Research Bulletin No. 33
April 2021

AEROBIC DRY DIRECT SEEDED RICE: A SYSTEM OF RICE CULTIVATION FOR WATER SHORTFALL IRRIGATED AND LOWLAND AREAS

A. Anandan, S.K. Pradhan, Siddharth Panda,
S.K. Dash, P. Panneerselvam, J. Meher and B.C. Patra

Crop Improvement Division
ICAR-National Rice Research Institute
Cuttack–753 006, Odisha, India

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

Phone: +91-671-2367757; **EPBX:** +91-671-2367768-783
Fax: +91-671-2367663
Email: director.nrri@icar.gov.in | crrictc@nic.in
directorcrricuttack@gmail.com | URL: http://www.icar-nrri.in

AEROBIC DRY DIRECT SEEDED RICE: A SYSTEM OF RICE CULTIVATION FOR WATER SHORTFALL IRRIGATED AND LOWLAND AREAS

A. Anandan, S.K. Pradhan, Siddharth Panda,
S.K. Dash, P. Panneerselvam, J. Meher and B.C. Patra

Crop Improvement Division
ICAR-National Rice Research Institute
Cuttack–753 006, Odisha, India

Citation
A.Anandan, S.K. Pradhan, Siddharth Panda, S.K. Dash, P. Panneerselvam, J.Meher and B.C. Patra (2021). Aerobic dry direct seeded rice: a system of rice cultivation for water shortfall irrigated and lowland areas. NRRI Research Bulletin No. 33, ICAR-National Rice Research Institute, Cuttack-753006, Odisha, India, pp.32

Published by
Director
ICAR-National Rice Research Institute,
Cuttack-753006, Odisha, India

April 2021

Disclaimer
ICAR-National Rice Research Institute is not liable for any loss arising due to improper interpretation of the scientific information provided in the research bulletin.

Printed at:
Print-Tech Offset Pvt. Ltd.
Bhubaneswar

PREFACE

The earth's climate is enduring drastic changes now more than ever before affecting the abundantly available resource; water. The realization of the fact that freshwater is limited and must be conserved, judiciously used to suffice our need has led to many changes in agricultural practices. Developing unique varieties bred to perform under aerobic conditions is such a change that has to be adopted by the farming community. Cultivation under aerobic conditions not only saves a large amount of water but also checks the greenhouse gas (methane) emission that is predominant in the transplanted system of paddy cultivation. Furthermore, the areas with low rainfall and the absence of irrigation facilities can also utilize the aerobic system of rice cultivation. Research activities in this direction have only started in the last two decades but the developments have been interesting and productive.

ICAR - National Rice Research Institute (ICAR-NRRI), Cuttack, Odisha started its aerobic rice breeding program in 2007 and since then has released 10 varieties for cultivation under aerobic upland ecosystems. Each of these varieties has unique features, is adapted to low moisture conditions, and has been recommended for cultivation under their suitable agro-ecological zones. They have been quite popular and yield at par with the transplanted rice varieties under field conditions. This bulletin offers a brief insight into the status of aerobic rice research and a concise presentation of all the aerobic varieties released from ICAR-NRRI.

We take this opportunity to acknowledge our gratefulness to all the scientists of ICAR-NRRI for investing in aerobic rice research and extending the information about their varieties mentioned in this bulletin, without their cooperation this compilation could not be possible. We sincerely believe this research bulletin provides insights to the rice scientific community and be useful in chalking out future breeding programs with newer objectives and also the farmers in providing a comprehensive idea about the basis of aerobic rice and the existing varieties.

CONTENTS

Introduction

Rice (*Oryza sativa* L.) serves as the prime source of carbohydrate/energy for more than half of the world's population. It is the second most cultivated cereal crop in the world after wheat, intensively practiced across varied topographies and climatic conditions. Exposure to a variety of climatic conditions has made rice to be adapt to the respective climatic scenarios. The rice cultivated area in Asia alone has 89%, and 90% of them are produced and consumed here (http://www.faost at.fao.org). In India, rice is cultivated in an area of 44 million hectares and contributes to a great extent to national food security. Additionally, Asia alone consumes 90% of the freshwater diverted to agriculture in the whole world. This will soon be a burden on the ecological balance in many areas leading to water scarcity.

Most of this cultivated rice is under a flooded ecosystem, three-quarters of the produce in Asia is from transplanted rice cultivation. Estimates suggest that around 3000-5000 liters of water are expended to produce 1 kg of rice through this system of cultivation (Anandan et al., 2015). It is predicted that by 2025, there will be a reduction of 10-15% of water available for agriculture. On the contrary, the cultivable area in Asia especially in India is decreasing due to an increase in demand for non-agricultural use. The increasing scarcity of water and the high demand in the traditional flooded system of rice cultivation compels one to think of a better alternative. The solution is to adopt a cultivation system requiring a lower amount of water and varieties that are apt at surviving and yielding high under low water availability. The aerobic system of rice cultivation could come to the rescue at this juncture.

Aerobic rice cultivation is a production management system wherein rice is grown in unsaturated and unpuddled field conditions. The soils are kept aerobic unlike in a flooded system where the soil due to saturated water, enters into a reduced anaerobic condition. The aerobic or the direct-seeded rice (DSR) system of cultivation has been in practice for centuries by farmers but the productivity has been lower than the transplanted condition, because of adverse environmental conditions and the inability of the native landraces to give higher yields. International Rice Research Institute (IRRI) used the term 'aerobic rice' for the first time to refer to DSR mode of cultivation under aerobic conditions of soil same as an upland crop with adequate inputs (fertilizers) and supplementary irrigation when rainfall is insufficient focusing mainly on the water crisis. This approach saves water significantly, for instance in China aerobic rice system of cultivation used 55-56% less water when compared to the traditional transplanted system of cultivation with water productivity of

1.6-1.9 times higher (Priyanka et al., 2012). Aerobic rice could be successfully cultivated with 600 to 700 mm of total water in summer and entirely using rain water in the wet season with even distribution of rainfall (Hittalmani, 2007). This difference in water requirement is due to the absence of puddling, reduction in seepage, percolation, and evaporation losses from the ponded water.

Further, it is important to note that the use of less water and avoiding standing water reduces the methane emissions from the rice fields. Thus, shifting from transplanted rice systems to aerobic conditions would also help in lowering greenhouse gas emissions and the approach proves to be more ecofriendly. Besides, the labour requirement is also reduced in DSR under aerobic conditions thus lowering the total production cost. Unlike in a traditional transplanted system, where rice is sown in the nursery, aerobic rice cultivation is being sown directly in the non puddled field in the same way as any other cereal crop like maize or wheat. Apart from lesser water availability, some other characteristics in this system include soil mechanical impedance, increased oxygen supply to the roots, accumulation of ethylene and carbon dioxide in root tissue, and availability of nitrogen in oxidized nitrate form instead of the reduced ammonium form and different scenario of soil fauna. However, this system needs some special care and operations to be taken care of like seed treatment, plant, soil, water, weed, and nutrient management. In the traditional method of rice cultivation, the crop gets a head start of 15 days as compared to weeds, the standing water also suppresses the weed growth. But in aerobic conditions, weed growth is one of the major problems. Next is nutrient management, due to dry aerobic conditions of the soil and lack of moisture, the plants are devoid of nutrients. This reflects eventually in the grain filling and grain yield of the rice plant. Micronutrients like Fe and Mn become the limiting factor, it is also advised to increase the dose of nitrogen in aerobic conditions compared to transplanted conditions. Addressing the weed competition, the adoption of weed-competitive cultivars would be a better alternative rather than utilizing chemical herbicides. This would decrease environmental pollution and the development of herbicide-resistant biotypes by reducing herbicide application.

Therefore, varieties for the aerobic system have to be specially bred for these growth conditions that can yield at par with transplanted rice. Traditionally, cultivated upland cultivars are tall, bear lesser tillers, and produce stable but yields low. The plant height leads to lodging under high fertility thus has a low harvest index. Thus, the breeding program involved in the development of aerobic rice should focus on the redesign in the plant architecture to survive under low moisture, bear more grains, and at the same time being more responsive to fertilizers. In the context of plant architecture, aerobic rice should possess a robust root system with long thick, and deep roots, medium plant height with upright leaves, improved water and nutrient use efficiency and increased harvest index. With reference to abiotic stresses, low moisture may lead to water stress and sometimes drought condition. The plant can either escape the drought by completing its life cycle before the onset of drought or be tolerant and face the drought spell with a minimum penalty on yield. For example, Jaldi Dhan 13, a rice variety from West Bengal, India has been released for drought-prone areas where the plant escapes the drought (Prasad, 2011). Most of the varieties developed so far for aerobic conditions are from the crosses between traditional upland cultivars (that can withstand low moisture) and improved lowland cultivars (with high yield). These cultivars yield lower in flooded conditions in comparison to lowland cultivars but give a better yield than varieties of other ecosystems under aerobic conditions.

The direct-seeded rice technique is being practiced successfully across several countries like the U.S.A., China, Sri Lanka, the Philippines, Brazil, Malaysia, India, Bangladesh, Cambodia, and some Caribbean countries. In India, the exploitation of groundwater has increased by more than 100-fold since 1950 resulting in lowering the water table gradually. Aerobic rice can be grown on water-deficit-prone bunded lands, usually upper fields or fields with light-textured soil which does not accumulate standing water for a long period. Thus, the crops remain aerobic for most of the growing season even though they can experience frequent moisture stress, particularly during and after the reproductive phase. Such land topographies are commonly found in the Eastern parts of India like Jharkhand (Chotanagpur Plateau), Chhattisgarh (Bastar Plateau), Odisha (western parts), and Bihar where the average yield is less than 2 t ha^{-1} and water-deficit risk is very high (Anandan et al., 2015; Tomar, 2002). These lands require varieties with durations ranging from 95 to 110 days. All of these areas require short-duration, photoperiod-insensitive varieties combining tolerance of water deficit with high yield potential. Thus, to achieve high yield under aerobic soil, new varieties that are high-yielding, nutrient-responsive, drought-tolerant, and weed-competitive are required.

History of ADSR: The traditional direct seeding system

Direct seeding was the usual practice of rice crop establishment before the introduction of semi-dwarf varieties, for rainfed shallow lowlands in eastern regions of India like Chhattisgarh, Odisha, Bihar, and Jharkhand. In this system, rice is broadcasted using a higher seed rate before the onset of monsoon, and the young crops are cross-plowed after 25 to 35 days of germination with a light country plow, when about 15 cm of rainwater accumulates in the crop field to reduce weed pressure, increase space between plants by thinning and soil disturbance in the root zone, which stimulates better crop growth. This technique 'beushening' or 'biasi' was commonly followed throughout the rainfed regions of eastern India (Singh et al., 1994). Traditional tall cultivars are preferred for beushening, which do not respond to higher doses of fertilizer application.

A shift in the rice cultivation system from transplanting seedlings and then back to direct seeding has been a phenomenon occurring in many rice-growing nations, especially in Asia. This is due to the rising production cost, reduction in labour and water availability. And this threat is likely to worsen in near future. These constraints threaten the sustainability of transplanted ecosystems for rice cultivation and it may not be feasible for farmers to flood their fields while enduring water shortages. At the same time, several advantages and solutions that the aerobic system of rice cultivation offers cannot be overlooked. International Rice Research Institute (IRRI), Philippines took a bold initiative to breed rice varieties for the aerobic dry direct-seeded condition in collaboration with South Asian partners *viz*., Bangladesh, India, Nepal, Philippines, and Pakistan under the ADB-supported project 'Developing and disseminating water-saving rice technologies in South Asia' (ADB RETA 6276) (Pradhan et al., 2016). This project places strong groundwork in support of developing rice varieties for aerobic systems and subsequently, several high-yielding varieties were released for the benefit of farmers across India.

Varietal development Programme for Aerobic Rice

Aerobic Rice Breeding: IRRI-Philippines

Several aerobic rice varieties have been developed in the last decade by the scientists of IRRI, the Philippines with a yield potential of 3.4 to 4.3 t ha^{-1} under moderate fertilization and non-stressed aerobic soil conditions, and 1.2 to 2.0 t ha^{-1} under severe drought stress at the reproductive stage (Zhao et al 2010). The variety Apo was the first-generation aerobic rice variety developed with a yield advantage of 10% to 36% under the non-stressed condition and by 12% to 91% under stress. They performed well under drought than upland-adapted varieties. The second generation elite aerobic rice varieties were vigorous and had a medium plant height (100 to 118 cm under non-stressed conditions), early flowering (69 to 79 days under non-stress), short to medium duration (99 to 113 days under non-stress), and relatively high harvest index (> 0.30 under non-stress). Some of the best lines such as IR74371-54-1-1 (Philippines)

IR74371-70-1-1 (India); IR74371-46-1-1, IR74371-54-1-1, IR74371-70-1-1, IR79913-B-176-B-4, and IR81449-B-B-109-3 (Nepal); and IR79971-B-149-2-3 (Bangladesh) were identified in several countries, with a yield of 4-5 t ha^{-1} under favorable aerobic soil conditions or alternate wetting and drying (AWD) (Bangladesh) under ADB RETA 6276 project.

Aerobic Rice Breeding in India

To keep up the pace with the changing scenario, ICAR-National Rice Research Institute (NRRI), Cuttack realized the importance and has played a significant role in aerobic rice varietal development as well as their popularization in India. A systematic breeding program for aerobic rice was initiated in 2007. The source material for the breeding programs was primarily the first-generation aerobic rice germplasm and other exotic lines that were used as donors for various ideal aerobic traits. These lines were then hybridized with existing elite high-yielding varieties under the ADB-funded project. Subsequently, the hybridized lines were selected and fixed using a pedigree breeding scheme. Apart from generating new crosses, NRRI, Cuttack was also involved in the selection of superior and suitable lines from segregating populations and already released varieties. For instance, the variety Apo, already released at IRRI, was evaluated for Indian conditions and was released as CR Dhan 200 in Odisha during 2012.

At the same time another variety Anagha, derived from a cross between Budda (a local *aus* accession) and IR64, a mega-variety from IRRI, proved to be very successful in surviving drought and at the same time giving yield as high as 5.0 t/ha in farmers' field (Shashidhar, 2012). These developments and their promising outcomes paved the way for further research in this direction. Several varieties have been developed in India in the last decade, including two hybrids, a complete list of which is furnished in Table 1.

Table 1: List of varieties and hybrids released for aerobic conditions in India

S. No	Name of the variety	Year of release	Duration (days)	Yield (t/ha)	Released by CVRC /SVRC
1	MAS 946-1 (Sharada)	2007	130	5.0 - 5.5	CVRC
2	MAS 26 (Onasiri)	2008	125	4.0 – 5.0	CVRC
3	ARB 6 (Anagha)	2009	115	4.0	SVRC

4	Indira Barani Dhan1	2010	115	4.0 - 4.5	SVRC
5	CR Dhan 200	2012	115-120	4.5	SVRC
6	CR Dhan 201	2014	118	3.8-4.0	CVRC
7	CR Dhan 202	2014	115	3.7-4.5	CVRC
8	CR Dhan 203	2014	110	4.05	SVRC
9	CR Dhan 204	2019	120	4.2	SVRC
10	CR Dhan 205	2019	110	3.7-4.5	CVRC
11	CR Dhan 206	2014	115	3.95	SVRC
12	CR Dhan 207	2016	110-115	3.7	SVRC
13	CR Dhan 209	2016	112-115	4.0	SVRC
14	CR Dhan 210	2019	110-115	4.75	SVRC
15	Indira Aerobic 1	2014	118	4.0 - 4.5	SVRC
16	Swarna Shreya	2016	115	4.55	CVRC
17	Sabour Ardhjal	2016	120	4.5 - 5.5	SVRC
18	DRR Dhan 41	2016	122	4.0	CVRC
19	KMP-175	2017	120	4.0 – 5.0	SVRC
20	Rajendra Neelam	2017	115	4.0	SVRC
21	Swarna Shakti Dhan	2019	115-120	4.5-5.0	CVRC
22	NICRA aerobic dhan 1	2019	115-120	4.0-4.5	CVRC
23	GK-5022	2017	123	4.2	First aerobic hybrid
24	KPH 272	2017	120	4.0	Aerobic hybrid

CR DHAN 200 (Pyari) (CR 2624-IR 55423-01)

The first aerobic variety from NRRI, Cuttack; CR Dhan 200 was developed from the segregating materials of cross UPL RI 5/ IR 12979-24-1(Brown). The variety is suitable for water limiting/ aerobic upland ecosystems in Odisha. The genotype is highly responsive to fertilizer application.

Name	CR Dhan 200 (Pyari)
Year of Release	2012 (State Variety Release Committee, Odisha)
Duration	115-120 days
Average Yield	4.0 t/ha
Plant type	Semi-dwarf (95-100 cm)
Average number of tillers	7-10
Average number of Panicles	272 per m^2
Grain type	Short bold
Test weight	24 g
Quality traits	No grain chalkiness, Intermediate alkali spreading value (4), Intermediate amylose content (21.8%), L/B ratio of 2.33, High milling recovery (68%)
Disease and Pest tolerance	Moderately resistant to leaf blast, neck blast, brown spot, stem borer dead heart and white ear damage, whorl maggot biotype 6 and leaf folder attack

Fig.1(a): Field view of CR Dhan 200 (Pyari)

Fig.1(b): Grains, panicles, and kernels of CR Dhan 200

CR DHAN 201 (CR 2721-81-3-IR 83380-B-B-124-1):

The variety CR Dhan 201 was developed from the breeding materials of a cross between IR72022-46-2-3-2 and IRRI 105. The areas suitable for adoption are aerobic areas of Chhattisgarh and Bihar with high grain yield in a normal season and resilient to changing climatic conditions of uneven rain distribution. This genotype has a high response to fertilizer.

Name	CR Dhan 201
Year of Release	2014 (Central Sub-Committee on Crop Standards, Notification, and Release of Varieties, India)
Duration	110-115 days
Average Yield	3.8 t/ha
Plant type	Semi-dwarf (95-100 cm), lodging resistance
Average number of tillers	7 - 10
Average number of Panicles	305 per m^2, compact panicle
Grain type	Long slender
Test weight	25.5 g

Quality traits	No grain chalkiness, Low alkali spreading value (7.0), Intermediate amylose content (23.26%), L/B ratio of 3.19, High milling recovery (67%)
Disease and Pest tolerance	Moderately resistant to leaf blast, sheath rot, stem borer (both dead heart and white ear heads), leaf folder, whorl maggot, and rice thrips attack.

Fig.2(a): Field view of CR Dhan 201

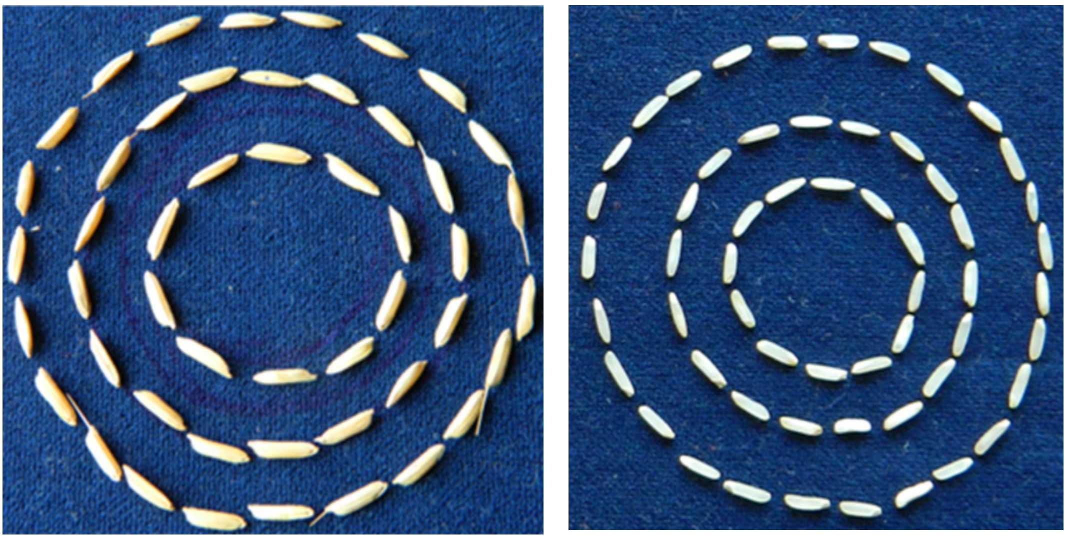

Fig.2(b): Grains and kernels of CR Dhan 201

CR DHAN 202 (CR 2715-13-IR84899-B-154)

Variety CR Dhan 202 is derived from a cross between IRRI 148 and IR78877-208-B-1-1. It is recommended for cultivation in the states of Jharkhand and Odisha under the aerobic system. It has shown a high response to fertilizer.

Name	CR Dhan 202
Year of Release	2014 (Central Sub-Committee on Crop Standards, Notification, and Release of Varieties, India)
Duration	110 days
Average Yield	3.7 t/ha
Plant type	Semi-dwarf (100-105 cm), lodging resistance
Average number of tillers	7-10
Average number of Panicles	285 per m^2
Grain type	Long bold
Test weight	21.3 g
Quality traits	No grain chalkiness, Low alkali spreading value (7.0), Intermediate amylose content (22.99%), L/B ratio of 2.33, milling recovery (68.5%)
Disease and Pest tolerance	Moderately resistant to leaf blast, brown spot, sheath rot, stem borer (both dead heart and white ear heads), leaf folder, whorl maggot, and rice thrips.

Fig.3(a): Field view of CR Dhan 202

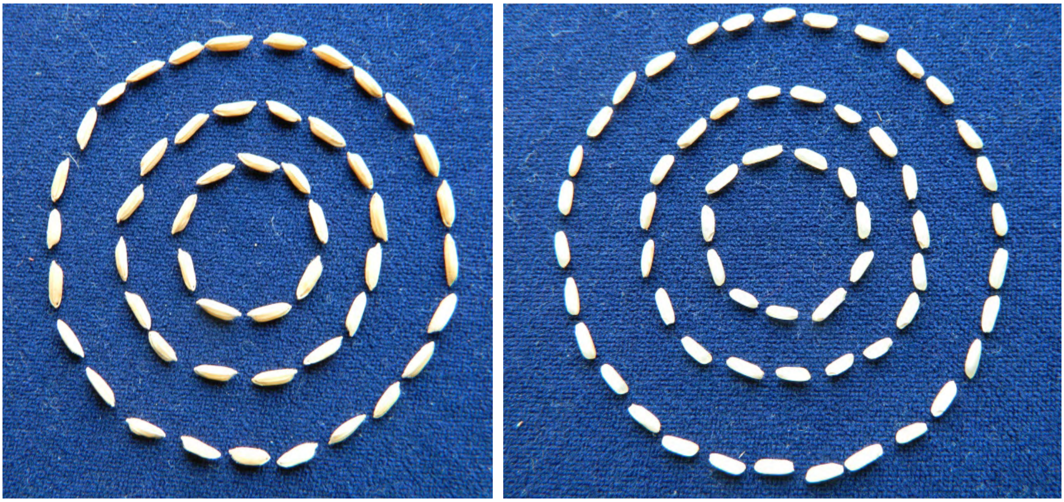

Fig.3(b): Grains (left) and kernels (right) of CR Dhan 202

CR DHAN 203 (Sachala) (CR2717-10-IR84899-B-185)

Variety CR Dhan 203 is derived from a cross between IR78877-208-B-1-1 and IRRI 132. It is suitable for cultivation in the states of Odisha, Maharashtra, and Madhya Pradesh under aerobic/ water limiting system. It was found responsive to a higher dose of fertilizer application.

Name	CR Dhan 203 (Sachala)
Year of Release	2014 (Central Sub-Committee on Crop Standards, Notification, and Release of Varieties, India)
Duration	110-115 days
Average Yield	4.0 t/ha (3.0-6.0 t/ha)
Plant type	Semi-dwarf (100 cm)
Average number of tillers	7-9
Average number of Panicles	225 per m^2
Grain type	Long slender grain
Test weight	24.6 g
Quality traits	Very occasionally chalky, Intermediate alkali spreading value (4), Intermediate amylose content (22.54%), L/B ratio of 3.16, milling recovery (66.85%)
Disease and Pest tolerance	Moderately resistant to leaf blast, brown spot, and sheath rot. It is moderately resistant to stem borer (both dead heart and white ear heads), leaf folder, whorl maggot, and rice thrips.

Fig.4(a): Field view of CR Dhan 203

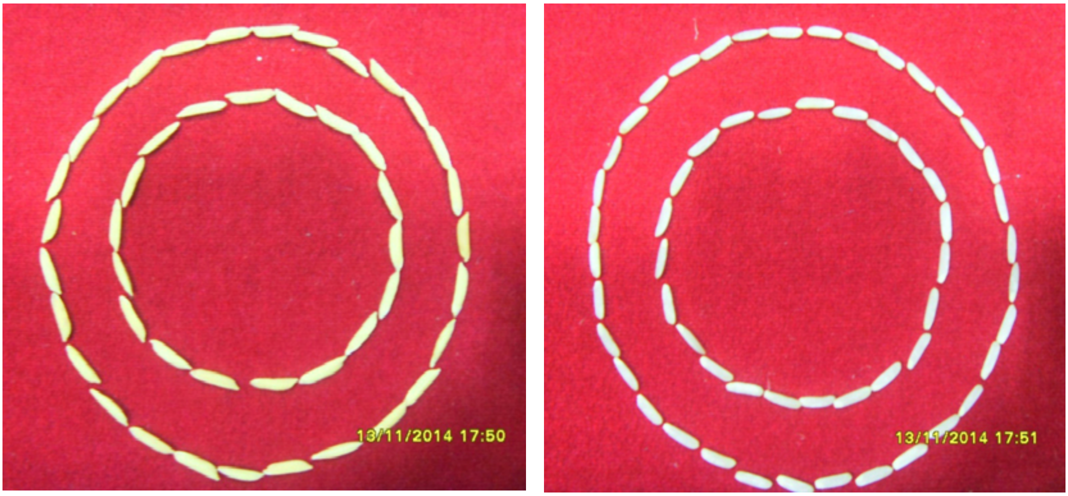

Fig.4 (b): CR Dhan 203 Grains (left) and Kernel (right)

CR DHAN 204 (CR2696-IR83920-B-B-CRA-103-14-1-1-1)

CR Dhan 204 is derived from the segregating lines from a cross between IRRI 76569-259-1-2-1 and CT 6510-24-1-2. It is suitable for cultivation in the states of Jharkhand and Tamil Nadu mid-early aerobic system. It was found responsive to a higher dose of fertilizer application.

Name	CR Dhan 204
Year of Release	2013 (Central Sub-Committee on Crop Standards, Notification, and Release of Varieties, India)
Duration	Semi-dwarf (110-115 days)
Average Yield	3-4.5 t/ha
Plant type	95-100 cm
Average number of tillers	7-10
Average number of Panicles	280 per m^2
Grain type	Medium slender
Test weight	21.3 g

Quality traits	Very occasionally chalky, Low alkali spreading value (7.0), Intermediate amylose content (22.43%), L/B ratio of 2.64, milling recovery 67.7%
Disease and Pest tolerance	Moderately resistant to leaf blast, neck blast, brown spot, and sheath rot. Moderately resistant to stem borer (both dead heart and white ear heads), leaf folder, whorl maggot, case worm, and rice thrips

Fig.5(a): Field view of CR Dhan 204

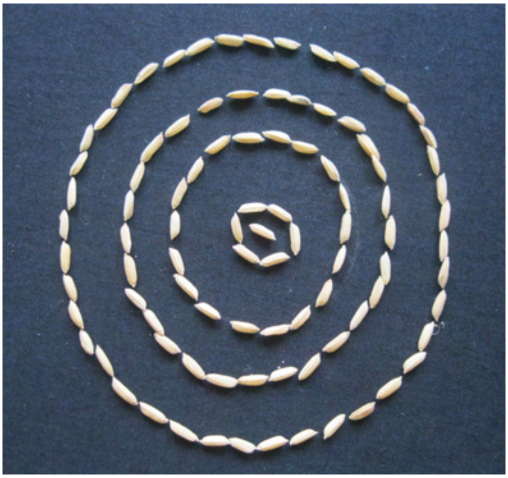
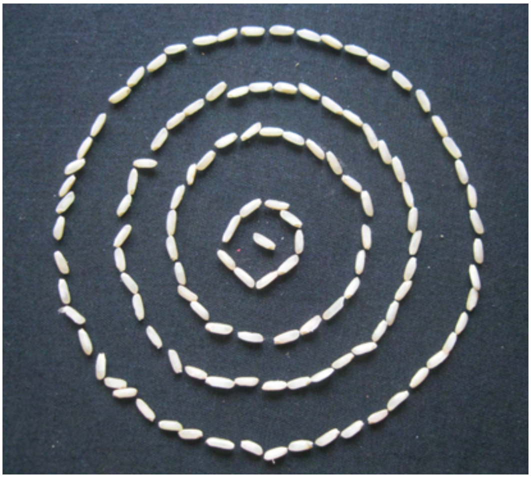

Fig.5(b): Grains (left) and kernels (right) of CR Dhan 204

CR DHAN 205

CR Dhan 205 is derived from the segregating lines from a cross between N22 and Swarna. It is suitable for cultivation in the states of Tamil Nadu, Gujarat, Odisha, Madhya Pradesh, and Punjab under an early aerobic system. It was found responsive to a higher dose of fertilizer application.

Name	CR Dhan 205
Year of Release	2014 (Central Sub-Committee on Crop Standards, Notification, and Release of Varieties, India)
Duration	105-110 days
Average Yield	3.7-4.5 t/ha
Plant type	Semi dwarf (100-105cm)
Average number of tillers	6-9
Average number of Panicles	230-300 per m^2
Grain type	Short Bold
Test weight	24.5 g
Quality traits	Very occasionally grain chalkiness present, low alkali spreading value (6.5) and intermediate amylose content (22.29%), L/B ratio of 2.46, milling recovery 69.9%
Disease and Pest tolerance	Moderately resistant to leaf blast, brown spot, and sheath rot, moderately resistant to stem borer (both dead heart and white ear heads), leaf folder, whorl maggot

Fig.6(a): Field view of CR Dhan 205

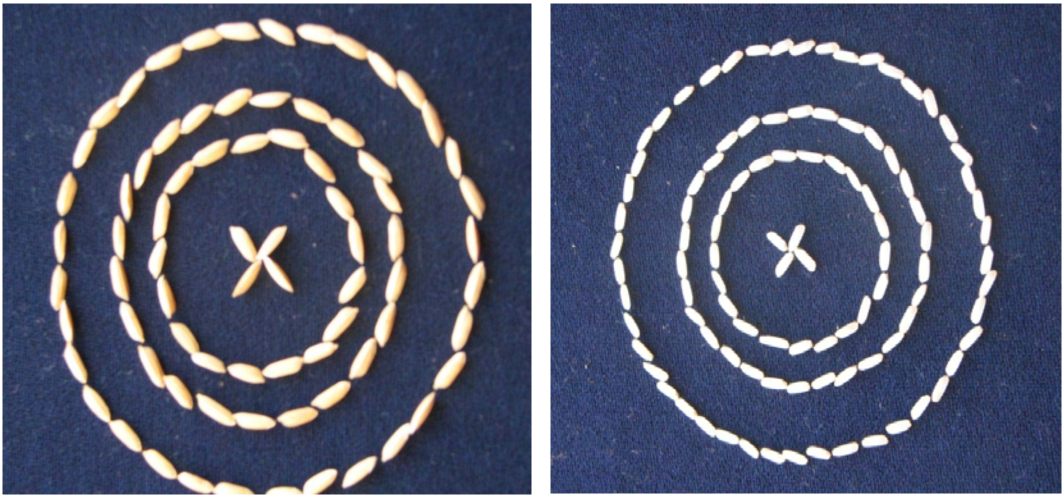

Fig.6(b): Grains (left) and Kernel (right) of CR Dhan 205

CR DHAN 206 (Gopinath) (CR 2996-1-14-29-3-1)

CR Dhan 206 is derived from the segregating lines from a cross between Brahma nakhi and NDR 9930077. It is suitable for cultivation in the state of Odisha under the aerobic system. It is responsive to a higher dose of fertilizer application.

Name	CR Dhan 206 (Gopinath)
Year of Release	2014
Duration	110-115 days
Average Yield	3.95 t/ha
Plant type	Semi-dwarf (97-107 cm)
Average number of tillers	8-10
Average number of Panicles	290-323 per m^2
Grain type	Short Bold
Test weight	22.6 g
Quality traits	High milling recovery (70.8), intermediate amylose content (24.27), intermediate Grain Chalkiness, L/B ratio (2.36), Intermediate alkali spreading value (4)
Disease and Pest tolerance	Moderately resistant to leaf blast, brown spot, sheath rot, moderately resistant to stem borer (both dead heart and white ear heads), leaf folder, and whorl maggots

Fig.7(a): Field view of CR Dhan 206

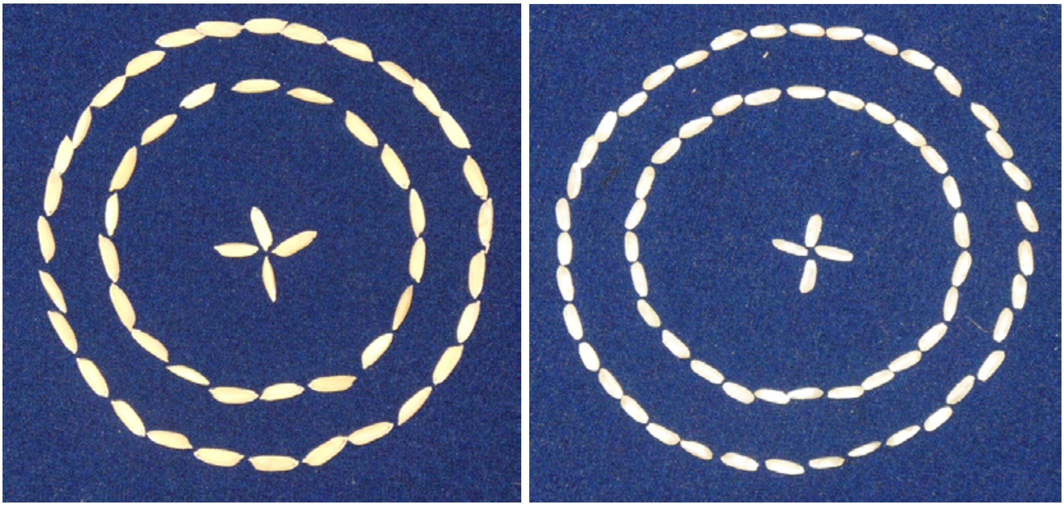

Fig.7(b): Grains (left) and Kernel (right) of CR Dhan 206

CR DHAN 207 (Srimati) (CR3629-1-5)

This elite variety, CR Dhan 207 is derived from the cross between IR71700-247-1-1-2 and IR57514-PMI 5-B-1-2. It is suitable for cultivation in the state of Odisha for the early aerobic system. It has a better response to a higher dose of fertilizer application.

Name	CR Dhan 207 (Srimati)
Year of Release	2016 (State Variety Release Committee, Odisha)
Duration	110-115 days
Average Yield	3.7 t/ha
Plant type	Semi-dwarf (95-100 cm)
Average number of tillers	6-9
Average number of Panicles	240-290 per m^2
Grain type	Medium slender
Test weight	24 g

Quality traits	High milling recovery (69.5%), very occasionally grain chalkiness present, 3.5 alkali spreading value and intermediate amylose content (22.62), L/B ratio 2.62
Disease and Pest tolerance	Moderately resistant to leaf blast, neck blast, brown spot, and sheath rot. It is moderately resistant to stem borer (both dead heart and white ear heads), leaf folder, green leaf hopper, and gall midge biotype 1and 4.

Fig.8(a): Field view of CR Dhan 207

Fig.8(b): Grains (left) and Kernel (right) of CR Dhan 207

CR DHAN 209 (Priya)

The elite line CR Dhan 209 was developed from the breeding materials of cross IR72022-46-2-3-3-2 and IRRI 105. It is suitable for cultivation in the state of Odisha for the irrigated aerobic system. It has a better response to a higher dose of fertilizer application.

Name	CR Dhan 209 (Priya)
Year of Release	2016 (State Variety Release Committee, Odisha)
Duration	112-115 days
Average Yield	4.0 t/ha
Plant type	95-100 cm
Average number of tillers	6-9
Average number of Panicles	230-300 per m^2
Grain type	Long slender
Test weight	24 g
Quality traits	High milling recovery (77.95), very occasionally grain chalkiness present, 3.5 alkali spreading value and intermediate amylose content (23.17), L/B ratio 3.46
Disease and Pest tolerance	Moderately resistant to leaf blast, neck blast, brown spot, and rice tungro disease, moderately resistant to stem borer (dead heart), leaf folder, WBPH and GLH

Fig.9(a): Field view of CR Dhan 209 (Priya)

Fig.9(b): Grains (left) and Kernel (right) of CR Dhan 209

CR DHAN 210

The elite line CR Dhan 210 was developed from the cross between IR717002-247-1-1-2 and IR77080-B-34-1-1. It is suitable for cultivation in the state of Odisha for the early aerobic system. It has a better response to a higher dose of fertilizer application.

Name	CR Dhan 210 (Sarumina)
Year of Release	2019 (State Variety Release Committee, Odisha)
Duration	110-115 days
Average Yield	3.0-4.5 t/ha
Plant type	Semi dwarf (95-105cm)
Average number of tillers	6-9
Average number of Panicles	240-290 per m^2
Grain type	Long slender grain
Test weight	24 g
Quality traits	High milling recovery (70.1), very occasionally grain chalkiness present, 3.5 alkali spreading value and intermediate amylose content (21.99), L/B ratio 3.34
Disease and Pest tolerance	Moderately resistant to leaf blast, neck blast, brown spot and sheath rot, stem borer (both dead heart and white ear heads), leaf folder, and green leafhopper

Fig.10(a): Field view of CR Dhan 210

Fig.10(b): Panicle (left) and grains (right) of CR Dhan 210

Package of practices to realize high yield under aerobic dry direct-seeded system

Seed selection

Obtain the seed from a reliable source, ensuring that the germination percentage must be more than 80%. While in seed production, one should select only the filled seeds from a healthy plant free from any type of damage (insect or disease).

Land preparation

Ploughing the land with a mouldboard plough and then a rotavator to bring soil to fine tilth is advisable to ensure uniform germination, easy root penetration, and growth. Leveling the field is another important aspect to maximize the water use efficiency, control weed, and obtain a proper crop stand.

Time and method of sowing

Sowing of seeds should preferably be done by the second week of June for the wet season and early December for the dry season, at the rate of 50 kg per hectare. They should be sown at a depth of 3-5 cm with 20 cm between rows and 15 cm within rows. Using of seed drill is advisable for sowing in a well-leveled field, where seed drill is not available, sowing can be done behind a country plough with the recommended spacing. Light irrigation should be followed immediately after sowing. Sowing can also be done at the onset of the monsoon.

Fertilizer management

Application of N: P: K @ 80:40:40 kg/ha is recommended with full of P and 50% of K as basal dose before going for land leveling. Apply N in 3 splits, first 30% at 10-12 days after germination, a second dose of 40% at 30 days after sowing, and the third dose of 30% N at the booting stage/ panicle initiation. The remaining 50% of K must be applied after 50 days of sowing. Additionally, as per the requirement and nutrient status of the field, Zinc sulphate @ 20 kg and Iron sulphate @ 12 kg per hectare can be applied at the time of sowing. Ensure sufficient moisture in the field before fertilizer application for the nutrient to be easily available to the plants.

Repeated growing of rice in the same field over and again may lead to depletion in organic matter and soil physical health. One can go for the incorporation of green manures like Dhaincha or Sunhemp or legumes can be raised for green manuring. However, crop rotation with pulses can be the best option to restore soil health and fertility status.

Weed management

To control major grass weeds and sedges, it is recommended to spray Bispyribac sodium @ of 30 g a.i/ha after 8-10 days of seeding as a post-emergence herbicide followed by nitrogen application. Spray Fenoxaprop-p-ethyl (60 g a.i/ha) at 20-25 days of seeding (spray volume of 350 liters/ha) to control late emergent weeds. Adding to this, hand weeding or intercultural operation with hand hoe or weeder can control weeds effectively and increase aeration for better root growth and increased tiller number.

Water management

The aerobic system of rice cultivation can be completed with 700-900 mm of total water. The first irrigation (surface) is to be given immediately after sowing in fine tilth. Irrigation can then be provided with an interval of 4-5 days depending on the available moisture and soil type. This can be continued up to 50 days of sowing and then irrigation should be given once in 3 days coinciding with the critical stages like active tillering, panicle initiation, flowering, and grain filling. No irrigation should be given one week before harvest to allow the crop for uniform ripening.

Pest and disease management

Insect Pests: Stem borer, brown plant hopper (BPH), leaf folder, gundhi bug and nematodes significantly damage the crop. In the stem-borer endemic areas, install pheromone traps @ 8 traps/ha for pest monitoring. If 2 egg masses / m^2 or 1 moth/m^2 or 25 moths / trap / week noticed, apply chlorantraniliprole 0.4 G @ 10 kg/ ha of imidacloprid 0.3 G @ 15 kg/ha or cartap 4 G @ 25 kg/ha or fipronil 0.3 G @ 25 kg/ha or carbofuran 3G @ 33 kg/ha. If standing water is available in the field, spray with chlorantraniliprole 18.5 SC @ 150ml/ ha or flubendiamide 20 WG @125g/ha. When gundhi bug population exceeds 2 per hill, spray imidacloprid 6 % + lambda cyhalothrin 4% SL @ 300 ml/ ha in afternoon hours. As BPH population reaches 10 insects / hill, spray imidacloprid 200 SL @ 125 ml/ha or thiamethoxam 25WG @ 100 g/ha or ethofenprox 10 EC @ 500 ml/ha or triflumezopyrim 10 % SC @ 237 ml/ha or pymetrozine 50 WDG @ 300 g/ha or Flonicamid 50 WG @ 150 g/ha for controlling the insect.

Diseases: Blast, bacterial leaf blight, sheath blight are important diseases. If bacterial blight is observed, streptomycin sulphate 9% + tetracycline hydrochloride 1% SP @ 1g + copper oxychloride @ 2 g/ liter of water may be sprayed to manage this disease. In case of leaf blast and sheath blight disease occurrence, spray hexaconazole 5 EC at 2ml/ liter of water. For blast, kasugamycin 3SL @ 2 ml/ liter or Carbendazim 12 % + Mancozeb 63% WP @ 1g/liter may be sprayed. Validamycin 3 L @ 2ml/ liter or propiconazole 25EC @ 1 g/liter may be sprayed for sheath blight management.

Harvesting

Harvest the crop 25-30 days after commencement of flowering or when the grains have fully ripened. Bringing the moisture level down to 12% before storage has to be assured through proper threshing, winnowing, and drying.

Points to remember

Careful observation is required in weed control and nutrient management throughout crop growth. There must not be a water deficit during critical stages of plant growth like tillering, panicle initiation, flowering, and grain filling. Water must be withheld one week before the harvest of the crop to facilitate the uniform ripening of grains.

Conclusion

The released rice varieties from ICAR-NRRI, Cuttack are performing well in their recommended ecologies. It is also noteworthy to mention that as they are from different pedigrees their characteristic features such as plant morphology, grain quality, yield, reaction to disease, and pest also manifest a wide variation. A study on a group of selected aerobic varieties was done to understand the variability in their response towards different diseases and pests (Table 2) (Pathak et al., 2019). The results have highlighted a few varieties that show a significant tolerant reaction or even resistance up to some extent. The noteworthy resistant responses were from CR Dhan 204 and CR Dhan 205 to blast disease, while CR Dhan 200, CR Dhan 203, and CR Dhan 206 were resistant in their response towards seedling blight, the trait necessary for direct-seeded condition. Nematode incidence is one of the major problems under direct-seeded aerobic conditions; all the screened varieties were moderately susceptible in their response towards nematode infestation.

Table 2: Scoring for diseases and pest incidence on aerobic varieties of NRRI, Cuttack

Genotype	Blast	Brown Spot	Sheath Blight	Bakanae	Seedling Blight	BPH	Gall midge	Nematode
CR Dhan 200	MR	MR	S	MR	R	HS	HS	S
CR Dhan 201	S	HS	S	HS	S	HS	HS	HS
CR Dhan 202	R	MR	HS	S	S	HS	HS	HS
CR Dhan 203	-	-	S	-	HR	HS	HS	-
CR Dhan 204	R	HS	HS	HS	HS	HS	HS	S
CR Dhan 205	R	-	HS	-	HS	HS	HS	HS
CR Dhan 206	-	HS	S	S	HR	HS	HS	S

There is a need to identify the desirable traits in each of these genotypes and then a breeding programme can be designed either for introgression of the desirable genes or even pyramid them into a single high yielding aerobic variety.

The aerobic system of cultivation has special needs in terms of plant morphological aspects. Especially concerning root traits, this forms the basis of all management practices in aerobic conditions. As it has already been established that there is reduced moisture and thereby nutrient deficit may arise in aerobic DSR practice, thus the root system architecture must be well-developed suiting to the aerobic ecology of rice cultivation. A study was conducted in NRRI, Cuttack to screen the root traits of the released varieties for aerobic condition. They were assessed for root length, the total number of roots, and the number of roots at the base during the late vegetative stage (Figure 11). It was seen that the average length at the late vegetative stage was found to be 29 cm, with the maximum in CR Dhan 202. The highest number of roots was recorded in CR Dhan 203, while CR Dhan 206 had the highest number of roots at the base/ hill. From a yield point of view, CR Dhan 205, has the potential of giving yield as high as 6.4 t/ha.

However, an ideal aerobic rice variety must possess a specific combination of all the root traits. For instance, at the early seedling growth stages, the plant would require a greater number of surface and sub-surface roots to uptake the maximum amount of P from shallow soil depths, whereas at a later stage, long deep roots help in mining water and nitrogen from the soil. There must also be some new roots formed at the reproductive phase of the rice plant to provide the developing grains with an adequate amount of moisture and nutrient.

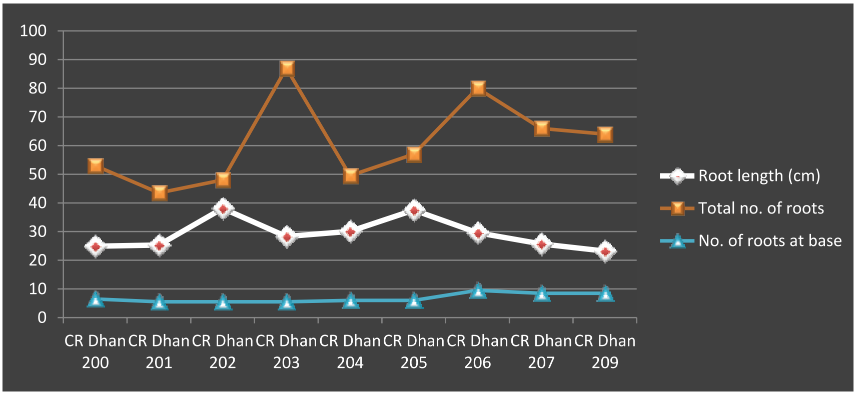

Fig.11: Root traits (root length, total number of roots, and number of basal roots) of different aerobic rice varieties of NRRI, Cuttack

Many genes and QTLs have been identified in relation to the above-mentioned traits of root system architecture. *PSTOL1* (an early root growth enhancer) (Gamuyao et al., 2012), QTLs like *qSOR1* (enhancing the formation of surface roots) (Uga et al., 2012), *DRO1* (for deep rooting and root angle trait) (Uga et al., 2015), etc. can be used in introgression programs to strengthen the varieties for root establishment. The next aspect that should be critically examined is the nutrient status, their dynamics, and acquisition by the rice plant under aerobic conditions. This is essential because the soil ecology under aerobic conditions is highly distinctive from that of flooded conditions. The soil pH, available form of nutrients, microfauna, etc. present a peculiar combination under aerobic conditions. For instance, nitrogen under the aerobic system of cultivation is available in the oxidized nitrate form to the plants, the microbial population such as that of mycorrhiza and other bacteria flourish at a better rate comparably. The nutrient acquisition must be focused upon and ideal genes and transporters must be identified and exploited while developing new varieties. Many such genes and transporters have already been reported for both major and micro nutrients. High-affinity transporters for P (*OsPT1* and *OsPT8*) (Li et al., 2015; Seo et al., 2008) and nitrogen transporters like *OsNRTs* (Suenaga et al., 2003; Yan et al., 2011) and *OsAMTs* can be utilized for nitrate and ammonium respectively. Additionally, other traits are worth highlighting such as root lodging tolerance, early uniform emergence among others that need to be focused upon might play an important role in the establishment, growth, and proper development of panicles in the aerobic crop.

These steps of improvement can be accomplished either by improving specific plant morphologies (such as roots) or utilizing transporters to increase the uptake by exploring the advanced genotyping and phenotyping techniques. Even where the traits in question are highly complex or polygenic in nature, marker-assisted selection can come to the aid. Apart from all these research initiatives, the main hurdle would lie in bringing the aerobic system of cultivation to the mainstream and popularizing it as a beneficial alternative to conventional transplanted rice cultivation. This would require a multidisciplinary holistic approach to realize the benefits of aerobic cultivation of rice.

References

Anandan, A., Mahender, A., Sah, R. P., Bose, L. K., Subudhi, H., Meher, J., Reddy, J. N., & Ali, J. (2020). Non-destructive phenotyping for early seedling vigor in direct-seeded rice. *Plant Methods*, *16*(1), 1–18. https://doi.org/10.1186/s13007-020-00666-6.

Anandan, A., Pradhan, S.K., & Singh, O.N. 2015. A system of rice cultivation for water shortfall irrigated and lowland areas: Aerobic rice an overview. Popular Kheti, 3(3): 8-13.

Barker, R., Dawe, D., Tuong, T. P., Bhuiyan, S. I., & Guerra, L. C. (1999). The outlook for water resources in the year 2020: challenges for research on water management in rice production. *Southeast Asia*, *1*, 1–5.

Gamuyao, R., Chin, J. H., Pariasca-Tanaka, J., Pesaresi, P., Catausan, S., Dalid, C., Slamet-Loedin, I., Tecson-Mendoza, E. M., Wissuwa, M., & Heuer, S. (2012). The protein kinase Pstol1 from traditional rice confers tolerance of phosphorus deficiency. *Nature*, *488*(7412), 535–539. https://doi.org/10.1038/nature11346

Hittalmani, S. (2007). Aerobic rice cultivation Brochure, MAS lab. *Univ. Agric. Sci., GKVK, Bangalore*.

Li, Y., Zhang, J., Zhang, X., Fan, H., Gu, M., Qu, H., & Xu, G. (2015). Phosphate transporter OsPht1;8 in rice plays an important role in phosphorus redistribution from source to sink organs and allocation between embryo and endosperm of seeds. *Plant Science*, *230*, 23–32. https://doi.org/10.1016/j.plantsci.2014.10.001

Pathak, H., Parameswaran, C., Anandan, A., Aravindan, S., Pandi, G. G. P., Gowda, G. B., Raghu, S., Keerthana, U., Meena, K. S., Lenka, S., & Kumar, A. (2019). *Rice Varieties of NRRI :*

Pradhan, S. K., Mall, A. K., Ghosh, A., Singh, S., Samal, P., Dash, S. K., Singh, O. N., & Kumar, A. (2016). Paper 3 Aerobic rice perspectives in India: progress and challenges. *Regional: Development and Dissemination of Climate-Resilient Rice Varieties for Water-Short Areas of South Asia and Southeast Asia*, 48.

Prasad, R. (2011). Aerobic Rice Systems. In *Advances in Agronomy* (Vol. 111). https://doi.org/10.1016/B978-0-12-387689-8.00003-5

Priyanka, S., Jitesh, B., & Babu, S. (2012). Aerobic rice, a new approach of rice cultivation. *International Journal of Research in BioSciences*, *1*(1), 1–6. http://www.ijrbs.in

Seo, H. M., Jung, Y., Song, S., Kim, Y., Kwon, T., Kim, D. H., Jeung, S. J., Yi, Y. B., Yi, G., Nam, M. H., & Nam, J. (2008). Increased expression of OsPT1, a high-affinity phosphate transporter, enhances phosphate acquisition in rice. *Biotechnology Letters*. https://doi.org/10.1007/s10529-008-9757-7

Shashidhar, H. E. (2012). An eco-friendly aerobic rice BI 33 (Anagha). *Available at Www. Aerobic Rice. In*.

Singh, R. K., Singh, V. P., & Singh, C. V. (1994). Agronomic assessment of 'beushening'in rainfed lowland rice cultivation in Bihar, India. *Agriculture, Ecosystems & Environment*, *51*(3), 271–280.

Suenaga, A., Moriya, K., Sonoda, Y., Ikeda, A., Von Wirén, N., Hayakawa, T., Yamaguchi, J., & Yamaya, T. (2003). Constitutive expression of a novel-type ammonium transporter OsAMT2 in rice plants. *Plant and Cell Physiology*. https://doi.org/10.1093/pcp/pcg017

Tomar, V. S. (2002). The beushening system of rice crop establishment in eastern India. *International Workshop on Direct Seeding in Asian Rice Systems'.(Eds S Pandey, M Mortimer, L Wade, TP Tuong, K Lopez, B Hardy) Pp*, 53–74.

Uga, Y., Hanzawa, E., Nagai, S., Sasaki, K., Yano, M., & Sato, T. (2012). Identification of qSOR1, a major rice QTL involved in soil-surface rooting in paddy fields. *Theoretical and Applied Genetics*. https://doi.org/10.1007/s00122-011-1688-3

Uga, Y., Kitomi, Y., Yamamoto, E., Kanno, N., Kawai, S., Mizubayashi, T., & Fukuoka, S. (2015). A QTL for root growth angle on rice chromosome 7 is involved in the genetic pathway of DEEPER ROOTING 1. *Rice*. https://doi.org/10.1186/s12284-015-0044-7

Yan, M., Fan, X., Feng, H., Miller, A. J., Shen, Q., & Xu, G. (2011). Rice OsNAR2.1 interacts with OsNRT2.1, OsNRT2.2 and OsNRT2.3a nitrate transporters to provide uptake over high and low concentration ranges. *Plant, Cell and Environment*, *34*(8), 1360–1372. https://doi.org/10.1111/j.1365-3040.2011.02335.x

Zhao, D. L., Atlin, G. N., Amante, M., Cruz, M. T. S., & Kumar, A. (2010). Developing Aerobic Rice Cultivars for Water-Short Irrigated and Drought-Prone Rainfed Areas in the Tropics. *Crop Science*, *50*(6), 2268–2276.