2nd Indian Rice Congress 2023
FEBRUARY 11-14| ICAR-NRRI, CUTTACK

Souvenir

2nd Indian Rice Congress

An International Event on

Transforming Rice Research: Recent Scientific Developments and Global Food Crisis

February 11-14, 2023

ICAR-National Rice Research Institute, Cuttack 753006, Odisha, India

Organizer

Association of Rice Research Workers

Cuttack, Odisha, India

In Collaboration with

ICAR   IRRI   NRRI   IIRR   Society for Advancement of Rice Research

ORYZA, an International journal on rice, published quarterly by the Association of Rice Research Workers (ARRW), National Rice Research Institute, Cuttack-753006, Odisha, India. It intends to foster rice research for widening the horizons of rice science and to increase world rice production. It is open to all the scientists engaged in rice research. It publishes peer reviewed original research articles, short communications and review articles on all aspects of rice research, covering basic and applied work on crop improvement, crop management, crop protection and environmental security.

Business correspondence including orders and remittances for subscriptions, back numbers and others should be addressed to the Secretary, Association of Rice Research Workers, National Rice Research Institute, Cuttack - 753 006, Odisha, India. e-mail : secretaryarrw@gmail.com. Claims for the missing issues of the Journal may be considered within six months of publication.

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Institutional member (p.a.)	₹ 5,000/-	US $ 550	

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SECOND INDIAN RICE CONGRESS

Transforming Rice Research :
Recent Scientific Developments and Global Food Crisis

February 11-14, 2023

SOUVENIR

ASSOCIATION OF RICE RESEARCH WORKERS
&
ICAR - NATIONAL RICE RESEARCH INSTITUTE
Cuttack, Odisha

SOUVENIR

Transforming Rice Research : Recent Scientific Developments and Global Food Crisis

Published in February 2023

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Dr. Rakesh Chandra Agrawal
Deputy Director General (Agril. Edn.)

MESSAGE

It is a pleasure to know that the Association of Rice Research Workers (ARRW) at ICAR - National Rice Research Institute, Cuttack is organizing an International Event: 2nd Indian Rice Congress on the topic "Transforming Rice Research: Recent Scientific Developments and Global Food Crisis" at Cuttack during February 11-14, 2023 in collaboration with Indian Council of Agricultural Research, New Delhi, International Rice Research Institute, Philippines, National Academy of Agricultural Sciences, New Delhi, ICAR - National Rice Research Institute, ICAR-Indian Institute of Rice Research, Hyderabad and Society for Advancement of Rice Research, Hyderabad.

I hope that the practical recommendations emerging from this scientific event would be helpful in attaining and sustaining enhanced profitability and productivity in rice farming.

I wish the scientific event a grand success.

(R.C. Agrawal)

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डा. एस. एन. झा
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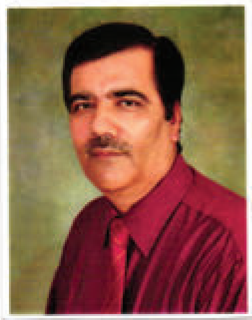
FNAAS, FIE, FISAE, FNADSI, FJSPS, Japan
उपमहानिदेशक (कृषि अभियांत्रिकी)
Deputy Director General (Agricultural Engineering)

Message



It gives me immense pleasure that ICAR -National Rice Research Institute, Cuttack is organizing an International Event: Second Indian Rice Congress (SIRC- 2023) on the topic "Transforming Rice Research: Recent Scientific Developments and Global Food Crisis" during 11-14 February, 2023 at Cuttack.

The symposium offers a premise for global experts to gather and interact intensively on the topics genomics and marker-assisted breeding, improvement in sensors, processing communications, threat to rice production and strategies to address challenges for sustainable rice production.

I hope eminent speakers will cover the theme virtual reality from different perspectives. I am privileged to say that this conference will definitely offer suitable solution to the global issues.

The success of this Conference is solely on the dedication and efforts of innumerable people who started working on the preparations for almost a year in many ways to make this symposium become a reality. Eventually I express my special thanks and appreciation to all. I wish SIRC- 2023 all the best for its success.

(Dr S. N. Jha)

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डॉ. सुरेश कुमार चौधरी
उप महानिदेशक (प्राकृतिक संसाधन प्रबंधन)
Dr. Suresh Kumar Chaudhari
Deputy Director General (Natural Resources Management)

17.01.2023

Message

Rice is the primary food in more than 100 countries worldwide, especially Asia. Cultivation of rice becomes critical in the era of climate change, thereby, enhancing the productivity without harming the natural resources is a big challenge.

I am delighted to know that Association of Rice Research Workers (ARRW) and Society for Implementation Research Collaboration *(SIRC) are* organizing an International Event (ARRW *SIRC - 2023)*: 2nd Indian Rice Congress on the topic "Transforming Rice Research: Recent Scientific Developments and Global Food Crisis" at ICAR - National Rice Research Institute, Cuttack during February 11-14, 2023 in collaboration with Indian Council of Agricultural Research, New Delhi, International Rice Research Institute, Philippines, National Academy of Agricultural Sciences, New Delhi, ICAR - National Rice Research Institute, ICAR-Indian Institute of Rice Research, Hyderabad and Society for Advancement of Rice Research, Hyderabad and a souvenir is being brought out to mark the occasion. I am sure the deliberations in this congress will come out with befitting recommendations for future research, new technologies for adoption in the field and policy formulations.

I extend my good wishes for a grand success of SIRC-2023.

(S.K. Chaudhari)

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डॉ. ए.के. नायक
निदेशक
Dr. A.K. Nayak, FNASc, FNAAS
Director

MESSAGE

It is a pleasure to know that the Association of Rice Research Workers (ARRW) at ICAR - National Rice Research Institute, Cuttack is organizing an International Event: 2nd Indian Rice Congress on the topic "Transforming Rice Research: Recent Scientific Developments and Global Food Crisis" at Cuttack during February 11-14, 2023 in collaboration with Indian Council of Agricultural Research, New Delhi, International Rice Research Institute, Philippines, National Academy of Agricultural Sciences, New Delhi, ICAR - National Rice Research Institute, ICAR-Indian Institute of Rice Research, Hyderabad and Society for Advancement of Rice Research, Hyderabad.

Rice is the most important food crop of the developing world and the staple food for more than half of the world's population. To feed an estimated 9 billion population by producing 65% more food in stressed climatic conditions is a big challenge. The only way to address new challenges is to harness uncommon opportunities offered by new rice science and technologies. Scientific advances in genomics and marker-assisted breeding provides opportunities to explore gene bank materials on a large scale to identify and embed the genes responsible for even complex target traits. Transgenic technologies offer the potential to engineer new plants. Improvements in sensors, processing, communications, and possibly nanotechnology offer the potential to revolutionize the input-use efficiencies. The theme areas of the Symposium are of direct relevance in this context and it is hoped that practical recommendations for attaining and sustaining enhanced profitability and productivity in rice farming would emerge from the deliberations.

I wish the scientific event a grand success.

(A.K. Nayak)

An ISO 9001:2015 Certified Institution
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ASSOCIATION OF RICE RESEARCH WORKERS - AN OVERVIEW

Pawal Kumar Agrawal & Sanjoy Saha

Association of Rice Research Workers
ICAR- National Rice Research Institute, Cuttack-753006, (Odisha) India
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The infamous great Bengal Famine of 1943 culminated in severe shortage of rice in the country. The then Imperial Government decided to establish one of the largest research institutes of its kind in the country to intensify research on all aspects of the crop to ensure food security. Dr .K. Ramiah, an eminent rice breeder was assigned the job as a Special Officer to select a location of the institute who later became its Founder Director and thus, the CRRI was set up on the 13th April, 1943 at Bidydharpur, Cuttack. However, the administrative control of the institute was transferred to the Indian Council of Agricultural Research (ICAR) in 1966. During the tenure of Dr. R.H. Richharia as the Director of the Institute, the Association of Rice Research Workers (ARRW) was formed in the year 1961 who was also its Founder President too. Since then, the headquarters of ARRW has been functioning at CRRI, Cuttack.

The ARRW publishes a quarterly international journal - the 'ORYZA' (ISSN No. 0474-7615) with peer reviewed research articles dedicated to rice and rice-based production systems. One of the objectives of 'Oryza' was to serve as a 'rice' information Centre during the initial years. The first issue of the journal was published in 1962 just after inception of the Association. During initial years, the journal was printed in the government press of Odisha with the help of the Govt. of Odisha. It intends to foster rice research for widening the horizons of rice science and to increase rice production and productivity. It is open to all scientists engaged in rice research throughout the world. The main objectives of the association are:

I. To provide and promote opportunities for contact and fellowship amongst workers interested or engaged in rice research, teaching and extension.

II. To publish a journal, quarterly in English called ORYZA, which will be exclusively devoted to information related to rice.

III. To serve as a bureau for information on rice research.

IV. Hold symposia/discussions on topics related to rice research and production.

The functioning of ARRW abides by its constitution registered under the Societies Registration Act, 1960 (No. XXI of 1860). Salient components of the ARRW are:

Executive Council :

The Executive Council is responsible to carry out all the activities of the Association. The council is headed by a President with two Vice-Presidents, a Secretary, a Treasurer, an Editor-in-Chief and eight Councilors duly elected by the General Body. As per the provision, one of the Vice-Presidents, the Secretary, the Editor-in–Chief and the Treasurer are elected from the headquarters of the Association. Similarly, out of the eight Councilors, one each represents North, South, East (except NRRI and OUAT) and West Zones. The remaining four Councilors are elected from NRRI and OUAT. As per the latest amendment of the constitution (2003), the last five Presidents of the

Association continue as ex-officio Members of the council. The immediate past President and the past Secretary remain as ex-officio Members of the executive council with voting rights. The terms of all the office bearers, except past Presidents (ex-officio), limited to a period of three years. The incumbency of the senior executive office bearers is given below in a tabular form.

General Body:

The general body comprises of all members of ARRW. The General Body meeting is convened once in a year and if required, more such meetings could be held. In GB meeting, all matters of ARRW are discussed thoroughly and important policy decisions are taken to improve ARRW. The Secretary, Treasurer and the Editor-in-Chief present their annual reports which are discussed, ratified and get approval of the house.

Table1. Incumbency Chart of Office Bearers of the Association of Rice Research Workers

Year	President	Vice-President	Secretary	Editor-in-Chief
1962-65	Dr. R. H. Richharia	Mr. S. Y. Padmanabhan	Mr. P. Israel	Mr. S. Sampath
1966	Mr. R. P. Padhi, IAS	Mr. K.S.Chandrasekharan Dr. G. V. Chalam	Mr. P. Israel	Dr. S. Govindaswamy
1966-70	Mr. R.P. Padhi, IAS	Mr. K.S.Chandrasekharan	Dr. S.Y. Padmanabhan	Dr. S. Govindaswamy
1971	Mr. K. Ramamurthy, IAS	Dr. B. Samantrai Dr. S. N. Bhoi	Dr. S.Y. Padmanabhan	Dr. S. Govindaswamy
1972-74	Mr. K. Ramamurthy, IAS	Dr. A. K. Sharma Dr.G. C. Sengupta	Dr. N. K. Chakrabarty	Dr. S. Govindaswamy
1975	Mr. K. Ramamurthy, IAS	Dr. A.K. Sharma Dr. G. C. Sengupta	Dr. S.K.Mohanty	Dr. S. Govindaswamy
1976-77	Mr. K. Ramamurthy, IAS	Dr. A.K. Sharma Dr. G. C. Sengupta	Dr. N. K. Chakrabarty	Dr. S. Govindaswamy
1978-80	Dr. B. Mishro	Dr. H. K. Panda Dr. N. K. Chakrabarty	Dr. S. K. Mohanty	Dr. Y.S. Rao
1981	Dr. I. C. Mahapatra	Dr. H. K. Panda Dr. K. S. Murty	Dr. J. K. Roy	Dr. N. Sethunathan
1982-83	Dr. I. C. Mahapatra	Dr. H. K. Panda Dr. K. S. Murty	Dr. J. K. Roy	D. N. Sethunathan
1984-85	Dr. S. Patnaik	Dr. G. B. Manna Dr. Biswas	Dr. J. K. Roy	D. N. Sethunathan
1986-87	Dr. S. Patnaik	Dr. G. B. Manna Dr. G. C. Rath	Dr. C. Gangadharan	Dr. R. Muralidhar
1988-89	Dr. B. N. Chatterjee	Dr. Y. S. Rao Dr. E.A. Siddiq	Dr. C. Gangadharan	Dr. R. Muralidhar
1990-91	Dr. E. A. Siddiq	Dr. G. Sahu Dr. M. Mahadevappa	Mr. P. J. Jahuck	Dr. K.V.S.R. Kameswar Rao
1992-93	Dr. E.A. Siddiq	Dr. N. Sethunathan Dr. B. K. Mandal	Dr. M. Nagaraju	Dr. K.V.S.R. Kameswar Rao
1994-95	Dr. B. Venkateswarlu	Dr. J. K.Roy Dr. (Mrs.) Padmaja Rao	Dr. S. K. Nayak	Dr. S. K. Mohanty

Year	President	Vice-President	Secretary	Editor-in-Chief
1996-97	Dr. K. C. Mathur	Dr. J. K. Roy Dr. J. S. Prasad	Mr. S. K. Nayak	Dr. S. K. Mohanty
1998-99	Dr. K. C. Mathur	Dr. S. K. Mohanty Dr. N. Sahoo	Mr. R. C. Dani	Dr. P. Nayak
2000-01	Dr. J. K. Roy	Dr. S. K. Mohanty Dr. U. Prasad Rao	Mr. R. C. Dani	Dr. B. N. Singh
2002-04	Dr. I. C. Mahapatra	Dr. Dinesh Chandra Dr. A. Ghosh	Dr. S. Sasmal	Dr. D.P.Singh Mr. S.K.Nayak
2005-07	Dr. J. K. Ray	Dr. A. K. Mishra Dr. D. K. Kundu	Dr. K. S. Rao	Mr. S.K. Nayak Mr. R.C. Dani
2008-10	Dr. S. K. Mohanty	Dr. A. K. Mishra Dr. N. Sahoo	Dr. K. S. Rao	Dr.. K. S. Behera
2011-13	Dr. T. K. Adhya Dr. K. S. Rao	Dr. K. S. Rao Dr. V.D. Shukla	Dr. Sanjoy Saha	Dr. K. S. Behera
2014-15	Dr. J. N. Reddy	-	Dr. R. Raja	Dr. Meera Kumari Kar
2016-18	Dr. S.R. Das	Dr.P. C. Rath Dr. S. K. Routaray	Dr. B. B. Panda	Dr. S. K. Pradhan
2019-21	Dr. H Pathak	Dr. Srikant Lenka Dr. R. M. Sundaram	Dr. M. J. Baig	Dr. A. K. Nayak
2022-24	Dr. PK Agrawal	Dr. Annie Poonam Dr. Lipi Das	Dr. Sanjoy Saha	Dr. Anjani Kumar

Journal of the Association:

'ORYZA' an international journal on rice of ARRW was published half yearly in its initial phase. During those days, ORYZA was the only journal on rice research in English language. Subsequently another journal - ILRISO, was published form Italy but it is non-existent now. Afterwards, the ORYZA journal was published quarterly. The articles of the journal are processed by Editor-in-Chief and an Editorial board. The Members of the Editorial board are eminent scientists of international repute. The journal enjoys a very wide circulation amongst rice scientists throughout the world. In addition to 'ORYZA' the Association also indulges in publication of Technical Bulletins on specific rice production technologies. It further publishes special proceedings of various symposia organized by the Association.

Members:

The ARRW has different categories of Members like, Patrons, Life Members, Annual Members and Institutional Members. At present, the ARRW has 9 Patrons, 801 Life Members including 23 Members from abroad and 5 Institutional Members.

Seminars and Symposia:

The ARRW organizes seminars and symposia from time to time on the topics of current problems on rice and rice based production systems as well as topics of common interest. The recommendations generated as outcome of the deliberations are published and also passed on to appropriate authorities for adaption and further action. In fact, they pave the way as road maps of future short- and long-term action plan including contingent action plans in case of exigencies under natural calamities etc. The ARRW is accredited for organizing following nineteen seminars and symposia (Table 2).

Table 2: List of Seminars/Symposia conducted by ARRW

Sl.No.	Topics	Year
1	International Rice year	1966
2	Recent Development in Rice Research and its Impact on Production	1969
3	Pest and Disease problems of High Yielding varieties	1970
4	Rice production under Environmental Stress	1971
5	Water Management in Rice	1974
6	Increasing Rice Yield in Kharif	1978
7	Advances in Rice Genetics and Breeding (Dr. K. Ramiah Centenary Celebration Symposium)	1993
8	Rice Research for Sustainable Food Security (International Symposium)	1996
9	Rice Research for 21st Century-Challenges, Priorities and Strategies	1998
10	IPM strategies in rice Production System	2001
11	Upland Rice Production System	2002
12	Recent Advances in Rice-based Farming System	2004
13	Research Priorities and Strategies in rice Production System for Second Green Revolution	2007
14	Sustainable Rice Production System under Changed Climate	2010
15	Sustainable Rice Production and livelihood security (International Symposium)	2013
16	Frontiers of Rice Research for Improving Productivity, Profitability and Climate Resilience (International Symposium)	2018
17	54th Annual AICRIP Meeting and Rice Workshop	2019
18	Rice Research and Development for Achieving Sustainable Development Goals (1ST Indian Rice Congress) (Virtual Mode)	2020
19	GenNext Technologies for Enhancing Productivity, Profitability and Resilience of Rice Farming (ARRW Diamond Jubilee National Symposium) (Virtual Mode)	2021

Memorial lecture:

The Association of Rice Research Workers in collaboration with Dr. Gopinath Sahu Memorial Trust conducts Dr. Gopinath Sahu Memorial Lecture Series every year in the month of November since 1992. Eminent scientists are invited to deliver the lecture on topics related to contemporary rice research and production. The speakers till the last year who profoundly enriched the audience with their topics were –

Sl. No.	Year	Speaker	Topic
1	1992	Dr. M. S. Kanungo, Director of Life Science, BHU	Genetic Engineering in the service and Mankind
2	1993	Prof. S. K. Sinha, Director, IARI, New Delhi	Rice and Food Security
3	1994	Dr. B. Venkateswarlu, Director, CRRI, Cuttack	New Frontiers of Rice
4	1995	Dr. I. C. Mohapatra, Renowned Agricultural Scientist	Rice Production Constraints and remedial measures for Eastern India
5	1996	Dr. Gokula Nanda Mohapatra, Eminent Professor, Chemistry	Science and Society for 21st Century
6	1997	Dr. J. K. Roy, Joint Director, CRRI, Cuttack	Rice for Life on the problems and prospects of breaking the yield barrier in rice
7	1998	Dr. Shyam Sunder Mohapatra, South Florida University, USA	Genome analysis; The state of the Art
8	1999	Dr. B.N. Singh, Plant Breeder	Challenge and strategies for rice production in 21st Century
9	2000	Dr. N. Panda, Ex-Vice-Chancellor, Sambalpur University	Role of Plant Physiologies in Food security
10	2001	Dr. Chandra Mohan Patnaik, Agriculture Scientist, World Bank, Washington	'World Bank' approach to Agriculture Development: my experience
11	2002	Dr. S. K. Sen, Head, Biotech, IIT, Kharagpur	Rice Transgenic and its future
12	2003	Dr. Prasanna Mohanty, Honorary Prof., Devi Ahalya University, Indore	Basic-Bio-energetic Studies of Rice
13	2004	Dr. Uday Chandra Biswal, Former Professor and Head, Dept. of Life Science, Sambalpur University	Photo Inhibition and Crop Productivity
14	2005	Dr. P.K. Mohapatra, Professor of Life Science, Sambalpur University	Physiology of Spikelet Development in Rice
15	2006	Dr. R.K. Singh, Secretary, NAAS, New Delhi	From Green Revolution to Ever Green Revolution

Sl. No.	Year	Speaker	Topic
16	2007	Dr. M.P. Pandey, Director, CRRI, Cutack	Present Scenario of Rice Research and Strategies for 21st Century
17	2008	Dr. S. R.Das, Rice Breeder, Department of Plant Breeding and Genetics, OUAT, Bhubaneswar	Genetic enhancement of short grain aromatic rices for higher productivity
18	2009	Dr. T.K.Adhya, Director, CRRI, Cuttack	Growing rice in Changing climate
19	2010	Prof. Dr. Karabi Datta, Dept. of Botany, Universityof Calcutta	Designer G.M. Rice
20	2011	Dr. Krishna Srinath, Director, DRWA, Bhubaneswar	Gender issues in Rice Farming System
21	2012	Dr. Jitendra P. Khurana	Genes and Genomics for crop improvement
22	2013	Dr. S. K. Datta DDG, Crop Science, ICAR	Biodiversity in crisis
23	2014	Prof. *S. K. Sopory*, Vice-Chancellor, JNU, New Delhi	Glyoxalase Pathway: Role in Stress Tolerance in Plants
24	2015	Dr. T. Mohapatra, Director, IARI, New Delhi	Rice Genomics: Past, Present & Future
25	2016	Dr. V. Ravindra Babu, Director, IIRR, Hyderabad	Present scenario and future prospects of rice in India
26	2017	Dr. H. Pathak, Director, NRRI, Cuttack	Crop productivity to Climate stability: The Journey of Carbon
27	2018	Prof. Ashok Kumar Singh, ICAR - IARI, New Delhi	Molecular Breeding for Biotic and Abiotic stresses Tolerance in Rice
28	2019	Prof. RB Singh, Former President, NAAS, New Delhi	Rice Research in India
29	2020	Dr. TR Sharma, DDG (CS), ICAR, New Delhi	Search for a novel rice blast resistant gene and its alleles
30	2021	Dr. Jon Hellin, IRRI, Philippines	Transformation of rice-based systems in India: implications for rice research
31	2022	Prof. Pravat Kumar Roul VC, OUAT, BBSR	Rice Research – Past and Future

Rewards to Eminent Rice Scientists

The Association has the provision to elect the "Fellow of the Association" from the active Members in recognition of their outstanding contributions to rice research and development activities. Till date, eminent personalities like Dr. M.S. Swaminathan, Dr. M.D. Pathak, Dr. I.C. Mohapatra, Dr. S. Patnaik and Dr. E.A. Siddiq have been befittingly honoured. The ARRW Fellow awardees details are given in Table 3.

Sl. No	Year	Awardees Name	Discipline
1	2018	Dr. S. K. Pradhan, ICAR-NRRI, Cuttack	Crop Improvement
2	2018	Dr. A K Nayak, ICAR-NRRI, Cuttack	Crop Production
3	2018	Dr. A K Mukherjee, ICAR-NRRI, Cuttack	Crop Protection
4	2018	Dr. M Raveendran, TNAU, Coimbatore	Basic Science
5	2018	Dr. S N Meera, ICAR-IIRR, Hyderabad	Social Science
6	2019	Dr. Gopala Krishnan S, ICAR-IARI, New Delhi	Crop Improvement
7	2019	Dr. Pratap Bhattacharyya, ICAR-NRRI, Cuttack	Crop Production
8	2019	Dr. S D Mohapatra, ICAR-NRRI, Cuttack	Crop Protection
9	2019	Dr. Maganti Sheshu Madhav, ICAR-IIRR, Hyderabad	Basic Science
11	2020	Dr. K. Chattopadhyay, ICAR-NRRI, Cuttack	Crop Improvement
12	2020	Dr. Upendra Kumar, ICAR-NRRI, Cuttack	Crop Production
13	2020	Dr. M Srinivas Prasad	Crop Protection
14	2020	Dr Padmini Swain, ICAR-NRRI, Cuttack	Basic Science
15	2020	Dr N N Jambhulkar, ICAR-NRRI, Cuttack	Social Science
16	2021	Dr. S L Krishnamurthy, ICAR-CSSRI, Karnal	Crop Improvement
17	2021	Dr. Anjani Kumar, ICAR-NRRI, Cuttack	Crop Production
18	2021	Dr. Kalyan K. Mondal, ICAR-NRRI, Cuttack	Crop Protection
19	2021	Dr. Rupesh Deshmukh, NABI, Mohali	Basic Science
20	2021	Dr. Lipi Das, ICAR-CIWA, Bhubaneswar	Social Science
21	2022	Dr. A Anandhan, ICAR-IISS(RS), Bangaluru	Crop Improvement
22	2022	Dr. S K Sarangi, ICAR-CSSRI(RRS), Canning Town	Crop Production
23	2022	Dr PC Rath, ICAR-NRRI, Cuttack	Crop Protection
24	2022	Dr. L Behera, ICAR-NRRI, Cuttack	Basic Science
25	2022	Dr. GAK Kumar, ICAR-NRRI, Cuttack	Social Science

Patrons of the Association:

Any person interested in research, teaching or extension in rice and rice-based cropping system and willingly contributes a minimum of Rs. 25,000/- or US $1000 to the Association can become a patron of the Association subject to approval of the Executive Body. Presently, the Association has 9 Patrons with Late Biju Patnaik, the then Chief-Minister of Odisha, being the first patron.

The journey of ARRW-ORYZA has been painted with finest history of innovative and value-added technologies vividly striving to enhance rice production and productivity at all cost. The revolutionary style was incredible, aggressive and ambitious. All these documented accomplishments created a wide net of loyalty and credibility enabling strength with harmony to host an international event of Second Indian Rice Congress with the motive of "**Transforming Rice Research: Recent Scientific Developments and Global Food Crisis**" in February 11-14, 2023 at ICAR-NRRI, Cuttack, Odisha, India. The Strong collaboration extended by Indian Council of Agricultural Research, International Rice Research Institute, National Academy of Agricultural Sciences and Indian Institute of Rice Research is not only unique but testifies the robust bondage to strengthen the holistic resilience to forge ahead with sustainable rice production strategies and livelihood security despite the vagaries and vicissitudes of climatic aberrations.

It is hoped that more and more rice research workers will patronize the ARRW and its journal ORYZA.

ECOLOGICAL AND SUSTAINABLE MANAGEMENT OF RICE-BASED PRODUCTION SYSTEMS

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Abstract

Rice is the food for half of the global population and it is principal source of livelihood for the majority of people in Asia. Cultivation of this crop is spread over in 100 countries under different agro-ecological conditions. Due to wider genetic diversity and ecological adaptability, rice had sustained climatic aberrations and edaphic alternations over years. To feed the ever-growing population, we need to produce quality rice in sufficient quantities superseding abiotic and biotic stresses. With the increased pressure from industrialization and urbanization, the scope for horizontal expansion of rice is very limited. It is high time to reorient the rice-based production system to induce maximum thrust on increasing the factor productivity. Biophysical, genetic and socio-economic drivers of rice farming need to be addressed diligently to bring down the imparity in rice production systems. Rapid technological innovations and strategic policy changes on the development of improved genotypes, adoption of water-saving rice cultivation, renovation of existing irrigation systems, maintaining soil health and establishment of rice-based agro-business will certainly sustain rice systems.

Keywords: *agro-ecosystem, climate change, food security, rice productivity*

The most alarming scenario of many developing countries demographic features can be revealed from their burgeoning population over the years. As the population rises, the demand for food to feed the teeming millions also jumps up in complete harmony. According to the Food and Agriculture Organisation of the United Nation, wheat, rice and maize account for about 51 per cent of the total dietary calorie intake, and near about 4,000 million people depend on these crops for their staple food. Under the dwindling wheat production, due to the much-touted global warming and consequent effects of the climate-change, catapulted with the transforming geopolitical configurations in the major wheat-producing countries, the world community is now compelled to concentrate on rice for satiating hunger and ensuring global peace and harmony. Due to its wider agro-ecological adaptability and genetic diversity, owing to its versatile evolutionary pathway, rice can very well be the best-trusted food crop under the changing scenario.

Rice is a dietary dish for half of humanity and a principal source of livelihood for the majority of people in Asia, its cultivation is spread over 100 countries in humid tropics to temperate, across six continents (Rao *et al*., 2017) covering one-fifth of the total area under cereals (Chakravarthi *et al*., 2006). Due to its wider adaptability to the tropics, rice is very often regarded as the ‘crop of tropics’ but it can be grown in wider climatic and ecological conditions, except Antarctica. It is grown as high as 2,400 m in Kashmir valley to 6 m deep in Bangladesh as ‘floating rice’ (McDonald, 1977). Its rich genetic diversity and inherent resilience to abiotic and biotic stress have enabled it to sustain severe ecological and climatic aberrations. Archaeological and linguistic shreds of evidence indicate its predominant worldwide cultivation way back to 3,000-2,500 BC in the late Neolithic era. Since its evolution in different geographical regions and adaptation to diverse ecological conditions over many civilizations and external aggressions, rice continues to remain as an important agricultural product for majority of the people. With current rate of population growth, to feed the growing population and meet the rice demand from industries, the projected global rice requirement will be 564 million tons by 2035, which could only be achieved through 1.2% annual growth rate (Becker and Angulo, 2019). Such a stupendous task amidst increasing climatic aberrations and agro-ecological constraints, although seems to be difficult, but is achievable with diligent ecological and sustainable management of rice-based production systems. The existing theoretical gap between on-station and on-farm productivity could be bridged by adopting technology innovations, site-specific production strategies and new cultivar development.

Evolution of rice-based production system

Modern technology-driven rice production systems are far different from traditional rice cultivation practices. The rice environment of today has radically changed and its cultivation is quite challenging due to agro-ecosystem restrictions and socio-economic constraints. With the advent of modern agronomic and breeding practices, rice farming has changed from traditional rainfed system to intensive market-oriented irrigated system. Monocropping and sole cropping of dry-seeded rainfed rice production systems have evolved into multiple cropping, transplanted and dry/wet-seeded stand establishment methods under complete submergence, intermittent flooding and aerobic culture. The first evidence of emergence of new production system, way back to 3,000 to 1,500 BC that enhanced rice yield through innovative field bund-making to minimize horizontal runoff and puddling to check downward vertical water losses, raising of seedlings in beds for transplanting and development of simple irrigation systems (Bebermeier *et al*., 2017). The process of soil puddling and seedling raising started in China and India around 2,000 BC, slowly spread to Korea and the Philippines, later to Japan and Indonesia (around 1,000 BC), and eventually distributed pan-tropically during the 16th to 19th centuries (Horie *et al*., 2005). Whereas, upland rice cultivation emerged in mountainous undulating terrains of Thailand, the Philippines and Indonesia predominantly as rainfed and partially irrigated lowland cultivation in wet season. In flood-prone areas of South, East and Southeast Asia; rice emerged to be the only crop during monsoon season as no other crop could sustain in such agro-ecological conditions (Becker and Angulo, 2019). Thus, rice area expansion in these befitting rice ecosystems of Asia was instrumental in sustaining the ever-growing human population in the past two millennia and the spread of human colonialism in Asian countries in the last few centuries (Huang *et al*., 2012). Such rapid expansion of rice areas and production could sustain the growing food demand of the poor developing and underdeveloped nations contradicting the catastrophic predictions of Thomas Robert Malthus in 1797 and 1820 (Kurz, 2008).

In the 19th and 20th century, breeding for higher yield and site-specific genotypes were based on the theory of evolution by Charles Darwin and principles of inheritance by Gregory Mendel, while the crop mineral nutrition was guided by Justus von Liebig and the Haber-Bosch process was instrumental in synthesis of urea that paved the way for 'Green revolution' (Zeigler and Mohanty, 2010). The green revolution of the 1960s although mostly aimed at wheat production, rice production also increased with development of fertilizer responsive, short stature and short-cycled genotypes that doubled rice yields during the 1960s and 1980s while production was tripled due to area expansion under irrigated cropping in the dry season (Peng *et al*., 1999). The success of the green revolution revolutionized the ever-food-starving Asian countries into marketable surplus, exporting rice to Africa and the rest of the world. Fertilizer and pesticide use increased rice yield and the use of farm machineries reduced labour costs for farm activities. Fertilizer use efficiency was enhanced through use of clay, *neem*, *mahua*, *karanja*, sulphur, microbial and micronutrient coating (mostly Zn and B) in flooded rice environments, while Propanil, a cheap pre-emergence herbicide revolutionized the labour saving direct sowing or planting in a weed-free environment in the 1980s, particularly in the dry season. Mechanized rice farming significantly minimized the labour cost and hidden losses due to untimely farm operations, very particularly, the use of precision farm machineries such as rotavator, laser land leveller, seed-cum-fertilizer drill, crop combined harvesters, etc. Development of stress-tolerant location and problem-specific genotypes assured yield stability (Mickelbart *et al*., 2015), while hybrid rice magnified its yield potential and input response under favourable conditions (Yuan *et al*., 1989).

Challenges to overcome

Population rise is at an alarming rate in the past few decades, which has synergistically aggravated other challenges in global rice production systems. The need for more food not only compelled us to expand the rice-growing areas horizontally, but also over-used the resources causing pollution to the environment beyond the natural process of remediation. With the current pace of demographic growth, we are on the verge of surpassing the carrying capacity of the earth within this century. Climate change, in its natural way, has been a driver of evolutionary processes. Increase in global temperature of 4.5 ^{0}C by the end of this century has enormous consequences not only in shifting rice ecological niche, but also in a reduction in yield performance, declining factor productivity, depleting groundwater, inundation of low-lying non-agricultural land, multiple nutrient deficiencies, enhanced disease pest incidence and higher cost of production, putting the sustainability of the farming as a whole in question. The consequences of global warming are far-reaching beyond the scope of direct antagonistic effects on different crops as reports of yield reduction in other major cereals such as wheat and maize would exacerbate the demands for rice to feed the burgeoning population in the future. Besides, the reduction in rainfall frequency, while increasing its quantity, would create havoc in terms of floods and large-scale water stagnation but prolong the dry spells and increase their frequencies on other hands. Apart from ecological conditions, the socioeconomic drive of rice consumption and market demand, amidst rising hyperglycemia (diabetes) of type 2 and change in food habits from rice to high-value nutrition would certainly influence rice-based production systems. Differential availability of resources such as land, labour, water, nutrients, capital, energy, and technological knowledge do have a tremendous influence on rice production systems across the globe. Increase in labour wages, fertilizer cost, non-availability of the seasonal workforce, higher water requirement and distress sale have significantly reduced profit, which negatively affects the enthusiasm for rice cultivation.

System configuration and adaptation strategies

With the changing pattern of on-farm resource and production factor availability and differential adaptability of innovative technologies depending on the social, economic and ecological perspective of individual household's production, the rice-based production system targets are tightly configured.

The evolution of rice-based production orientation in Asia in the pre-green revolution era (before 1960s) was of subsistence with low intensification of rainfed monocrop without use of external inputs that resulted in low yield of rice. During the green revolution (1960 to 1970), production orientation was mainly subsistence with medium intensification under irrigated transplanted rice monocropping and with little external input addition and medium yielding ability. In the post-green revolution phase (1990s), production orientation was mainly market-oriented, highly intensive, fully irrigated and transplanted double-cropped with a profound use of agro-chemicals. Whereas, the current production orientation in post green revolution is only market-driven, very highly intensive, fully irrigated multiple cropping, direct seeded mechanised precision farming and off-season soil less cropping that results in higher yield and profit (Rao *et al*., 2017).

All the above stages of productive transformation of rice farming are appropriate to the irrigated systems, converging diverse production systems into uniform, highly mechanised, intensive and innovative. On the other hand, rainfed rice production, covering an area of 18 million hectares in Southeast Asia alone, plays a pivotal role in household security in remote marginal areas of Myanmar, Thailand and Cambodia (Rao *et al*., 2017). Low yield response to external input addition mostly limited the profitable adoption of such capital-intensive innovations (hybrid seeds, fertilizers, farm mechanisation, etc.). An important strategy undertaken in Thailand and Cambodia and localized areas of Bangladesh and India is to cultivate sticky, pigmented and scented rice for self-consumption and selling in local market. But certified organic rice production was intended for export thereby making the rainfed lowland production system technologically and economically viable (Rao *et al.*, 2017).

Sustainable adaptation and mitigation strategies

Rice-based production system, being the oldest and most widely adopted system in Southeast Asia, needs ecological and sustainable management by adopting the following drivers of change for feeding the global population and protecting the environment from degradation. External forces mostly refer to a global scale, such as climate change, edaphic and demographic behaviour and international market networking, while internal drivers concentrate on socio-cultural preferences and farmers' need, aspiration and vision. However, both exo- and endogenous forces, being complex, are interlinked, but not linearly related as cause-effect linkages, and thus, the prediction of future pathways of rice production systems is highly unpredictable. Biophysical risks with perceived and real effects of demographic rise, global climate change, emerging water shortages and quality land losses due to soil salinization, desertification and sea water ingress intermingled with economic and social concerns appear to act as drivers of system shifts and uncertainties in rice cultivation and investments in rice-based production systems. Impeccable mitigation plans, policies and strategies could sustainably manage such drivers effectively and efficiently.

Biophysical drivers

As discussed before, a curb on uncontrolled surge in global demographic patterns particularly in East, South and South-eastern Asia not only had a tight grip over the ever-rising demands for food, but also had smothering effect on the anthropogenic climate change, over-exploitation of critical resources and environmental degradation. Rice accounts for 55% of the global greenhouse gas emission from agricultural soils. More environmental problems from rice fields such as methane from irrigated rice fields and nitrous oxide from excess overuse of nitrogenous fertilizers and mid-season drainage intermingled with huge water requirements very often raise the eyebrows of many planners. Consequently, adoption of various alternate water-saving and direct seeding rice production systems not only assure food and water security, but also address global climate change issues. Increase in early-season heat waves (in Northern India, Bangladesh, and Myanmar) and unexpected diurnal temperature variations can result in spikelet sterility in dry-season rice (Ishimaru *et al.,* 2016). Delay in onset of monsoon can damage rice seedlings in nursery and dry-seeded main fields, while early recession or too much rainfall at maturity may affect the grain quality. As the ingress of saline sea water affects 1% of rice area every year, global warming-driven cyclonic storms and melting of polar ice-caps can have catastrophic impacts on coastal low-lying rice farming. As rice uses 3,000-5,000 liters of water for production of a kilogram of rice, which is 2-3 times higher than the water footprints of other cereals (Bouman *et al.,* 2002).

Climate change and extreme weather events have severe impact on disease pest incidence in rice (Skend•iæ *et al.,* 2021). Higher incidence of plant hoppers and leaf blasts in rice has already been reported by Huang *et al.* (2010). Adoption of hybrid and high-yielding rice genotypes, water-saving cultivation practices such as aerobic rice and aero/aquaponics system, direct seeding and judicious nutrient and water management can address such climate change issues.

In situ rice stubble burning in rice-rice cropping system is another challenge that aggravates GHG emissions and air pollution at the cost of valuable nutrients and organic matter loss (Singh *et al*., 2008). Alternate rice residue management such as composting, paper, insulated cardboard, particle board and briquette making or 2G bioethanol production could sustainably manage such huge amount of crop wastes into valuable wealth (Dwibedi *et al.,* 2021).

Rice soils in continuous double and triple-cropped areas are constrained with the basic soil qualities such as organic carbon, nitrogen and micronutrients like zinc and boron followed by calcium and copper. Deficiencies of organic carbon and nitrogen have wider visibility in rice systems while deficiency or toxicity of other essential plant nutrients is location specific. *In situ* incorporation of rice residues and straw biochar application is reported to have enhanced soil organic carbon pool in rice-based production systems (Bal *et al*., 2022).

Groundwater pollution is a serious concern in rice areas with light-textured soils under continuous flooding or frequent irrigation. Nitrate leaching affects grain quality and human and animal health. Recent developments in nano fertilizers for supplementing major plant nutrients and micronutrients could be the timely answer to such nutrient losses. Site-specific nutrient management in rice enhances fertilizer use efficiency for higher productivity and profitability in rice farming, while reduces environmental pollution through various losses. Cultivation of high water requiring crops like rice with heavy metal contaminated irrigation water above the threshold levels can lead to soil and grain toxicity. Apart from heavy metal toxicity, selenium in irrigation water may lead to toxicity in soils and plants. It is recommended to avoid such contaminated water for irrigation or else, prior water treatments, soil amendments and crop rotation can be practiced (Sara *et al.,* 2017). Shifting from monoculture to rice-fish farming shows ameliorative effects on labile carbon pool, soil microbial populations, soil fertility level and environmental sustainability (Bihari *et al.,* 2015).

Intensive cultivation with soil puddling aggravates elemental toxicity and deteriorates soil aggregate composition. Soil health risk associated with grain and soil toxicity deteriorates with frequent tillage and puddling. Rice monoculture leads to soil toxicity while flooded rice cultivation increases pesticide and metalloid toxicity (Shah *et al.,* 2021). In fine soils, capital and energy-intensive puddling should be minimized with zero-till-based mechanized planting, dry direct seeding and strip tillage based planting.

Runoff, volatilization, leaching, long-term soil fixation, inadequate soil moisture, improper placement, untimely and inadequate application, low soil organic matter and competing weed uptake are reasons for poor crop a response to applied fertilizers (Chauhan *et al.,* 2012). Although P and K fertilizers show response in long-term of 5-10 years these two should be applied along with N-fertilizer, because sole N application in long-term can decline yield in the rice-based cropping system. If the current trend in crop response remains unattended, it can pose a hindrance to the furtherance of the rice productivity. Thus, judicious soil and water management, integration of green manuring *in-situ* or *ex-situ* and brown manuring, engagement of microbes for harnessing and solubilizing plant nutrients, the addition of healthy organic manure with timely application of soil test-based chemical fertilizers and growing dual-purpose pulses are needed for long-term reversal and improvement of crop response.

With depleting groundwater, crop water productivity has been a major concern for C3 crops like rice. Lowland rice is less water productive (0.2 to 1.2 kg m^{-3}) than wheat (0.8 to 1.6kgm^{-3}) and maize (1.6 to 3.9kgm^{-3}) (Sharma *et al.,* 2015). Puddling and continuous flooding consume the maximum unproductive water causing lesser water productivity in the rice production systems. Bouman and Tuong (2001) reported at par yield when saturated soil condition was maintained, but the yield reduced below saturation level. Alternate wetting and thawing (system of rice intensification), direct seeded rice (DSR) cultivation, bed planting and mulching had increased water productivity (Tuong *et al.,* 2005). Alternate wetting and drying are usually adopted in DSR where water for nursery and puddling are eliminated. But the concern in DSR is the longer duration of crop in the field than puddled transplanting (PTR), which requires more water for meeting the evapotranspiration requirements (Humphreys *et al.,* 2010). However, some researchers asserted lower water requirement in DSR than in PTR, with or without yield penalty, as the frequency of irrigation is lesser in the former due to longer intervals (Jat *et al.,* 2009; Yadav *et al.,* 2010). Yield reduces only when soil is allowed to dry above soil moisture tension of 20 kPa (Yadav *et al.,* 2010). Thus, it is imperative from the above findings that unproductive water flow should be minimized to enhance water productivity, which can be achieved through soil water potential-based irrigation scheduling in DSR. Agronomic measures such as irrigation in furrows and skipped furrows, micro-irrigation systems, straw mulching and conservation agriculture should be promoted and practiced on a large scale for enhancing water productivity of crops in the rice-based production systems. Production of high water-requiring crops such as rice and sugarcane in water-stressed areas needs thorough scrutiny and should be discouraged (Dhawan, 2017).

Weeds are the major problem in rice cultivation, especially in dry cultivation, while PTR followed by continuous water stagnation significantly reduces the weed infestation. However, after continuous intensive rice cultivation and herbicidal application develop eco-biodiversity of weed spectrum and thus, specific weed floras develop herbicide resistance. Crop diversification effectively controls crop associate weeds (Chhokar and Malik, 2002). Species composition and abundance depend on the crop, method of establishment, cultural practices, climatic condition and weed load from the previous crop. *Echinochloa crusgalli* and *Echinochloa colona* are the major weeds of aerobic and wet rice ecosystems, whereas many other weeds such as *Digitaria sanguinalis, Digera arvensis*, *Dactyloctenium aegyptium, Trianthema portulacastrum and Cyperus rotundus* are abundantly present in DSR, but rare in puddled transplanted rice (Chhokar *et al.,* 2014). Both dry and wet direct-seeded rice has more influence on weed intensity and density than PTR. Researchers have estimated a yield loss of 15-66% in DSR (dry/ wet) and 6-30% in PTR (puddled/non puddled) (*Gharade et al.*, 2018). Some other researchers have also assessed 30-100% yield loss in DSR in absence of weed management practices (Kumar and Ladha, 2011; Chhokar *et al*., 2014). In DSR, weeds very often germinate earlier than rice but in PTR, rice has a month of growth advantage over weeds. In majority of the rice ecologies, PTR is usually the preferred establishment method for rice but labour shortage during planting forces to switch over to DSR. Labour scarcity, in the COVID-19 pandemic situation, has compelled the farmers to shift to DSR from PTR. However, selection of appropriate variety and efficient weed management are the prerequisites for success of DSR (Chhokar *et al*., 2014). Weedy rice or red rice (*O. sativa* f. *spontanea*) in DSR has been the major flora that can be controlled by shifting back to PTR.

Genetic drivers

Rice has vast genetic diversity and is adapted to a wider ecological niche. It is the first crop with complete genome sequencing, which help-support in molecular marker-assisted gene discovery and crop improvement (IRGSP 2005). Out of 24 rice species, 22 are wild and 2 (*Oryza sativa* and *Oryza glaberrima)* are cultivated. *O. sativa* with the maximum area coverage is classified into five major groups such as *indica*, aromatic *japonica*, tropical *japonica*, temperate *japonica* and *aus* (Garris *et al*., 2005). A large number of wild, indigenous and exotic accessions are maintained at the International Rice Genebank Collection Information System (IRGCIS) of International Rice Research Institute (IRRI), the Philippines and National Bureau of Plant Genetic Resources (NBPGR), New Delhi. Biotic and abiotic stress-tolerant rice genotypes are developed by marker-assisted selection, introgression (Das *et al.*, 2017) and CRISPR/Cas technology of genome editing (Zafar *et al.,* 2020).

Economic drivers

With the increased cost of cultivation, owing to higher market price of inputs (agrochemicals and labour), the net profit of rice has narrowed down in absence of corresponding price enhancement of the produce. Unlike wheat and maize, the price of rice in international market has remained more or less similar over the last few years. Relying solely on rice farming invites a considerable risk for the farmers (Singh and Varshney, 2010). The market price for rice has been fluctuating widely over years and even seasonal market price volatility is too high exposing poor farmers to large uncertainties (Dawe *et al.*, 2015). The situation remains grim when the farmers fail to store their produce for long period in anticipation of fetching better price in the future. Very often the producer prefers to sell rice to middlemen, millers or traders after harvest getting a price tag much lower than its prevailing market price. Although many countries have the provision for minimum support price for rice as a price guarantee, but its implementation with full scale is yet to be confirmed. During the crisis due to flood and drought, the rice farmers usually struggle for their own cause without any or minimum incentives. Faced with market price fluctuations, farmers have to diversify their cropping system with vegetables, sugarcane, oil palm and other cash earning crops. However, strict implementation of minimum guaranteed price for major crops, including rice, can bridge the gap between a decent supply and distress sale.

Social drivers

Rice is not only a staple food, but also a cultural identity and a way of life for many. Cultivation of rice in country like India is a part of rich heritage and culture. Special dishes such as sticky, pigmented and scented rice are prepared and social events & rituals are observed in relation to rice phenophases. Even though the traditional genotypes are generally low yielders, but have high economic and cultural values. These traditional less improved rice genotypes are season-bound and very sensitive to fluctuation in photoperiods. Use of agrochemicals is discouraged in view of their lodging habit and dilution of natural aroma, hence intensification to fetch higher yield is nearly impossible with these traditional genotypes (Sarkar *et al.,* 2014). Rice farming, to the young generation, neither provides social status nor is an alluring economic endeavour.

Conclusion

Achieving the targeted minimum annual growth rate of 1.2 per cent in rice production is the greatest challenge for rice growers and policy planners due to the ill effects of climate change and diversion of rice land for use in non-farm activities. This stupendous task of food grain production is instrumental in arriving at the United Nations' Sustainable Development Goals designed in Agenda 2013 (Griggs *et al.*, 2014). Any accomplishment in this line will certainly have global interest. Rapid technological innovations and strategic policy changes on research efforts on the development of hybrid rice, C4-rice, fortified rice and stress-tolerant rice genotypes, adoption of water-saving rice cultivation, renovation of irrigation network systems, building soil carbon pool for promoting microbial growth, conserving nutrient & moisture and converting rice crop as a profitable agri-activity will certainly sustain rice production systems to ensure global food security.

ENHANCING THE GENETIC POTENTIAL OF RICE FOR STRESS TOLERANCE AND NUTRITIONAL QUALITY

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During the initial stages of the establishment of ICAR-National Rice Research Institute (NRRI), earlier Central Rice Research Institute (CRRI), the major objective was to carry out basic and applied research in all disciplines of rice so as to optimise per hectare yield. The objectives have undergone changes from time to time to meet the newer challenges with the hope to improve the income and livelihood of resource poor farmers who are depending mainly on rice cultivation under rainfed condition. Many improved varieties were selected for different ecologies through pure line method and several breeding lines were developed under *indica-japonica* hybridisation programme before the real ushering of Green revolution in the country in mid 1960s. With time, the nation has acquired self-sufficiency in rice productivity, now the consumers' demands is focused towards nutritional quality and develop high yielding climate resilient varieties suitable for different agro-climatic regions of the country.

The traditional rice varieties and their wild relatives preserved in gene banks constitute a valuable gene pool for many resistance gene sources to different biotic and abiotic stresses. At present, more than 109,000 rice accessions are conserved in the National gene bank as long term storage (LTS) at -18^{0} C and with 3-4% RH. All these germplasm collections are now being characterized for agro-morphological traits based on 30 distinctive, uniformity and stability (DUS) characters as per the descriptors which include 19 qualitative and 11 quantitative characters at appropriate stages of plant growth and maturity. So far, NRRI has released 160 varieties including five hybrids. The first high yielding varieties of NRRI 'Padma' and 'Jaya' were released in 1968 for the irrigated ecology. Varieties such as Pooja, Naveen, Shatabdi and Savitri are very popular among the farmers of India. Presently, more than 50 rice varieties of the institute which accounts to about 20% of total indents are in formal seed-supply chain, among them Swarna *Sub1*, Pooja, Naveen, Shatabdi, CR Dhan 500, CR Dhan 201 and CR Dhan 303 are highly demanded varieties by the farmers.

Breeding for biotic and abiotic stress tolerance

The rainfed ecologies comprising about 50% of the rice area, located mostly in the eastern part of the country are highly affected by abiotic (submergence, drought) and biotic (pest and diseases) stresses. The stresses are intensifying with the emerging threats of climate change. Climate-smart varieties are, therefore urgently needed to address these challenges to make rice farming sustainable. The recent IPCC report has predicted 1.5°C increase in the average temperature of earth which will definitely be detrimental to agricultural productivity of developing country like India having large dependence (agriculture) on rainfall. The intensity and occurrence of flood, drought, and high temperature are predicted to be highly variable and expected to be on the higher side of scale. The alterations in weather due to climate change are likely to interfere with the biology of disease and insect-pests and sudden large scale occurrence of pest and disease outbreaks may become routine in future.

The NRRI is continuously working towards development of superior varieties for tolerance to biotic, abiotic stresses and improving the grain quality for the benefit of farming community. However, challenges due to climate-change driven occurrence of biotic/abiotic stresses require genetic enhancement of rice varieties using novel genes through conventional, marker assisted selection, doubled haploid and genome editing technologies. The modern molecular and tissue culture techniques removed the barriers of gene transfer through inter-specific hybridizations and hasten the process of rice improvement. Traditional cultivars and wild species serving as source of novel QTLs/ genes are better adapted to different environments and offer resistance to many biotic and abiotic stresses. The biotic stress breeding programme has evolved over time depending on the dynamic pest profile of the crop and advances in the technologies available. The *Xa21* gene was identified at NRRI in the wild species *Oryza longistaminata* and was highly effective against BB races in South and South-Eastern Asia. Improved lines with resistance genes (*xa5*, *xa13* and *Xa21;* either singly or in different combinations) were developed through marker assisted backcross breeding in the genetic background of Lalat, Tapaswini, Swarna and IR64. The genotypes Tetep and CR 1014, showed consistently moderate resistant reaction for sheath blight tolerance. Several landraces such as Salkathi, Dhobanumberi were found to be promising in durable resistance to brown plant hopper. Wild rice like *O. brachyantha, O. officinalis, O. ridleyi* and *O. coarctata* are found to be resistant to yellow stem borer.

In India, before the green revolution, varietal development was confined to pure line selection. Rice being a self-pollinated crop, landraces are considered as mixture of several pure lines and some are genetically heterozygous. Selection of outperforming strictly pure line from such population is difficult. Therefore, progeny performed based selection results in stable and homogenous-homozygous variety. The pure line section resulted in development and release of more than 445 varieties across the country, for example, for rainfed low lands -Manoharsali and Latisail, for rainfed uplands - N22 and Dular and for irrigated areas GEB 24 and MTU 15 occupied major rice growing area. Later, selections were made from cultivated varieties and released as improved varieties like- N12 (a selection from Safeda), T3 (a selection from Basmati) and T9 (a selection from Duniapat). Some varieties such as, T9 and N22 are still popular and grown in sizeable area in north-western parts of the country. The post-green revolution era has been focused on breeding varieties for high yield, stress tolerance and enhancing nutritional quality of rice crop. In that context, evaluation for abiotic stress tolerance traits like seedling and reproductive stage drought, submergence tolerance (15 days & 21 days), salinity tolerance (seedling and reproductive stages), cold/high temperature tolerance, anaerobic germination ability, viviparous germination, stagnant flooding tolerance, combined multiple stress tolerance (salinity + stagnant flooding, salinity + submergence, drought + salinity), low light tolerance, low arsenic uptake, herbicide tolerance, high photosynthetic efficiency, and lodging resistance are being going on in massive scale.

The major landmark in the rice gene discovery is submergence tolerance gene in the rice research. The submergence, which was designated as the *Sub1* gene on chromosome 9 with 70% of the total phenotypic variance in the population (PI543851 x IR40931-26) was identified (Xu and Mackill, 1996; Xu et al., 2006). This QTL *Sub1*was recently introgressed in many popular varieties (Swarna *Sub1*, Sambha *Sub1*, Cherang *Sub1*, Ranjit *Sub, Pooja Sub 1* etc.).

There are several other varieties which have been developed for tolerance to abiotic stresses like Bala, Annada, Heera, Vandana, Phalguni were developed for upland ecologies where relatively less amount of water is used for cultivation. Currently, focus is made on development of climate resilient varieties by combining multiple abiotic stress tolerance genes/QTLs. Varieties namely, CR Dhan 801, CR Dhan 802 are the new climate-smart varieties possessing both submergence and drought tolerance genes in the background of popular variety Swarna and CR Dhan 803 in the background of Pooja. Novel screening protocol for precise screening for salt tolerance at reproductive stage was standardized and validated. Landraces from Sunderbans region were found diverse in respect of salt tolerance. Salt tolerant cultivars from this area such as Kamini, Talmugur, etc. had allelic difference from the widely used *Saltol*- introgression line, FL 478 in the *Saltol* - QTL region. More than five saline tolerant varieties have been released for cultivation, among them CR Dhan 412 (Luna Ambiki) is a recent release high yielding rice variety developed for coastal salines areas.

Similarly, for obtaining donors against biotic stress tolerance, mass screening is going on for the traits like BPH, gall midge, leaf folder, stem borer, nematode, WBPH, stored grain pest, blast, brown spot, sheath blight/ rot, leaf blight, BB, bakanae, tungro virus and false smut. Though many insects are pest to the crop, BPH, YSB, GM, WBPH and LF are considered to be of national significance as they cause severe damage in rice yield. Brown plant hopper has become a dreaded pest of paddy in major rice growing tracts of India, the symptom being known as 'hopper burn'. Several resistant donors have been identified like PTB 33, Manoharsali, Rasi, PTB 10, PTB 20 etc.

Breeding for high protein content

High yielding rice varieties with high nutritional values developed through breeding intervention can significantly contribute towards the better nourishment of millions of poor in India who depend mainly on rice for their nutrition. Protein energy malnutrition is frequent among children in villages of India. High protein rice in mid-day meal programme can give benefits to underprivileged school-going children in villages of India. In addition, for improving the nutritional quality of the rice grains, the evaluation of germplasm is being carried out for high protein, high Zn, high Fe, low amylose content/glutinous rice, high antioxidant activity, gamma oryzanol content, low GI, low phytic acid, good fodder quality, short grain aromatic rice. Further, work has been initiated for getting donors for metal toxicity/ deficiency wrt Fe toxicity, Fe deficiency tolerance, low Arsenic uptake, Zn deficiency tolerance, high weed competiveness etc.

Rice provides around 30% dietary protein to the millions of people who depend mainly on rice for nutrition. Still it is deficient in protein (7%) as compared to other cereals. It is also deficient in zinc (12-14 ppm) which causes a chronic problem among populations having rice based diets. Protein content in rice kernels varies from 6.1% to 10.1% while the aleurone layer thickness varied from 11.2ì to 75.0ì. Using a high grain protein content donor (ARC10075) several introgression lines in the high yielding varieties such as Swarna and Naveen were developed by ICAR-National Rice Research Institute, Cuttack and tested in multi-locations. High protein trait was transferred to high yielding backgrounds of Naveen and Swarna through backcross breeding to release the first high protein variety in Naveen background as CR Dhan 310 and CR Dhan 311 for commercial cultivation. CR Dhan 315 **is** released as another biofortified rice variety which contains 24.9 ppm zinc in milled rice. The low GI varieties (Shaktiman, & Improved Lalat) are going to contribute in a big way to overcome the diabetic problem of the country and may cater the need of future requirements. Telangana Sona (Chittimallelu) is yet another low glycaemic index (GI) rice variety of 51.5% compared to the popular BPT 5204 rice variety (GI of 56.5) and is a preferred choice for health conscious consumers, particularly diabetic patients. Low GI rice is effective in the reduction of postprandial glucose response in type-2 diabetes and increase in plasma HDL levels and therefore useful in the management of type-2 diabetes and in the long term management of cardiovascular diseases. Further, due to low GI, the rice has export potential. Several consignments are being sent to Kuwait in recent years.

Breeding for Aromatic Rice

Aromatic rice varieties have been most sought-after commodity among the consumers across the world due to their greater economic returns and palatability. Many aromatic varieties exist, among them Basmati and Jasmine rice are the two most demanded varieties in the global market. Besides, there is huge diversity of short grain aromatic rice available meeting the taste and specific quality preferences of many consumers which have hardly gained any attention in the international market. The short grain aromatic rice 'bhog' of eastern India and 'joha' of north east India, especially Assam form separate groups. The names of the rice varieties like Krishnabhog, Prasadbhog etc. indicate that they were used in temples while the names like Badshabhog, Raj bhog, Kaminibhog etc. signify their usage in royal palaces for kings and emperors in the past. Even now these aromatic types are cultivated in areas under the control of temples for their subsequent use as 'prasad' in different sacred places of the state. Besides, several other aromatic short grain rices of different states, to name a few, Kalanamak, Dubraj are found to be low yielders, photosensitive, tall and therefore prone to lodging. The diversity of all these varieties have been collected, characterised, conserved and documented from Odisha, West Bengal, Assam, Chhattisgarh, Jharkhand and few other states. Pure line selection in the local popular landraces of short grain aromatic rice of Odisha has led to the release of Nua Kalajeera, Nua Dhusara, Nua Chinikamini without changing the physical and biochemical characters including aroma could enhance the yield from meagre 1.5 t/ha to 3.5 t/ha. Efforts are now made to overcome the tall plant structure and lodging aspect of few other important aromatic landraces using different breeding approaches and molecular tool. Biotic stress tolerance is another aspect while breeding for aromatic rice varieties as blast, bacterial blight, stem borer, gall midge sometimes causes huge loss. Speed breeding techniques need to be incorporated to reduce the time gap. Besides the short grain aromatic breeding at NRRI, long slender grained genotypes with aroma have been developed through mutation of Basmati rice. Ten aromatic rice varieties have been developed at NRRI since 2005 and they are Geetanjali, Keteki Joha, Nua Kalajeera, Nua Dhusara, Nua Chinikamini, Poornabhog, CR Sugandh Dhan 907, CR Sugandh Dhan 908, CR Sugandh Dhan 909 and CR Sugandh Dhan 910. Among these, Geetanjali and Nua Kalajeera are becoming popular among the farmers and are being set for developing rice value chain in Odisha. Research efforts should be made to incorporate bacterial blight resistance gene in to the high yielding short grained aromatic rice through marker assisted selection so that they can yield better.

It is known that scent is present only in a handful of rice varieties, and that it is conspicuously absent in wild rice. Biotechnological studies have revealed that scent originated as a mutation in normal rice in the *BAD2* gene. Even in the ancient times, the existence of several groups of aromatic rice was known. Like other rice, these have shown a spread from one area to another, revealing important links with important people and events in history. The aromatic rice has always played an important role in many regional economies, and has been the favourites of kings, religious heads, royalty, and the elite of society. It is estimated that about one per cent of the total rice area i.e., 40-50 thousand hectares is put under aromatic rice cultivation with a production level of 30-35 thousand tons of aromatic rice annually in the state of Odisha. The indigenous aromatic rice mainly, Kalajeera, Neelabati, Krushnabhog, Govindabhog, Padmakeshari, Haldigundi, Tulasiphoola, are predominant in coastal belts, while a few traditional aromatic varieties like Pimpudibasa, Dubaraj, Karpurakranti, Badshabhog, Kalikati, Laxmibilas and Makarakanda are common in the plateau regions of Odisha.

Conclusion

The change in climate is introducing new problems in developing new high yielding rice varieties. Apart from resolving the problems of climate change, it is now required to breed for nutritional security to overcome malnutrition. Besides biotic stresses, rice crop frequently also faces problems of drought, low temperature, submergence, water-logging, salinity/alkalinity etc. These abiotic stress situations cause drastic reduction in yield and thus varieties with in-built resistance to such stresses are desirable. Gene banks have served as the source of many novel genes against many diseases and pests in the past and contributed to achieve food security. Wild rice types are rich source of genes against many stresses caused by biotic and abiotic agents. Genes or QTLs controlling resistance to many diseases have been mapped, cloned and characterized from wild rice species.

EFFICIENT TECHNOLOGIES FOR SUSTAINABLE MANAGEMENT OF RICE BASED PRODUCTION SYSTEMS

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Rice is a staple food for more than half of the global population. It is grown under diverse ecologies spread over about 43 million hectares of India. Significant advancements have been made in the area of production technologies to increase the rice yields for different ecologies. However, new challenges have emerged for rice production mainly due to climate change, degradation of soil quality, less per capita water availability, low nutrient use efficiency and increased incidence of insects and diseases. Hence, emphasis is being given on developing efficient technologies for ensuring sustainable management of rice based production systems. Under the changing climate scenario, the rice is increasingly grown in highly diverse, complex and fragile environment. Therefore, the crop production technologies should be focused on the priority areas mentioned below:

1. Crop establishment methods under changing rice environments
2. Efficient water and nutrient management strategies for enhancing resource use efficiency
3. Crop diversification and promotion of allied sectors under changing climate scenario
4. Customized farm mechanization for energy efficient rice production systems

1. Efficient rice establishment methods for different rice environments

Among various methods of rice planting, transplanting of young seedlings in puddled field is the most popular method of rice establishment. This method of rice cultivation has been criticized because of intensive use of labor, water, capital, and energy. Thus, several options of mechanical direct-seeding and transplanting under unpuddled/ non-flooded conditions have been developed and evaluated. Notably, Direct seeded rice and non-puddled transplanted rice have drawn major attention and therefore, these alternative tillage and crop establishment methods are being discussed in this section.

Direct seeded rice (DSR)

Direct seeding of rice refers to the process of establishing a rice crop from seeds sown in the field rather than by transplanting seedlings from the nursery. Major advantages of DSR include saving of labour and irrigation water. Production costs are drastically cut and thus increases the total income of farmers. There are three principal methods of direct seeding of rice (DSR): (1) Dry-DSR: Dry rice seeds are drilled or broadcasted on non-puddled soil either after dry tillage or zero tillage or on a raised bed. (2) Wet-DSR: Pre-germinated (sprouted) rice seeds are either broadcasted or sown in lines on wet/puddled soil. (3) Water seeding: Sprouted rice seeds are broadcasted in standing water.

Sowing time, variety, nutrient and water management under DSR

In wet season under rainfed condition, seeding is done at least 10–12 days before the onset of monsoons. During dry season, the seeding can be done during early January or it can be deferred for some time depending on atmospheric temperatures. The suitable varieties for DSR possess the traits viz., weed-competitiveness, early seedling vigor, high spikelet fertility, lodging resistance, early heading with drought tolerance, vigorous root system for better anchorage and soil moisture extraction, shorter duration of the crop, high crop growth rate during the reproductive phase. In dry-DSR, nutrient management practices such as deep placement and use of controlled-release fertilizers performs well under rainfed conditions. Optimum fertilization is also an important component of integrated weed management in DSR. Life-saving irrigation at early crop establishment stage and grain filling stage is necessary under rainfed condition. Alternate wetting in drying is the best way to irrigate the dry-DSR. Precision irrigation practices like micro irrigation, drip irrigation and other automated irrigation technologies can be used for enhancing WUE under DSR. Drip and sprinkler irrigation technologies were found effective in saving irrigation water in rice up to 67%, and nearly doubling in the grain yield. Some of the sensor-based technologies used for scheduling irrigation include gypsum block sensor, time domain reflectometry (TDR), frequency domain reflectometry (FDR), neutron probe sensors. Recently developed advancement in precision irrigation management is the development of Customized Colour Coded Tensiometer, NRRI-ARM sensor and Eco-friendly Irrigation Alert System. Some of these sensors are being made farmer friendly and easy to handle and have the potential to save irrigation water by up to 41% without any significant decline in the grain yield.

Weed management under DSR

Some of the best weed control options for dry-DSR include proper ploughing followed by land levelling to ensure uniform germination. The selection of herbicide/herbicide mixture and its correct time of application with proper application rate is one of the most important criteria for effective weed control in DSR. Generally, integrated approach is recommended with one-time herbicide application and one mechanical weeding.

1. Non-puddled transplanted rice

Non-puddled transplanted rice has emerged as important management strategies to address many of the challenges related to tillage and puddling. This establishment method involve minimum soil disturbance and permanent soil cover.

Seed treatment, Field preparation and transplanting in non-puddled transplanted rice

Prior to sowing, seed treatment is recommended for control of sucking pests and termites and stale seed bed technique is recommended for weed management. Transplanting is done using mat type nursery in non-puddled soil with mechanical transplanter. Ride-on type or walk- behind type transplanters are useful for this purpose.

Nutrient, water and weed management in non-puddled transplanted rice

Recommended dose of fertilizers (NPK) is 80:40:40 wherein full dose of P and K and, 25% of N is applied as basal dose before transplanting, 50% N at maximum tillering stage and rest 25% at panicle initiation stage. For water management, 3-5 cm water is maintained throughout crop cycle (transplanting to physiological maturity). Choice of herbicides or mechanical control of weeds should be done on the basis of severity of weed infestation. Herbicide options include application of early post emergence and late post emergence herbicide. Mechanical weeding or late post emergence is resorted only when application of early post emergence herbicide fail to give desired result.

Benefits

It saves time and labor required for land preparation and transplanting. Zero tillage results in less soil erosion with better soil aggregate stability. Emission of greenhouse gases like methane is reduced as primary tillage is completely skipped. It reduces soil compaction which helps in successful germination of succeeding crop.

2. Efficient nutrient management strategies for enhancing resource use efficiency

Rice is one of the input intensive crops in the world and input of nutrient contributes approximately 20–25% to the total production costs of rice. Annually, rice production alone consumes nearly 14.0 % of total global fertilizer consumption. With increasing demand for food production, demand for nutrients is likely to increase further.

Nutrient management research in the changing climatic scenario

Under the changing climate scenario, attempts have been made to develop single and multi-abiotic stress tolerant rice cultivars that can withstand drought, submergence or both to some extent. Advent of newer germplasms make it necessary to devise appropriate nutrient management strategy to maintain the productivity level. Additionally, development of alternate fertilizer materials and deployment of locally available organic and inorganic source of nutrients coupled with resource conservation technology is desirable for nutrient management under changing climatic scenario. All the ingenuity of sciences supported by appropriate policy initiative like that of soil health card, neem coated urea and nutrient based subsidy etc. need to be employed to enhance the nutrient use efficiency, enhancing the productivity and profitability of rice cultivation while maintaining the ecological integrity and sustainability.

Different facets of Efficient Nutrient management: Existing and Emerging approaches

Government has launched a soil health card scheme in 2014 to promote the balanced and efficient use of fertilizers. It has been established that only 35 to 40% of the applied N is recovered by the crop leading to large losses of reactive N, this loss not only negatively affects yield but simultaneously drains national exchequer and also pollutes the environment. Efforts have been made to develop slow release or controlled release urea fertilizers to check the losses. Besides these, several chemical and natural inhibitors for inhibiting and/or slowing down the process of urea hydrolysis (urease inhibitors) and biological oxidation of ammonical-N to nitrate-N (nitrification inhibitors) have been identified and evaluated. Nayak and Panda (1999) reported that hydroquinone and neem cake extract were effective in reducing the N loss. The government has been promoting Neem coated urea (NCU) since 2008. It is predicted that NCU can improve nitrogen use efficiency (NUE) by about 10% and enhance the yield by 7.1 to 13.4 %.

One-time root zone fertilization (RZF) technique of urea as basal application is effective in reducing fertilizer-N loss by 56.3–81.9 % as compared to broadcasting of urea (Liu 2016). Crop-based approaches *viz*., use of leaf colour chart (LCC), chlorophyll meters and optical sensors. The real time nitrogen management (RTNM) has the potential to ensure efficient utilization of applied N and it could increase the yield by 15 -31%. LCC is economical and farmer's friendly diagnostic tool for RTNM. Customized LCC helped in enhancing yield by 10.3 to 13.3% in DSR. The rice yield increase was 11.4–18.0 % with LCC based NCU in dry-DSR (Mohanty et al., 2021).

Rice crop manager is a software (computer and android mobile based) tool jointly developed by IRRI, OUAT and ICAR-NRRI with a personalized crop and nutrient management guidelines which help the farmers in efficient N management. SPAD based nitrogen management could save the nitrogenous fertilizer by 20-35%.

RiceNxpert is another web based and android based application designed by a team of ICAR-NRRI to analyze rice leaf colour and recommend N fertilizer dose that will synchronize the demand and supply of N in plants. Crop simulation-based decision support tools such as DSSAT, ORZA-2000, InfoCrop have been developed to help determine N fertilizer recommendations matching with crop requirement.

Micronutrients, particularly Zn, B and Fe play key roles in growth and metabolism of rice plant. The most commonly observed micronutrient disorder in rice based cropping system is zinc deficiency. Among the different available Zn fertilizers; $ZnSO_4$ is the most commonly used. However, government is emphasizing on use of nano-scale ZnO particles as fertilizers. Fe toxicity is the major problem wetland rice soil whereas B deficiency is common in weathered, acid upland, coarse textured sandy and calcareous soils. Practices of resource conserving technologies (RCTs) viz., reduced tillage, zero-tillage, integrated nutrient management (INM), and residue retention are highly preferable to increase the micronutrient status of the soil.

Microbes play a significant role in sustaining the soil environment. The application of bio-fertilizer for rice crop like BGA, *Azolla*, AM fungi and *Azotobacter* etc. increase the grain yield of rice. Nitrogen fixer and phosphate solubilizer can provide 25-30% of chemical fertilizer equivalent N. Strains of beneficial microbes viz, potassium solubilizing bacteria, Zn-solubilization microbes, Siderophores producing microbe have also been identified.

3. Crop diversification and promotion of allied sectors under changing climate scenario

In most of the rice growing areas, particularly in eastern India, the available resources need to be utilized efficiently to reduce the risk related to land sustainability. It is important to understand the interaction and linkages between the components under rice based integrated farming system to fully utilize the resources. Integrated farming system provides an opportunity to increase the economic yield per unit area per unit of time by virtue of intensification and integration of crop and allied enterprises.

The most remarkable aspect of IFS is recycling of wastes which is inbuilt in IFS, it helps to reduce dependence on external high-energy inputs and thus conserving natural and scarce resources. Additionally, multiple uses of resources reduce cost, making farming sustainable. Another aspect of soil health is taken care of through recycling of residues. IFS also helps to reduce the risk involved in farming especially due to market price crash as well as natural calamities.

To upscale the adoption of IFS, integration of market-oriented diversification and livelihood improvement is needed. Further, a National Mission on IFS may be initiated by state governments targeting large scale spread of IFS concept by converging schemes of crops, horticulture, livestock, fisheries etc. Skill development of stakeholders by capacity building should include finance management for more scientific crop integration with sustainability in addition to crop management skills. In addition to this, farm perception-based location-specific livestock components especially small ruminants like goats, sheep, poultry which Improves monthly income inflows should be introduced.

4. Customized farm mechanization for energy efficient rice production systems

Mechanization in rice cultivation in India is increasing, however, machinery adoption in the rice cultivation is facing challenges due to fragmentized lands of 80% of farm holdings. Also, the poverty of small and marginal farmers is posing hindrance in the farm mechanization. Some attempts have been made to mechanize the rice cultivation for efficient and sustainable production system.

The rice cultivation mainly uses three types of power sources such as tractor, power tiller and animal. Depending on the availability of power, farmers are also practicing use of mixed powers to accomplish agricultural operations. The package of technology for land preparation (tillage and puddling), sowing (DDSR and WDSR), transplanting (walk behind and riding type transplanter), intercultural operations (spraying and weeding), harvesting, threshing and rice straw management ensures timeliness in farm operations, increases the land use, enhances the effectiveness of other inputs, makes farming cost effective, reduces losses, improves quality and adds value to the produce.

Depending on the requirement and soil condition different machinery/equipment have been developed to carry out field operations. Operation wise some advanced machinery used in rice cultivation is briefed in this section.

Field preparation

Tillage operation: Tractor drawn MB plough and disc plough; cultivators are used for primary tillage operation. The rotavator operation can save time and fuel up to 60-70 % and 55-65% as compared to traditional primary tillage operation.

Puddling operation: Puddling is generally done using tractor drawn rotavator and power tiller. Power tiller is advised in small and marginal landholding for proper puddling. Other equipment like tractor operator disc-harrow, cage wheel with cultivator, animal drawn cono puddlers, disc harrow cum puddler, etc. can also be used.

Land Levelling: For efficient and uniform crop establishment, laser guided land levelling is recommended. The machine is tractor operated and having scraper, transmitter, controller and receiver as major components.

Sowing/ Planting Operation

Sowing and planting operations can be completely done using machinery. Many implements and machinery have been developed and standardized till date.

Seed cum Fertilizer drill: Seed-cum-fertilizer drill enables dry direct sowing of rice which is cost effective and less laborious method as compared to transplanting and wet sowing of rice. By using these implements the seed can be sown at uniform depth as well as fertilizer can be placed deep inside the soil. The advantages of this method are (i) highly economical as puddling is avoided (ii) adjustable row to row distance and (iii) seed and fertilizer application rate can be maintained.

Mechanical rice transplanter: Mechanical transplanting of rice is the process of transplanting young rice seedlings, which have been specifically raised in a mat type nursery, using a rice transplanter. These are mainly two types of rice transplanter available in Indian market i.e., self-propelled riding type rice transplanter and walk behind type rice transplanter. The seedlings are ready for planting within 15-18 days after seeding. The transplanter can control the number of seedlings per hill as well as distance between the hills.

Weeding

Manual weeding is not cost effective and therefore mechanically is recommended as efficient and sustainable alternative to manual weeding. It can be integrated with chemical weeding in areas where weed pressure is high.

Self-Propelled power weeder: Dry and wet land weeders are suggested for weeding operation of upland and lowland rice, respectively. The number of rows covered by this weeder varies from 1 to 6 rows. The advantages of this weeder are (i) suitable for intercultural operation, (ii) reduced drudgery and (iii) low cost of operation.

Harvesting

Mechanically, paddy harvesting can be done by reaper and combine harvesters depending on the field size. The manual harvesting of paddy mostly done with sickles are labour and time intensive.

Reaper: Reapers are either self-propelled walk behind type or tractor front mounted. The most popular model of reaper is self-propelled walk behind type with working width 0.75 m. Three horse power engine is used in this machine and fuel consumption is aorund 1 l/h. Reaper cum binder machines have also beeb developed and standadised for simultaneous crop cutting and binding.

Combine harvester: The combine harvester used for multiple operation in single run i.e., first it cut the crop then threshing followed by cleaning and feeding through conveying system. The combine consists of cutting unit, threshing unit and cleaning and grain handling units. Combine harvester is used for cutting to feeding of the paddy crop in trolley for transportation. There are two types of combine harvester available in India i.e., rubber wheel type (for dry soil) and track type (for moist soil).

Paddy straw management machinery

Paddy straw utilization is one of the biggest concerns in the country and its management is impertinent for sustainable development. Open field burning of rice straw is cause of serious pollution issues. Burning of straw adversely affect the soil health and environment.

Paddy straw chopper: The choppers chop down the standing stubbles as well as loose straw thrown by combine harvester. These choppers either chop down the straw and spread on the field itself or feed the chopped straw in the tractor trolley. These machines are highly effective for quick transportation.

Conclusion

For feeding the burgeoning population, the agricultural production needs to accelerate at a faster pace in an eco-friendly manner. Resource conservation agricultural practices like zero or minimum tillage, direct-seeded rice, precision agriculture, site-specific nutrient management (SSNM) etc. provides an opportunity to make agriculture sustainable with right balance of productivity enhancement with reduced environmental footprint. Integration of artificial intelligence, machine learning, robotics, sensors and remote sensing for enhancing the input-use efficiency will continue to remain as priority area of research. The potential of microbial formulations for enhancing the nutrient use efficiency in rice ecosystem needs to be exploited, validated and upscaled.

BIOTIC STRESS MANAGEMENT IN RICE: RECENT SCIENTIFIC ADVANCES

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Rice is one of the most important pillars of food security in India. It is estimated that about 140 Mt of rice would be required by 2050. Productivity of rice in India is still 2.56 t ha^{-1} which is lower than global average (2.95 t ha^{-1}). To sustain present self-sufficiency and meeting future demand of food and export, productivity has to increase from present 2.56 to 3.25 t ha^{-1} by 2050. One of the major constraints of increasing rice productivity is pest problems. On an average 37% loss of rice yield is due to pest problems (Sparks et al., 2012). Besides yield loss, some of the major rice diseases has impact on rice grain qualities. Cumulatively quantity and quality loss together have huge negative impact on national exchequer. As per the information available from All India Coordinated research Project on Rice (1965 to 2017), at present in India number of major rice insect pests and diseases are 20 and 10 respectively. Global climate change also influences the behavioral changes of insect pests that force the researchers to be more dynamic in their researches in finding out and updating the data bases with more and more resistant donors and application of latest technologies like CRISPER/CAS9 for developing resistant/tolerant varieties. Crop health management is really a complex subject and has a tremendous impact on farmer's welfare. Lot of scientific advancements has tremendous potentials to deploy resistant or tolerant varieties in endemic areas, and timely application of eco-friendly green pesticides or Nano formulation of botanicals /chemicals to intervene further spread of disease and pests. Modern techniques of pesticide spraying through drone technologies, in the area where manual operations are not possible or non-competitive, are desirable solutions for rice pest management. Moreover, recent advancements in the internet of things (IoT) have the potential impact and will bring radical changes in the areas of pest and disease management.

A. Applications of modern tools for rice pest and disease management

Development of disease and pest resistant varieties by means of applying biological tools is one of the main activities in biotic stress research for increasing production and sustainable yield. This also has an important implication in environment safety. But durability of resistance depends on the extent of genetic variability present in the insect and pathogens. It is likely to break down if the pest population is highly migratory, genetically diverse or the rate of mutation is high. Hence precise characterization of genetic diversity of the pest is one of the essential pre-requisites in development of resistant varieties (Sahu et al., 2008). The demand of crop protection and plant breeders is not only to develop a resistant variety for a particular pest or pathogen, but also with a good degree of broad base resistance to many pathogens or pests along with potential yield. Plant biotechnology impinges or helps rice pathologists in many ways (Fagwalawa et al*.,* 2013; Gilchrist, 1998) like, controlling plant diseases by inserting resistance genes into potential high yielding or mega varieties by genetic engineering techniques. Moreover, the study of genes, responsible for plant resistance to disease and for virulence of pathogen, has already added considerable knowledges.

i) RNAi/ gene silencing and CRISPR/Cas9 approach for pest management

Double stranded RNA (dsRNA) is used to initiate the homology-based RNA silencing process, which silences genes in a sequence-specific way and suppresses gene expression. Both transcriptional gene silencing (TGS) and post transcriptional gene silencing (PTGS) can be used to silence genes. Targeting genes at the DNA level is a component of TGS. The mRNA is broken down by a variety of technologies, including antisense RNA, ribozymes, DNAzymes, microRNAs, and RNA interference (RNAi). Among all of these methods, RNA interference (RNAi) is the most effective tool for selective gene silencing. In the RNAi mechanism, particular RNAs are targeted and destroyed. A complex called Dicer, which belongs to the RNase II family, basically breaks down the lengthy dsRNA into short (21–25 nucleotide) fragments that are subsequently incorporated into a complex called the RNA-induced silencing complex (RISC). Then, the short RNAs' sequences are used to direct the RISC to degrade single-stranded RNA (ssRNA) in a sequence-specific way. RNAi is currently often used in genetic research and agriculture, particularly for controlling nematodes, plant diseases, and insect species in various crops. *Magnaporthe oryzae*, the causal organism of rice blast, was more resistant to rice plants that had the OsDCL1 gene silenced in a non-race specific way. In order to silence genes and give resistance to plant diseases, RNA-dependent RNA polymerase (RdRp) genes were thought to be essential. Inactivation of rice RdRp6 gene showed increased susceptibility to *Rice necrosis mosaic virus, Xanthomonas oryzae pv. oryzae (Xoo)* or *Magnaporthe oryzae*. Tiwari et al. (2017) made the first demonstration of host-delivered RNA interference (HD-RNAi) technology by employing a hybrid RNAi construct to silence the RPMK1-1 and RPMK1-2 genes responsible for pathogenicity of *Rhizoctonia solani* that cause sheath blight disease of rice causing. In comparison to non-transformed controls, the results demonstrated that transgenic rice lines exhibited delayed development of sheath blight symptoms and decreased disease. RNA interference (RNAi) has gained prominence over the past two decades as a crucial molecular tool for silencing essential gene transcripts in a variety of insects belong to the orders Coleoptera, Hemiptera, Diptera, Hymenoptera, and Lepidoptera. Ecdysone receptor (EcR), for instance, is a suitable target for an RNAi strategy to suppress brown planthopper (BPH) in rice. Slow growth and 100% mortality were caused by knocking out the NlFer1 or NlFer2 genes (Shen et al., 2021).

ii) Genome editing technology for pest and disease management

Genome editing tools like Clustered Regularly Interspaced Short Palindromic Repeats (CRISPR)/Cas9 (CRISPR-associated protein 9) has recently gained popularity because of its efficiency, speed, and effectiveness. This tool is highly useful for a better knowledge on biological function of genes in crop plants. In addition, CRISPR/Cas9 is more reliable in completely silencing genes than RNAi, which results in partial silencing and lower specificity. In rice, the use of the CRISPR/Cas9 tool was observed for knocking out the cytochrome P450 gene, CYP71A1, which encodes tryptamine 5-hydroxylase. This resulted in elevated SA levels and reduced serotonin levels in rice plants, conferring increased resistance against the brown plant hopper, the most notorious pest of rice. They examined the effectiveness of knocking out and adding the E-cadherin gene and EGFP using the CRISPR/Cas9 tool and discovered that the E-cadherin gene causes problems in dorsal closure, which is similar with RNAi-induced phenotypes. Nearly 14% of the injected individuals showed homology-directed knock-in of marker transgenes, and 6% of the injected individuals showed homology-directed knock-in in the following generation. Rice blast resistance was shown to be enhanced by RNAi silencing of the ethylene responsive factors (OsERF922) by Liu et al. (2012). Thus Wang et al. (2016) used CRISPR/Cas9 to knockdown gene OsERF922 in rice plants. The rice bacterial blight pathogen *Xoo* stimulates the expression of susceptibility factor genes (S genes) in plants and translocate transcription activator-like effector (TALE) proteins into host cells via type III secretion system. Bacterial blight is caused by the susceptibility gene OsSWEET13, which was brought on by the *Xoo* effector protein (PthXo2). OsSWEET13 gene mutation, caused by CRISPR/Cas9, improved resistance to *Xoo* infection. Similarly, the mutation in the SWEET11, SWEET13 and SWEET14 was resulted a broad-spectrum resistance to Bacterial blight pathogen.

B. Advances in diagnostics of pest and diseases of rice

Monitoring plant health and diagnosis of pest and diseases at right time preferably at the early stage of crop is essential to check further spread and facilitate effective management practices. On-time identification of disease pest and its distribution over the affected region could provide useful information for minimizing the crop losses and help in sustaining quality of the produce. Lots of advances were done in the domain of pest and disease diagnosis. Number of different techniques are there in the field of diagnostics, some of which have limited use and mostly laboratory based like polymerase chain reaction (PCR), immunofluorescence (IF), fluorescence in-situ hybridization (FISH), enzyme-linked immunosorbent assay (ELISA), loop mediated isothermal amplification (LAMP) etc. There are some other methods that have good potential and might be the future of pest disease diagnosis like Flow cytometry (FCM), Recombinase Polymerase Amplification (RPA), Thermography (TG), Fluorescence imaging (FI) and Hyperspectral techniques (HT) and lastly, sensor-based detection methods. Out of these, works on diagnosis of rice diseases has commendable progress in the field of HT. Recent advancements in diagnosis of false smut disease of rice through RPA technique has potential benefit because the disease is not detectable at initial stages of infection and development. Hyperspectral data is reported to be highly useful for detection of bacterial blight disease of rice at different stages of infection (Singh et al., 2012; Das et al., 2015).

C. Advances in application nanotechnology in pest and disease management

Nanotechnology is the next emerging fields in recent past and its interventions in agriculture have been attracting the scientific community. It has the potential to address some of the important problems in pest management. The benefits of nano pesticide intended for reduction of the pesticide quantity per hectare, costs, and enhancement of properties such as efficacy and specificity. Generally, management of the pest and diseases depends mostly on the use of persistent uses of pesticides. But their continuous application may arise problems like, resistance development, environmental pollution and handling hazards that lead to unintended poisoning threats to humans. In recent years, more scope is there for the development of safer eco-friendly pesticides from products of plant origin *viz*., essential oils (EOs) and botanical extracts. These are another novel alternative to chemical (pesticides) to meet new regulatory norms and consumers demand of safe foods which have significant effects against a large number of stored grain insects. EOs can be obtained in large or sufficient quantities through different extraction methods viz., hydro-distillation, dry distillation, steam distillation and through mechanical freeze pressing the plants. Nowadays some of modern methods of extraction which are widely used include extraction by supercritical fluid and microwave-assisted process. EOs are non-phytotoxic compounds and potentially successful against numerous insect pests and diseases. They contain chemicals that act through ingestion and by contact which exert fumigant, repellent and anti-feedant effects. Therefore, they can be used as a natural therapy to protect the crop from different biotic stresses.

Plant origin essential oils (Eos) are promising substitute of synthetic insecticides can protect the post-harvest produce and are conventionally been used to eradicate stored-grain pests (Isman, 2006), because of their low level of mammalian toxicity and high volatile characters. Basically, these are volatile in nature and their secondary metabolites are characterized by strong aroma and having density lower than water (Bakkali et al., 2008). It has been also proved that biologically originated products have useful insecticidal attributes (Arthur, 1996). Now, these EOs are leveled at par with pesticides in terms of efficacy (Isman et al., 2011), because of its properties like selective bioactivity and little or no harmful effects on non-target organisms and environment (Regnault et al., 2012). Hence the present proposal is aimed at identifying natural, safer and ecofriendly option as an alternative to chemical insecticides to manage stored product insect pests.

There are four types of nano-pesticides: nano-emulsion, nano-suspension, nano-capsules and nano-particles. Nano-emulsion formulations are the emulsion of either water in oil (W/O) or oil in water (O/W) that produces a transparent product having 20-200 nm droplet and does not have the propensity to coalesce. Controlled release of nano-formulation can overcome problems like chemical instability in the presence of high temperature, light, and moisture. Some of the high-energy emulsification methods used to make nano-emulsions are high-pressure homogenization, high-shear blending and ultrasonication (Ghosh et al., 2013). These nanoparticles act like magic bullets having precise, target oriented delivery system and effective penetration of molecules through cuticle and tissues. The main objectives of these formulations are i) deliver precisely on target site and ii) its property of slow releasing pesticides. Thus, nano-formulations are more potent compared to conventional formulations. Thus, nanotechnology can provide efficient and safe alternatives for pests and disease management as well as stored products also.

D. Smart technology for pest and disease management

Agriculture sector is now adapting slowly and steadily the modern technologies and thus the pest and disease management also is on the way of deploying those technologies.

i) Drone technology

Pests have always plagued agriculture and the numbers of challenges are being multiplied following the post-green revolution era. After water, pests are perhaps the most worrisome to a farmer in India, and, take a major chunk of his finances. Indian Agriculture has gone through much advancement and is benefited by the researches and adoption of new technologies. The application of pesticides is inevitable for pest management for better crop yields. Drone technology is a phenomenal innovation that have enough potentiality to transform the conventional farm practices followed in Indian agriculture. Spraying pesticide operation in the rice crop is most tedious. Pesticide spraying has to be standardized with mechanization/advanced equipment like drone in order to meet labour shortage, avoiding pesticide exposure, and to reach into the uncovered field area for smarter way of pest and disease management.

There is huge potentiality of drone technology for growth in agricultural fields. With constant improvement of technology, imaging process of the crop also needs improvement so that the farmers are being able to analyze their crops and can make proper decisions for further process by means of analyzing the data captured by drone and help them to get accurate crop information. The drone technology has the potential to provide a sustainable solution in context of enhancing the productivity as well as efficiency in the agriculture sector. It empowers the farmer to manage some of the specific environment and make pertinent choices to regulate crop health.

Recently Government of India has recommended the usage of drones for spraying operations to control the locust as band application and save the crops as a special case. But for other cases, Unmanned Aerial Vehicle (UAV) spraying is not recommended in India. More recently (16th July, 2021), the Directorate of Plant Protection, Quarantine & Storage, Faridabad has published a draft 'Standard Operating Procedures (SOP)' for use of drone application with pesticides for crop protection. However, there is no crop-specific SOP for rice, hence, there has to be some preparedness in terms of robust and pragmatic science-based research.

ii) Internet of things (IoT)

Basically, the internet of things (IoT) is one of the most advanced technologies that facilitates smart agriculture. IoT generally add sensing, automation and analytics technologies to modern agricultural process. The common applications of IoT in pest and diseases management that have direct or indirect role in smart agriculture are: sensor-based systems for crop monitoring with respect to pest disease diagnostic, disease pest forecasting, predictive modelling and planning, smart agricultural vehicles, drones, robotics, data analytics, visualization and management systems. This IoT is a system of interrelated computing devices, mechanical and digital machines, objects, animals or people that are provided with unique identifiers (UIDs). This technology has the ability to transfer data over a network in absence of human-to-human or human-to-computer interaction. An IoT system consists of web-enabled smart devices that use embedded systems, like processors, sensors and communication hardware, to collect, send and act on data they acquire from their environments. It shares the sensor data which are collected by connecting to another IoT gateway where data is either sent to the cloud to be analyzed or analyzed locally. Maximum work is done by this system without human intervention, though people can interact with the devices, like setting and give them instructions or access the data. IoT is a comprehensive adoption of new information technology. Combination of IoT technology with modern agriculture gradually bring smart agriculture into people's lives, thus improving crop yield and the quality of crops.

Intelligent agriculture that is based on IoT started late in China, and is still in the juvenile stage. Hence, there are only few numbers of investigations, and thus development in this field is not satisfactory. The progress of agriculture towards intelligence and automation is also severely restricted. On the other hand, the present system has collected abundant data, which seems to be chaotic but contains great value and proper analysis and addition of a data preprocessing module is necessary before data analysis. The effective and accurate processing of data can provide a scientific basis for the automatic control and intelligent management of the environment.

Epilogue

Lots of researches have already been done for all round development in the area of rice pest and disease management of which some are really new but progress is commendable and have high potentiality to get the breakthrough. But focus research is required in some of the highly emerging and potential threatening pest and diseases of rice. Possible integration of genome editing techniques to be done to incorporate rice resistance against major pests. Host resistance may be good solution for endemic areas but pest monitoring, detection and application of appropriate molecules at proper time and doses are the key to manage crop pests. Hence, some of the techniques like HT is very promising because of its robustness, high specificity, and rapid data analysis. Another field like nanotechnology combined with drone technology and IoTs also have huge potential which is encouraging for another new green revolution with reduced farming risks. However, there are still huge gaps in our knowledge of understanding in realistic way. Therefore, continuous focused research is required in straightaway to unravel the behavior and fate of these potentially good techniques.

RICE GRAIN QUALITY AND ABIOTIC STRESSES: PHYSIOLOGICAL AND BIOCHEMICAL PERSPECTIVES

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Rice is the world's most important staple crop and is a primary source of energy and nutrition for about half of the world's population. So it is the most important cereal crop for the food security of common people. Due to the increasing world population and shrinkage of farmland holdings, there is an urgent need to increase grain productivity. Therefore, increasing grain yield has become the primary objective in many rice-breeding programs. India is the second highest rice producer (about 120 million tons/year) in the world and is able to meet the demand for rice for the entire population. Rice is grown under diverse range of ecosystems and under changing climatic conditions it gets exposed to different environmental stresses reducing grain yield. But along with yield improvement, quality has now become a foremost consideration for rice consumers and millers. Quality is defined as "the totality of features and characteristics of a product or service that bears its ability to satisfy stated or implied needs" (International Standard Organization (ISO) 8402 1986). The concept of grain quality covers many physicochemical properties such as grain shape and size, milling and cooking properties, amylose content, stickiness, chalkiness, texture, colour, gelatinization characters, and various nutritional properties. Thus, rice grain quality generally includes five main classes i.e. milling quality, physical quality, cooking and eating quality, sensory quality, and nutritional quality. Grain quality and its assessment are very important to consumers, millers, and rice breeders who are engaged in varietal improvement programmes, related to new features such as high nutritional quality, high yield potential, highly resistant to abiotic or biotic stresses, higher water use efficiency, etc.

Rice starch digestibility and its biochemical indicators:

Rice is the staple food and energy source for two-thirds of the world's population, especially for poor people who have limited access to a varied diet. It provides half of the dietary calories and vital nutrients to people in Asian countries. Rice consumers with a sedentary lifestyle are more likely to develop obesity, type-II diabetes, and colon diseases in the long run (Lal et al., 2021). International Diabetes Federation has reported 463 million diabetics, most of them in poor countries resulting in 4.2 million deaths and high expenditure on treatment. The number of diabetes cases may rise to 629 million by 2045. The situation warrants the development of cost-effective low glycemic index (GI) foods for diabetics as well as the general masses. The glycemic index measures the extent to which blood sugar level rises after consuming carbohydrate-rich food. Based on GI, foods are categorized as low GI (55 or less), intermediate GI (between 56-69), and high GI (70 or more) types. Glycemic load (GL) determines in what amounts and how quickly one serving of food releases glucose into the blood. Hence, both GI and GL are considered indicators of starch digestibility (Kumar et al., 2022).

Rice is consumed mainly as milled white rice, which is poor in dietary fiber and thus could be one of the factors for the high prevalence of type-II diabetes. Brown rice is slowly digested as it is richer in dietary fiber and thus enhances colonic fermentation. Food's starch digestibility is the main determinant for changing postprandial blood glucose level and hence the GI value. Based on its rate of digestibility, starch is generally categorized into three types viz., rapidly digestible starch (digested within 20 min); slowly digestible starch (digested within 120 min), and non-digestible or resistant starch (RS) that remains undigested even after 120 min (Miller et al., 1992). Resistant starch plays important role in reducing postprandial blood glucose levels, decreasing the risk of obesity, changing sensitivity for insulin in humans with type-II diabetes, and guarding against the risk of chronic kidney disease (Lal et al., 2021). Therefore, foods rich in RS contribute to human health. It was reported that rice with less than 2% RS is significantly low in GI (Kumar et al., 2018). Thus, GI, GL, and RS are important biochemical indicators of lower starch digestibility in the gastrointestinal tract. Therefore, consumption of high RS rice-based foods may help control type-II diabetes, due to slower starch digestibility and reduced postprandial glucose and insulin responses. Besides the above indicators, Phytic acid (PA) also play role in the modulation of starch digestibility. Phytic acid is stored in rice in the outermost aleurone layer and bran. It acts as an antioxidant as it guards the rice grain against oxidative stress (Kumar et al., 2021). Phytic acid is generally considered an anti-nutrient, as being polyanionic, it strongly binds cationic nutrients like Fe, Zn, and Ca in the gastrointestinal tract of monogastric animals as well as humans and blocks their absorption. However, low starch digestibility in rice with intermediate to high PA content was reported by Kumar et al., (2020) and they proposed an inverse relationship between PA and GI values. Phytic acid chelates calcium ions required by alpha-amylase and lowers starch digestibility. Thus, low PA foods may help a healthy colon and prevent hyperglycemia in diabetic people by reducing starch digestibility. A study on mice shows reduction in blood glucose when PA is added to the diet (Kim et al., 2010).

Amylose polymers have linear chains with a smaller surface area which form complexes with matrix compounds and hence are digested slowly as compared to branched amylopectin. Thus, starchy foods having high amylose reduce the blood glucose response compared to low amylose foods. Though, views differ about the correlation between amylose content (AC) and starch digestibility of raw rice starch. Rice starches with high AC are reported to have high RS content (Zhu et al., 2011). It was assumed that amylose-lipid complexes form an immiscible structure that restricts the amylase from accessing starch granules. Another study, however, found no correlation between AC and starch digestion rate kinetic parameters (Dhital et al., 2014). Establishing a definite relationship between AC and its starch digestion is complicated by the fact that the researchers used different rice genotypes. Recently, it was reported that besides AC, the magnitude of linear chains of amylopectin also play role in reducing starch digestibility. The starch debranching enzyme pullulanase cleaves á, 1-6 glycosidic bonds in amylopectin. Increased pullulanase activity releases various chain lengths of linear polyglucose molecules which facilitate the formation of type 3 RS by starch retrogradation resulting in lowers starch digestibility (Krishnan et al., 2020). Modern technologies have helped in the modification of RS content in rice, making it more suitable for consumption by diabetics. The development of new technologies like CRISPR has opened new frontiers in nutritional quality research, which may help in the development of nutritionally rich crops for diabetics and general people.

Pigmented rice as a functional food

Functional foods are defined as foods that are consumed as a part of the usual diet with normal quantity and having a good sensory quality that promotes health through enhanced immune response and minimizing disease infection so that the aging process slows down. These types of food may be specially processed or unprocessed plant and animal products that contain a higher concentration of bioactive compounds in addition to normal nutrients as compared to conventional foods. Pigmented rice particularly black rice is considered a functional food in Indonesia. Red rice is also recognized as a functional food in Japan because of its high phenolics and anthocyanin content. In India, China, and other South East Asian countries, black rice is utilized to promote health and combat many diseases. There are various types of pigmented rice exist in the world such as red, purple, yellow, and black. Interestingly, the pigmentation of rice is mainly associated with bran or pericarp layers, not with the edible endosperm of the grain. As brown rice is not so popular among consumers, the percent adherence of coloured bran with the endosperm after milling is very important to get the benefits of pigmented rice. Pigmented rice is enriched with many bioactive compounds and these bioactive compounds like anthocyanin, phenolic acids, flavonoids, pro-anthocyanidins, tocopherols, tocotrienols, α-oryzanol are present in higher quantities as compared to white rice. Therefore, it exhibits a higher rate of antioxidant activity also. These antioxidant compounds scavenge reactive oxygen species (ROS) such as lipid peroxide and superoxide anion radicals and lower the cholesterol content of animals (Nam, Nam, & Kang, 2008).

Black rice is a good source of fibre and minerals besides basic nutrients. Anthocyanin is the prime component of pigmentation in case of all the pigmented rice cultivars. Pigmented rice is rich in medicinal properties. The red rice cultivar of South India *Njavara* was used to treat arthritis, cervical spondylitis, muscle wasting, skin diseases, and certain neurological problems. Previous investigators demonstrated that the black rice diet significantly inhibits atherosclerotic plaque formation in rabbits (Ling, Wang,& Ma, 2002).

Rice grain aging- pros and cons

Rice has a finite shelf life, much like any other food grain; hence it is kept in storage facilities. By choice, stored rice is preferred over raw rice in some parts of the world, due to an improved flavor perceived. Therefore, rice aging is one of the important steps in the post-harvest processing of paddy. During storage, rice undergoes numerous changes in physicochemical properties that can be identified after three months of storage. Storage also has implications on the cooking and eating quality of rice. Texture, pasting, and thermal properties of rice are important attributes that are the signature of aged rice (Sodhi et al., 2003; Prabhakaran and Moses, 2016). Rice aging is a spontaneous process. The colour, gelatinization traits, flavour, and content of rice alter as storage time increases. As a result, the nutritional quality, cooking, and eating quality of rice change (Champagne, 2004). People in different countries have different choices of rice: the population in South East Asia prefers fresh rice, but Indians prefer aged rice after storage. However, the mechanism of rice aging is still unclear. Therefore, it is of great theoretical significance and potential application prospects to discuss rice aging in depth. Rice aging is a very complicated process. The storage of rice inevitably leads to its aging effect. As a result, the enzymatic activity of rice decreased and respiratory ability also decreases (Faruq et al., 2015).

Although, understanding the biochemical changes during storage is important in the evaluation of cooking and eating quality. Overall physicochemical and physiological changes are the outcome of biochemical changes which occurs during ageing. Rice lipids are usually stable in the intact spherosomes in the cell. However, when the lipid membrane is destroyed by phospholipase, physical injury, natural ageing or high temperature, lipid (triacylglycerides) hydrolysis is initiated by the action of lipases. The product of this hydrolysis forms free fatty acids (FFA) and carbonyls (Srikaeo and Panya; 2013). During this process, a change in pH can be observed which changes from neutral to slightly acidic. There are many factors affecting the aging of rice, including the changes in the main nutrients (such as protein, starch and lipids), the relative content of amylose and amylopectin, the changes of debranching enzymes, carbonyl compounds, sulfhydryl and carbonic acid, etc. External factors, including storage temperature, storage time, humidity, and their interaction, were important factors affecting rice aging (Peng et al., 2019).

Overall, the studies show that ageing process has a positive influence on major cooking quality parameters such as kernel expansion, water absorption, alkali spreading value, and gelatinization temperature. Besides this, ageing can improve the quality of rice and its marketability, especially in countries like India where aged rice is preferred over fresh rice (Faruq et al., 2015). However, the ageing of rice increases cooking time compared to that of fresh rice; there is no standard guideline or ingenious technique to differentiate aged rice from freshly harvested rice. However, recently a chemical method-mixed pH-based indicator method is used to identify freshly harvested rice and old rice. In this method, based on the change in color of the mixed pH indicator the age of rice can be identified in milled raw rice. Up to six months of ageing, the specific colour change can be seen, but beyond that, no discernible change can be noted. This suggests that the first six months following harvest are characterized by a rapid biochemical change in rice grain. Hence, in conclusion, ageing is an intricate phenomenon that starts at pre-harvest and lasts until consumption; but is incompletely understood to date.

Changes in grain quality under abiotic stress

Rice quality traits include milling, physical appearance, nutritional value, and cooking and eating quality. The assessment criteria for milling quality generally include brown rice percentage, milled rice percentage, and head rice percentage, which reflects the proportion of entire kernels and broken kernels that are produced during the milling of rough rice. These criteria are closely associated with the market value because broken milled rice fetches less price than entire head milled rice (Koutroubas et al., 2004). The appearance quality of rice is primarily determined by the grain size, translucency, chalky grain percentage, chalky area, and chalky degree. Chalky grains have opaque spots in the endosperm that range in size, either on the dorsal side of the grain (white belly) or in the center (white center). Cooking and eating qualities are primarily specified based on the amylose content, gelatinization temperature, and starch gel consistency. Environmental stresses not only affect milling yield, but they also lead to a significantly elevated proportion of chalky grains which in turn alters starch and cooking quality. Thus abiotic stresses, in particular high temperatures, have a negative effect on various grain quality traits while also reducing sensory attributes. Rice is more susceptible to high temperatures at the flowering stage than it is at the vegetative stage; thus, making the reproductive stage crucial for high-temperature stress. During kernel development, environmental temperature plays a fundamental part in generating unexpected variations in rice grain quality (Jagadish et al., 2010; Cooper et al., 2008). Grain development is accompanied by filling and accumulation of storage substances such as starch, storage protein, and lipids, which ultimately determine the relevant indicators of rice quality. As the most abundant component in rice grain, starch has been proven to be sensitive to elevated temperature. Heat stress (HS) at the grain-filling stage results in poor rice quality, expressed as reduced palatability, undesirable grain appearance, and increased grain chalkiness. Chalky kernels are the most obvious symptoms caused by HS at the grain-filling stage. HS triggers non-uniform filling and impairment of starch biosynthesis, resulting in irregular and smaller starch granules with reduced amylose and amylopectin content resulting in the deposition of loosely packed starch granules, thus increasing chalky kernel formation. Major genes involved in the starch biosynthetic pathway such as *GBSS*, *SBEI*, and *SBEIIb* are also down-regulated in grains exposed to high-temperature stress (Sreenivasulu et al., 2015). Amylose content is lower under HS suggesting that lower activity of amylose synthesis may be involved in chalk formation. In addition, the elevated temperature during grain-filling increased the contents of grain storage proteins, with a significantly increased composition of glutelin and decreased prolamin. Furthermore, the activity of protease gets enhanced under elevated temperatures and further accelerates the protein transformation into soluble nitrogen compounds, which would significantly increase the total amount of amino acids in rice grains. Overall, elevated temperature mainly accelerates the rate of grain-filling and shortens its active duration, resulting in insufficient accumulation of photosynthetic substances in rice grains. Grain quality traits are controlled by many major QTLs, implying that the genetic mechanisms underlying quality traits are complex. More than 600 QTLs related to grain quality have been reported in the Gramene Genome Database (http://www.gramene.org). From the 3000 whole genomes of cultivated rice relatives (3,000 Rice Genomes Project, 2014), genetic and genomic information will be available for mining different alleles related to grain quality traits that are involved in adaptation to different climatic conditions.

E-TIPS FOR DOUBLING FARMERS' INCOME BY 2022

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Introduction

Aiming to boost the Indian agriculture, the Government has set an ambitious goal to double the farmers' income level by the year 2022. To fulfill the aim, a range of approaches and strategies need to be adopted starting from transformation of production-driven as well as market-driven factors and an enabling environment which support farmers in all their endevaours. Current level of Average income of an Indian farmer is about Rs. 6,430 per month (NSSO, 2012-13) with huge disparity among different regions, like farmers of Punjab earned highest income (Rs. 18,060) followed by those in Haryana (Rs. 14,440), Jammu & Kashmir (Rs. 12,685) and Kerala (Rs. 11,890), whereas farmers of Bihar earn the least (Rs. 3,560) per month. Hence, instead of 'one solution fit for all', a mix of strategies will need to be embraced which not only enhance the income to double or nearly double but discourage the level of disparity among different regions of India.

Sources of farmers' income

Among the various sources of farmers' income, share from crop cultivation increased from 46% in 2002-03 to 47% in 2012-13 (Fig. 1). Share of income from livestock increased from 4% to 13%, while the contribution from both non-farm business and wages & salaries declined during this period.

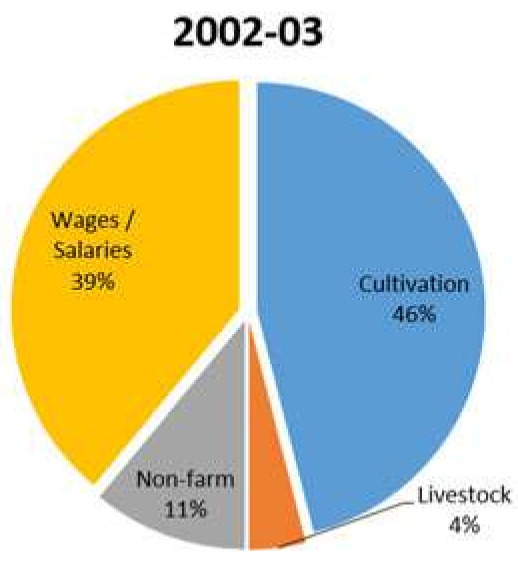

Fig. 1. Contribution of different sources to farmers' income in 2002-03 and 2012-13.

(Source: Farmers' Income in India: Evidence from Secondary Data a Study Submitted to Ministry of Agriculture by Thiagu Ranganathan, IEG, New Delhi)

Growth rate of farmers' income

At the national level, the compound average growth rate (CAGR) of farmers' nominal income was 11.8% between 2002-03 and 2012-13 (Fig. 2). Haryana registered the highest growth (17.5%) and West Bengal the lowest (6.7%). In real income terms, Odisha emerged as the top performer with a CAGR of 8.3%, closely followed by Haryana (8.0%), Rajasthan (7.9%) and Madhya Pradesh (7.3%), as against a national average of 3.5%. Bihar and West Bengal had negative real growth rates in the farmers' income.

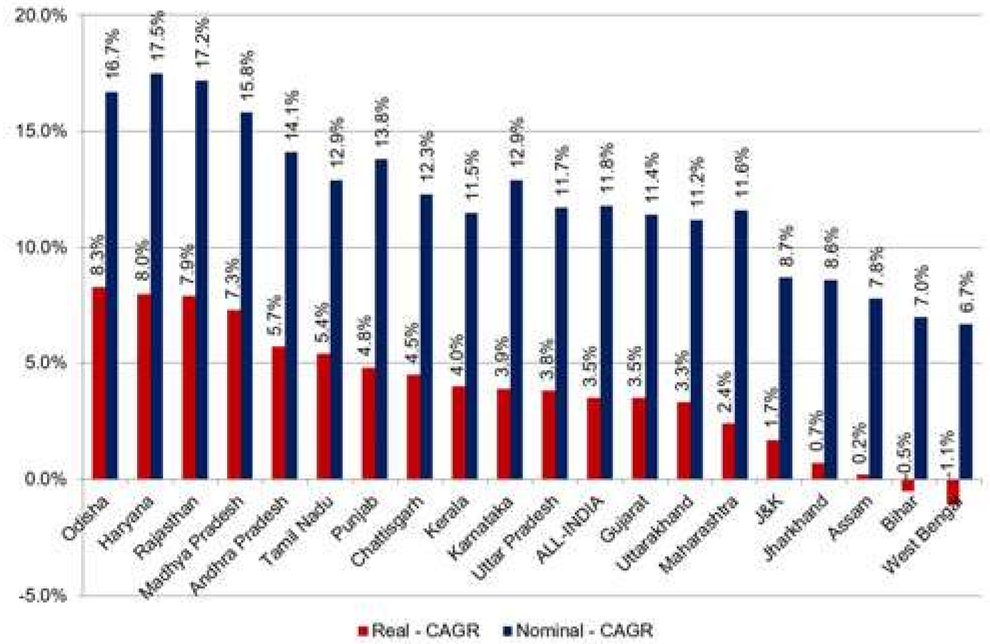

Fig. 2. Compound average growth rate of farmers' income during 2002-03 and 2012-13.
(Source: The Indian Express, July 28, 2016)

The above data corroborates that under a BAU (Business as Usual) scenario, nominal farmer incomes can double almost every six years, whereas doubling of real incomes needs more than 20 years. Clearly, if the aim is to double REAL income by 2022, the effort and resources necessary to achieve it would have to be at least three times that of current BAU-scenario levels (Gulati and Saini, The Indian Express, July 28, 2016).

Disparity in Farmers' Income among the states

There is large disparity existing in annual farm household income of different states (Fig. 3). To analyse the disparity, the states have been divided into four Income Zones as per their annual farm household income (Fig. 4). The national average annual farm household income is Rs. 107780. If the income of the farmers of various states is doubled from their present income, the disparity and gap of income will also be doubled in absolute terms. To address the problem, instead of doubling the farmers' income of every Income Zone equally, the focus should be increasing the farmers' income by different factors in different Income Zones so that overall the countries average farmers' household income would be doubled. The following strategy may be adopted to achieve overall doubling of famers' income at all India level without doubling the gap in the annual farm household income among the Income Zones.

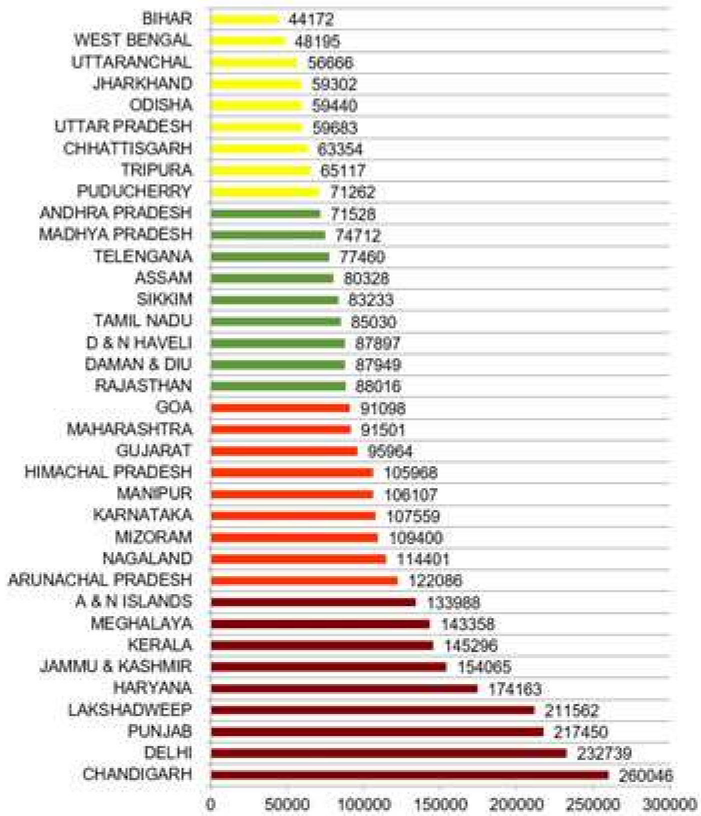

Fig. 3. Annual farm household income in different states of India

Table 1: Distribution of different States and UTs in Income Zones based on their Average annual farm household income

Income Zone 1- Average annual farm household income: **Rs.185852 (100%)** CHANDIGARH DELHI PUNJAB LAKSHADWEEP HARYANA JAMMU & KASHMIR KERALA MEGHALAYA A & N ISLANDS	**Income Zone 2-** Average annual farm household income: Rs.104898 (56.44%) ARUNACHAL PRADESH NAGALAND MIZORAM KARNATAKA MANIPUR HIMACHAL PRADESH GUJARAT MAHARASHTRA GOA
Income Zone 3- Average annual farm household income: Rs.81795 (44.0%) RAJASTHAN DAMAN & DIU D & N HAVELI TAMIL NADU SIKKIM ASSAM TELENGANA MADHYA PRADESH ANDHRA PRADESH	**Income Zone 4-** Average annual farm household income: Rs. 58577 (31.5%) PUDUCHERRY TRIPURA CHHATTISGARH UTTAR PRADESH ODISHA JHARKHAND UTTARANCHAL WEST BENGAL BIHAR

All India Average
Rs.107780

Table 2: FACTOR by Which Average Annual Farm Household income should be increased to minimize disparity among states

Group	Present Average Annual Farm Household Income	FACTOR by Which Average Annual Farm Household income should be increased	Average Annual Farm Household Income by 2022
Income Zone1	Rs.185,852 (100%)	1.25	Rs. 232,315
Income Zone2	Rs.104,898 (56.44%)	2.0	Rs. 209,796
Income Zone3	Rs.81,795 (44.0%)	2.5	Rs. 204,488
Income Zone4	Rs. 58,577 (31.5%)	3.5	Rs. 205,020
All India	Rs.107,780	1.98	Rs. 212,905

Doubling Farmers' Income in Rice-based Systems

Out of 141 million hectare of total cultivated land, India has nearly 44 million hectare land under paddy cultivation, which is maximum for any single crop i.e., 30%. Rice is majorly grown in eastern region to the tune of 50.5% (Table 3). Therefore, if we have to double the farmers' income by 2022, special emphasis has to be given to rice farmers. However, doubling of income of rice farmer is much more challenging than that of any other farmers.

Table 3: Contribution of rice cropping compared to other commodities in different regions of the country.

Region	% Rice in Various	%Rice among Cereals	% Rice among all Crops	% Rice among all Crops, all Crops, Livestock and Fish
Regions				
Eastern Region	50.5	55.5	18.8	12.9
Western Region	5.4	21.0	2.9	2.0
Northern Region	17.2	40.2	21.6	14.2
Southern Region	21.1	68.7	14.2	8.6
NE Region	5.8	94.1	23.2	17.1
All India	100	50.9	14.1	9.5

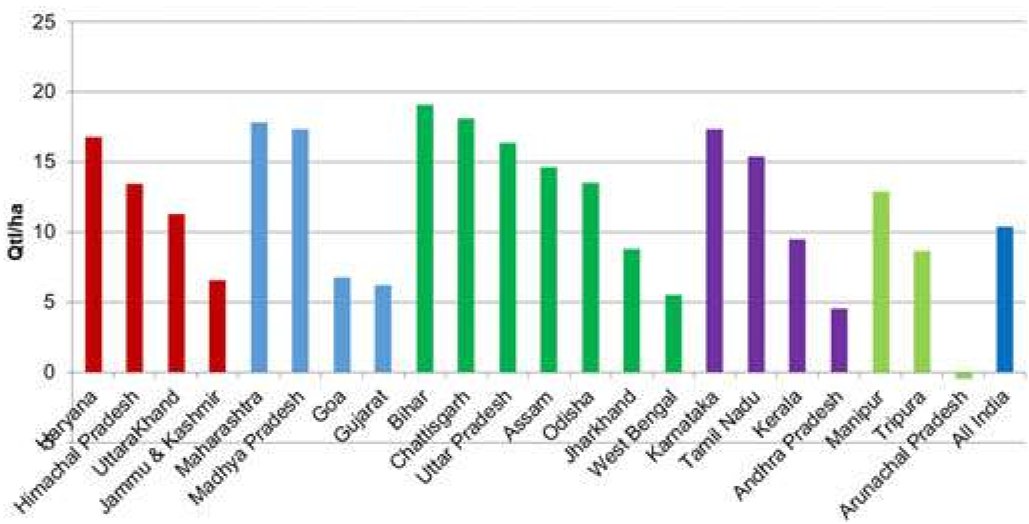

Fig. 4. Yield gap between FLD and average state yield of various states

Table 4 Recommendations on E-TIPS –Economic, Technological, Infrastructural/Information, Political/ Policy and Social factors that will enhance annaul average annual farm household income

	All Zones	Income Zone1 Increase by 1.25 times	Income Zone2 Increase by 2.0 times	Income Zone3 Increase by 2.5 times	Income Zone4 Increase by 3.5 times
States E-TIPS Factors	All States and UT	Chandigarh, Delhi, Punjab, Lakshadweep, Haryana, Jammu & Kashmir, Kerala, Meghalaya and A & N Islands	Arunachal Pradesh, Nagaland, Mizoram, Karnataka, Manipur, Himachal Pradesh, Gujarat, Maharashtra and Goa	Rajasthan, Daman & Diu, D & N Haveli, Tamil Nadu, Sikkim, Assam, Telengana, Madhya Pradesh and Andhra Pradesh	Puducherry, Tripura, Chhattisgarh, Uttar Pradesh, Odisha, Jharkhand, Uttaranchal, West Bengal and Bihar
Economic	- Subsidy on solar energy may be increased to encourage farmers. - Cover almost all farmers under crop insurance scheme. - Integrating all central and state subsidies in agriculture	-Setting up Special Agricultural Export Zones	-Setting up Special Agricultural Export Zones -Creating crop-value chain	-In addition to MSP special bonus should be provided to farmers of this Income Zone. -Creating crop-value chain	- In addition to MSP special bonus should be provided to farmers of this Income Zone. -Creating crop-value chain
Technological	-Linking of all weather stations to provide location specific weather information. -Soil health card programme to be given further impetus. -Bridging the gaps between achievable (FLD) and actual yields of crops -Popularizing insect-pest resistance varieties of all crops.	-Precision Agriculture in 1st Green Revolution states -Organic farming in NE states and hill states -Diversified Integrated Farming System for sustainability	-Popularizing Hybrid, Doubled Haploid and New Generation Plant seed production. -Organic farming in NE states and hill states -Diversified Integrated Farming System for sustainability	-Popularizing Hybrid, Doubled Haploid and New Generation Plant seed production. -Special emphasis on Animal husbandry for landless and marginal farmers. -Diversified Integrated Farming System for sustainability	-Popularizing Hybrid, Doubled Haploid and New Generation Plant seed production. -Special emphasis on Animal husbandry for landless and marginal farmers. -Organic farming in NE states and hill states -Diversified Integrated Farming System for sustainability

Table 4 contd...

Infrastructural/ Information	-Setting up Agribusiness Incubation (ABI) Centres at District level in KVKs -National level information system on Soil health. -Setting up National Level export information system. -Setting up e-Surveillance monitoring system for insect & pest	-Expert system for Basmati rice	-Popularizing Rice Xpert, Rice Crop manager and Rice Doctor -A comprehensive production, preserving, value addition, storage processing, transportation and marketing system -Further emphasis for improving irrigation facility. -Expert system for rice	-Popularizing Rice Xpert, Rice Crop manager and Rice Doctor -A comprehensive production, preserving, value addition, storage processing, transportation and marketing system -Special budget for water conservation or watershed development -Double the number of KVKs	-Popularizing Rice Xpert, Rice Crop manager and Rice Doctor -A comprehensive production, preserving, value addition, storage processing, transportation and marketing system -Improving irrigation facility -Double the number of KVKs
Political / Policy	-Formation of Crop Planning Department at national and state level. -Policy implementation for research on GM rice to reduce cost of cultivation. -Setting up more organic food certification agencies -Policy for setting up of FPO for block level seed production with subsidy.	-Policy to restrict cultivation of water intensive crops in 1st Green Revolution region. -Promotion policy for high protein, high Zn and scented rice in non 1st Green Revolution region -Land consolidation, community farming, cooperative farming for farm mechanization benefits in non 1st Green Revolution region	-Promotion policy for high protein, high Zn and scented rice. -Promotion policy for ancillary activities like poultry, beekeeping and fisheries -Land consolidation, community farming, cooperative farming for farm mechanization benefits.	-Promotion policy for high protein, high Zn and scented rice. -Promotion policy for ancillary activities like poultry, beekeeping and fisheries -Land consolidation, community farming, cooperative farming for farm mechanization benefits.	-Promotional policy for high protein and high Zn rice in public distribution system (PDS) and Mid-day meal schemes -Promotional policy for scented rice. -Promotion policy for ancillary activities like poultry, beekeeping and fisheries -Land consolidation, community farming, cooperative farming for farm mechanization benefits.
Social	-Forming comprehensive framework for community farming / corporate farming. -Online marketing of agricultural produce. -Nationwide multilevel training on Hybrid, Doubled Haploid and NGP for its popularization.	-Land consolidation, community farming, cooperative farming for farm mechanization benefits in non 1st Green Revolution region	-Land consolidation, community farming, cooperative farming for farm mechanization benefits.	-Land consolidation, community farming, cooperative farming for farm mechanization benefits.	-Land consolidation, community farming, cooperative farming for farm mechanization benefits

Further, region-wise analysis of yield gap between FLD and average state yield shows that most of the eastern states have larger yield gap as compared to other regions. Out of 11 states which has yield gap of more than 1 t/ha, five belongs to eastern region. Eastern region accounts for 25.94 m ha (61.16%) area under rice. Therefore, if technological intervention is intensified in Eastern region to achieve FLD level of rice production then this region can produce 35.59 m t additional rice. On an average the increment in production per hectare would be 1.37 t which will result into Rs. 20,139 additional income per hectare to farmers which accounts for 68.5% increase in farmer’s income.

Conclusion

The vision of the Prime Minister is achievable, if Niti Ayog and Ministry of Agriculture constitutes a Task Force having representation from ministries concerned. Agriculture being state subject, it is utmost necessary that a Coordination Committee may also be constituted involving state governments for better implementation of the recommendations. The E-TIPS (Economic, Technological, Infrastructural/Information, Political/Policy and Social) can be relooked for every state separately and emphasis can be given to weak areas. However, the doubling of farmers' income by 2022 should come with minimizing the regional disparity with respect to farmers' total household income.

Second Indian Rice Congress

on

TRANSFORMING RICE RESEARCH: RECENT SCIENTIFIC DEVELOPMENTS AND GLOBAL FOOD CRISIS

Date: February 11-14, 2023

Venue: ICAR-National Rice Research Institute, Cuttack-753006

Local Organising Committee (LOC)

Chairperson: Dr A K Nayak, Director, ICAR-NRRI, Cuttack
Co-Chairperson: Dr (Mrs) A Poonam & Dr (Mrs) Lipi Das
Member Secretary: Dr Sanjoy Saha

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Invitation, Reception and Registration Committee Chairperson: Dr Annie Poonam Co-Chairperson: Dr S Munda Convener: Dr Nabaneeta Basak	Dr D Bhaduri Dr S Sarkar Dr P Karthikeyan Dr P Golive Dr B Gayatri	Mr Narayan Mahavoi Dr Sushma M Awaji Dr J P Bisen Mrs Baijayanti Nayak Mrs Chandmani Tudu Mrs R Swain	Finalisation of Invitation cards; Printing, invitation and reception of dignitaries; Registration, arrangement of kits and distribution
Hall Management Committee Chairperson: Dr M J. Baig Co-Chairperson: Dr R Tripathi Convener: Dr N Jambulkar	Dr. T Adak Dr M Chakraborti Dr J L Katara Dr Supriya Priyadarshani Mr P Maharana Mr Susanta Mohapatra	Mr Sunil Sinha Mrs Sandhya Rani Dalal Mr Santosh Sethi Mr Srinivas Panda Mr J Sai Anand Mr Bhagawan Behera	Arrangement of public address system, visual aids; technical sessions; lamps, standby generators along with operators; Photography, posters, banners, Certificate and memento, etc.
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Site Tour/Field Visit Committee Chairperson: Dr S K Dash Co-Chairperson: Dr Md Shahid Convener: Dr Dibyendu Chatterjee	Dr N N Jambulkar Mr Prahallad Maharana Mr Dharmendra Baral	Mr Parimal Behera Mr Bidyasagar Mondal Mr Jitendra Senapati	Arrangement for site tour/field visits.
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Finance and Accounts Committee Chairperson: Dr S Samantaray Co-Chairperson: Dr P Sanghamitra Convener: Dr R L Verma	Dr B C Patra Dr G P Pandi Dr S D Mohapatra	Dr R L Verma Dr T Adak Mr Rishi Kant Singh	Fixation of Tariffs, collection of funds; Visits/reminders to Prospective clients; Contact with organisations for sponsoring.
Side Events Committee Chairperson: Dr Lipi Das Co-Chairperson: Dr K Chakraborty Convener: Dr Sudipta Paul	Dr Rahul Tripathi Dr J L Katara Dr Totan Adak	Dr K Chattopadhyay Mr Jeevan B Dr N Basak	Contacting CGIAR institutes in and around Bhubaneswar, fixing the date, venue by coordinating with the hall management committee.

S. S. 09/12/22
Organizing Secretary,
2nd IRC 2023

09/12/22
Director, ICAR-NRRI, &
Chairman, LOC, 2nd IRC 2023


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