.70 t ha^{-1}, while CR Dhan 802 exhibited yields varying between 4.50 and 4.84 t ha^{-1}. Notably, CR Dhan 307 demonstrated the highest yield, reaching 7.71 t ha^{-1}, as observed in the Front Line Demonstration (FLD) conducted at Pakorkona village in the Kamrup district. These findings underscore the potential of these climate-smart varieties and high-yielding cultivars in contributing to enhanced rice productivity under diverse agro-climatic conditions.

Survey of insect-pests

A survey was conducted during the *kharif* season of 2023 in the districts of Baksa, Goalpara, and Kamrup, Assam, to assess the prevalence of insect-pests on rice crop. The recorded incidence of dead heart ranged from 5.06 to 7.07 per cent at the maximum tillering stage. The survey revealed the presence of rice leaf folder (*Cnaphalocrosis medinalis*)

Fig. 6.5. Outbreak of army worm on paddy in Assam during *kharif* 2023.

Fig. 6.6. Comparison of Temperature Trend in Sali Season with current year.

at rates of 0.83, 1.39, and 1.36 per cent in the districts of Kamrup, Baksa, and Goalpara, respectively.

Notably, armyworm (*Mythimna separate*) infestations affected approximately 28,000 hectares of paddy fields spanning 15 districts in Assam during the months of October and November after flood in July, 2023. The monthly rainfall recorded in July to September was much lower than the previous sixteen years trend (Fig. 6.5) and the minimum temperature was found to be consistently about 3ºC higher than the normal range of 19.8ºC to 22.9ºC during June to October (Fig. 6.6). The surge in temperature coupled with aridity in post-flood situation of Assam created a conducive environment for the proliferation of the armyworm population. In response to this pest outbreak, efforts were made to generate mass awareness regarding preventive measures through the publication of informative article in local newspaper. This proactive approach aimed to disseminate knowledge and encourage preventive actions against armyworm attacks, contributing to the overall management of pest-related challenges in rice cultivation.

Population dynamics of stem borer and leaf folder

Per cent dead heart (DH) and leaf folder folded leaves were recorded at fortnightly intervals and were correlated with corresponding meteorological data. Incidence of dead heart (DH) was first recorded at the end of first fortnight of September (3.21%), which gradually increased to 8.79% in second fortnight of September and attained peak 15.00% at end of first fortnight of October. Thereafter DH percentage started declining and recorded 3.93 % white ear head at second fortnight of November. Incidence of dead heart was significantly correlated with rainfall (r=0.85), number of rainy days (r=0.84) and evening RH (r=0.88). Leaf folder folded leaves (LFFL) percentage was 0.85% at first fortnight of September and found to be gradually increased in the successive observation at fortnightly intervals and attained peak during second fortnight of October (1.80%) before declining in November month. LFFL percentage was non-significantly correlated with meteorological parameters.

Coastal Saline

Mapping of soil physicochemical properties

Soil samples collected at 15 cm and 30 cm depths from RCRRS, Naira experiment field showed that soils were non-saline (<0.45 dsm^{-1}), slightly alkaline (7.56), high in organic carbon (>0.75%), low available nitrogen (<280 kg ha^{-1}), low to medium available phosphorous (<55 kg ha^{-1}), medium potassium (141 kg ha^{-1}), deficient in zinc (<0.6 mg kg^{-1}), deficient to sufficient in iron (<4.5 mg kg^{-1}) and sufficient in manganese (>2.0 mg kg^{-1}) and copper (>0.2 mg kg^{-1}) (Fig. 6.7).

c

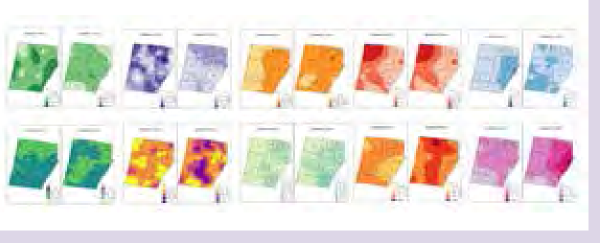


Fig. 6.7. Maps illustrating the different soil parameters at RCRRS, Naira experimental field.

Evaluation of the rice varieties suitable for the coastal ecosystems Evaluation of different NRRI rice varieties in coastal ecology revealed that CR Dhan 412 (7.77 t ha^{-1}) and CR Dhan 414 (7.8 t ha^{-1}) varieties significantly provided higher yield i.e., 35% more grain yield compared tolocal variety MTU 7029 (5.74 t ha^{-1})

Seasonal patterns and forecasting rice pest in coastal ecosystem Spatial and temporal distribution maps were generated for yellow stem borer (YSB) damage, leaf folder (LF) damage and Brown Planthopper (BPH)over six villages *viz.,* Ponnampeta, Batteru, Naira, Karajada, Bhyri and Singupuram in Srikakulam tehsil, Andhra Pradesh covered approx. 2302 ha. of rice crop (Fig. 6.8). A spatial

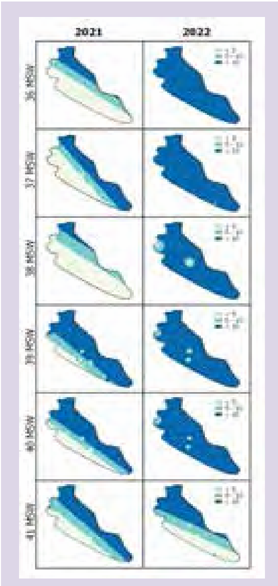


Fig. 6.8. Spatial distribution map of YSB damage deadhearts.

autocorrelation of 260 m, 370 m and 403 m in YSB, LF and BPH population was identified in sampling area.

Diversity of plant parasitic and beneficial nematodes in coastal rice ecosystems

Nematode genera belonging to 21 different nematode families were identified and high nematode abundance was observed at soil pH ranging from 6-6.5. Diversity index and evenness index of all soil samples were calculated and high nematode diversity was observed at sampling location Selagapeta village of Santhabommali mandal, Srikakulam, Andhra Prasedh with soil pH of 5.36 (Fig. 6.9).

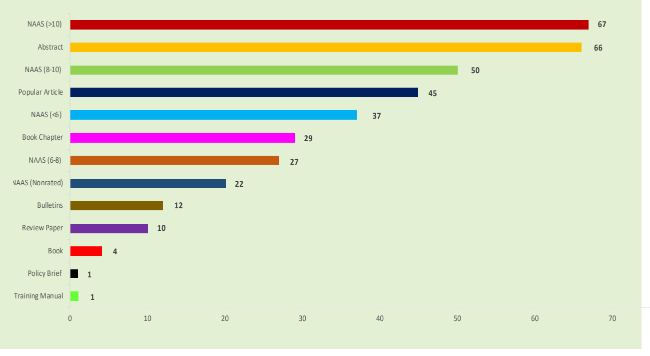
Fig. 6.9. Different nematode genus identified from north coastal district of Andhra Pradesh.

Conclusion

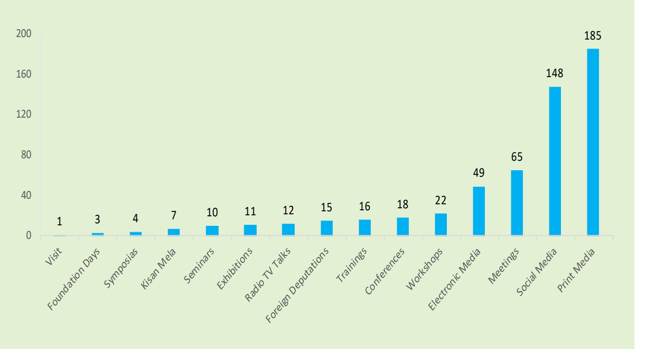
NRRI Research Stations situated at Hazaribag, Gerua and Naira have developed and validated several rice varieties suitable to improve the climate resilience of rice production. CRURRS, Hazaribag has developed several rice varieties suitable for drought-prone rainfed ecologies along with crop production technologies to improve the climate resilience of rice production in rainfed drought-prone ecologies. RRLRRS, Gerua has produced breeder seeds of many HYV of rice suitable for the region and supplied to the seed chain of Assam state. Plant protection technologies evolved at the research station benefited the rice farmers in managing insect-pests and diseases of rice in rainfed ecologies. The research and extension activities undertaken through the Program has greatly supported this objective. The farming communities in the target ecologies along with the students have also been benefited through regular demonstrations, workshops and hands on training organized on various aspects of crop management.

PUBLICATIONS & PARTICIPATION IN SCIENTIFIC EVENTS

During the year 2023, the institute has published research, technology and extension materials which is shown by the below given figure

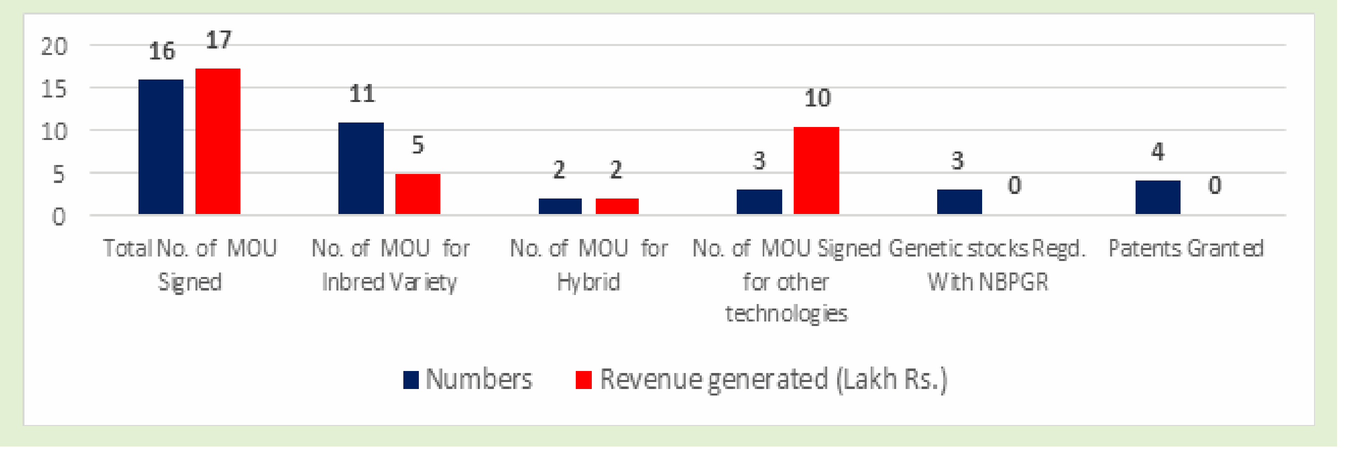


Participation in Conferences/Symposia/Meetings/Trainings/ Workshops/Kisan mela/Seminars/Radio & TV talks/ Media coverages



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

COMMERCIALIZATION OF ICAR-NRRI TECHNOLOGIES



PATENT GRANTED

The Patent Granted for Formulation of Fungal Entomopathogen Beauveria Bassiana TF6 to Control Rice Leaf Folder on 8 November 2023 with Patent No. 467237. The Patent Granted for Formulation of Bacterial Entomopathogen Bacillus Thurigiensis TB160 to Control Rice Leaf Folder on 6 December 2023 with Patent No. 477890. The Patent Granted for Invention of Efficient Portable Insect Collector with Automated Counter on 12 December 2023 with Patent No. 480911. The Patent Granted for Environment friendly microbial mediated method of rice straw pulp preparation and uses thereof on 28 December 2023 with Patent No. 473791.

ACTIVITIES AND EVENTS UNDERTAKEN

During the year 2023, ICAR-NRRI has organized several events and conducted diverse set of routine and extracurricular activity to comply with the council's vision and the Government of India programmes. The brief account of the undertaken events and activities are as follow-

ACTIVITIES

Activities	Distinguished participants
43rd Institute Research Council (IRC), 4 to 7 July 2023	Dr. A.K. Nayak (C), Dr. B Mondal (S, IRC & I/c PME Cell), Head of Divisions and Scientists of the Institute and KVKs
The Institute Joint Staff Council (IJSC) Meeting, 30 November 2023	Dr. A.K. Nayak (C), Dr. MJ Baig, Head, Crop Physiology & Biochemistry Division, Dr. R Tripathi, Sr. Scientist, Dr. B Gowda, Scientist, Shri V Ganesh Kumar, Head of Office, Shri RK Singh, Head of Finance, Shri SK Sahu, AAO (Secretary official side), Shri M Mohanty, AAO, Shri NP Behura, AAO, Shri PK Jena, TO, CJSC Member, Shri SK Rout, TO, Shri B Pradhan, Sr. Technician (Secretary staff side), Shri D Naik, SSS, Shri B Naik, SSS and Shri BK Naik, SSS
The 24th Scientific Advisory Committee meeting of KVK, Cuttack, 19 July 2023	Dr. A.K. Nayak (C)
The Scientific Advisory Committee meeting of KVK, Koderma on 18 January 2023	Dr. NP Mandal (C)

C: Chairman; M: Member; S: Secretary

PROGRAMMES AND EVENTS

S.N.	Events	Participants
1.	ICAR Eastern Region Pensioners Association New Year Meet on 19 January 2023	30
2.	Awareness campaign on "potential of millets: from farm to plate" on 19 January 2023	30
3.	Parakram Diwas, the 126th birth anniversary of Netaji Subhas Chandra Bose on 23 January 2023	50
4.	Workshop on upscaling RESILIENCE project activities on 24 Janu-ary 2023	45
5.	Workshop on Natural Farming on 8-9 February 2023	70
6.	Natural Farming Awareness Programme on 10 & 20 February 2023	200
7.	Honourable President of India Shrimati Droupadi Murmu ji inaugu-rated the Second Indian Rice Congress (SIRC-2023) on 11 February 2023 Second Indian Rice Congress (SIRC-2023) on 11-14 February 2023	500
8.	International Women's Day on 10 March 2023	60
9.	Hindi workshop on Hindi Typing through Unicode System on 14 March 2023	25
10.	Animal Health Camp-cum-Disease Awareness Campaigns on 10, 15, 16 and 20, 26-28 March 2023	804
11.	Under the Jan Bhagidari programme of third G20 Education Working Group Meeting, 6-20 April 2023	200
12.	78th Foundation Day and Dhan Diwas on 23 April 2023	300
13.	World Intellectual Property Day on 26 April 2023	60
14.	ICAR-NRRI sports contingent participated in the ICAR Zonal Sports Tournament-2022 during 24-27 April 2023	50
15.	World Veterinary Day 2023 on 29 April 2023	285
16.	Regional Workshop on 'PPV&FRA and Agro-biodiversity Exhibi-tion' during 11-12 May 2023	100
17.	Seed sale at ICAR-NRRI, Cuttack	3000
18.	Pension Adalat at ICAR-NRRI, Cuttack on 17 May 2023	60
19.	A workshop was organized to discuss the possibility to export of Ar-omatic rice from Cuttack on 19 May 2023	100

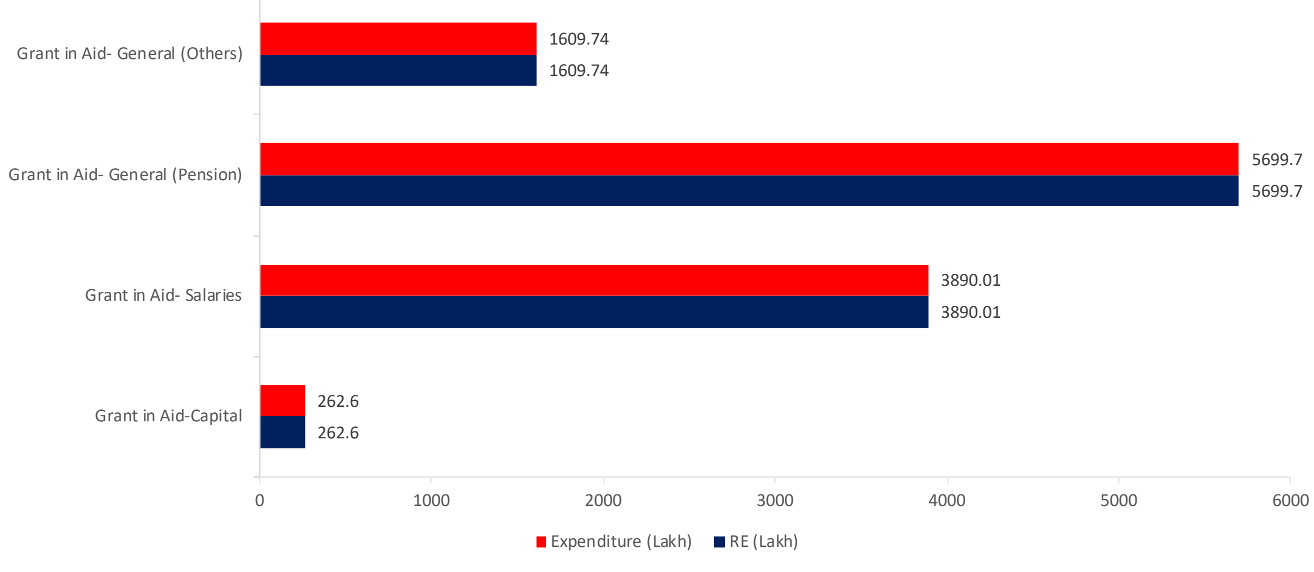
S.N.	Events	Participants
20.	World Environment Day 2023 during 23-25 May 2023	270
21.	The 56th meeting of Town Official Language Implementation Com-mittee (TOLIC), Cuttack on 29 May 2023	30
22.	A workshop cum awareness programme on energy and water con-servation in agriculture	37
23.	World Milk Day 2023 on 1 June 2023	40
24.	World Environment Day 2023 on 5 June 2023	80
25.	Workshop on the IARI-Cuttack-Hub Academic Programme on 6 June 2023	30
26.	Annual Review Meeting of Incentivizing Research in Agriculture on 10 June 2023	40
27.	Blood Donation Camp on 14 June 2023	51
28.	The 9th International Yoga Day (IYD) on 21 June 2023	40
29.	World Zoonoses Day on 6 July 2023	100
30.	Celebration of ICAR Foundation Day & Technology Day on 16-18 July 2023	90
31.	A review meeting for the member offices of Town Official Language Implementation Committee (TOLIC), Cuttack on 18 July 2023	20
32.	The Institutional Biosafety Committee (NRRI-IBSC) on 27 July 2023	30
33.	KVK, Cuttack and KVK, Koderma organized PM Kisan Samelan on 27 July 2023	110
34.	Rice Walk and Rice Research Orientation Programme for Students on 1 August 2023	129
35.	77th Independence Day one 15 August 2023	200
36.	Inauguration of Mushroom Spawn Production Unit on 15 August 2023	200
37.	Parthenium Awareness Week during 16-22 August 2023	200
38.	ICAR-NRRI-CRURRS, Hazaribag, RRLRRS, Gerua, KVK, Koderma and KVK Cuttack Parthenium Awareness Week from 16-22 August 2023	658
39.	Workshop for the Rice and Vegetable Seed Growers of West Bengal on 18-19 August 2023	62
40.	A seminar on 'Sustainable Rice Production under Climate Change' on 31 August 2023	120
41.	eries of demonstrations on Drone Technology on 8 August-20 Sep-tember 2023 (210 acres of rice cropped area in 21 villages)	1000
42.	ICAR-NRRI sports contingent participated in the ICAR Inter-Zonal Sports Tournament-2022 during 9-12 September 2023	42
43.	Hindi Divas and Hindi Fortnight-2023 during 14-30 September 2023	106
44.	Hindi Scientific Seminar on "Contribution of modern technologies in the upgradation and development of the country through natural resources" on 25 September 2023	50
45.	The Live webcasting program of the inauguration of Sankalp Saptah Program by Hon'ble Prime Minister of India on 30 September 2023	21
46.	Birth Day of Father of the Nation – Mahatma Gandhi and Lal Ba-hadur Shashtri, a special campaign 3.0	45
47.	National Millet Expo-2023 on 6 October 2023	200
48.	A Project Launching workshop of project "Economic and environ-ment-friendly utilization of Basic-Slag and Fly Ash as Soil amend-ments to Reclaim Acid soils of Odisha [SAFAR]: Waste to wealth for promoting circular economy on 10 October 2023	41
49.	National Brainstorming Workshop on Integrated Pest Management: Challenges and Way Forward (WinPest - 2023) on 11 October 2023	153
50.	NRRI Scientists team visited the BPH and Leaf Folder affected areas of Odisha on 16 October 2023	20
51.	KVK, Cuttack organized various events on Special Campaign 3.0 during 2-31 October 2023	250
52.	Vigilance Awareness Week-2023 during 30 October to 5 November 2023	60
53.	PM Live telecast regarding Bharat Sankalp Yatra on 15 November 2023	80
54.	A Press Meet for NRRI Makes History: Unveils Nine Revolutionary Rice Varieties Across India in a Single Year on 22 November 2023	35
55.	Review Meeting on 'Crop Diversification under CDP-MLIP of Cut-tack district on 22 November 2023	80
56.	The Institute Joint Staff Council (IJSC) Meeting was held on 30 No-vember 2023	30
57.	Agriculture Education Day was celebrated by IARI, New Delhi on 3 December 2023	45
58.	National workshop on "Navigating Climate Change and Livelihood Development of Farmwomen in India " on 4 December 2023	100
59.	World Soil Day and Awareness Training on theme "Soil and Water: Source of Life" on 5 December 2023	80
60.	World Soil Day on 5 December 2023	100
61.	ICAR Sports Tournament for Eastern Zone 2023 from 13-16 De-cember 2023	500
62.	Special Day-Kisan Diwas on 23 December 2023	30
63.	Shri Arjun Munda, Hon'ble Union Minister of Agriculture and Farmers Welfare and Minister of Tribal Affairs, Govt. of India graced Kisan Samman Samaraoh as chief guest at Keonjhar on 24 December 2023	200
64.	Live watching programs of Viksit Bharat Sankalp Yatra on 30 No-vember, 9 and 27 December 2023	85
65.	A Stakeholder's Workshop on 'From Trash to Treasure: Unlocking the Secrets of Waste Conversion for Wealth Creation and Sustaina-ble Disposal Strategies on 28 December 2023	21

AWARDS AND RECOGNITION

During the year 2023, ICAR-NRRI and its staff members have bagged several prestigious awards and recognitions. The details of the awards are given below.

1	Dr. A.K. Nayak received the Basudha Samman Award-2023
2	Dr. Sanghamitra Samantaray, received the prestigious 'Dr. Darshan Singh Brar Award in Agriculture-2022' by Dr. Gurdev Singh Khush Foundation
3	Dr. Sanghamitra Samantaray received Professor Sushil Kumar Mukherjee Lecture Award from Indian Photobiology Society, Jadavpur University Campus, Kolkata
4	Dr. Dibyendu Chatterjee received Membership, National Academy of Sciences in India (NASI), Prayagraj
5	Dr. K. Chakraborty is selected as Member of the National Academy of Sciences, India (NASI) in the category of Biological Sciences
6	Dr. Dibyendu Chatterjee conferred Associate (2023) of National Academy of Agricultural Sciences (NAAS)
7	Dr Totan Adak selected as Associate of the National Academy of Agricultural Sciences for the year 2024
8	Dr Totan Adak selected as member in the Indian National Young Academy of Sciences (INYAS) for a period of 5 years (2024-29)
9	Dr. Devanna received Invited Research Fellowship from Heinrich Heine University Düsseldorf, Germany, 2022-23
10	Dr. Rahul Tripathi received The Mosaic Company Foundation Young Scientist Award in the area of Plant Nutrition 2021-22 from The Mosaic Company Foundation
11	Dr. Debarati Bhaduri received 'SCON-Recognition Award' for the year 2022 by Society for Conservation of Nature (SCON) & Sustainable India Trust (SIT), New Delhi
12	Dr. Awadhesh Kumar received Asia's Innovative Researcher Award in Plant Biochemistry- 2023 by Asia International Research Awards Congress on 01-10-2023, Trichy, Tamil Nadu, India
13	Dr. Awadhesh Kumar received Best Researcher Award- 2023 at International Award Ceremony on Academic Excellence Awards (AEA 2023) by Knowledge Research Academy, Coimbatore, Tamil Nadu, India
14	Dr. Chanchila Kumari received Best Extension Professional Award in International Extension Education Congress (IEEC)-2023, organized by Society of Extension Education, during December 18-20, 2023 at Jaipur, Rajasthan
15	VIKAS R-ABI Incubation Center of ICAR-National Rice Research Institute (NRRI) has been awarded with Diamond Award for innovative startups on 19 February 2023
16	**Young Scientist Award - 11**
17	**Fellow Awards - 5**
18	**Editor in Referred Journals - 17**

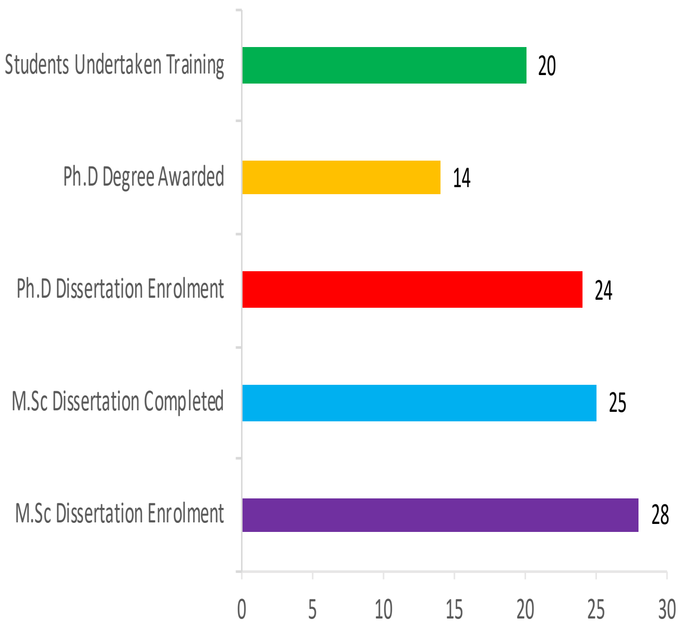
FINANCIAL STATEMENT (JANUARY-DECEMBER 2023)



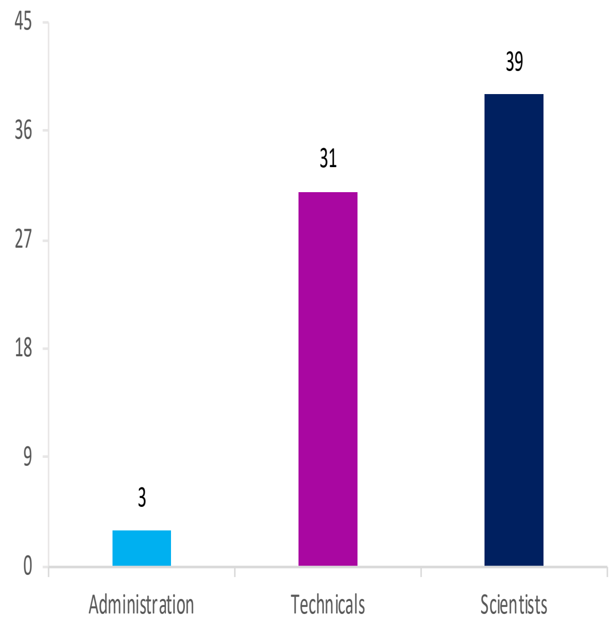
HUMAN RESOURCE DEVELOPMENT AND CAPACITY BUILDING

Human Resource Development (HRD) Cell of NRRI has been established to strengthen and facilitate the training and capacity building of the students/scientists/other staffs to work in the emerging areas of rice research and management. The financial targets and achievements of HRD cell of the institute is 3.46.

Achievements of the HRD programmes for the students during 2023



Physical targets and achievements of HRD Cell



IARI-NRRI, CUTTACK HUB

New Education Policy – 2020 aimed at improving the gross enrolment ratio in educational institutions and strengthening the quality of higher education in the country. In this direction, the Indian Council of Agricultural Research, New Delhi integrated the principles of NEP 2020 into the Agricultural Education Framework of the country. To give tangible shape to the goals outlined in the National Education Policy 2020 with regard to Agricultural Education in India, a committee, led by the Director-General of ICAR, has established 14 academic hubs at the Indian Agricultural Research Institute in New Delhi. Among these, the IARI-NRRI, Cuttack hub, with its nodal institute based at ICAR-NRRI in Cuttack, stands as one of the distinguished hubs. From the current year academic session-2023-24, ICAR-NRRI, Cuttack, through its partner institutes is entrusted with the responsibility to contribute towards the implementation of NEP in the Agricultural Education Framework of the country. NRRI Cuttack hub has seven partner institutes in Cuttack and Bhubaneswar and faculties in the institute are approved by the Academic Council of IARI, New Delhi. Presently 23 students enrolled for BSc (Hons) Agriculture, two students each for MSc and PhD in the discipline of Genetics and Plant Breeding, Plant Pathology and Soil Science & Agricultural Chemistry. All the academic programmes in the institute are monitored by the Academic Management Committee which includes the Director as the Hub Coordinator, Academic Coordinator, Programme Coordinators (UG and PG), Chairman, Student Welfare Committee, and Hostel Wardens.

EXTENSION/ OUTREACH ACTIVITIES

To impart knowledge and develop skill to various groups of stakeholders, ICAR-NRRI, Cuttack had undertaken several extension activities during 2023 as detailed below:

Field demonstrations

One hundred thirty-seven demonstrations of newly released rice varieties and crop production as well as protection technologies in the farmers' field were conducted. About 19 promising rice varieties were demonstrated with 410 farmers in about eight states of the country which include Uttar Pradesh, Bihar, Chhattisgarh, Jharkhand, Madhya Pradesh, Maharashtra, Odisha, and West Bengal. The CRURRS, Hazaribag also conducted Front Line Demonstrations on drought tolerant rice variety IR 64 *Drt1* under ICAR-IRRI Collaborative project.

Exhibitions

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

Visitor's advisory services

A total of 4408 visitors comprising of farmers & farm-women, students and agriculture officers from the states of Jharkhand, Karnataka, Odisha, Andhra Pradesh, Tamil Nadu, Telangana, Bihar, Assam, Uttar Pradesh, Madhya Pradesh, Maharashtra and West Bengal visited experimental sites and demonstration plots, net houses, agricultural implement workshop and *Oryza* museum of the institute and regional stations during the year.

Fortnightly agro-advisory services

Overall 24 agro-advisories on rice were issued on fortnightly basis in English as well as Odia language during the year 2023. 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. In addition, block wise weather forecast based agro-met advisory bulletins of Cuttack district were issued 4-5 times per month. Advisories were also issued through 'NRRI Video *Barta*' every fortnight and circulated through social media for wider reach.

Training programmes for farmers and extension professionals

A total of 3871 participants including farmers, extension officials, administrative personnel and others were trained through 89 programmes of different durations (2-8 days) conducted physically or through virtual mode on various aspects of rice production and protection technologies.

Mera Gaon Mera Gaurav (MGMG) Programme

A group of 4-5 scientists has been constituted for a cluster of five villages who provide technical backstopping, training, advisories, etc. There are 21 such multi-disciplinary teams working at 21 clusters of villages (comprising 5 villages each) covering eight districts of Odisha.

Tribal Sub-Plan (TSP) Programme

Tribal sub plan (TSP) is under operation in three NRRI adopted villages *i.e.*, Bandasahi, Pitabari and Titrapanga of Phulbani, Kandhamal District, Odisha. More than 180 tribal farmers were provided the benefits through various trainings, frontline demonstration, exposure visits, field schools and other societal development activities. During 2023-24, the institute has distributed more than 45 quintals of popular rice varieties.

Scheduled Caste Sub-Plan (SCSP) Programme

During the year 2023, under SCSP programme seven more villages were selected in addition to earlier adopted eight villages. During *kharif* 2022, 127 quintal paddy seeds of improved varieties were distributed to 1023 farmers and bio-control agents (1200 tricho-cards) were provided for control of pest. Total 10 User Groups (UGs) were created (all farmers are member of one or other group) and developed agricultural machine custom-hiring centre in adopted villages. A total number of 659 medium equipment/ machinery like sprayer, power thresher, pump sets, etc. were distributed.

NEH Programme

STVR and HYV were disseminated through distribution of 280 kg seeds to beneficiary farmers of Assam under NEH Component. Additionally, 1161 kg of DAP, 1890 kg of urea, and 891 kg of MOP were distributed to 48 beneficiary farmers in the Kamrup, Nalbari, Baksa, and Darrang districts of Assam. Furthermore, Leaf Colour Charts (LCC) was provided to 173 beneficiaries of the NEH component.

PERSONNEL (JANUARY-DECEMBER 2023)

Dr. Amaresh Kumar Nayak, Director

CROP IMPROVEMNENT DIVISION

Scientist								
S Samantaray (Head)	ON Singh	BC Patra	MK Kar	H Subudhi	L Behera	LK Bose	K Chattopadhyay	SK Dash
J Meher	M Chakaraborti	JL Katara	RL Verma	RP Sah	BC Marndi	P Sangha-mitra	K Ali Molla	S Sarkar
Parames-waran C	Devanna	Reshmi Raj K.R.	Anil Kumar C					
Technical Staff								
B Nayak	JS Anand	PL Dehury	LK Singh	M Soren	N Barik	KC Mallik	B Mondal	B Mishra
D Nayak	D Samal	B Behera	A Parida	D Majhi	B Hembram	B Ray	M Patra	S Sarkar
R Rana	KC Munda							
Administrative Staff								
M Swain								
Skilled Support Staff								
J Biswal								

CROP PRODUCTION DIVISION

Scientist								
P Bhatta-charya (Head)	S Saha	A Poonam	P Panneer selvam	R Tripathi	S Mohanty	M Shahid	D Bhaduri	U Kumar
A Kumar	S Munda	D Chatterjee	PC Jena	NT Borkar	S Chaterjee	M Debanath	R Khanam	M Sivasha-nkari
BR Goud	S Priyadarsani	K Kumari						
Technical Staff								
R Chandra	KK Suman	AK Mishra	JP Behura	B Das	AK Moharana	P Moharana	SK Ojha	P Behera
BC Behera	KC Palaur	PK Jena	R Jamunda	S Panda	PK Parida	SC Sahoo	SP Lenka	P Samantaray
EV Ramaiah	S Baskey	G Mandi	PK Ojha	D Parida	D Baral	D Behera	G Bihari	S Mohanty
CK Ojha	S Pradhan	R Beshra	JK Sahu	S Kumar	KK Meena	SP Sahoo	TK Behera	AK Suman
A Choudhary								
Administrative Staff								
Nil								
Skilled Support Staff								
S Biswal	B Marandi							

CROP PROTECTION DIVISION

Scientist								
SD Mohapa-tra (Head)	PC Rath	KR Rao	S Mondal	AK Mukherjee	MK Bag	S Lenka	T Adak	NKB Patil
Raghu S	Keerthana U	GP Pandi G	Basan Gowda G	Prabhu Karthikeyan SR	MS Baite	M Annamalai	G Prasanthi	Jeevan B
Rupak Jena								
Technical Staff								
PK Sahu	R Swain	EK Pradhan	H Pradhan	A Mohanty	S Biswal	AK Naik	MN Das	D Dash
JP Das	KC Barik	S Das	Md Shadab Akthar					

Administrative Staff								
Nil								
Skilled Support Staff								
D Naik								

CROP PHYSIOLOGY & BIOCHEMISTRY DIVISION

Scientist								
MJ Baig (Head)	K Chakra-borty	TB Bagchi	PS Hanjagi	SM Awaji	A Kumar	N Basak	G Kumar	MK Lal
Technical Staff								
C Tudu	J Bhoi	J Senapaty	S Banerjee	DB Sahoo	S Haldhar	S Kumar		
Administrative Staff								
Nil								
Skilled Support Staff								
G Sahoo	J Dei	N Naik						

SOCIAL SCIENCE DIVISION

Scientist								
GAK Kumar (Head)	B Mondal	NN Jambhu-lkar	Sudipta Paul	JP Bisen	AK Pradhan			
Technical Staff								
B Behera	AK Parida	A Panda	MK Nayak	SK Sethi	SR Dalal	G Sinha	SK Rout	C Majhi
SK Mohapatra	A Anand	SK Tripathy	AK Panda	SK Roul	HS Sahoo			
Administrative Staff								
L Trivedi								
Skilled Support Staff								
Surubali Hem-bram								

NRRI RESEARCH STATION, HAZARIBAGH

Scientist								
NP Mandal (Head)	SM Prasad	S Bhagat	BC Verma	S Roy	A Banerjee	Priya Medha	Soumya Saha	Arun Ku-mar CG
Technical Staff								
S Oran	U Saw	J Kumar	J Prasad	S Akhtar				
Administrative Staff								
R Paswan	S Kumar	CR Dangi	AK Das	SK Pandey				
Skilled Support Staff								
G Gope	HC Bando							

RRLRRS, GERUA, ASSAM

Scientist								
K Saikia (OIC)								
Technical Staff								
S Baruah	D Khan	TK Borah	B Kalita					
Administrative Staff								
J Das								
Skilled Support Staff								
M Das								

NRRI RESEARCH STATION, NAIRA

Scientist								
BB Panda (Head)	Kiran Gandhi B	B Gayatri	Shyam CS					
Technical Staff								
RP Rao								

KVK, SANTHPUR

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

KVK, KODERMA

Technical Staff								
AK Rai (Head)	C Kumari	B Singh	R Ranjan	M Kumar	S Kumar	BK Khuntia		
Skilled Support Staff								
M Ram								

ADMINISTRATIVE SECTION

Administrative Staff								
V Ganesh Kumar (SAO)	RK Singh (FAO)	SK Satapahy	NK Swain	CP Murmu	SK Behera	S Nayak	SK Sahu	
RK Behera	RC Das	R Kido	NP Behura	SK Sahoo	M Mohanty	N Mahavoi	D Khuntia	N Jena
MB Swain	SP Sahoo	S Sahoo	SK Nayak	SK Lenka	SK Sahoo	M Das	RC Nayak	S Pradhan
A Sethi	R Sahoo	DK Parida	MK Sethi	KC Behera	PC Das	AK Pradhan	RC Pradhan	V Kumar
D Muduli	SK Bhoi	H Marandi	S Maharana	AK Sinha	RK Singh	RPS Sabarwal	SK Patra	SK Das
J Bhoi	B Daspattanayak							
Technical Staff								
BK Mohanty	P Kaleem	SK Sinha	N Biswal	KC Das	PK Sahoo	B Pradhan	AK Nayak	B Sethi
S Mahapatra	R Behera	S Mishra	S Kumar					
Skilled Support Staff								
B Das	D Das	M Sahoo	SR Das	G Singh	S Bhoi	R Soren	R Naik	B Naik
P Naik	B Naik	B Das						

INSTITUTE RESEARCH PROGRAMMES FOR THE YEAR 2023-24

Code No.	Title of the Projects	Programme Leader (PL), Principal Investigator (PI) and Co PIs
	Programme 1: Genetic improvement of rice for enhancing yield, quality, and climate resilience	
1.1	Managing Rice genetic resources for sustainable utilization	BC Patra/P Sanghamitra, BC Marndi, S Samantaray, M Chakraborti, JL Katara, NN Jambhulkar, S Roy, Parameswaran C, Devanna, Anilkumar C
1.2	Maintenance Breeding and Genetic dissection of seed Quality Traits.	BC Marndi, RP Sah, Anil Kumar C, A Kumar, NKB Patil, Raghu S, Annamalai M, G Kumar, BC Patra, GAK Kumar
1.3	Pre-breeding for broadening the genetic base of rice by utilizing wild species of Oryza	MK Kar, LK Bose, M Chakraborti, S Samantaray, BC Patra, SK Dash, KA Molla, P Sanghamitra, JL Katara, Parameswaran C, Devanna, PC Rath, S Lenka, AK Mukherjee, GP Pandi G, S Sarkar, Priyamedha Associates: K Chakraborty, NP Mandal, A Kumar, N Basak, G Kumar, BC Marndi
1.4	Developing genetic solutions for enhancing input use efficiency in rice for rainfed and irrigated ecologies	J Meher, RP Sah, Reshmi Raj KR, C Parameswaran, LK Bose, SK Dash, P Panneerselvam, Prabhu Kartikeyan SR, D Chatterjee, Devanna
1.5	Breeding for Aroma and Grain Quality in Rice	S Sarkar, K Chattopadhyay, P Sanghamitra, SK Dash, M Chakraborti, MK Kar, S Roy, HN Subudhi, J Meher, N Basak, TB Bagchi, A Banerjee, Basana Gowda G, M Sivashankari and Reshmi Raj KR Associates: S Samantaray, DR Pani, AK Mukherjee, L Behera, T Adak and G Kumar
1.6	Gene mapping and precision breeding for enhancing climate resilience in lowland varieties	SK Dash, RP Sha, P Sanghamitra, Resmi Raj KR, GP Pandi G, SM Awaji and L Behera Associates: AK Mukherjee, MK Bag, PS Hanjagi, K Chakraborty, J Meher, LK Bose, S Lenka, Annamalai M
1.7	Genetic Enhancement for Multiple Stress Tolerance in Rice for Coastal Ecosystem	K Chattopadhyay, BC Marndi, K Chakraborty, LK Bose, KR Rao, A Poonam, KA Molla Associates: AK Nayak, AK Mukherjee, SD Mohapatra, Devanna
1.8	Hybrid rice for enhancing yield, quality and sustainability	RL Verma, JL Katara, Reshmi Raj KR, S Sarkar, S Samantaray, Parameswaran C, BC Patra, SK Dash, Devanna, Priyamedha, M Chakraborti Associates: AK Mukherjee, SD Mohapatra, BC Marndi, MK Kar
1.9	Development of New Generation Rice for enhancing yield potential in favourable ecology	LK Bose, SK Dash, MK Kar, J Meher, HN Subudhi, RP Sah, S Sarkar, L Behera, JL Katara, Parameswaran C, Devanna, Anilkumar C, RL Verma, S Roy, SD Mohapatra, A Banerjee, NN Jambhulkar, K Chakraborty Associates: N Mandal, AK Mukherjee, N Basak, S Lenka, M Chakraborti
1.10	Utilization of genome editing, transgenics and doubled haploid technologies for rice improvement	S Samantaray, Devanna, Parameswaran C, JL Katara, KA Molla, RL Verma, Anilkumar C, Reshmi Raj KR, A Kumar, SM Awaji Associates: S Lenka, Raghu S, Basana Gowda G
1.11	Development of Novel Genomic Resources for Rice Improvement	L Behera, Devanna, Parameswaran C, RP Sah, M Chakraborti, J Meher, Anilkumar C Associates: GP Pandi G, Raghu S, PS Hanjagi, A Kumar, SK Dash, MK Kar, HN Subudhi

Code No.	Title of the Projects	Programme Leader (PL), Principal Investigator (PI) and Co PIs
Programme 2: Enhancing the productivity, sustainability and resilience of the rice-based system		
2.1	Enhancing nutrient use efficiency in rice through advance agronomy using smart sensors, models and nano fertilizers	S Mohanty, AK Nayak, R Tripathi, D Bhaduri, D Chatterjee, U Kumar, Anjani Kumar, BC Verma, R Khanam, Md. Shahid, B Raghavendra Goud, Shyam Shiddaiah
2.2	National level zonation of rice ecologies, site specific planning and development of cropping and farming system models	A Poonam, R Tripathy, D Chatterjee, N Jambhulkar, B Raghavendra Goud Associates: S Saha, M. Nedunchezian (RC of CTCRI), G Acharya (CHES), SC Giri (RC of DPR), AK Nayak, S Saha, SM Prasad, Basana Gowda G, U Kumar, S Paul
2.3	Vulnerability analysis and assessment of climate smart agricultural technologies for enhancing resilience in stress prone rice ecologies	M Shahid, AK Nayak, R Khanam, D Chatterjee, S Mohanty, D Bhaduri, S Munda, R Tripathi, P Bhattacharyya, BB Panda, B Mondal, M Debnath and B Raghvendra Gouda
2.4	Developing agronomy for new generation rice and rice-based cropping systems	BB Panda, S Munda, Anjani Kumar, SK Dash, B Raghavendra Gouda, S Saha and Shyam CS
2.5	Ecosystem services quantification and analysing the nexus of climate change-land use change-food security in rice production systems	R Tripathi, M Debnath, Supriya Priyadarsani, Md. Shahid, JP Bisen, B Mondal, BB Panda, S Mohanty, D Chatterjee, B Raghavendra Goud, D Bhaduri, P Bhattacharyya, AK Nayak
2.6	Environment friendly management of rice straw and value addition for income generation to rice-farmers.	P Bhattacharyya, AK Nayak, D Bhaduri, P Panneerselvam, S Munda, Supriya Priyadarsani, M Shivashankar, BC Verma Associates: T Adak, S Lenka
2.7	Harnessing microbiome for enhancing rice productivity and improving soil health.	P Panneerselvam, U Kumar, GP Pandi G, Parameswaran C, Anjani Kumar, AK Nayak
2.8	Development of weed management strategies and assessing the risk of herbicide resistance in rice weeds	S Munda, B Mondal, B Raghavendra Goud
2.9	Development and Refinement of Farm implements, Post-harvest and Value addition Technologies for small farm mechanization	Sivashankari M, PC Jena, M Debnath, Supriya Priyadarsani, A Kumar, TB Bagchi, R Khanam, G Kumar Associates: P Panneerselvam, S Sarkar
2.10	Enhancing water use efficiency in rice-based cropping system	Anjani Kumar, AK Nayak, R Tripathi, BB Panda, D Chatterjee, BC Verma, R Khanam, PS Hanjagi, M Debnath, B Raghavendra Goud, D Jena Associates: D Bhaduri, S Munda, S Mohanty, P Panneerselvam
Programm 3: Biotic Stress Management in Rice		
3.1	Identification and characterization of donors against biotic stresses	MK Bag, PC Rath, AK Mukherjee, SD Mohapatra, S Lenka, S Mandal, A Banerjee, Raghu S, GP Pandi G, Basana Gowda G, NBK Patil, Prabhukarthikeyan SR, MS Baite, Annamalai M, Keerthana U, P Golive, R Jena, B Gayatri Associate: MK Kar
3.2	Ecology, diversity and interaction of plant, pests & natural enemies in rice	KR Rao/ Prashanti Golive, SD Mohapatra, Annamalai M, MS Baite, P Golive, MK Bag, G Kumar, Prabhukarithikeyan SR, B Gayatri, Kiran Gandhi B Associates: T Adak, Basana Gowda G, GP Pandi G
3.3	Use of Precision Tools and Techniques in Rice Insect Pest and Disease Management	SD Mohapatra, R Tripathi, Raghu S Associates: NN Jambhulkar

Code No.	Title of the Projects	Programme Leader (PL), Principal Investigator (PI) and Co PIs
3.4	Search for novel mediators in plant defense response to pathogenic infections in rice through molecular techniques	AK Mukherjee, S Mandal, Raghu S, GP Pandi G, Prabhukarthikeyan SR, MS Baite, KA Molla, P Golive, TB Bagchi, Devanna Associates: MK Kar, MK Bag, A Banerjee, Parameswaran C, K Chakraborty, T Adak
3.5	Plant protection molecules: efficacy, distribution, toxicity and remediation	T Adak, PC Rath, MK Bag, S Lenka, Prabhukarthikeyan SR, MS Baite, Annamalai M, Raghu S, Basana Gowda G, NBK Patil, GP Pandi G, U Kumar, R Jena, Jeevan B Associates: AK Mukherjee, P Bhattacharyya
3.6	Dissemination of integrated pest management strategies for insect pest, diseases and nematodes in rice	Guru Pirasanna Pandi G, PC Rath, AK Mukherjee, S Mandal, S Lenka, SD Mohapatra, MK Bag, T Adak, Annamalai M, Prabhukarthikeyan SR, MS Baite, Raghu S, Basana Gowda G, NBK Patil, R Jena, Jeevan B, GAK Kumar Associates: A Banerjee
Programm 4: Photosynthetic Enhancement, Abiotic Stress Tolerance and Grain Nutritional Quality in Rice		
4.1	Photosynthesis and productivity of rice under changing climate	MJ Baig, K. Chakraborty, N Basak, Gaurav Kumar, PS Hanjagi, SM Awaji
4.2	Evaluation of rice genotypes for new sources of multiple abiotic stress tolerance and understanding the underlying mechanism	K Chakraborty, MJ Baig, PS Hanjagi, SM Awaji, M Chakraborti, KA Molla, Anilkumar C Associates: K Chattopadhyay, A Kumar, BC Marndi, NP Mondal, S Roy
4.3	Characterization of rice genotypes for improved Physico-chemical and Nutritional properties	A Kumar, TB Bagchi, N Basak, G Kumar, RP Sah, Sivashankari M Associates: L Behera, S Sarkar, K Chattopadhyay
Programm 5: Research to enhance socio-economic wellbeing of rice stakeholders		
5.1	Reaching stakeholders to Enhance their socio-economic CAPacities (RECAP) through rice technologies	S Paul, GAK Kumar, B Mondal, NN Jambhulkar, JP Bisen, AK Pradhan, AK Mukherjee, KR Rao, S Lenka, Anjani Kumar, Supriya Priyadarsani, S Saha, Sivashankari M, SM Prasad, K Saikia
5.2	Working to Increase farm Net Gain through Socioeconomic research (WINGS)	B Mondal, GAK Kumar, SK Mishra, NN Jambhulkar, S Paul, JP Bisen, AK Pradhan, SM Prasad, K Saikia Associates: MK Kar, S Saha, K Chattopadhyaya, SK Dash, S Sarkar, MK Bag, S Roy, BS Satapathy, RP Sah, KR Rao, Basana Gowda G
Programme 6: Development of climate resilient technologies for rainfed upland, rainfed low land and coastal rice ecology		
6.1	Development of resilient production technologies for rice under rainfed drought-prone agro-ecosystems	S Roy, NP Mandal, SM Prasad, S Bhagat, BC Verma, A Banerjee, Priyamedha, Soumya Saha, K Chakraborty, N Basak, L Behera, D Bhaduri, S Saha
6.2	Rice production and productivity improvement in Rainfed lowland ecosystem	K Saikia
6.3	Development of Resilient technologies for Coastal Rice Ecology	Kiran Gandhi B, B Gayatri, Shyam CS, BB Panda Associates: KR Rao, MK Kar, K Chattopadhyay, BC Marndi, R Tripathi, Md Shahid, MS Baite

EXTERNALLY AIDED PROJECTS (EAPS)

Sl. No.	Project No.	Title of the Project	Source of Funding
1	EAP-27	Revolving fund scheme for seed production of upland rice varieties at CRURRS, Hazaribagh – NP Mandal, Priyamedha	AP Cess
2	EAP-49	Revolving fund scheme for breeder seed production - BC Marndi, RP Sah, Md. Azharudheen, Anil kumar	NSP/Mega seed
3	EAP-130	All India Network Project on Soil Biodiversity – Biofertilizers - BC Verma	ICAR
4	EAP-139	AICRP on energy in agriculture and agro-based industries – N T Borkar, PK Guru	AICRP (DRET-SET/ DRET-BCT)
5	EAP-140	Intellectual Property Management and Transfer/ commercialization of agricultural technology under National Agricultural Innovation Fund (NAIF) – BC Patra, GAK Kumar	ICAR
6	EAP-141	DUS Testing of Rice under Centrally sponsored scheme of PPV&FRA under "Sub-Mission on Seeds and Planting Material" – BC Patra, Anilkumar C	PPV&FRA
7	EAP-193	Future rainfed lowland rice systems in Eastern India (Climate-smart management practices: Crop and Natural resource management for stress-tolerant rice varieties in Odisha) - AK Nayak, M Shahid, D Bhaduri, R Tripathi, K Chakraborty, B R Goud	ICAR-IRRI collaboration
8	EAP-197	Consortia research platform (CRP) on bifortification - K Chattopadhyay, S Samantaray, TB Bagchi, M Chakraborty, A Kumar, N Basak, LK Bose, A Poonam, S Sarkar, BC Marndi, D Bhaduri	ICAR Plan-CRP
9	EAP-198A	Incentivizing Coordinating Unit - MJ Baig	ICAR
10	EAP-198B	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, N Umakant	ICAR Plan
11	EAP-199	Incentivizing Research in Agriculture: Towards understanding the C_3-C_4 intermediate pathway in *Poaceae* and functionality of C4 genes in rice – MJ Baig, P Swain, L Behera, Gaurav Kumar, A Kumar, K Ali Molla	ICAR Plan
12	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
13	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, Mathew Baite, NP Mandal, S Samantaray, Devanna, KA Molla, M Chakraborti, LK Bose	ICAR Plan
14	EAP-204	CRP on Agro-biodiversity: PGR Management and Use of Rice (Component I) - B C Patra, BC Marndi	ICAR-NBPGR
15	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, SD Mohapatra, P Guru, R Khanam, B R Goud	CAP - ICAR
16	EAP-209	CRP on hybrid technology - RL Verma, JL Katara	CRP - ICAR
17	EAP-211	CRP on molecular breeding - MK Kar, L Behera, GP Pandi, A Mukherjee, M Chakraborti, PC Rath, LK Bose	CRP - ICAR
18	EAP-215	Agri-Business Incubation Centre - GAK Kumar, BC Patra, NC Rath, S Saha, RK Sahu, BB Panda, B Mondal, AK Mukherjee, PK Guru, JP Bisen, GP Pandi, NN Jambhulkar	NAIF, IP&TM – ICAR
19	EAP-227	Creation of seed hub for increasing indigenous production of pulses in India - S Sethi, DR Sarangi, TR Sahoo, M Chourasia, RK Mohanta	DAC &FW
20	EAP-228	Increasing productivity and sustaining the rice-based production system through Farmer FIRST approach - SK Mishra, B Mondal, SK Pradhan, S Saha, S Lenka, SD Mohapatra, BS Satapathy, R Tripathi, JP Bisen, NT Borkar, Supriya Priyadarsani, Lipi Das, GC Acharya, SC Giri, S Paul	ICAR-Farmer FIRST

Sl. No.	Project No.	Title of the Project	Source of Funding
21	EAP-245	Strategic research component of National Innovation in climate resilient agriculture (NICRA) - P Swain, AK Nayak, P Bhattacharyya, K Chattopadhya, A Anandan, S Mohanty, D Chatterjee, K Chakraborty, H Pathak	ICAR Net work
22	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 Chattapadhyay, SK Lenka, LK Bose, PK Guru	RKVY, Odisha
23	EAP-260	Development of climate smart practices for climate resilient varieties - Anjani Kumar, H Pathak, AK Nayak, S Saha, BR Goud	IRRI
24	EAP-271	Harvest Plus Programme: Biofortification of rice - K Chattopadhyay, Awadhesh Kumar, P Sanghamitra, G Kumar, LK Bose	IFPRI & CIAT
25	EAP-272	Strengthening entrepreneurs in marketing and export of value added agricultural products by establishing a state of art quality assessment laboratory in Odisha - Sutapa Sarkar, N Basak, P Sanghamitra, T Adak, B Mondal, M Chakraborty, MJ Baig, G Kumar, S Priyadarsani, Sivashankari M, TB Bagchi	RKVY-Odisha
26	EAP-274	Bio-Bank: Production and promotion of biocontrol agents and entrepreneurship development in aspirational districts of Odisha - Basana Gowda G, NKB Patil, GP Pandi, Totan Adak, Prasanthi G, Annamalai M, Raghu S, Prabhukartikheyan SR, PC Rath, AK Mukherjee	RKVY-Odisha
27	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	RKVY-Odisha
28	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, H Pathak, DR Sarangi	Norwegian Institute of Bioeconomy Research (NIBIO), Norway
29	EAP-284	RKVY-RAFTAAR-Agribusinees incubation - GAK Kumar, BC Patra, RK Sahu, AK Mukherjee, Sanjoy Saha, BB Panda, Narayan Borkar, M Sivashankari, B Mondal, Rameswar Saha, Sutapa Sarkar, G Prasanthi	RKVY
30	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 (On study leave)	SAC-ISRO
31	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
32	EAP-291	Attracting and Retaining Youth in Agriculture (ARYA) - S Sethy, DR Sarangi, TR Sahoo, RK Mohanta	ICAR
33	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, H Pathak, S Chatterjee	DBT
34	EAP-296	Development of multiple stress tolerant versions of rice varieties Gomati and Tripura Chikan Dhan through molecular breeding – SK Dash, M Chakraborti, AK Mukherjee	DBT
35	EAP-297	Exploration and utilization of endophyte diversity in wild rice for health management of rice crops - Rupalin Jena, (AK Mukherjee)	DST Inspire
36	EAP-307	Climate Smart Management Practices under DSRC - Sanjay Saha, BS Satpathy, Virendra Kumar-IRRI, Sudhanshu Singh-IRRI, Pradip Sagwal-IRRI	IRRI
37	EAP-308	IRRI-ICAR collaborative Project- "Accelerating impact and equity"– Sivashankari M	IRRI
38	EAP-310	Development of superior haplotype based near isogenic lines (Haplo-NILs) - L Behera, Devanna, Koushik Chakraborty, GP Pandi, N Basak	DBT
39	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 - L Behera, JL Katara, BC Marndi, Devanna, Amrita Banerjee, Somnath Ray, Kaushik Chakraborti, MK Bag, Prasant KS Hanjagi, Gourav Kumar, Aravindan S, Annamalai M, AK Mukherjee	DBT

Sl. No.	Project No.	Title of the Project	Source of Funding
40	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, Devanna, RL Verma	DBT
41	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
42	EAP-318	Exploring insecticide induced hormesis to develop superior strain of egg parasitoid, Trichogramma japonicum and its molecular characterization - Basana Gowda G, Totan Adak, NKB Patil	Science and Technology Deptt., Odisha
43	EAP-319	Evaluation of zinc oxide suspension concentrate (39.5% Zn) on rice against Zn SO4 through soil application with urea - M Shahid, AK Nayak	Yara Fertilizer India Pvt. Ltd.
44	EAP-321	Promotion of pheromone traps for managing fall army worm and related insect pests in various crops – K Rajasekhara Rao, M Annamalai, T Adak, PK Nayak, Gaurav Kumar, Bapatla Kiran Gandhi, Sunil Kumar Das	RKVY
45	EAP-322	Global challenges research fund (GCRF), South Asian Nitrogen Hub (GCRF-SANH Project) - D Chatterjee, S Mohanty, J Meher, B Mondal, AK Nayak, Parameswaran C	GCRF
46	EAP-323	Value chain and nutritional research output: Fish for nutritional and health of women and children - GAK Kumar, Sujata Sethy, R Mahanta, J Pani, PK Sahoo	CGIAR (WorldFish-ICAR W3)
47	EAP-324	Study on impacts of primary and secondary pollutants on soil and crops around Vedanta Limited factory, Jharsuguda - M Shahid, AK Nayak, U Kumar, R Khanam	Vedanta Ltd
48	EAP-326	Accelerated genetic gain in rice (AGGRI-Alliance)- Irrigated rainfed (Drought, salinity & submergence) and DSR ecologies - SK Dash, NP Mandal, K Chattopadhyay, S Roy, RP Sah, LK Bose	IRRI
49	EAP-328	Creation of seed infrastructure facility (only for construction) - RL Verma	Government of India Ministry of Agriculture & Farmers Welfare
50	EAP-330	Formation and promotion of FPOs in Balasore - GAK Kumar, BC Patra, SK Das, B Mondal, RP Sah, Basana Gowda, AK Mukherjee, AK Pradhan, SR Dalal, S Paul	NCDC
51	EAP-331	Study on chemical constituents of rice root modulating herbivory by the rice root knot nematode: a chemical ecology perspective - Totan Adak, Rupak Jena	DST
52	EAP-334	DST Inspire Fellow - Sonali Panda, (MJ Baig)	DST Inspire
53	EAP-335	Exploring AUS rice for drought, submergence and phosphorus starvation tolerance: Mining superior alleles and deciphering mechanism of tolerance - S Roy, NP Mandal, A Banerjee, BC Verma, Koushik Chakraborty, Padmini Swain, PS Hanjagi, D Bhaduri	NASF
54	EAP-337	Formation and promotion of FPOs in Odisha - GAK Kumar, BC Patra, SK Das, RP Sah, B Gowda, AK Mukherjee, A Pradhan, SR Dalal, Ankit Anand, S Sethi, SK Rout, BK Jha, SM Prasad, S Paul	Govt. of India (SFAC)
55	EAP-339	Ph.D Dissertation work - Priya Das, (MJ Baig)	DBT JRF
56	EAP-340	Targeting serotonin and senescence pathways for enhancing brown plant hopper resistance and yield in rice - Bijayalaxmi Sahoo (Parameswaran C)	DST Inspire fellowship
57	EAP-343 (Merger of EAP-36 and EAP-100)	AICRIP on Seed (Crops) - BC Marandi, Anil Kumar, AK Mukherjee, NKB Patil, RP Sah, Md. Azharudheen, Raghu S, Annamalai M	ICAR
58	EAP-344	Development of Steel slag based cost-effective eco-friendly fertilizers for sustainable agriculutre and inclusive growth - M Shahid, AK Nayak, Rubina Khanum	Ministry of Steel
59	EAP-345	Evaluation of bio efficacy of MCI 9197 10% WG against sucking insect pest of rice - Guru Pirasanna Pandi G, Totan Adak, PC Rath	PI industries ltd
60	EAP-346	Bio-Efficacy and phytotoxicity of pesticides applied through drone technology in rice - Basana Gowda G, Totan Adak, PC Rath, RP Sah	M/s Mahindra and Mahindra Mumbai

Sl. No.	Project No.	Title of the Project	Source of Funding
61	EAP-347	Droplet deposition and phyto-toxicity studies of Tetraniliprole 200 g/l SC (Vayego) and Tebuconazole 50% + Trifloxystrobin 25% WG Native in rice crop using an unmanned aerial vehicle (UAV) - Basana Gowda G, Totan Adak, RP Sah	M/S Bayer Crop Science Limited, Mumbai
62	EAP 348	Evaluating performance of *Nano*- urea with respect to yield and nitrogen use efficiency of rice - S Mohanty, AK Nayak	Indian Farmers Fertiliser Cooperative Limited (IFFCO)
63	EAP-350	Biological Nitrification Inhibition (BNI) in Rice: A novel approach to enhance Nitrogen use efficiency vis a vis reducing denitrification N-loss - U Kumar	ICAR (LalBahadurShastri Award)
64	EAP-351	Identification of rice cultivars with low As concentration in grain through As specific study and developing management practices to mitigate As contamination - M Shahid	ICAR (Lal Bahadur Shastri Award)
65	EAP-352	Decrypting the chemical interaction of rice and its specialist herbivore, *Scirpophaga incertulas* - Totan Adak, B Gowda	SERB, DST
66	EAP-353	Network programme on precision agriculture (NePPA) - R Tripathi, AK Nayak, S Mohanty, SD Mohapatra, Raghu S, BR Goud	ICAR
67	EAP-354	Development of azadirachtin based zinc-oxide nano-formulation for sustainable management of brown plant hopper and other key pest of rice in Odisha - GP Pandi G, T Adak, Raghu S	DST, Odisha
68	EAP-355	Improvement of aromatic indica rice cultivars for bacterial blight disease resistance through marker assisted doubled haploid breeding - Prakash Singh, S Samantaray	SERB-Tare, DST
69	EAP-356	Understanding the effect of aerobic adaptation loci on yield of drought tolerant rainfed shallow lowland cultivar rice using genome editing tool – Parameswaran, Devanna	SERB
70	EAP-357	Identification of genomic region(s) for 21 days submergence tolerance in rice using sequence based trait mapping approach - JL Katara, S Samantray, Parameswaran	SERB
71	EAP-359	Enhancing resilience of smallholders to climate change through sustainable intensification and digital driven knowledge dissemination (E- CHASI) - AK Nayak, S Mohanty, R Tripathi, SD Mohapatra, BS Satpathy, B Mondal, D Maiti, U Kumar, Anjani Kumar, Raghu S, PC Jena, PP Panneerselvam	OIIPCRA, Deptt. Of Water Govt. of Odisha
72	EAP-360	Biodegradable nanofibre encapsulated bio-fertilizer to enhance phosphorus and other micronutrient uptake in rice - P Panneerselvam	DBT
73	EAP-361	National mission mode program on nutritional improvement of digestible protein content and quality in rice - K Chattopadhyay, S Sarkar, TB Bagchi	DBT
74	EAP- 362	Identification and characterization of low starch digestibility rice based on types of resistant starch and cooking quality - Awadhesh Kumar	SERB, DST
75	EAP-363	Evaluation of rice lines and hybrids for yield traits - RP Sah, Md Azharudheen TP, Raghu S, B Gowda G, BC Patra, Anilkumar C, Reshmi Raj	PAN Seed Pvt. Ltd.
76	EAP-364	Improving vegetative stage drought tolerance by integrating Genomic selection, GWAS and QTL mapping in rice - JL Katara	SERB, DST
77	EAP-365	Nanoherbicide: A controlled release formulation to improve rice production - Totan Adak, S Munda	DST
78	EAP-366	Transformative strategy for controlling rice disease in developing countries – Devanna, M Chakraborti (PI in absence of Devanna), KA Molla, AK Mukherjee	BMGF (collaborative project with Heinrich Heine University, Germany)
79	EAP-367	Development of bacterial blight and sheath blight resistant rice plants through CRISPR/ Cas mediated genome editing of host susceptibility gene - S Karmakar, MJ Baig	NPDF, DST
80	EAP-368	Comparative Assessment of Aldor as an Alternative to Urea on Rice growth, Yield, Nitrogen use efficiency and Soil Health - Mohammad Shahid, AK Nayak	Sirius Minerals India Pvt Ltd (SMIPL)
81	EAP-369	Popularization of BPH resistant rice variety for uplifting the Odisha rice farmers' income - Guru-Pirasanna-Pandi G, PC Rath, B Gowda, T Adak, GAK Kumar, Annamalai M, Raghu S, MK Kar, NKB Patil, Parameshwaran, SK Mishra, R Sah, LK Bose	RKVY, Govt. of Odisha

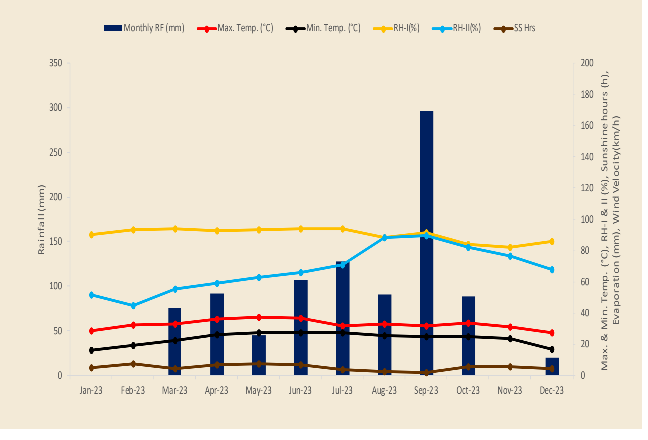
Sl. No.	Project No.	Title of the Project	Source of Funding
82	EAP-370	Biotech- Krishi Innovation Science Application Network (Biotech-KISAN) Hub at Sikkim University - P Panneerselvam	DBT
83	EAP-371	AICRIP (Rainfed) – BC Patra, K Chattopadhyay, SK Dash, M Chakraborti, A Kumar, S Saha, AK Mukherjee, GP Padhi, Md. Shahid, K Chakraborty, NN Jambhulkar, A Pradhan, N Basak	ICAR
84	EAP-372	Development of haploid inducer rice lines using CRISPR/ Cas9 gene editing system for high induction frequency - S Samantaray, Devanna, Parameswaran, JL Katara	DBT
85	EAP-373	Sub Mission on agricultural mechanization for implementation of its component No.1 under drone technology demonstration - Asit Kumar Pradhan, Basana Gowda	DAC
86	EAP-374	Allele mining for the epigenetic regulator NGR5 and other yield associated gene (GRF4) and their modulation using multiple genomic and molecular approaches to enhance rice yield under low nitrogen conditions - Kutubuddun Molla, MJ Baig	NASF
87	EAP-375	To evaluate the bio efficacy and phytotoxicity of Tebuconazole 430 G/ L SC against rice leaf and neck blast diseases - Raghu S, Mathew S Baite, Prabhukarthikeyan SR, Basana Gowda G, PC Rath	Bayer Crop Sciences Ltd.
88	EAP-376	To evaluate the bio efficacy and phytotoxicity of Fluopyram 400 g /L SC (Velum Prime) against major nematode pests of rice - Rupak Jena, Raghu S, Basana Gowda G, PC Rath	Bayer Crop Sciences Ltd.
89	EAP-377	Quantitative assessment of soil quality, yield sustainability and grain quality of rice in Eastern India: A unified triangular approach - Debarati Bhaduri	DST-SERB
90	EAP-378	Evaluation of Bio-efficacy and phytotoxicity of IIF-222 against diseases of Paddy - SR Prabhukarthikeyan, Raghu S, Mathew S Baite, PC Rath	Indofil Industries Ltd.
91	EAP-379	Deciphering and deploying low phosphorus tolerance and nitrogen use efficiency in rice - J Meher, Parameswaran, D Chatterjee	NASF
92	EAP-380	Blue carbon sequestration and climate change mitigation by managing mangrove-soil-algae system in coastal wetland - Sujit Kumar Nayak, P Bhattacharya	DST-Inspire
93	EAP-381	CRISPR Crop Network: Targeted improvement of stress tolerance, nutritional quality and yield of crops by using genome editing - Parameswaran C, S Samantaray, Awadesh Kumar, Kutubuddin Ali Molla, Prabhukarthikeyan SR	NASF
94	EAP- 382	Identification and characterization of fungal effectors and host factors in rice- false smut pathosystem – Devanna, S Samantray, (PI in absence of Devanna), MK Bag	NASF
95	EAP-383	Improvement of stress adaptive traits in crops using endophytes under different agroecology - Prashantkumar Hanjagi	NICRA
96	EAP-384	Studying the Effect of Adopting Regenerative Agriculture Practices on Smallholder Farmer Livelihoods – AK Nayak, Rahul Tripathi	J-PAL
97	EAP-385	Evaluation of Dammu: Propargite 50% + Bifenthrin 5% SE for bio-efficacy (against Lepidopteran, Hemipteran and Mite pests), phytotoxic effect and impact on natural enemies in coastal rice ecosystem - Kiran Gandhi B	Indofil Industries
98	EAP-386	Evaluation of bio-efficiency and phytotoxicity of Chlorantraniliprole 0.6% + Thiomethoxam 1.25% + Fipronil 1.25% GR (TAS0211) against major insect pests of paddy - Naveen B Patil, B Gowda, T Adak, P Golive	Tropical Agrosystem (India) Pvt. Ltd. Chennai
99	EAP-387	Computer vision for plant phonemics and smart agriculture - Rahul Tripathi, SK Dash, Prashant Kumar Hanjagi, P Swain	IIT, Jodhpur
100	EAP-388	Phyto-toxicity evaluation of Dinetofuran 15% + Pymetrozine 45% WG and Iprobenfos 48% EC on rice crop - Guru-Pirasanna-Pandi G, B Gowda, T Adak, PC Rath	PI Industries Pvt. Ltd.
101	EAP-389	Establishment of hybrid rice seed system and state of art for genetic purity testing in Odisha – RL Verma, JL Katara, S Samantaray, BC Patra, GAK Kumar, AK Mukherjee, U Kumar	RKVY
102	EAP-390	Outscaling of Natural Farming through KVKs - Dillip Ranjan Sarangi, Sujata Sethy, TR Sahoo, RK Mohanta	ICAR
103	EAP-391	4S4R Model for production, marketing and export of Odisha aromatic rice – GAK Kumar, BC Patra, B Mondol, T Adak, S Sarkar, M Chakraborti, S Priyadarshini, SK Dash, S Sethy, JP Bisen, Asit Kumar Pradhan	RKVY

Sl. No.	Project No.	Title of the Project	Source of Funding
104	EAP-392	Improving rice genetics and its ecosystem through genome engineering and bioagents to reduce dependency on chemical N_2 fertilizer – KA Molla, MJ Baig, AK Mukherjee, T Adak, J Meher	Ignite Life Science Foundation
105	EAP-393	Scaling of Natural Farming through KVKs (Koderma) - SM Prasad	ICAR
106	EAP-394	Evaluating efficacy of Nano- DAP with respect to P and N nutrition and yield of rice- Sangita Mohanty	Indian Farmers Fertilizer Cooperative Limited (IFFCO)
107	EAP-395	Bio-efficacy of Sai Power Plus on growth and yield of rice- D Chatterjee, B Gowda, S Saha	Sai Crop Science Pvt. Ltd.
108	EAP-396	Engineered mesoporous silica nanoparticle-biochar complex for decontamination of phosphate and glyphosate in water- S Munda	DST
109	EAP-397	Impact of farm mechanization in reduction of cost of cultivation- B Mondal, JP Bisen	Directorate of Agril. & Food Production, Govt. of Odisha
110	EAP-398	Advisory services for general overview and specific challenges of sustainable rice project in India- Anjani Kumar, AK Nayak	Mitsubishi Corporation India Pvt. Ltd.
111	EAP-399	Common Laboratory Services at ICAR-NRRI- P Bhattachatyya, T Adak	Service Providing Project
112	EAP-400	Genome editing of rice targeting submergence and reproductive stage salinity tolerance for yield enhancement in coastal ecology- Swetapadma Sahu, S Samantray	INSPIRE DST
113	EAP-401	Transfer of bacterial leaf blight and sheath blight resistant gene(s) / QTL(s) into popular rice variety 'Maudamani' through marker assisted breeding.- Sushree Sangeeta, SK Pradhan, L Behera	INSPIRE DST
114	EAP-402	Assessing the water productivity, GHG emission, yield and economics of rice based cropping systems under transplanted and direct seeded rice- Anjani Kumar, AK Nayak, S Mohanty, B Raghavendra Goud	IRRI
115	EAP-403	Tackling emerging diseases and insect-pest problems in rice through innovative genomic approaches- Amrita Banerjee, NP Mandal, S Roy, Priya Medha, MK Bag	DBT
116	EAP-404	Developing precision nitrogen management protocols for rice using remote sensing and geospatial tools (LBS Award- 2021)- Rahul Tripathi	ICAR
117	EAP-405	Deciphering the role of OsSnRK (Sucrose nonfermenting-1 [SNF1] related kinase) gene family as a potential master regulator governing multiple abiotic stress tolerance in rice- Koushik Chakraborty	ICAR
118	EAP-406	Identification and quantification of different volatiles emitted by Trichoderma and utilization of identified isolates/volatiles for plant growth promotion and soil borne pathogen management - Totan Adak, Arup Kumar Mukherjee	BRNS, BARC
119	EAP-407	Ecosystem, Agribusiness and Institutions Component I: Impact assessment of Agricultural technology- JP Bisen, Biswajit Mondal, Sudipta Paul, Mridul Chakraborti	ICAR-NIAP
120	EAP-408	Demonstration, capacity building and Up-scaling of Integrated Farming Systems for Livelihood Security of Small and Marginal Farmers in Rainfed Ecosystem of Jharkhand'- SM Prasad, Soumya Saha, Bibhash Chandra Verma, Someshwar Bhagat, Chanchila Kumari, Sudhanshu Shekhar, Bhoopendra Singh, RK Singh, VP Rai	RKVY, Jharkhand
121	EAP-409	Strengthening the entrepreneurship in the production, promotion and marketing of biocontrol agents in the rainfed ecosystem of Jharkhand- Someshwar Bhagat, Amrita Banerjee, BC Verma, SM Prasad, NP Mandal	RKVY, Jharkhand
122	EAP-410	Sulphur enriched bio-nanoformulation of methanotrophs for greenhouse gas emission, mitigation and sustains production in rice- Monalisha Rath, Pratap Bhattacharyya	BPRF (Govt. of Odisha)
123	EAP-411	Economic and Environment-Friendly Utilization of Basic-slag and Fly Ash as Soil Amendments to Reclaim Acid Soils of Odisha- Pratap Bhattacharyya, Rubina Khanam, Debarati Bhaduri, Mohammad Shahid, GAK Kumar, Amaresh Kumar Nayak	Department of Agriculture and Farmers'Empowerment (DAFE), Government of Odisha

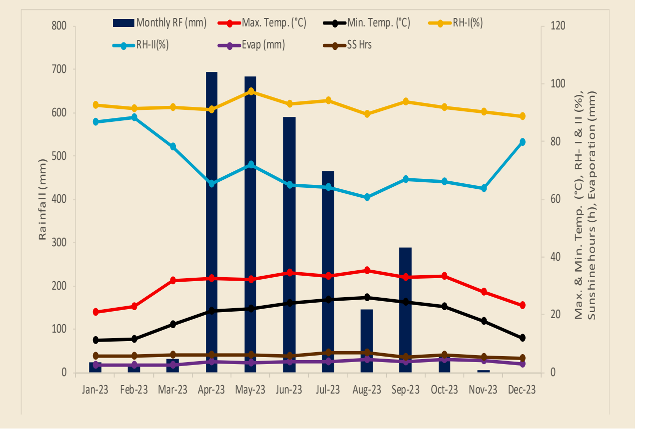
Sl. No.	Project No.	Title of the Project	Source of Funding
124	EAP-412	Development of liquid formulation of Halotolerant Plant Growth Promoting Rhizobacteria (H-PGPR) Consortia to alleviate salt stress for sustainable rice production in saline coastal soil- U Kumar, G Rastogi, P Panneerselvam, AK Nayak, K Chakroborty, A Poonam, Mahesh Dharne	DST, Odisha
125	EAP-413	Bio-efficacy of PIX-20002 20% SC and PII 070 70% WG against insect pest of rice and their natural enemies through drone and conventional spraying- SD Mohapatra, Guru Pirasanna Pandi G, Basana Gowda, Totan Adak	PI Industries Pvt. Ltd.
126	EAP-414	Development of jute bags for protection and quality presentation of stored seeds- SD Mohapatra, NKB Patil	NTTM, Govt. of India
127	EAP-415	Atlas of climate adaptation in South Asian Agriculture (ACASA)- Rahul Tripathi, Manish Debnath, NN Jambhulkar	BISA
128	EAP-416	Production, popularization and supply of quality bioinoculants for rice based cropping and farming system of Odisha- Upendra Kumar, P Panneerselvam, GAK Kumar, B Mandol, A K Mukherjee, Annie Poonam, Md. Shahid, D Chatterjee, S Paul, RL Verma, A K Nayak	DAFE, Govt. of Odisha
129	EAP-417	Development and refinement of sensor and AI based tools for enhancing water use efficiency- Anjani Kumar, AK Nayak	Fine trap India

WEATHER

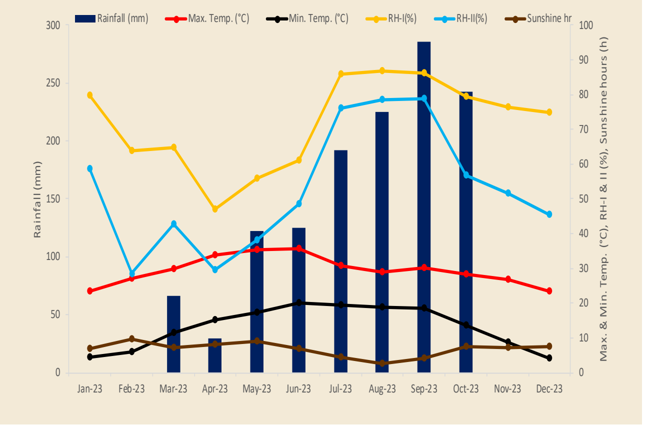
NRRI, Cuttack



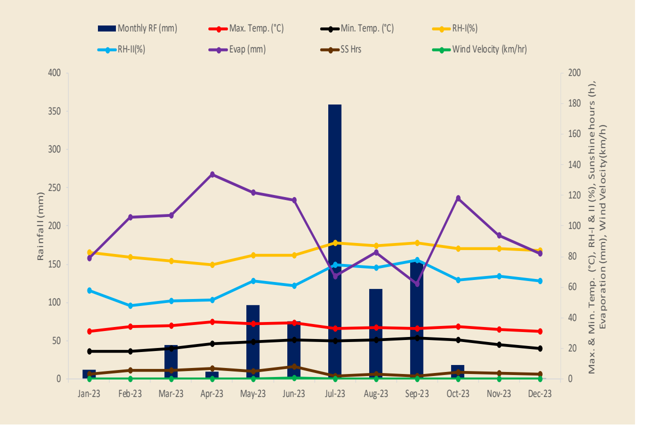
RRLRRS, Gerua



CRURRS, Hazaribag



RCRRS, Naira



ISBN 81-88409-09-X

ICAR-NATIONAL RICE RESEARCH INSTITUTE
Cuttack 753006, Odisha, India
Phone: 91-671-2367757, Fax: 91-671-2367663
Email: director.nrri@icar.gov.in | directorcrricuttack@gmail.com

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

BSCIC NABCB QM 030 ISO 9001 REGISTERED BN10448/9364:0914

An ISO 9001 : 2015 Certified Institute

Scan for Report online

@RiceICAR RiceICAR RiceICAR