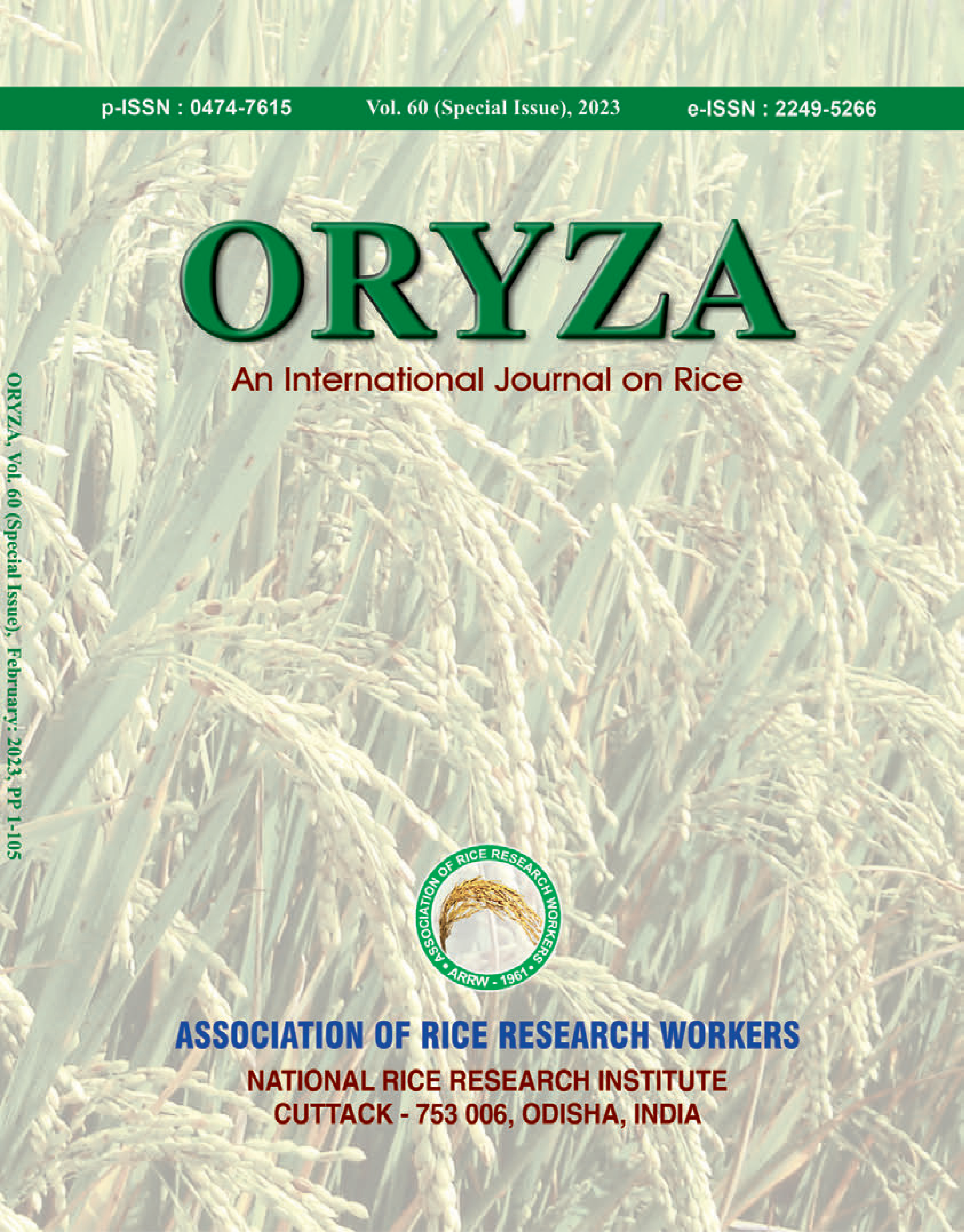

p-ISSN : 0474-7615 Vol. 60 (Special Issue), 2023 e-ISSN : 2249-5266

ORYZA

An International Journal on Rice

ORYZA, Vol. 60 (Special Issue), February, 2023, PP 1-105

ASSOCIATION OF RICE RESEARCH WORKERS
NATIONAL RICE RESEARCH INSTITUTE
CUTTACK - 753 006, ODISHA, INDIA

ASSOCIATION OF RICE RESEARCH WORKERS

(Founded in 1961)

Registered under Societies Registration Act, 1960 (No. XXI of 1860)

EXECUTIVE COUNCIL FOR 2022-2024

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Vol. 60 **Special Issue** **2023**

ORYZA
An International Journal on Rice

Official Publication of

Association of Rice Research Workers
National Rice Research Institute
Cuttack - 753 006, India

Oryza Vol. 60 Special Issue 2023 (1-20)
DOI https://doi.org/10.35709/ory.2023.60.0.1

Conventional and new breeding approaches to enhance grain yield in rice

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Received : 02 February 2023 Accepted: 04 February 2023 Published : 07 February 2023

ABSTRACT

From a ship-to-mouth existence at the time of its Independence, India became a food sufficient country due to the research and policy interventions during the green revolution era and in the last six decades. The country witnessed a phenomenal increase in the production and productivity of rice and wheat and presently the country is exporting significant quantities of rice. However, there are multiple challenges in ensuring food and nutritional security through rice in the coming decades including a rapidly changing climate and a plateauing of rice yields has been witnessed in the last two decades in many rice growing countries across the world including India. It is therefore imperative to enhance rice productivity and production through application of modern tools of science. This review traces the developments related to rice research and yield improvement over the last six decades and discusses about the conventional and modern approaches to enhance grain yield in rice. These approaches include pre-breeding, wide-hybridization, new plant type/ideotype breeding, heterosis breeding, marker and genomics-assisted breeding, haplotype-based breeding, transgenic breeding and genome editing.

INTRODUCTION

Globally, climate change is a major factor that significantly reduces crop yield, thereby limiting food availability and nutritional security. Rice (*Oryza sativa* L.) is a staple food of more than 3 billion people, who reside primarily in Asia. India is the world's largest producer of rice after China and ranks first in terms of area under rice crop. It is pertinent to note that there has been no significant expansion in the area under rice cultivation in India; it was roughly 40.15 million ha in 1980 and 44 million ha in 2021, but the production has significantly increased from around 53.63 million tons in 1980-81 to 124.37 million tons in the year 2021 (Fig. 1). The rate of world population growth has exceeded the rate of growth in food-grain production. By the end of 2022, the world's population has already exceeded 8 billion, and by 2050, it is expected to surpass 9.7 billion. To fulfil the world's growing food demand, global food production needs increase by up to 40% by 2030 and by 70% by 2050. Accelerated genetic gain is therefore required to boost rice production potential and yield stability across the ecologies (Sundaram et al., 2018).

Severe loss of yield due to various biotic stresses like diseases such as blast, bacterial blight (BB), sheath blight and pests such as brown planthopper (BPH) yellow stem borer (YSB), gall midge, nematodes, and abiotic stresses like drought, heat, submergence, cold and salinity are a serious threat to the rice production (Fiyaz et al., 2022). The outbreak of new biotypes/pathotypes and unpredictable occurrence of abiotic stresses across growth stages have demanded stacking of resistant/tolerant genes into high yielding cultivars to ensure durability of resistance. The most economical and environment-friendly approach of stress management is the enhancement of host-plant resistance/tolerance through breeding. Systematic breeding for rice improvement began more than a century ago and has made rapid strides in the past six decades utilizing conventional, molecular and genomics-assisted breeding approaches.

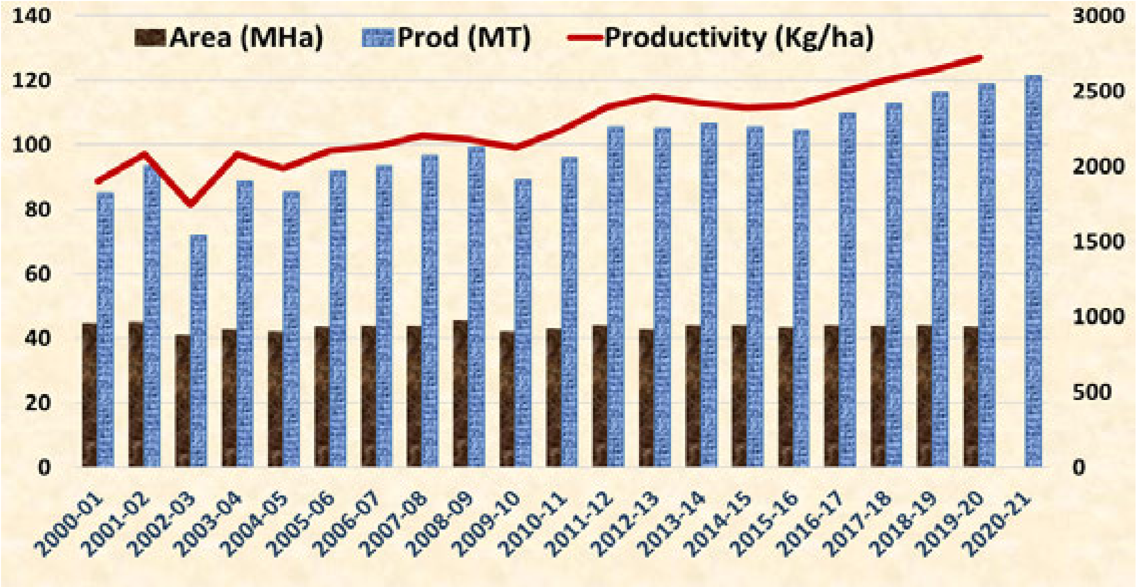

Fig. 1. Rice, Area, Production and Productivity in India in last two decades.

Transformation from conventional to modern breeding approaches

By adopting conventional breeding techniques, several rice varieties have gained popularity in farmer's fields. It is accomplished by crossing plants possessing various characteristics and choosing the progeny with the desired combination of traits. The concept of breeding new crops has changed over time, and many cutting-edge techniques like marker-assisted selection, marker-assisted backcross breeding, genome-wide association studies (GWAS), genomic selection, and gene editing are now being used to create crops with a specific trait of interest.

Pre-breeding and wide hybridization

Breeding and adoption of high yielding varieties is prioritised in modern agriculture, and as a result, traditional varieties and landraces have been largely displaced with high yielding homozygous cultivars. Breeders generate crosses within improved germplasm for rapid yield gain, thereby, narrowing the genetic base resulting in vulnerability of the modern varieties to biotic and abiotic stresses and also thus decreasing the overall productivity. Modern plant breeding in any crop cannot sustain without a systematic pre-breeding component, which harnesses the genetic repertoire from primary, secondary and tertiary gene pools of a crop. Genes from the wild relatives have already proved immense in saving the 'crop status' of several cultivated species.

Wild species of *Oryza* are important reservoirs of genes for agronomically important traits such as yield, quality and nutritional characteristics, resistance to biotic and abiotic stresses such as grassy stunt virus, tungro virus, stem borer, brown plant hopper, bacterial blight, blast, salinity, deep water and other useful special traits such as cytoplasmic male sterility system (Virmani and Shinjyo, 1988; Brar and Khush, 1997). The discovery of CMS sources and their restoration systems have demonstrated that wild relatives are also important sources for improving yield through hybrid rice technology. Diversification of male sterility system, improving the heterosis by introgressing yield enhancing QTL and out crossing rate is the future thrust area which can be met from the wild rice introgression (Song et al., 2005; Kang et al., 2005).

The introgression lines derived from the wild species *O. rufipogon*, *O. nivara* and *O. longistaminata* at ICAR-IIRR, Hyderabad showed tremendous de novo useful variability traits related to yield enhancement, tolerance to pest and diseases and resource use efficiency. The hidden agronomically useful traits such as high yield, dense panicles, good grain filling and stay-green leaves, drought& salinity tolerance and resistance to brown plant hopper, bacterial leaf blight and leaf blast were observed in introgression lines of KMR3/*O. rufipogon*, Swarna/*O. nivara* and Swana/ *O. longistaminata*. The wild introgression lines of B 32-Sel-4 x *O. rufipogon* and Swarna x *O. nivara* was released as 'Dhanrasi' and 'DRR Dhan 40' respectively for unfavourable environments. 'Dhanrasi' possessed resistance to blast and rice tungro disease and moderate resistance to bacterial blight. A restorer line Q611 with yield enhancing QTL from *O. rufipogon* has been released in China. Many species of Oryza have been screened for salinity tolerance and few of the accessions of *O. rufipogon* showed better tolerance to salinity compared to cultivated donors (Mazumdar et al., 2006). The efforts of introgression of salt tolerance from *O. rufipogon* have resulted in development of a high-yielding rice variety Jarava, with tolerance/resistance to salinity, blast, bacterial leaf blight and BPH (Ram et al., 2012).

New plant type (NPT) / Ideotype breeding

Predominantly, indica cultivars are grown in India, China, Southeast Asia and South Asia, occupying approximately 70% of the rice-producing area in the world, while japonica cultivars are grown mainly in East Asia (Huang et al., 2012). Stagnant yield potential of semi-dwarf indica inbred rice varieties has been observed in the tropics, since the release of IR8 (Peng et al., 1999), despite the fact that a moderate genetic gain in yield per day has been achieved due to a reduction in total growth duration. It was postulated that this stagnation might be the result of the plant type of these varieties. A large number of unproductive tillers, limited sink size, and lodging susceptibility were identified as the major constraints to yield improvement in these varieties. Ideotype approach to plant breeding is in contrast to the empirical breeding approach, which essentially focusses on defect elimination and selection for yield per se (Donald, 1968). Crop ideotype is an idealized plant type with a specific combination of characteristics favourable for photosynthesis, growth, and grain production based on knowledge of plant and crop physiology and morphology.

To break the yield potential barrier and enhance the ceiling, new plant type (NPT) was proposed with tillering capacity and few unproductive tillers; 200-250 grains per panicle; a plant height of 90-100 cm; thick and sturdy stems; leaves that are thick, dark green, and erect; a vigorous root system; 100-130 days' growth duration; and increased harvest index (Peng et al., 1994). This plant type design was mainly based on the results of simulation modelling and the proposed traits were mostly morphological due to the relative ease in selection for compared with physiological traits in a breeding program. Breeding with the designed plant type approach using tropical japonica that began in 1989, resulted in development of the first generation NPT lines. But this effort did not culminate in release any rice variety with the expected performance. Though they had large panicles, few unproductive tillers and lodging resistance, they had lower yield levels due to low biomass production and poor grain filling. Reduced tillering capacity might contribute to low biomass production, because the crop growth rate during the vegetative stage of NPT lines was lower than that of indica varieties. The poor grain filling of NPT lines was also probably due to a lack of apical dominance within a panicle (Yamagishi et al., 1996), the compact arrangement of spikelets on the panicle, a limited number of large vascular bundles available for assimilate transport and source limitation due to early leaf senescence (Ladha et al., 1998). The first-generation NPT lines were also susceptible to pests and diseases and had poor grain quality. The poor yield of the first generation NPT lines was attributed to low harvest index, which was the result of small sink size (*i.e*., few spikelets per m^2), low grain-filling percentage, and poor translocation of biomass accumulated before flowering to the grains during grain filling (Laza et al., 2003).

Development of second-generation NPT lines began in 1995 by crossing first-generation NPT lines with elite indica parents. Yield improvement was achieved in the second-generation NPT lines as compared with the first-generation lines. This yield increase was attributed to increased tillering capacity, enhanced panicle number per m^2, improved grain-filling percentage and also grain quality, disease and insect resistance through the introduction of genes from elite indica parents to the first-generation NPT lines. A few second-generation NPT lines produced significantly higher yield than the indica check variety, IR72, in several seasons. This increase was due to enhanced above-ground total biomass production, improved harvest index and increased grain weight. Spikelet number per panicle of these second-generation NPT

Table 1. Morphological characteristics of indica Vs first, second generation NPT and modified plant type traits.

Trait	Semi dwarf indica	1st generation NPT	2nd generation NPT	Redesigning indica plant type/modified plant type
Tillering capacity	High with large number of unproductive tillers	Low with few unproductive tillers	Increase in tillering capacity	Moderate (270-300 panicles/m^2)
Leaf area	excessive	Thick, dark green & erect leaves	Thick, dark green & erect leaves	Narrow V-shaped thick leaves, LAI= 6.0
Plant height	<90 CM	90-100 cm	At least 100 cm	Up to 120 cm
Panicles	small	large	Slightly smaller than 1st NPT without a change in panicle length	Drooping at maturity, at 60 cm from soil surface for a plant height of 100 cm
Grain number	Less	200-250	45-75%>indica check IR72	>300
Sink size	limited	Small	Improved over 1st NPT	large
Lodging	susceptible	resistant	resistant	resistant
Stem	Semi-dwarf,	Thick and sturdy	Thick and sturdy	Thick and sturdy
Root system	Less vigorous	Vigorous	Vigorous	Vigorous
Duration	Wide range	100-130 days	Up to 135 days	Up to 135 days
Harvest index	Low	Low	Improved over 1st NPT	0.55
Biomass	Low	Low	Improved over 1st NPT	High
Grain filling	Poor	Poor	Improved over 1st NPT	High
Panicle weight	Low	low	Improved over 1st NPT	Heavy (5 g/panicle)
Leaf senescence	Early	Early	Late	Late
Vascular bundles		Limited and large		
Pest/disease	Susceptible	Susceptible	Resistant	Resistant
Grain quality	Good	Poor	Good	Good

lines was 45-75% greater than that of IR72. When the check varieties were newly developed indica varieties and lines instead of earlier high yielding indica varieties like IR72, the advantage of second generation NPT lines over indica checks in grain yield became smaller and even disappeared because yield progress had also been achieved in indica inbred breeding programs (Yang et al., 2007). If a comparison was made between two groups of varieties, there was no significant difference in grain yield between the second-generation NPT lines and indica check varieties. These results suggest that second-generation NPT lines have not increased the yield potential and pushed the yield ceiling as expected.

Considering the above mentioned limitations of the second generation NPTs, the next generation modified plant type varieties in rice were proposed with redesigned morphological traits viz., moderate tillering capacity (270-300 panicles m^{-2}), heavy (5 g per panicle) and drooping panicles at maturity, plant height of at least 100 cm (from soil surface to unbent plant tip), panicle height of 60 cm (from soil surface to the top of panicles with panicles in natural position) at maturity, narrow V-shaped (2 cm leaf width when flattened) thick leaves (specific leaf weight of top three leaves = 55 g m^{-2}), leaf area index (LAI) of top three leaves of about 6.0 and harvest index of about 0.55. The specific leaf characteristics of top three leaves proposed were 45 cm flag-leaf length and 50 and 55 cm for the 2nd and 3rd leaves. All three leaves should be above panicle height and remain erect until maturity. Leaf angles of the flag, 2nd, and 3rd leaves should be around 5°, 10°, and 20°, respectively. The comparative morphological descriptors of semi-dwarf indica, first and second generation NPT and modified plant type are given in Table 1. Towards development of an NPT with aforementioned redesigned morphological traits, Jyothi et al. (2018) characterized NPT traits among 650 genetically diverse rice genotypes of tropical japonica and indica and established an initial core set for NPT traits. Morphological and molecular characterization of NPT core set novel NPT trait combinations with heavy panicle weight, high grain number and strong culm (Rachana et al., 2020)

Lodging in rice production often limits grain yield and quality by breaking or bending stems. The proportionality between the physical strength of lower internodes and the weight of the upper parts determines a plant's vulnerability to lodging (Mulder, 1954). In cereals, the reduction of plant height has been the main target for improving lodging resistance. Plant breeders have reduced lodging risks by introducing semi-dwarf traits to produce shorter cultivars (Khush, 1999) however, the plant height of semi-dwarf rice and wheat may limit canopy photosynthesis and biomass, thereby limiting grain yield. Another problem with semi-dwarfism is that the gene regulating the semi-dwarf trait may exhibit negative pleiotropic effects on stem morphology. For example, semi-dwarf 1 (sd1) gibberellin (GA) synthesis is used for the reduction of rice plant height but also decreases stem stiffness by lowering the culm diameter and thickness (Okuno et al., 2014). Ma et al. (2004) studied the optimum length of internodes in rice that would increase lodging resistance and found that plant height is not a primary factor for lodging risks (Islam et al., 2007). According to a previous study by Berry et al. (2003), the lodging of cereal plants can be classified into two types. Root lodging results from intact and unbroken culms leaning from the crown due to a failure of root anchorage in the ground, while stem lodging refers to the bending or breaking of the lower culm internodes as a result of excessive bending pressure at the higher internodes. Stem strength *i.e.*, the bending or breaking strength of the culm, is important for stem lodging resistance, particularly for the basal internodes of crops. Thus, the new major focus for improving lodging resistance and grain yield is increasing the stem strength of the lower internodes of rice plants.

Heterosis breeding

Hybrid rice is a proven and successful technology for increase in rice production and productivity, immensely contributed toward improving food security and livelihood over the past three decades. Remarkable progress continues as hybrid rice technology makes its way across Asia and to other countries. The area grown to hybrid rice in India has increased to3.5-4.0 million hectares in 2021. The advantage of yield improved through hybrid rice technology is possible by exploitation of heterosis to its maximum level.

Heterosis in rice was reported first by Jones (1926) and the role of cytoplasm in causing male sterility in rice was reported way back in the fifties (Sampath and Mohanty, 1954; Katsuo and Mizushima, 1958). The first commercially usable CMS line was developed in China in 1973 from a spontaneous male sterile plant isolated in a population of the wild rice O. sativa f. spontanea on Hainan Island (Yuan, 1977). Discovery of this source, designated as 'Wild Abortive' or "WA' type, is considered a landmark in the history of rice breeding. China released the first hybrid for commercial cultivation in 1976 (Yuan, 1977). Yield advantage of 15-20% over the best inbred varieties (7.2 t/ha as against 5.9 t/ha) proved the key factor for wide adoption of the hybrid technology. Area under hybrid rice in China increased as a result to 63% (18.6 million ha) of the rice area contributing to enhanced rice productivity by 44%. Following the success of hybrid rice in China, the International Rice Research Institute augmented research to evolve hybrids ideally suited to tropical environments. Development of stable male sterile lines in the tropical varietal background by IRRI has facilitated intensive hybrid breeding research there and a few countries like India, the Philippines, and Vietnam. India, which launched a mission mode network project on hybrid rice in 1989 has made significant progress with release of 137 commercial hybrids tilldateand our country has earned the distinction of being the second country after China to make hybrid technology a field reality on larger scale.

Table 2. Extent to standard heterosis observed in some of the recently released hybrids.

S. no.	Name of the hybrid	AICRIP years of testing	Yield advantage over best check (%)
1	PAC 8744+	2016-2020	14
2	US 303	2015-2020	26
3	KPH 471	2017-2020	20
4	JKRH 2354	2017-2020	20
5	NPH-XI	2017-2020	16
6	DRRH-4	2018-2021	11

CMS-based three-line breeding approach

Table 3. Different CMS resources used in the hybrid rice breeding program.

CMS type	MS model	Origin of CMS
WA-CMS	Sporophyte sterility	Natural wild rice abortive plant in Hainan
G-CSM	Sporophyte sterility	Gambiaka from West Africa
D-CMS	Sporophyte sterility	Indica rice Dissi D52/37
ID-CSM	Sporophyte sterility	Indonesia 6 from Indonesia
DA-CSM	Sporophyte sterility	Dwarf wild rice in Jiangxi
K-CSM	Sporophyte sterility	Japonica rice K52
HL-CSM	Gametophyte sterility	Red-awned wild rice
BT-CSM	Gametophyte sterility	ChinsurahBoroII/ Taichong 65
DT-CSM	Gametophyte sterility	Japonica rice Taibei

Table 4. Hybrids currently available for cultivation.

Sector	Central releases	State releases
Public Sector	DRRH 4, KRH 4, DRRH3	CR Dhan 702, CR Dhan 703,CNRH 103,GRH 2, GNRH-1,Chhattisgarh Rice Hybrid-2 (IRH-103)
Private Sector	28S41.27P37,28P67,VNR-2228,VNR- 216 VNR Laxmi Plus, US 380,SAVA 134,KPH 471,PAC 8744+,27P27,AZ 8433 DT	SAVA 200,SAVA 300,MRP 5433,MRP 5626, RH 9000 Plus, LG 93.01

Development of stable male sterility system is the pre-requisite for commercial hybrid seed production. Among different kinds of male sterility systems known in rice, cytoplasmic-genetic male sterility based 3-line approach has proved most stable and commercially viable as is the case in traditional hybrid crops. In this system, male sterility results from interaction between sterility factor present in the cytoplasm and those in the nucleus. Absence of the sterility-inducing factor (gene) either in the cytoplasm or nucleus makes a line male fertile. This system involves a CMS (A-line), a maintainer (B line) and a restorer (R line). A CMS line is maintained by crossing it with its B line. The A and B lines are similar in all respects except that the former is male sterile and the latter male fertile. The restorer line possesses dominant fertility restoring gene(s) and hence when crossed with a CMS line, produces a fertile F_1 hybrid. Since the system involves the use of three (A, B and R) lines, hybrids developed by using this method are called three-line hybrids. Three factors are crucial for the commercial success of hybrid rice technology. They are high standard heterosis, stable male sterile source and efficient package for obtaining high seed yields. The recently released hybrids in the country are showing the standard yield heterosis of around 30% (Table 2).

As for the male sterility source, our country continues to exploit till now the 'WA-based male sterile lines such as IR 58025A, IR 68897A, APMS 6A, Pusa 6A etc. However new cytoplasmic sources such as 'Kalinga cytoplasm' is also being utilized in the development of rice hybrids. The CRMS 32A (from CRRI, Cuttack) is in the background of Kalinga cytoplasm. In China, although the predominant cytoplasmic source is 'WA' cytoplasm (around 50%), another cytoplasmic source 'ID-CMS' has been used widely in recent years because of its good flowering habits and grain quality (Table 3). Its proportion has increased quickly from less than 10% in 1996 to more than 20% in recent years.

Though 137 hybrids have been released in the country so far, some of them have been outdated, and some are not in the production chain. Such hybrids which are in the production chain and available for commercial cultivation are listed below (Table 4).

Three-line parental line Improvement for enhanced level of heterosis

Development of hybrids utilizing cytoplasmic-genetic male sterility system involved identification of restorers and maintainers from a large number of elite lines. The frequency of restorers and maintainers among the available elite indicaand Japonica lines is around 25% and 10% respectively. Unlike in indica it is difficult to find good restorers in the Japonica germplasm. More than 75% of the elite lines tested have turned out to be either partial restorers or partial maintainers, which are not usable in commercial hybrid breeding. Dependence on the inbred breeding program on a continual basis for new elite lines would hardly help improve the situation. In order to improve the efficiency of hybrid rice breeding, it is essential to augment it with an exclusive parental line improvement programme so that a large number of usable lines are available for developing more and better heterotic hybrids.

Improved gene pool with higher frequency of restorers and maintainers can be developed by different approaches. The most common is through establishing specific restorer and maintainer breeding programme by meticulously planned R x R and B x B crosses. By this, it is possible to combine desirable traits from different parents, besides increasing the frequency of restorers and maintainers. Another effective method of improving parental lines is genetic male sterility-facilitated recurrent selection, which not only broadens the genetic base of parental lines but also helps in the accumulation of desirable genes.

Parental lines are improved by effecting single, double or multiple crosses among genetically diverse maintainers or restorers followed by pedigree selection. The choice of parents for the crossing should be such that they are of complementing types so as to meet various breeding objectives. The most commonly used approaches are R x R, partial restorer x R, partial maintainer x R and B x B crosses. For R x R and B x B crosses, promising lines having complementary traits are used so that probability of isolating desirable plants in the segregating generations is high. Some partial restorers or partial maintainers having exceptionally good traits can also be crossed with good restorers to obtain segregants having restorer genes coupled with desirable floral traits. The frequency of restorers in such cases will be relatively low, which necessitates rigorous selection in large populations and resorting to backcrossing in certain cases. The material so generated is test/top-crossed in advanced generations using good CMS lines to assess their restoring and combining ability.

Heterosis Improvement through genetic male sterility facilitated population improvement

Population improvement is a medium to long term activity and is also deployed in the development of parental lines of hybrid rice. As against quick fixation of genes during selfing generations of recombination breeding, genetic male sterility facilitated recurrent selection provides for continuous recombination, accumulation of favorable genes, broadening of the genetic base and breaking of undesirable linkages.

As for the improvement of restorers and maintainers by genetic male sterility facilitated recurrent selection, genetically diverse restorers, having useful traits, are crossed with the genetic male sterile line of a restorer background. F_1's are grown and equal quantity of F_1 seed produced from each cross is pooled to raise the F_2 generation. The population is subjected to random mating and seed set on male sterile plants is used to grow the next generation. After 3-four cycles of random mating, the fertile plants are selected and handled by pedigree method to extract useful derivatives. Selected ones are test-crossed to the CMS lines to confirm their restoring and combining abilities. Similar procedure is followed for improving the maintainer lines. Through this method the composite populations in the background of maintainers and restores are developed and productive segregants identified with desired traits are handled by pedigree method, which will ultimately result in development of new and improved parental lines. This strategy has been found quite rewarding for broadening the genetic base of the parental lines. Detailed procedures for parental line improvement have been outlined by Virmani et al. (1997).

Genetic enhancement for yield heterosis through exploitation of New Plant Types (NPT)

Most of the commercial hybrids now in cultivation belong to intra sub specific group (indica/indica or japonica/japonica) and have few ancestors with narrow genetic base. The insufficient genetic diversity is recognized as a major cause for the yield ceiling in hybrid rice that has appeared for nearly 20 years. Standard heterosis in these hybrids is in the range of 10-20 percent (0.75 to 1.5 t/ha) over the popular high yielding inbred varieties. One of the strategies contemplated to further enhance the yield potential of hybrid rice is development of inter sub specific (indica/japonica) hybrids. This strategy is based on the experience that the magnitude of heterosis is in the order of *indica/japonica* > *indica/javanica* > *japonica/javanica* > *indica/indica* > *japonica/japonica*. Utilization of NPT based CMS and restorer lines in hybrid development are likely to raise level of heterosis multifold.

Exploiting heterosis through two-line breeding system

The greater dependence on a single source of cytoplasmic male sterility (CMS) by the use of WA system and the most difficult and laborious process of seed production and parental line development warrant the development of alternate methodologies to exploit hybrid vigour in rice. Two-line breeding based on two new kinds of genetic tools *viz*., photosensitive genic male sterility (PGMS) and thermo-sensitive genic male sterility (TGMS) systems is one such possibility. The former system emerged following chance discovery in 1973 of a male sterile plant called Nongken 58S, in the japonica variety Nongken 58 by Prof. Shi Ming Song of China and a temperature sensitive genic male sterility (TGMS) line Annorg is by Chinese in Hunan and also Japanese scientists. Using the PGMS system, Yuan (1987) put forth a new strategy of hybrid rice breeding which did not involve a maintainer, as the maintenance is taken care of by the shorter photoperiod (< 13 hr),

Table 5. Marker assisted introgression for sequential and simultaneous introgression of two or more biotic and abiotic stress resistance/tolerance.

Recurrent parent	Trait(s) improved	Genes/QTLs introgressed	Variety/Reference
		Sequential introgression in the background of ISM with inherent xa5, xa13 and Xa21	
ISM	Salinity tolerance	*Saltol*	DRR Dhan 58 (Rekha et al., 2022)
ISM	Low soil phosphorous	*Pup 1*	DRR Dhan 60 (Swamy et al., 2020)
ISM	Blast	*Pi2+Pi54*	DRR Dhan 62
		Simultaneous introgression involving inter-crossing	
Swarna	Blast, BB, gall midge and drought	*xa5, xa13, Xa21, Gm4, gm8, qDTY1.1, qDTY3.1*	Dixit et al., 2020
Naveen		*Pi9, Xa21, Gm8, qDTY1.1, qDTY2.2, qDTY4.1*	Janaki et al., 2021
Lalat	blast, BB and drought	*Xa4, xa5, xa13, Xa21, Pi9, qDTY1.1, qDTY3.1, qDTY12.1*	Singh et al., 2021
Krishna Hamsa		*xa5, xa13, Xa21, Pi9, Pi54, qDTY1.1, qDTY2.1, qDTY3.1, qDTY12.1*	Badri et al., 2022

hence it was called as two-line method (*i.e*., PGMS and Non PGMS line).

Advantages of two-line v/s three-line system of heterosis breeding

- Wide choice of parental lines; hence increased chances of identifying heterotic hybrids.
- Seed Production system is simpler and more efficient.
- Risk of outbreak of epidemics associated with large scale use of unitary source of cytoplasm as well as the negative effects of sterility inducing cytoplasm are avoided altogether.
- Magnitude of heterosis in two-line hybrids is 5 to 10% higher than in three line hybrids.

Marker-assisted breeding

Conventional breeding selects genotypes indirectly through phenotypes of the plant, which is generally effective for qualitative traits only but not for quantitative and for traits to which are difficult to screen phenotypically. It is due to that quantitative traits with continuous variations are controlled by multiple genes and environmental factors. Over the past few decades, advances of molecular markers technology and genomics approaches have exerted extensive influences on the concepts of conventional rice breeding, allowing applications of modern breeding technology in rice. Molecular breeding refers to the development of new rice varieties by integrating modern biotechnology tools into conventional breeding methods.

Sequential introgression refers to incorporation of two or more genes/QTLs in the background of an earlier developed near isogenic line and at ICAR-IIRR, in the background of Improved Samba Mahsuri with inherent *xa5, xa13* and *Xa21*, DRR Dhan 58 (IET 28784), DRR Dhan 60 (IET 28061) and DRR Dhan 62 (IET 28804) have been developed and released as cultivars with introgression of Saltol QTL for salinity tolerance, *Pup1* QTL for low soil P tolerance and *Pi2* and *Pi54* for blast resistance, respectively (Swamy et al., 2020; Rekha et al., 2022) (Table 5). Simultaneous introgression on the other hand refers to introgression of multiple QTL and genes for two or more biotic and abiotic stress employing MABB coupled with several rounds of inter-crossing (Badri et al., 2022). Simultaneous introgression of multiple biotic and abiotic stresses has been reported in elite cultivars like blast, bacterial blight, gall midge and drought tolerance in the background of Swarna (Dixit et al., 2020) and Naveen (Janaki et al., 2021), blast, BB and drought tolerance in Lalat (Singh et al., 2021) and blast, bacterial blight and drought in Krishna Hamsa (Badri et al., 2022) (Table 5). An example of marker assisted introgression involving inter-crossing done at ICAR-IIRR for simultaneous introgression of resistance to bacterial blight, blast, BPH and gallmidge and tolerance to drought stress in the background of WGL 14 is given in Fig. 2.

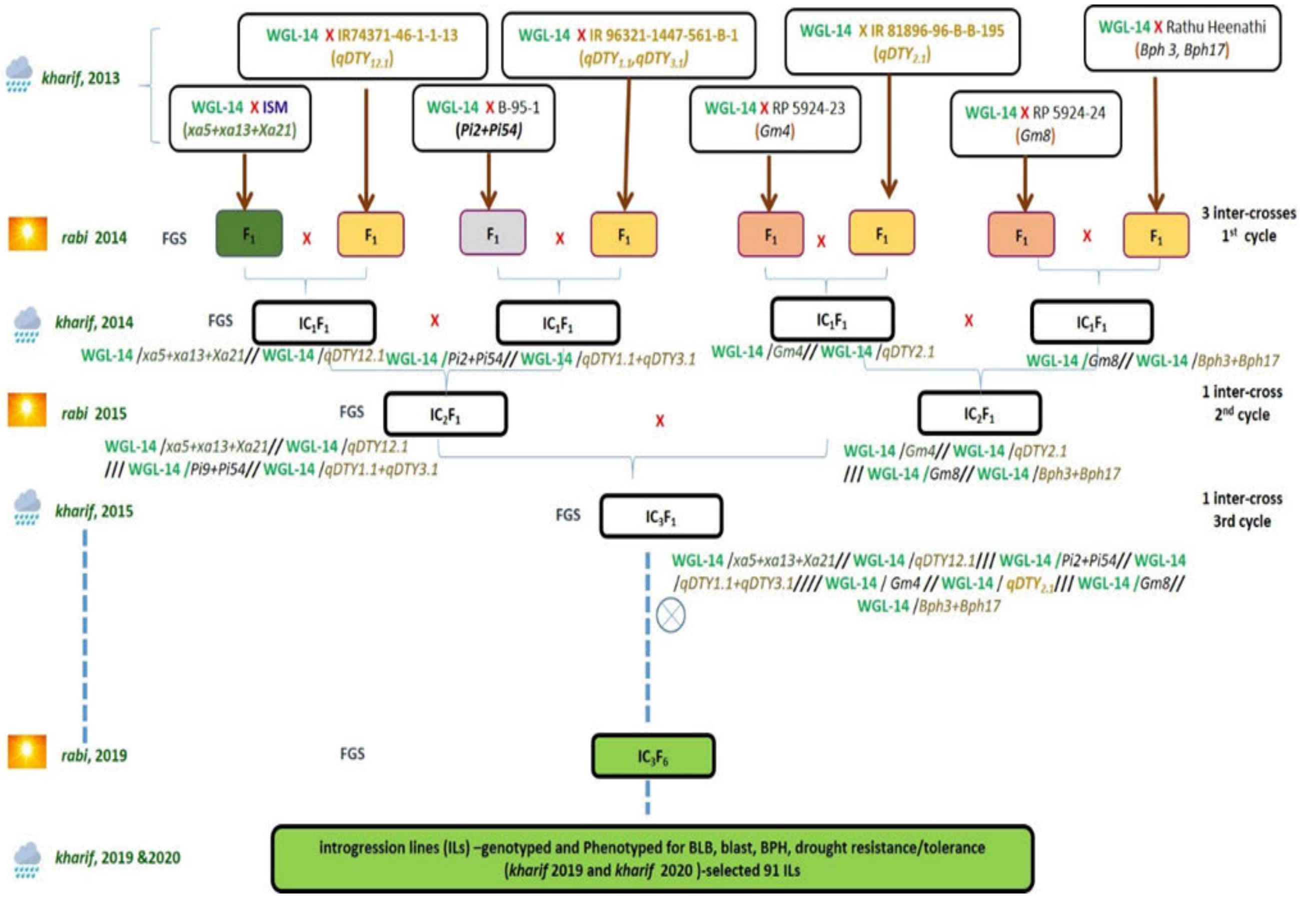

Fig. 2. Introgression scheme involving elite recurrent parent-WGL 14 and eight donor parents for bacterial blight, blast, gall midge, BPH and drought resistance/tolerance.

Many successful stories in rice have been reported wherein some of these resistance genes (Single or combination of genes) have been successfully incorporated into rice cultivars or parental lines of Hybrids that are extensively cultivated in many rice-growing countries (Huang et al., 1997; Singh et al., 2001; Rao et al., 2017). Genes/QTLs for important agronomic traits have been deployed in elite cultivar

Table 6. Biofortified rice varieties released with high Zn and protein in India.

S. no.	Released variety	Trait(s) improved		Year of release	Developer
		Zn (ppm)	Protein (%)		
1.	CR Dhan 310	-	10.3	2016	ICAR-NRRI, Cuttack
2.	DRR Dhan 45	22.6	-	2016	ICAR-IIRR, Hyderabad
3.	DRR Dhan 48	24.0	-	2018	-do-
4.	DRR Dhan 49	25.2	-	2018	-do-
5.	Zinco Rice MS	27.4	-	2018	IGKV, Raipur
6.	CR Dhan 311	20.1	10.3	2018	ICAR-NRRI, Cuttack
7.	CR Dhan 315	24.9	-	2020	-do-
8.	CR Dhan 411	-	10.1	2021	-do-
9.	DRR Dhan 63	24.2		2021	ICAR-IIRR, Hyderabad

NRRI: National Rice Research Institute; IIRR: Indian Institute of Rice Research; IGKV: Indira Gandhi Krishi Vishwavidyalaya

Table 7. Haplotype analysis based on re-sequencing of candidate genes.

Trait	Gene/ QTL	Genetic material	No of haplotypes	No of SNPs	Reference
Grain weight	*GW2*	93	10	4	Dixit et al., 2012
Red pericarp	*Rc*	202	4	4	Singh et al., 2017
Grain size	*GS3*		9	9	
Starch synthase	*BGSSI*		7	8	
	SSS1		46	17	
	SSIIa		5	7	
	SSIIb		4	6	
	SSIIIa		20	18	
	SSIIIb		7	11	
	SSIVa		19	12	
	SSIVb		9	9	
Heading date	*Ghd7*	200	21	47	Vemireddy et al., 2019
Grain number	*Gn1a*		25	12	
Grain size	*GS3*		111	89	
Seed width	*qSW5*		19	14	
Semi dwarf	*sd1*		17	28	

backgrounds through MAS/MABB and derived NILs have been released as varieties and are widely grown in the farmer's fields. Some of the examples of MABB developed cultivars are varieties for bacterial leaf blight resistance (Improved Samba Mahsuri, Improved Pusa Basmati 1, Improved Lalat, Improved Tapaswini, PR 124, Pusa 1592, PR 123, PR 122, PR 121, Pusa Basmati 1728, Punjab Basmati 3, Pusa Basmati 1718, CR Dhan 800, Punjab Basmati 4, Punjab Basmati 5, PR 127, DRR Dhan 53, DRR Dhan 59); Blast resistance (DRR Dhan 51, Pusa 1612, Improved Basmati 1609, Pusa Basmati 1637, Pusa Samba 1850); Bacterial and Blast resistance (DRR Dhan 62, Pusa basmati 1847, Pusa Basmati 1885, Pusa Basmati 1886); Bacterial blight resistance & seedling stage salinity tolerance (DRR Dhan 58); Bacterial blight resistance & low soil phosphorous tolerance (DRR Dhan 60); Submergence tolerance (Swarna Sub 1, Samba Sub 1, CR 1009 Sub 1, Ranjit Sub 1, Bahadur Sub 1, Co 43 Sub 1, IR 64 Sub 1, CR Dhan 803); Drought tolerance (DRR Dhan 42); Submergence & drought tolerance (DRR Dhan 50, CR Dhan 801, CR Dhan 802) and Herbicide (Imazethapyr) tolerance (Pusa Basmati 1979, Pusa Basmati 1985) [Yadava et al., 2022].

Breeding for biofortified varieties

The polished rice, the most preferred form for consumption is observed to consist promising grain zinc and protein content (Neeraja et al., 2022). The base line derived from Zn content in polished rice of the popular rice varieties ranges from <12-14 mg kg^{-1}, while even up to 35 mg kg^{-1} has been reported in rice germplasm (Haritha et al., 2022). The base line of protein in polished grain of varieties widely grown by the farmers is about 7 to 8 % (Chattopadhyay et al., 2018). Conventional breeding efforts deploying the existing genetic variability could increase of zinc and protein in polished rice leading to the release of nine biofortified rice varieties through All India Coordinated Rice Improvement Project (AICRIP) (Table 6). For the biofortified rice varieties to be released under AICRIP in India either their Zn content should be 24 mg kg^{-1} or their protein content should be ≥10 % in polished rice, yield should be on par with yield check genotype along with desired cooking quality (Rao et al., 2020).

Haplotype based breeding

Haplotype-based breeding, a recent promising breeding approach to develop tailor-made crop varieties, deals with identification of superior haplotypes and their deployment in breeding programmes (Sinha et al., 2020). The advances in genomics and other allied fields render a great opportunity for translational research in plants (Varshney et al., 2014). Several key genes associated with rice grain yield and related traits have been functionally characterized in the past. Various high-throughput OMICs platforms have been established in the past which aided in the functional characterization of several key genes controlling major traits in rice (Li

Table 8. List of gene utilized in rice for yield improvement using transgenic or genome editing approaches.

S. No	Gene Name	Approach	Cultivar	Trait	References
1	Gn1a/ OsCKX2	Knockout/ Genome editing.	japonica variety Zhonghua11 (ZH11)	The plants with loss?of?function of Gn1a created by CRISPR/Cas9?mediated gene editing or with the R498 null gn1a allele produced more grains and developed stronger culms.	Bin Tu et al., 2022
2	lncRNA LAIR	Overexpression	MingHui63 (MH63)	LAIR overexpression increases rice grain yield and upregulates the expression of several LRK genes.	Wang et al., 2018
3	TIFY	Overexpression	Nipponbare	The grains of TIFY11b-overexpressing plants exceeded those of non-transformants in length, width and thickness, resulting in 9-21% increases in grain weight.	Hakata et al.,2012
4	OsDREB1C	Overexpression	Nipponbare, Xiushui 134 (japonica)	OsDREB1C-Over Expressed plants exhibited 41.3 to 68.3% higher yield than wild-type (WT) plants due to increased grain number per panicle, elevated grain weight, and enhanced harvest index, flowered 13 to 19 days earlier and accumulated higher biomass at the heading stage than WT plants under longday conditions.	Shaobo Wei et al., 2022
5	WD40/	Knockout/Genome editing	Nipponbare OsKRN2	Knockout of KRN2 in maize or OsKRN2 in rice increased grain yield by ~10% and ~8%, respectively, with no apparent trade-offs in other agronomic traits.	Chen et al., 2022
6	OsBMY4 and OsISA3	Co-Overexpression		Systematic analyses of the transgenic rice indicated that co-overexpression of OsBMY4 and OsISA3 not only promoted rice yield and quality, but also improved seed germination and stress tolerance.	Wang et al.,2022/2023
7	OsOTUB1	Knockout using CRISPR/Cas	Japonica Chunjiang06	Down regulation of OsOTUB1 enhances meristematic activity, resulting in reduced tiller number, increased grain number, enhanced grain weight and a consequent increase in grain yield in rice.	Wang et al., 2017
8	ACYL-CoA-BINDING PROTEIN2 (OsACBP2)	Overexpression	Hwayoung and cv Zhonghua11	The overexpression of rice ACYL-CoA-BINDING PROTEIN2 increases grain size and bran oil content in transgenic rice.	Guo et al.,2019
9	OsSNB	Knockout/Genome editing	Nipponbare	OsSNB negatively regulate grain size. Knockout mutant plants by CRISPR/Cas9 technology showed increased grain length, width, and weight, while overexpression of *OsSNB* yielded the opposite.	Ma et al.,2019
10	GSN1	Knockdown	Japonica variety ZH11	The knockdown of GSN1 using an artificial microRNA in ZH11 resulted in significantly increased grain size and reduced grain number per panicle.	Guo et al., 2018
11	GIF1	Overexpression	japonica Zhonghua 11	Transgenic lines had larger and heavier grains.	Wang et al.,2008

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12	GNS4	Overexpression	Nipponbare and Wuyunjing7	Overexpression of GNS4 significantly increased organ size, 1000-grain weight, and panicle size, and subsequently enhanced grain yields in both the Nipponbare and Wuyunjing7 (a high-yielding cultivar) backgrounds.	Zhou et al.,2017
13	OsDof12	Overexpression	Nipponbare (Japonica)	Overexpressed OsDof12 mutant plants showed reduced plant height, erected leaf, shortened leaf blade, and smaller panicle resulted from decreased primary and secondary branches number.	Wu et al., 2015
14	miR396	RNA Interference	Yuetai-B (Indica)	Blocking miR396 greatly increased the grain yield by modulating development of auxiliary branches. and spikelets through direct induction of the growth regulating factor 6 (OsGRF6) gene.	Gao et al., 2015
15	DST	Knockdown/RNAi	Zhefu 802 (ZF802), a cultivated Indica rice variety in China	DST RNA interference (RNAi) transgenic plants showed increased panicle branches and enhanced grain number.	Li et al., 2013
16	DEP1	Knockdown/RNAi	Shao 314 (Nipponbare)	Enhanced panicle branching and grain yield	Huang et al., 2009
17	SP3	Knockout/Genome editing	Nipponbare	In this study, Short Panicle 3 (SP3) was identified from a short panicle 3 (sp3) mutant in which T-DNA was inserted in the promoter of SP3, resulting in a knockdown mutation.	Huang et al., 2018
18	TAC1	Knockout	indica variety ZH8015& japonica variety 02428	Knock-out lines showed compact plant architecture.	Wang et al., 2022
19	OsASN1	Overexpression	Hwayoung, Dongjin, Japonica	The OsASN1 Overexpressed rice plants produced grains with increased N and protein contents without yield reduction compared to wild-type (WT) rice.	Lee et al., 2020
20	OsSPL7	Knockdown/RNAi	Japonica (ZH11)	Plants overexpressing OsSPL7 had a reduced tiller number, while OsSPL7 RNAi plants had an increased tiller number and a reduced height.	Dai et al., 2018
21	OsSPL16	Knockout/Genome editing	Indica rice variety VP4892	To increase the grain size in rice, OsSPL16/qGW8 was mutagenized through CRISPR/Cas9. CRISPR/Cas9 mediated mutant lines showed a significant increase in grain yield without any change in other agronomic traits in T0, T1, and T2 generations.	Usman et al., 2021
22	GW2	Knockout/Genome editing	Indica rice variety MTU1010	Endosperm of GW2-KO mutant seed displays a thick aleurone layer with enhanced grain protein contentwith increased mineral content. Additionally mutantsdisplayed early growth vigour, improved, grain filling with an improved root and shoot architecture.	Acharyet al., 2021
23	OsAT1	Knock-down	Japonica (ZH11)	Knock-down of OsAT1 in rice reduces copper accumulation and improves the accumulation of storage starch, hence, increasing the grain size and weight.	Liu et al., 2022

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24	MIR396e/ MIR396f	Knockout/Genome editing	Oryza sativa L. spp. Japonica, varNipponbare	Knockout of MIR396ef (MIR396e and MIR396f), enhanced both grain size and panicle branching, resulting in increased grain yield.	Zhang et al.,2020
25	REG1	Overexpression	Indica variety 5150 R498 and 93-11	Transgenic plants overexpressing the reg1 mutant allele of DST (DSTreg1) had increased panicle branches and produced more grains	Li et al., 2013
26	Rab6a	Overexpression/RNAi	(Oryza sativa L. ssp. japonica) cv. Zhonghua 10	Under elevated CO2 conditions, growth and grain yield of the Wild type and OsRab6a-over expressed plants were enhanced, with a greater effect being observed in the latter, while no effect was observed on OsRab6a-RNAi plants	Yang et al.,2020
27	OsMKKK 10-OsMKK 4-OsMAPK6	Overexpression	japonica variety Kuanyejing	Overexpression of constitutively active OsMKKK10(CA-OsMKKK10) causes large and heavy grains, long panicles and tall plants in rice.	Xu et al.,2018
28	OsmiR530	RNAi	Nipponbare	OsmiR530 negatively regulates grain yield. Blocking OsmiR530 increases grain yield	Wei Sun et al.,2019
29	FZP	RNAi	Nanyangzhan and Chuan 7	Three independent FZP RNA mediated-interference (RNAi) lines (T2) had significantly decreased FZP expression, and had more secondary branches, a higher number of SPP and a smaller grain size. The rare CNV-18bp duplication leads to decreased FZP expression, thus resulting in increased grain yield per plant.	Bai et al., 2017
30	OsMFT1	Knockout/Over Expression	japonica rice variety Zhonghua 11	Overexpressing OsMFT1 delayed heading date by over 7 days and greatly increased spikelets per panicle and the number of branches. In contrast, OsMFT1 knockout mutants had an advanced heading date and reduced spikelets per panicle.	Song et al., 2018
31	Ghd7	Overexpression	Zhenshan 97 and Minghui 63	Enhanced expression of Ghd7 under long-day conditions delays heading and increases plant height and panicle size.	Xue et al., 2008
32	miR1432	RNAi	Lijiangxin Tuan Heigu (LTH) Nipponbare (ssp. Japonica)	Overexpression of miR1432 leads to compromised resistance against blast and decreased yield, whereas blocking miR1432 using a target mimic of miR1432 results in enhanced resistance and yield.	Li et al.,2021
33	AP37	Overexpression	Oryza sativa (cultivar not specified)	The overexpression of AP37 in rice under the control of the constitutive promoter OsCc1 increased the tolerance to drought and high salinity at the vegetative stage & plants showed significantly enhanced drought tolerance in the field, which increased grain yield by 16% to 57%.	Se-Jun Oh et al.,2009
34	NOG1	Overexpression	-	Overexpression of NOG1 can increase the grain yield by 19.5% without a negative effect on the number of panicles per plant or grain weight.	Xing Huo et al.,2017

et al., 2018). About 2296 genes associated with various traits such as rice grain yield (189 genes), growth and development (513 genes), disease resistance (221 genes), nutrient-use efficiency (207 genes), fertility (174 genes), floral organ and heading date (276 genes), phytohormone (472 genes), insect resistance (31 genes), grain quality (63 genes), stress responsiveness (367 genes) etc., are cloned and functionally validated (Wing et al., 2018).

Targeted re-sequencing of the key genes controlling major traits in various diverse germplasm lines would aid in identifying and exploring allelic/haplotype variations. The positive phenotypic association with the allelic/haplotype variation would lead to identification of superior haplotypes, novel donors and novel alleles for the trait of interest. There are a few reports in the recent past on the haplotype identification based on the targeted re-sequencing of the candidate genes *viz*., grain weight, red pericarp, grain size, starch synthase, heading date, grain number, grain size, seed width and semi dwarf stature (Table 7). Dixit et al. (2013) investigated the haplotype diversity of GW2 locus in 93 indica and aromatic rice germplasm and identified four new SNPs. Using the four new SNPs, they constructed a total of ten haplotypes,however, they did not have any association with grain traits. Singh et al. (2017) analyzed haplotype networks and phylogenetic relationships in a 202 diverse set of genotypes including Indian *Oryza nivara*/*Oryza rufipogon* wild rice accessions and representative varieties of four rice cultivar groups based on pericarp color (Rc), grain size (GS3) and eight different starch synthase genes (*GBSSI, SSSI, SSIIa, SSIIb, SSIIIa, SSIIIb, SSIVa*, and *SSIVb*). They identified 4-18 novel SNPs and constructed about 4-46 haplotypes which supported polyphyletic origin of cultivated rice with a complex pattern of migration of domestication alleles from wild to different rice cultivar groups. Based on the targeted resequencing of six key genes influencing the yield, such as *DEP1, Ghd7, Gn1a, GS3, qSW5* and *sd1* in 200 rice genotypes, Vemireddy et al. (2019) identified 91 superior haplotypes that showed significant association with the yield related traits based on targeted resequencing.

The rice gene bank collections serve as a potential source of allelic diversity for important genes and availability of 3K rice genome in the public domain holds great promise for harnessing genetic diversity in rice (Li et al., 2014). Phenotyping of the sub-sets of 3K RG for the trait of interest would aid in the identification of superior haplotypes of previously cloned genes and newly identified marker trait associations. Abbai et al., 2019 analyzed the haplotype diversity of about 120 previously characterized major genes that influence grain yield and grain quality in rice across the entire 3K RG panel and found that 21 among them influence the target grain yield and quality traits in the target environment. They also identified superior haplotypes for each documented trait which could be employed in haplotype-based breeding.

Transgenic and genome editing approaches to enhance the grain yield in rice

Rice yield and productivity can be enhanced by over-expression, knock-down or knock-out approaches through either enhancing the expression of genes or their suppression. The past two decades have witnessed tremendous progress in rice genomics, sequencing and re-sequencing of more than 3000 accessions, QTLs discovery, gene mapping, and functional genomics leading to better understanding of gene regulations and their function coordination in determining the grain yield. Many genes in rice associated with grain yield characteristics such as grain number/panicle, panicle architecture, panicle branching, grain weight, grain length, grain width etc. have been identified and characterized (Xing and Zhang, 2010; Li et al., 2022). In addition to protein coding genes, microRNAs and long non-coding RNAs (lncRNAs) determining the grain yield in rice have been identified and validated. The powerful biotechnology tools have been employed to harness the potential of these well characterized genes and microRNAs for enhancing the grain yield. There are number of genes whose over-expression resulted in yield enhancement by improving one or more yield components (Table 8). Most recently, Wei et al., (2022) deciphered the critical role of dehydration-Responsive Element-Binding Protein 1C (*OsDREB1C*) in yield enhancement in rice. The *OsDREB1C* is a member of *APETALA2*/ethylene-responsive element binding factor family. The over-expression of *OsDREB1C* (*Os06g0127100*) in *Oryza sativa* cv. *Nipponbare* resulted in 13 to 19 days earlier flowering and 41.3 to 68.3% higher grain yield than the non-transgenic plants. The enhanced yield was recorded due to increased grain number/panicle, enhanced grain weight and harvest index. The *OsDREB1C* interacts with several genes associated with key physiological processes such as nitrogen utilization, photosynthesis, and flowering, thereby enabling the over-expression plants to yield more under low nitrogen conditions. The high expression alleles of *DREB1C* can be explored in rice germplasm for their utilization in breeding programs. Alternatively, the promoter or enhancers of such genes can be edited to increase the expression in original background to obtain high grain yield under low nitrogen conditions. To utilize non-coding RNAs for yield enhancement, Wang et al. (2018) over-expressed alncRNA named LAIR (LRK Antisense Intergenic RNA) in rice MH63 under 35S Cauliflower Mosaic Virus (CaMV) promoter. The over-expression of LAIR up-regulated the expression of many leucine-rich repeat receptor kinases (LRKs) and resulted in more grain yield due to larger primary panicles and more panicles per plant. More intensive research on discovery and characterization of lncRNAs is necessary for effective utilization of these unexplored genetic elements in crop breeding. Similarly, over-expression of miRNA397 enhanced overall 25% grain yield under field trial. The over-expression of miRNA397 under CaMV35S promoter resulted in down regulation of its target gene LOC_Os05g38420 (OsLAC) that encodes laccase like protein. The miRNA over-expression plants showed slightly reduced tiller numbers and early flowering (Zhang et al 2013). In addition to over-expression, the genome editing of yield genes has been attempted to increase the grain yield. Li et al (2016) developed genome edited lines of *Gn1a, DEP1, GS3*, and *IPA1* genes using Clustered regularly interspaced short palindromic repeats (CRISPR)/CRISPR associated protein 9 (*Cas9*) approach in the background of *Oryza sativa* L. ssp. *japonica*. Zhonghua 11. The edited lines showed significant increase in the trait components associated with grain yield. Interestingly, the CRISPR/Cas9 based editing of pyrabactin resistance 1 (PYR1)/PYR1-like (PYL) ABA receptors, particularly PYL1, PYL4, and PYL6, resulted in improved growth and yield of rice due to longer panicle, more primary and secondary branches in panicle, and increased spikelet number per panicle. Overall, 25-31% yield increase was reported in field conditions (Miao et al., 2018).

CONCLUSION

Conventional breeding focussing on improvement of plant morphology together with the right policy interventions in to the green revolution era ensured our country's food security through enhanced rice productivity and production in the 70s and 80s. Post green revolution era, several innovative breeding approaches like heterosis breeding, plant type based breeding, concerted pre-breeding, marker-assisted breeding, etc. have stabilized rice production in the country and presently the surplus rice production is targeted for export markets. However, considering the threats posed by factors such as climate change, dynamic pest and pathogen populations, anticipated reduction in rice area and also considering plateauing rice yields in the recent decades, a radical shift in our rice breeding approach is warranted. Marker-assisted breeding efforts should focus on utilizing the knowledge gained in rice genomics and efforts on genomics-assisted breeding should be accelerated for improving the yield levels of varieties and rice hybrids. Increased emphasis should also be given for understanding the physiological basis of yield associated traits in rice for their better manipulation through breeding.

ACKNOWLEDGEMENT

The authors thankfully acknowledge the financial support provided by the Indian Council of Agricultural Research, Department of Biotechnology, Govt. of India, Department of Science and Technology, Govt. of India and the International Rice Research Institute, Philippines. They also thank the kind support and facilitation provided by the past Directors of ICAR-IIRR, Hyderabad, India.

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Oryza Vol. 60 Special Issue 2023 (21-44)
DOI https://doi.org/10.35709/ory.2023.60.0.2

Genetic diversity of indigenous aromatic rices of Odisha and its use for economic development of rural poor

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Received : 01 February 2023 Accepted: 04 February 2023 Published : 07 February 2023

INTRODUCTION

Rice is a unique creation of crop plant domestication; it is unique in having cultivars of maturity duration varying from less than 80 days to more than 180 days and showing adaptability to a wide range of land situation and water regimes including conditions of water stagnation where no other crop could possibly be grown. Jeypore tract in South Odisha has been identified as a putative secondary center of origin of cultivated rice (Ramiah and Ghose,1951; Ramiah and Rao, 1953).The regions comprising western Odisha, Jharkhand and Chhattisgarh is recognized as the centre of origin of only aus ecotypes of rice (Sharma et al., 2000).

Rice in Odisha is synonymous with food and agriculture to a considerable extent means growing rice. Age-old social customs and festivals in Odisha have strong relevance to different phases of rice cultivation: Akhyatrutiya in May-June marks the seeding of rice, Rajasankranti in mid-June marks the completion of sowing, Garbhanasankranti in October symbolizes reproductive phase of long duration photosensitive rice while Nuakhaee and Laxmipuja coincide with harvesting of upland and lowland rice respectively. Makarsankranti in mid-January is celebrated as Chaita Parab by the tribal people as by this time rice is threshed and brought to the granary (Das, 2012).

Agriculture is the mainstay of state economic and substance of life of the people. Odisha is an agrarian state with agriculture and allied sectors contributing 17.49% of Net State Domestic Product (NSDP) in 2011-12 and 15.35% to Gross State Domestic Product (GSDP) at current prices and providing employment, to 70% of its population as per 2001census. Therefore, Agriculture plays an important role in the economy and livelihood of the people of the state (Odisha Agricultural Statistics, 2018-19)

Rice covers more than 70 percent of cultivated area and is the major crop covering about 63 percent of total area under food grains. It is the staple food of almost entire population of Odisha, therefore, the state economy is directly linked with the improvement in production and productivity of rice in the state Presently rice in Odisha is grown over an area of 3.71 million hectares, which accounts to 91 percent of the area under cereals and contributes about 93 percent of total cereal production in the state.

Despite its economic, strategic, and cultural importance, rice productivity in Odisha is one of the lowest in the country. The state remained untouched by the effects of the Green Revolution for three decades since the mid-1960s, with paddy yield hovering around 1.5 tons per hectare. This has resulted in a decline in its share in the country's rice production from more than 11% in the pre-high yielding variety period to less than 8% in recent years. However, in the past 15 years, the rapid increase in yield growth saw paddy yield increasing from 1.5 tons per hectare in the mid-1990s to more than 2.5 tons per hectare now. Despite this, the average paddy yield in the state is still well below the national average of more than 3 tons per hectare. In the last four decades, rice area in the state has been stagnant at 4.5 million hectares, with production growth completely dependent on yield growth (Mohanty et al., 2012).

Odisha has been considered as the centre of origin and genetic diversity for the cultivated rice. Thousands of rice varieties were cultivated in Odisha earlier and even after the spread of the high yielding rice varieties, the farmers are still cultivating hundreds of these traditional types. Many traditional rice varieties like Bobblibhuta, Mahulakunchi, Kulia, Kulia sankar, Kumarmani, Anjana, Benibhog, Chhetka, Kalakeri and Badamfarm etc. for rainfed uplands; Barangachudi, Sarumundabali, Assam chudi, Boropanko, Saruchinamali, Rangalata, Kakudimanji etc. for medium lands; Karandi, Bayahunda, Ratnachudi, Galleiganthi, Dudumani, Padmakeshari, Machhakanta, Magura, Kalambanka, Cuttackchandi, Mahipal, Mayurakantha, Champeisiali, Kedargouri, Champa etc. for lowlands and Sanakalasura, Badakalasura, Matiaburus, Khajuria chanar, Bankosa, Pani begunia, Potia and Pateni etc. for semi-deep water situations are grown in the state. Majority of these traditional cultivars are low yielders and their low yielding ability is primarily due to tall stature, weak culm making them susceptible to lodging, low tillering ability and poor panicle features. These cultivars were grown for specific traits like maturity duration, plant stature, panicle features, yield potential, tolerance to biotic and abiotic stresses and other elusive traits like aroma, cooking quality and grain quality.

However, in recent years, the development and spread of semi-dwarf high yielding rice varieties replaced the diversity of these locally adapted varieties developed by the farmers over generations. Thus, the loss of diversity and genetic erosion is a serious concern. The traditional varieties grown by the farmers are likely to be lost in near future if measures are not taken to protect the valuable genetic resources. Recently the Directorate of Agriculture & Food Production, Government of Odisha has taken a massive effort for collection of more than 1000 indigenous rice varieties still available with the farmers from different districts of the state. Efforts are being taken for their systematic evaluation and characterization during the current wet season. It is proposed to register them as farmer's varieties with all passport traits in Protection of Plant Varieties and Farmer's Rights authority, Ministry of Agriculture, Government of India (Das, 2012).

These traditional tall types are still favoured by the farmers in rainfed uplands, semi-deep and deep-water situations and saline areas of the state. Despite their low yield potential, they are preferred due to a number of favourable traits like early seedling vigour, rapid germination, deep root system with higher proportion of thick roots, superior grain quality, better yield stability and tolerance to moisture stress, submergence and salinity. Dixit and Challam collected nearly 3000 rice germplasm mainly from the six districts then constituting the State of Odisha: Balasore, Cuttack, Puri, Ganjam, Koraput and Sambalpur. Some of the traditional talls like Kalakartik in Sambalpur district; Saruchinamali in Cuttack and Puri districts, Bayahunda and Ratnachudi in Ganjam district; Karandi in Koraput district; Machhakanta, Pateni and Kalambanka in Balasore district and Magura in Puri and Cuttack districts are most adaptable types and are widely grown (Mohanty et al., 1995 and Das, 2012).

The traditional rice varieties have been explored, collected and conserved in NRRI, Cuttack, Odisha. The Central Rice Research Institute, under an ICAR project known as Jeypore Botanical Survey, collected about 1745 accessions of cultivated rice and 150 accessions of wild rices from the Jeypore tract of Odisha. These are known as JBS varieties. In recent years the CRRI and NBPGR have collected almost all the traditional rice varieties of Odisha numbering about 2000 and which are conserved in the medium term storage at CRRI and in the long term storage at NBPGR (Pani and Patra, 2004)

Aromatic land races and their importance for economic developments of farmers of Odisha:

It has been estimated that more than 100 varieties of traditional aromatic rices with pleasant aroma are grown in various parts of the state. These indigenous scented rices mainly Kalajeera, Neelabati, Krushnabhog, Govindabhog, Padmakeshari, Tulasiphoola, are predominant in coastal belts, while a few number of traditional scented varieties like Pimpudibasa, Jubaraj, Karpurakranti, Badsabhog, Kalikati, Laxmibilas and Makarakanda are common in the plateau regions of the state (Table 1 and Fig. 1)

Aromatic or scented rices have occupied a prime position in Indian society. The Basmati types like Basmati 370, Kernal local, Pusa Basmati 1, Taroari

Table 1. Varietal distribution of aromatic rices in Odisha.

Sl. no	Name of the variety	Name of the districts where it is grown
1	Kalajeera	Kendrapara, Puri, Rayagara, Sambalpur, Kalahandi, Ganjam, Jagatsinghpur, Jharsuguda, Dhenkanal
2	Jubraj	Keonjhar, Deogarh, Sambalpur, Jharsuguda, Bolangir,Sonpur, Bargarh, Nuapara
3	Karpurakranti, Gaganadhuli, Suragaja, Laxmibilas	Bolangir,Deogarh,Sambalpur,Raygara, Kalahandi
4	Mugajai, Rangasura, Makarakanda	Phulbani, Rayagada,
5	Karpurakeli, Kusumakenda, Nababi	Nayagarh,Khurda, Sambalpur, Angul, Kalahandi
6	Chinikamini, Saragadhuli, Padmakeshari	Puri, Cuttack, Khurda, Kendrapara ,Dhenkanal
7	Pimpudibasa	Keonjhar, Mayurbhanj, Angul
8	Durgabhog	Keonjhar, Mayurbhanj, Phulbani
9	Krushnabhog, Kalia	Puri, Angul,Dhenkanal
10	Govindabhog	Cuttack, Ganjam,Khurda, Puri
11	Kalikati	Kalahandi; Rayagada, Nabarangpur, Sonepur,
12	Thakurabhog	Puri,Cuttack,Jagatsinghpur,Jajpur
13	Badshabhog	Bolangir, Koraput, Kalahandi
14	Tulasiphoola	Puri,Cuttack, Jagatsinghpur,Kendrapara
15	Gangaballi	Ganjam,Gajapati,Kalahandi
16	Jabaphoola, Jaiphula	Nuapara, Sambalpur
17	Lectimachi	Koraput,Nawrangapur,Kalahandi
18	Basapatri, Malpatri	Bargarh,Sonepur, Sambalpur
19	Acharamati	Kalahandi,Nawapara
20	Leelabati	Balasore, Bhadrak

Basmati, Type 3 etc. among them enjoy a unique place for three distinct quality features like pleasant aroma, extra-long superfine grain and extreme grain elongation and soft texture of cooked rice. On the contrary the scented rices traditionally grown in the state have pleasant fragrance with small and round grains, white colour and softness without much elongation on cooking (Fig. 2). The small and medium grain aromatic rices are regarded as a separate class of non-basmati aromatic rice (Singh et al., 2000)

Fig.1. Indigenous aromatic rices of Odisha.

The areas of cultivation of the traditional basmati types are limited due to non-retention of their aroma when grown in relatively warmer parts of Odisha and the adjoining Eastern-Indian states. However, the scented rices indigenously grown in the state usually have small and round grains without much elongation on cooking but have very strong aroma under the prevailing warmer climate during grain maturity period in *kharif* season.

No concrete information on the exact area under aromatic rices in Odisha is known. However, Roy et al. (1983); Dikshit et al. (1992) and Malik et al. (1994) during collection of rice germplasm in the state observed that these aromatic types are grown in small pockets, practically in every districts of the state. It is estimated that about one percent of the total rice area *i.e.*, 40-50,000 hectares is put under scented rice cultivation with a production level of 30-35,000 tons of aromatic rices annually in the state.

However, due to their inherent low yield potential only big and affluent farmers afford to grow them for their personal consumption and a very small

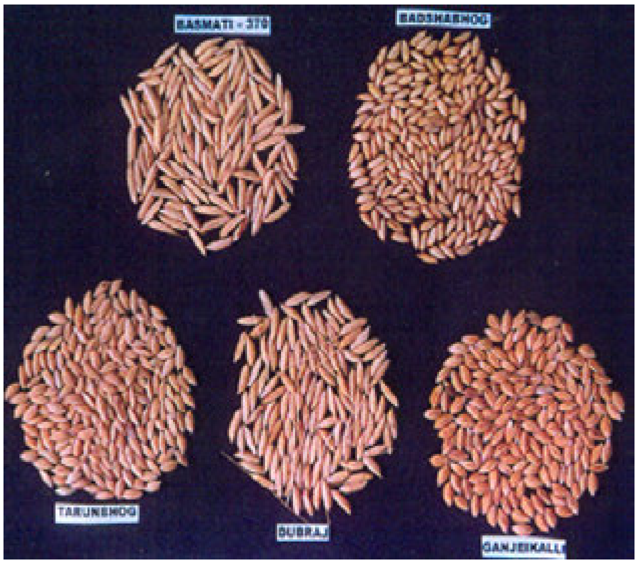


Fig. 2. Long grain Basmati and short grain non-basmati aromatic rice varieties.

fraction comes to the market. A survey of the rural as well as urban markets indicated that generally these small and round grain aromatic types of local origin are sold with a price range of Rs. 100-150 per kg (about double the price of normal non-aromatic rice). Therefore, there is a continued demand for the production and marketing of these indigenous scented rices for socio-economic developments of the farmers of Odisha

Genetic Improvement of aromatic rices of Odisha:

Like several other states, Odisha has its own set of aromatic rices. The names of the rice varieties like Krishnabhog, Prasadbhog etc. indicate that they were used in temples while the names like Badsabhog, Raj bhog, Kaminibhog etc. signify their need in royal palaces for kings and emperors in the past (Gangadharan, 1985). Even now these aromatic types are cultivated in areas under the control of temples for their subsequent use as 'prasads' in different sacred places of the state.

These cultivars were developed by the farmers and were maintained under different names often on the basis of their morphological and grain features, quality and the originating locality. However, due to adoption and spread of semi-dwarf high yielding varieties, the traditional tall scented varieties with poor yield potential are only confined to small pockets of their native area of cultivation. Unfortunately, no systematic effort has been made so far, for the collection, evaluation and genetic improvement of these much-valued short grained scented rices of the state which will help all categories of farmers to fetch more prices and also the consumers to get quality scented rice at a reasonable cost (Das et al., 2003).

Germplasm Collection, Characterization and Evaluation

The Jeypore tract of Odisha is known as a putative secondary center of origin of cultivated rices in India and Koraput district in particular owns overwhelming rice diversity. In Odisha University of Agriculture & Technology, Bhubaneswar efforts were made to collect indigenous scented rice varieties available in different parts of the state under an ICAR adhoc project and RKVY project on "Improvement of Short grain Aromatic rices for increased productivity and Export in Odisha State" during the period from 1997-2003 and 2007-2010 respectively. Special collection trips were made and helps were taken from the Directorate of Agriculture, Odisha, District Agricultural Officers and VAWs to collect material from remote areas.

The programme yielded a collection of 115 local scented varieties. Characteristically, these varieties were tall, prone to lodging at maturity, having seed dormancy and poor in yield. However, they were highly adapted to local conditions, had field tolerance to pests and diseases and better cooking qualities. During seed increase and purification of material at Rice Research Station, Bhubaneswar, it was observed that despite agronomic uniformity, the majority of collections showed heterogeneity for several quantitative traits. It is thus, obvious that the farmers used land races which even though more or less uniform for agronomic traits often were heterogeneous for several other quantitative traits which provided a sort of genetic resilience for their adaptability to the varied agro-climatic conditions (Das et al., 1990).

Realizing the importance of short grain aromatic rices for economic development of rural poor, an attempt has been made to evaluate 65 indigenous short grain aromatic rice varieties collected from different parts of the state along with Pusa Basmati-1 and Lalat as traditional Basmati and non-aromatic high yielding checks respectively to assess the genetic variability, nature and magnitude of character association, path analysis, multiple criteria of selection for identification of promising cultures, nature of genetic divergence, stability analysis and nitrogen response and N use efficiency of selected aromatic rice.

Study of Variability

The genetic variability in respect of a character is the direct measure as to how far it could be manipulated in a desirable direction. Analysis of variance measured for nine quantitative traits including yield and twelve physiological parameters showed highly significant differences among the test genotypes in respect of all the characters. The magnitude of variability in respect of mean, range, co-efficient of variation for all the nine different traits indicated that the test genotypes could be placed in mid-early to medium maturity duration groups, intermediate to tall plant types with medium to long panicle length, moderate panicle number, moderate number of grains with improved fertility, low 100-grain weight and moderate grain yield.

In the context of the variability of the above mentioned traits and in the light of the views of Prof. L. P. Yuan it may be mentioned that the plant type should be characterized by tall erect-leaf canopy (~125 cm) *i.e.,* Plant height of at least 100 cm (from soil surface to unbent plant tip) and panicle height of 60 cm (from soil surface to the top of panicles with panicles in natural position) at maturity, with moderate tillering capacity (270-300 panicles/ m^2)., medium-medium late duration (135-145d), long upper three leaves (50-55 cm) and all three leaves are above panicle height, should remain erect until maturity. Leaf angles of the flag, 2nd, and 3rd leaves are around (50,100 and 200) respectively, narrow thick V-shaped leaves (2 cm leaf width when flattened) and (specific leaf weight of top three leaves 55 g/ m^2), Leaf Area Index (LAI) of top three leaves is about 6, long panicle, high number of spikelets (190/ panicle) with higher percentage of grain filling (>80) and relatively higher test grain weight (26-28 gm. /1000 grains), high harvest index (0.55) and healthy and active root system. The combination of such traits in a genotype ensures LAI above 6, with higher RUE, HI more than 0.5 and medium late maturity can yield as high as 18 t/ha. Prof. Yuan believes that designing of such genotypes with a unique set of characteristic would not be difficult, as these proposed traits are simply inherited (Siddiq, 2013).

Heritability and genetic advance

The heritability in broad sense and genetic advance as percentage of mean estimated for all the traits. . As genotypic variance for a trait alone may not reflect the heritable proportion of variation, hence such studies assume special significance for consideration of the magnitude of different components related to the total genetic variations. Though heritability is the genetic property of a character, it is much influenced by the genotypic architecture, background history of the plant population and genotype-environment interaction. It is also subjected to certain experimental error (Falconer, 1960; Kaul and Bhan, 1974; Mather and Jinks, 1977). As genetic advance in conjunction with heritability gives a more reliable index value than heritability alone, therefore, efforts were made to indicate both heritability and genetic advance values for various traits estimated during the present investigation.

A moderate to high degree of heritability estimates were associated with moderate to high genetic gain for plant height, panicle length, fertile grain number, 100-grain weight, flag leaf area, harvest index, grain yield per plant, plot yield, relative growth rate, crop growth rate, net assimilation rate, leaf area index, leaf area ratio, relative leaf area growth rate and leaf area duration indicating the presence of additive gene effect and hence selection based on phenotypic performance would be effective (Akter et al., 2019; Singh et al., 2020; Sudeepthi et al., 2020).

The characters like days to 50 per cent flowering, and fertility percentage exhibited moderate to high heritability value and moderate to low genetic gain, suggested that inheritance of such traits might be under the control of both additive and non-additive gene effects (Longjam and Singh, 2019; Nanda et al., 2021).

Low to moderate heritability estimates with moderate to high genetic gain were observed for traits like relative leaf growth rate and total dry matter production at maturity indicated that inheritance of such traits is governed by additive gene effects. The low heritability as being exhibited due to high environmental effects, hence selection based on phenotypic performance may be effective (Murty et al., 1999).

Low to moderate heritability estimates with moderate to low genetic gain were observed for panicle number, leaf weight ratio, specific leaf weight and specific leaf area suggested that dominance and epistatic gene effects might be operating in the inheritance of these traits which indicates that these characters are highly influenced by environmental effects and selection would be ineffective (Gebregers and Mekib, 2020; Patel and Patel, 2020).

A review of literature from the published reports on heritability and genetic advance indicated very inconsistent results by Nithya et al. (2020) and Bhargavi et al. (2021). However, the anomalies observed in the estimates of heritability and genetic advance in various morpho-physiological and metric traits from large volume of research publications are possibly due to difference in composition of the test materials. Furthermore, the inter-genotypic competition resulted from single plant measurements might have reduced or inflated the apparent additive-dominance variance and consequently affected heritability estimates for various characters under study.

Nature of Character association

Grain yield exhibited positive correlation with days to 50% flowering, panicle number, number of fertile grains / panicle, fertility percent and harvest index. It was interesting to note that panicle number exhibited positive association with grain yield per plant but negatively correlated with almost all the component traits and therefore the utility of this trait in improving yield potential is doubtful (Kumar et al., 2019; Hossain et al., 2020; Nath and Kole, 2021).

Further, the number of fertile grains / panicle exhibited positive association with fertility percentage, plant height and days to 50% flowering but was negatively associated with 100- grain weight. As expected grain number was found to show negative association with 100-grain weight and which might have been resulted due to compensating mechanism. It is a foregone conclusion that where genetic selection has been made for large seeds, there has usually been compensating decrease in grain number, therefore, the best means to increase grain yield may be to select for more number of grains per panicle and allow the seed size to move as more or less a random variable (Grafius et al., 1976).

The positive association of both plot yield and grain yield per plant with harvest index during the present investigation (Dhavalesvar et al., 2019; and Arathi et al., 2019) reflects that yield is a function of total dry matter and harvest index and yield can be increased by increasing biomass or harvest index or both (Khush and Virk, 2000; Virk et al., 2004). In other words the physiological efficiency of crop plants broadly includes higher biomass production and efficient translocation of dry matter for realization of high yield. Increasing biomass production is determined by higher photosynthetic rate, high photosynthetic area, slow leaf senescence, high nitrate assimilation, high nitrate reductase activity, low respiration and photorespiration, high uptake and accumulation of nitrogen and minerals during early phase of growth. Efficient translocation of dry matter includes total dry matter production and partitioning of dry matter between grains and other plant parts. This is determined by large and active sink (high grain number per unit area and stability in grain number, high grain weight and lower spikelet sterility) thus reflecting high harvest index and increased yield (Siddiq et al., 2013).

High positive correlation existed between crop growth rate, relative growth rate, net assimilation rate, relative leaf growth rate and leaf area index. Leaf area index found to exhibit positive association with leaf area ratio, relative leaf growth rate, relative leaf area growth rate and strongly associated with leaf area duration. Further grain yield was found to exhibit positive association with leaf area ratio, leaf weight ratio, specific leaf area, leaf area index and leaf area duration, which is in agreement with the results obtained by Venkateswarulu et al. (1977);Sharma and Singh (2000); Laza et al. (2001) and Pradhan and Das (2001). These correlations clearly reflect that leaf is the ultimate functional source of increased biomass production and their translocation through efficient transport network to the sink for higher yield. This can be achieved by developing genotypes with higher leaf area and rapid area development to establish a desirable canopy structure for realization of high yield in rice. Various published reports thus clearly indicate that these traits may be considered as important selection criteria for further exploitation of potential yield in rice.

Analysis of path coefficients

Path analysis has been used to organize the relationship between predicted variables and responsible variables. To understand direct and indirect effects of each character on grain yield and the application of selection pressure in a better way for yield improvement, partitioning of correlation coefficient into direct and indirect effect through path coefficient analysis is very important.

The leaf area index exhibited maximum positive direct effect on grain yield followed by harvest index, net assimilation rate, fertile grain number, panicle number, leaf area ratio, crop growth rate, specific leaf area, days to 50 per cent flowering, leaf weight ratio, panicle length and 100-grain weight thus indicating the importance of such traits as criteria for selection in that order for realization of higher productivity. In other words the physiological efficiency of crop plants broadly includes higher biomass production and efficient translocation of dry matter for reliazation of high yield. Increasing biomass production is determined by higher photosynthetic rate, high photosynthetic area, slow leaf senescence high nitrate assimilation and high nitrate reductase activity, low respiration and photorespiration, high uptake and accumulation of nitrogen and minerals during early phase of growth. Efficient translocation of dry matter includes total dry matter production and partitioning of dry matter between grains and other plant parts. This is determined by large and active sink (high grain number per unit area and stability in grain number, high grain weight and lower spikelet sterility) thus reflecting high harvest index and increased yield (Siddiq et al., 2004).

Direct and multiple criteria of selection for improvement of yield and identification of promising varieties for use in future rice improvement programmes:

Since grain yield is a complex trait, controlled by non-additive gene action and is believed to have low heritability, hence direct selection for grain yield per se is often not reliable and effective. Further inter-genotypic competition and large experimental error associated with yield measurements often biases the outcome of selection for higher yield. Therefore, several workers in different crop plants have emphasized the importance of indirect selection for yield through the use of component traits governed by genes with additive effects and which show strong positive correlation with grain yield. Therefore it would be rewarding and the efficiency of single plant selection for yield could be improved via selection for panicle number, number of grains per panicle and 100-grain weight (Mohapatra and Mohanty, 1986). As no single trait could be taken as adequate criterion of selection for yield, therefore, selection indices provide an useful method by making use of several correlated traits for greater efficiency of selection in yield (Das et al., 2000).

The selection indices were constructed with grain yield as the economic criterion and nineteen different characters namely grain yield per plant, days to 50 % flowering, panicle number, panicle length, fertile grain number, fertility percentage, 100-grain weight, harvest index and physiological traits like leaf area index, leaf area ratio, leaf weight ratio, specific

Table 2. Expected genetic advance and relative efficiencies of selection index over direct selection on grain yield.

Index no/No. of characters	Characters	Expected genetic advance	Relative efficiency in percentage
1 (One character index)	Grain yield per plant	3.88	100.00
2 (Eight character index)	Grain yield per plant + other quantitative traits (DF + PN + PL + FGN + F % + 100 grain weight + HI)	3.96	101.77
3 (Twelve character index)	Grain yield per plant + Physiological traits (LAI+ LAR + LWR + SLA + RLAGR+ RLGR + LAD + CGR + RGR + NAR + TDM)	4.39	113.01
4 (Nineteen character index)	Grain yield per plant + other quantitative traits + physiological traits	4.45	114.45

leaf area, relative leaf area growth rate, relative leaf growth rate, leaf area duration, crop growth rate, relative growth rate, net assimilation rate and total dry matter per plant at the time of maturity were chosen for the construction of nineteen selection indices. The expected genetic advance in yield from selection and other three different selection indices along with their relative efficiencies over direct selection on yield are presented in Table 2.

The predicted genetic advance from different indices at 5 % selection intensity ranged from 3.38 g/plant in index 1 to 4.45 g/plant in index 4 and in terms of relative efficiency it varied from 101.77 per cent in index 2 to 114.45 per cent in index 4 during the present investigation. Thus in terms of predicted genetic advance, the results of the present study brought out superiority of different selection indices over direct selection on yield per se.

Out of nineteen, four selection indices namely one characters index including grain yield, eight character index including grain yield and seven component traits, twelve character index including grain yield and eleven physiological traits and nineteen character index including all nineteen traits were used for selection of genotypes among the genotypes under study. Those genotypes which occupied better ranking in all the above selection indices were selected for their future use. On the basis of each of the above four selection criteria, the genotypes were ranked and promising genotypes occupying better ranking in the four selection indices were selected for their future use. Out of sixty-five local aromatic types twenty-two cultivars could be considered promising yielding more than 2500 kg/ha were selected on the basis of four selection criteria (Table 3).

Table 3. Promising aromatic rice varieties selected on the basis of four different selection criteria.

Sl. no.	Name of the variety	Days to flowering (days)	Plant height (cm)	Plot yield (Kg/ha)
1	Acharmati	107	109.0	3292
2	Neelabati	121	133.0	3167
3	Gatia	112	133.0	3069
4	Ganjeikalli	104	116.0	2951
5	Gangaballi	109	134.0	2916
6	Kalajira	113	138.0	2903
7	Badshabhog	110	147.0	2889
8	Maguraphulla	109	124.0	2888
9	Nanu	112	146.0	2882
10	Jaiphulla	105	113.0	2750
11	Basuabhava	97	141.1	2695
12	Dhobaluchi	100	106.0	2680
13	Barikunja	108	130.0	2673
14	Jhingisiali	119	151.0	2667
15	Deulabhog	104	113.0	2660
16	Sujata	104	124.0	2653
17	Krushnabhog	108	131.0	2638
18	Dhoiabankoi	113	130.0	2611
19	Jubraj	104	126.0	2597
20	Tulsiphulla	120	128.0	2555
21	Seetakeshari	111	124.0	2514
22	Thakurabhoga	104	122.0	2448
23	Lalat	103	85.0	3472
24	Pusa basmati-1	108	94.0	2500

Superior yield performance of these promising varieties may be ascribed to higher grain number with improved fertility, increased flag leaf area, higher grain yield per plant and higher harvest index which serve as a basis of higher yield in aromatic rice. These aromatic types also express many desirable yield related traits like longer panicles, higher panicle number, large and active sink with improved fertility and higher 100-grain weight, thereby indicating their utility as potential donors for improvement of yield and quality in short grain aromatic rice.

It is interesting to note that majority of the local scented cultivars emit aroma while cooking the rice from the freshly harvested crop. However, the scent gets reduced on storage and in majority of cases gets practically lost within six months from harvest. Since rice is stored for a longer period (about a year) to improve the cooking quality and better digestibility, there is always a preference for such quality rices which retain aroma for a longer period. Kalajira is one of such indigenous aromatic rice, which combines better cooking quality and retain aroma for a longer period as compared to other types (Das and Rout, 2006; Puhan and Das, 2018).

Similarly mention may be made up of Jubraj which is an excellent traditional cultivar with intermediate amylose, gelatinization temperature (GT), hard gel consistency and highest kernel length after cooking (elongation ratio 1.71) comparable with the best quality rice "Betis" of Spain (Nanda et al., 1993; Malik et al., 1994).

The result of this study is in general agreement with those of Govindarasu et al. (2000); Rabiei et al.

(2004); Habib et al. (2007); Bastia et al. (2008); Anshori et al. (2019) and Farid et al. (2021). Most of the published work on selection indices based on index scores reflects the genotype worth of a particular culture and relative efficiency has been assessed in terms of genetic advance. However, the validity of such expectation in selecting different genotypes on the basis of different selection indices is often questioned as it varies due to difference in composition of material, selection of characters for the construction of indices and the experimental precision associated with yield measurement. Therefore, it becomes imperative to study the relative efficiency of different selection criteria and to test the validity of expected superiority of selection indices over direct selection by testing the promising genotypes through appropriate field trials.

Studies on nature of genetic divergence

The loss of small and medium grain aromatic types of Odisha state is not an exception and therefore, efforts were made for the collection, evaluation and genetic improvement of these much valued short grained scented rices of the state. In the present study the traditional aromatic types collected from the different parts of the state, exhibited high degree of genetic variability with respect to grain yield and other morpho-physiological traits.

Genetic improvement mostly depends upon the amount of genetic variability of the population and information about the nature and degree of genetic divergence would help the plant breeder in choosing the right type of parents for genetic improvement of yield and quality in aromatic rice. Hence, a meaningful classification of experimental material that enables to distinguish genetically close and divergent types is a pre-requisite for theoretical and applied plant breeding. With the development of multivariate analysis, based on Mahalanobis' D^2 statistics it is now possible to emphasize the sensitiveness and utility of this technique in identifying genetically diverse parents for success in recombination breeding for number of crop plants including rice (Murty and Arunachalam, 1966; Arunchalam, 1981; Muthuramu and Sakthivel, 2018; and Singh et al., 2020).

It is now possible to classify the biological populations into distinct groups and assess the contribution of different component traits in the total divergence. It is a well-established fact that the choice of parents on the basis of genetic diversity is an index as to how far the parental traits could be improved by genetic manipulation. The data recorded for nineteen characters, in sixty five varieties were subjected to estimation of aggregate effect of all characters and there were highly significant differences among the genotypes, when tested by Wilk's criterion. It would be therefore, worthwhile to classify the populations on the basis of character studied. Therefore, an attempt has been made during the present investigation by including simultaneous variations in all the nineteen characters, of sixty-five aromatic rice genotypes for the assessment of the nature and magnitude of genetic divergence and to identify diverse genotypes for future breeding programmes. In most of the works both D^2 statistic and canonical analysis have been concurrently used and in general, there had good agreement between the two approaches in grouping of the populations studied. In the present study, the D^2 grouping obtained by Tocher's method showed close resemblance with that of canonical analysis as reported by Islam et al. (2003), Shiv Datt and Mani (2003), Mishra et al. (2004), Guru et al. (2017) and Saha et al. (2019).

The D^2 analysis of sixty five genotypes based on all the nineteen characters indicated that D^2-values ranged from ($D^2 = 15.4$) between Ganjeikalli and Shrabanamasi to ($D^2 = 945.6$) between Kanikabhog and Taroarori Basmati. Other divergent combination were Kanikabhog and Type-3 ($D^2 = 889.3$), Dubrajsena and Taroarori Basmati ($D^2 = 833.4$), Bhulasapuri and Taroarori Basmati ($D^2 = 803.8$). Among genetically close combinations mention may be made up of Thakursuna and Sheetabhog ($D^2 = 2.5$), Dhoiabankoi and Lajkulibadan ($D^2 = 2.6$) etc. The results of the D^2 analysis thus indicated the genetical proximity as well as the diversity of the genotypes under study. The magnitude of D^2 values, in general, indicated considerable amount of genetic diversity among the genotypes studied.

Relative contribution of the characters

The relative contribution of different characters to the total divergence was assessed by rank average and average D^2. The order of contribution of different characters to the total genetic divergence estimated on the basis of rank average were 100-grain weight, days

Table 4. Relative contribution of different characters to genetic divergence.

Sl. no.	Characters	Rank total	Rank average	Average D^2	Percent of total D^2
1	Days to 50 % flowering	14660	7.04	19.096	11.55
2	Panicle number	21829	10.49	5.376	3.25
3	Panicle length	19714	9.47	6.811	4.11
4	Fertile grain number	19254	9.25	8.753	5.29
5	Fertility percentage	24295	11.68	3.485	2.10
6	100 grain weight	13385	6.43	33.311	20.14
7	Harvest index	23285	11.19	4.105	2.48
8	Leaf area index	20073	9.65	7.512	4.54
9	Leaf area ratio	25159	12.09	2.894	1.75
10	Leaf weight ratio	27088	13.02	2.022	1.22
11	Specific leaf area	24093	11.58	3.485	2.10
12	Relative leaf area growth rate	14549	7.01	17.927	10.84
13	Relative leaf growth rate	27594	13.26	2.096	1.26
14	Leaf area duration	18590	8.93	10.013	6.05
15	Crop growth rate	19643	9.44	9.337	5.64
16	Relative growth rate	21818	10.48	5.457	3.30
17	Net assimilation rate	19968	9.60	8.607	4.87
18	Total dry matter	22397	10.76	5.364	3.24
19	Grain yield per plant	17806	8.56	9.667	5.84

to 50 % flowering, relative leaf area growth rate, grain yield per plant, leaf area duration, fertile grain number, crop growth rate, panicle length, net assimilation rate, leaf area index, relative growth rate, panicle number , total dry matter, harvest index, specific leaf area, fertility percentage, leaf area ratio, leaf weight ratio and relative leaf growth rate in descending order. The contribution of characters to divergence on the basis of average D^2 were high for 100-grain weight (20.14 %) and days to 50 % flowering (11.55 %), moderate for relative leaf area growth rate (10.84 %) and low (1.22 to 6.05 %) for the rest of characters under study. The order of contribution by both methods was same for seven characters and there was a slight variation in the order of contribution in the rest of the twelve characters (Table 4).

The genotypes included in the present study showed considerable variation in respect of all the nineteen characters. It was observed by Murty and Arunachalam (1966) that days to heading, plant height and tiller number had major role in interspecific differentiation particularly in grain crops. Further D^2 analysis and size of the canonical roots revealed parallel

Table 5. Average D2 Intra-inter cluster distances of treatments (Intra cluster distances in diagonal.

Cluster	I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII	XIII
I	83.81	104.2	155.2	417.3	238.7	224.3	126.4	242.7	141.8	108.3	181.4	165.8	122.8
II		77.67	246.0	613.2	174.2	301.8	191.7	356.8	159.1	118.0	125.1	165.9	165.3
III			42.74	278.0	337.3	369.6	158.1	235.2	181.9	177.1	396.0	184.6	189.9
IV				76.84	727.7	266.2	266.7	214.7	457.8	517.9	723.0	514.8	394.7
V					60.71	506.2	364.9	466.7	352.6	319.2	195.7	101.6	401.6
VI						83.83	145.5	196.8	296.1	294.7	307.0	391.7	204.9
VII							99.47	218.0	199.2	161.3	248.2	233.3	140.0
VIII								120.93	296.5	307.8	372.9	270.0	214.1
IX									0	123.5	312.9	210.9	138.9
X										0	218.0	236.2	177.3
XI											0	180.1	263.6
XII												0	191.7
XIII													0

features in the mechanism of genetic diversity in all the five crop species studied by them, in spite of contrasting breeding behavior of those species. Relative importance of days to heading, plant height, flag leaf area, tiller number, grain number, grain yield, 1000-grain weight has been reported by several workers. In the present study days to 50 % flowering, 100-grain weight, relative leaf area growth rate and to some extent grain yield per plant, grain number and leaf area duration were found to be major characters contributing to varietal divergence.

The relative contribution of each character to the total divergence indicate that days to 50 % flowering, 100 grain weight had contributed substantially towards genetic diversity (Table 4).Therefore, the varieties chosen as parents for recombination breeding on the basis of such characters are likely to throw transgressive segregants for varietal improvement. It may be mentioned that varieties possessing high degree of diversity with respect to days to 50 % flowering, 100-grain weight, and relative leaf area growth rate are likely to bring about yield improvement in indigenous aromatic rice through recombination breeding. The relative contribution of characters to genetic divergence has been reported by Guru et al. (2017), Muthuramu and Sakthivel (2018), Shoba et al. (2019), Perween et al. (2020) and Swamy et al. (2020)

The principal characters contributing towards genetic divergence were found to vary from report to report. However, in general days to flowering, 100-grain weight, plant height, panicle number, grain yield per plant and grain number were found to largely contribute to genetic divergence. This anomalous contribution of different characters towards genetic divergence might have resulted due to choice of characters for analysis, the extent of variability and fitness of characters associated with grain yield.

Clustering pattern/group constellation

Based on the relative magnitude of D^2 values, following Tocher's method, all the test entries were grouped into thirteen clusters. Cluster I was the largest accommodating forty varieties, followed by Cluster II with six varieties like Lalkanhu, Dubrajsena, Nanu, Sheetabhog, Jhingisialli and Thakurbhog. Cluster III includes Durgabhog and Basnadhan, Cluster IV includes Type 3, Taroari Basmati and Basmati-370. Acharmati, Kanikabhog and Bishnubhog were placed under cluster V. Cluster VI consists of 2 varieties namely Baranamgomati and Pusa Basmati-1, while Kalakrishna and Basumati were placed under Cluster VII. Cluster VIII includes Deulabhog and Dhobaluchi whereas clusters IX, X, XI, XII and XIII, consist of one variety each like Pimpudibasa, Nalidhan, Bhulasapuri, Sujata and Krushnabhog, respectively.

Grouping of large number of varieties in cluster-I might have resulted due to identical ecological condition and similar selection pressure favoring identical expression of characters influencing grain yield during course of human selection. It is generally suggested that genetic diversity must form the sound base for selecting parent for hybridization rather than ecological diversity. The present study revealed that the cluster I included genotypes originating from different geographical regions, indicating that there is no relationship between clustering pattern and geographical distribution of genotypes.

In the past, ecological/geographical diversity must have been largely relied upon as an index of genetic diversity. This criterion being only inferential obviously can not be used for discrimination among region. Published results are highly conflicting with regard to relation between geographical distribution and genetic diversity. A number of workers indicated some what close relationship between the two (Ram and Panwar, 1970; Rao et al., 1981, Mahajan et al., 1981). On the other hand, a large number of crop plants with different breeding system showed no parallelism between genetic diversity and eco-geographical distribution. The distribution also indicated that genotypes originated from similar geographical regions were classified in different clusters and genotypes originated from different geographical origin belong to same cluster. The local aromatic rice like Ganjeikalli, Shrabanimasi, Acharmati, Dubraj etc are under cultivation in areas far away from one another, entered into the same cluster indicating that geographical fence is not that important in varietal diversity. Therefore, the kind of genetic diversity found among the genotypes belonging to same geographical region might be due to differences in adaptation, selection criteria, selection pressure and environmental conditions (Nayak et al., 2004). Sizable diversity in the population may be found in a single location, specifically where ecological condition differ widely. This is evident from the fact that farmers at a particular area use different rice varieties for different agro-ecosystem. Naturally these results in accumulation of commence variability in the materials even at a single location. However, Mohammad Nisar et al. (2017), Ankit kumar et al. (2020) and Nyo Mar Htwe and Chen Nyein Thu (2019) indicated that the genetic proximity of varieties grouped them in one cluster.

Intra and inter cluster divergence

The statistical distance (D^2) represents the index of the genetic diversity among the clusters. The perusal of Table.5 showed that maximum intra cluster distance was observed in cluster VIII (120.93) and minimum intra cluster distance (0.00) in cluster IX, X, XI, XII and XIII indicating limited genetic diversity in these clusters. The relative magnitude of each cluster from other clusters (inter cluster distances indicating greater genetic diversity between cluster IV and V (727.7) followed by IV and XI (723.0), IV and II (613.2) were treated highly divergent groups. The selection of divergent groups from the above clusters would produce broad spectrum of variability for yield and yield attributing traits, which may enable further selection and genetic improvement. The hybrids developed from the selected genotypes within the limit of compatibility of these clusters may produce desirable transgressive segregates that would be useful in rice breeding programme. Therefore, it is suggested that in the present investigation parents should be chosen from the most divergent groups *i.e.*, between cluster IV and cluster V for hybridization and these parental combinations are expected to throw transgressive segregants for realization of high yield and quality. However, the best workable alternative for selection of parents from each of these divergent groups would be on the basis of per se performance or on the basis of component traits, which would complement with each other for the expression of final output.

Characteristic features of the clusters

The classification of genotypes through different classificatory analysis like multivariate analysis including D^2 method for quantification of genetic divergence among the set of biological population have been questioned by many authors. There are also instances to show that in D^2 analysis even the different selections from the same cross or those from the different crosses can be grouped into different or same clusters respectively depending upon the similarity or dissimilarity of characters. Also in many cases parents with diverse taxonomic differences are often grouped in the same cluster. Due to this limitation in such

Table 6. Average mean performance of different clusters in rice.

Sl. no.	Characters	I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII	XIII
1	Days to 50 % flowering	100.50	104.58	91.00	88.66	100.16	104.00	99.00	96.00	99.50	104.56	106.50	95.50	101.00
2	Panicle number	7.49	8.33	6.15	8.46	6.87	9.87	8.37	8.39	6.13	13.00	5.86	9.00	10.13
3	Panicle length	24.86	25.93	23.50	26.11	24.00	26.38	26.71	20.30	26.37	27.65	23.15	24.66	24.07
4	Fertile grain number	143.24	156.93	101.95	59.90	165.90	95.35	79.55	105.55	160.40	173.90	148.40	139.90	109.90
5	Fertility percentage	87.77	85.89	87.71	79.91	91.46	76.67	76.32	79.09	85.95	93.09	85.79	90.00	72.75
6	100-grain weight	1.36	1.14	1.39	2.49	1.31	2.21	1.69	2.21	1.30	1.23	1.53	1.41	1.34
7	Harvest index	0.37	0.35	0.39	0.42	0.35	0.37	0.23	0.54	0.38	0.38	0.31	0.52	0.53
8	Leaf area index	2.41	2.74	2.98	2.74	4.54	2.27	3.26	3.61	1.43	3.49	3.82	4.39	1.61
9	Leaf area ratio	101.86	98.47	105.72	87.53	97.22	99.16	114.42	138.95	40.61	104.02	149.81	220.32	103.19
10	Leaf weight ratio	0.44	0.46	0.45	0.39	0.42	0.42	0.43	0.53	0.33	0.55	0.49	0.54	0.46
11	Specific leaf area	256.51	247.24	273.15	250.40	284.40	230.55	230.82	314.03	203.34	244.34	270.00	319.33	240.83
12	Relative leaf area growth rate	0.23	0.25	0.22	0.24	0.41	0.22	0.21	0.32	0.10	0.09	0.53	0.55	0.08
13	Relative leaf growth rate	0.27	0.33	0.29	0.27	0.49	0.22	0.14	0.39	0.27	0.16	0.44	0.35	0.12
14	Leaf area duration	3.91	4.30	4.80	4.34	6.32	3.67	5.40	5.41	2.61	6.42	4.71	5.37	2.98
15	Crop growth rate	219.12	301.56	214.00	296.44	613.33	207.00	157.83	174.50	42.67	119.33	135.67	211.00	52.34
16	Relative growth rate	0.30	0.36	0.24	0.33	0.57	0.30	0.16	0.20	0.47	0.10	0.15	0.35	0.08
17	Net assimilation rate	0.29	0.37	0.23	0.36	0.52	0.32	0.15	0.16	0.82	0.09	0.14	0.21	0.09
18	Total dry matter	24.01	26.53	23.51	23.96	24.12	23.85	21.88	12.52	29.48	42.78	28.75	26.66	25.86
19	Grain yield per plant	7.86	8.15	5.35	7.01	7.43	8.24	4.78	14.21	8.17	9.21	8.20	17.13	15.10

analysis, a meaningful classification of test genotypes on the basis of their mean performance have been relied upon for future use of the test genotypes in a breeding programme.

The average cluster mean values based on all the nineteen characters together are presented in Table 6. It is evident from cluster means of nineteen characters that Cluster III, IV, VII, VIII, IX and XII were characterized by mid-early in maturity duration whereas the clusters I, II, V, VI, X, XI and XIII can be classified under medium maturity group. Cluster IV was distinguished for earliest in flowering whereas the genotypes in cluster XI were late in maturity duration.

A perusal of data from the average mean values of clusters, it is revealed that different clusters exhibited superior performance for various traits and no single cluster could be identified promising combining all the desirable traits. Considering the average mean values of different clusters, it is clearly evident that the clusters V, X, XII and XIII were quite distinguished for isolated as most divergent clusters, consisting of genotypes, combining many desirable quantitative and physiological traits and could be successfully employed in a breeding programme for genetic enhancement in yield and quality (Table 6).

On the basis of higher cluster mean for all most all component traits, most divergent clusters have been isolated as V containing genotypes like Acharmati, Kanikabhoga and Bishnubhoga, and Cluster X consists of a single genotype Nalidhan. The crosses involving parents from these clusters may exhibit higher heterosis and better recombinants are likely to be recovered in segregating generations for realization of higher productivity in rice (Arunachalam, 1981).

Stability analysis

The stability of performance of a genotype is as important as its inherent yield potential. It is one of the most desired properties of a variety for its general cultivation over a wide range of environments, which relates to the interaction between genotype and environment. Varietal stability or adaptability is differentiated into general and specific adaptability. General adaptability refers to the consistent yield performance of a genotype under varying environmental condition whereas the specific adaptability relates to the ability of the crop variety to react and resist conditions arising out of physiological and biological stresses. In other words it is the genotype environment interaction which interplay the genetic and non-genetic effects and influence the phenotypic expression of a genotype in different environments. Stability analysis based on regression model is a technique to quantify

Table 7. Mean yield of genotypes (q/ha) in different environments.

Sl.no.	Environment Genotypes	BBSR (1)	CHM(2)	RAN(3)	JEY(4)	MST(5)	SGD(6)	BHN(7)	BPT(8)	SKG(9)	NPR(10)	Mean
1	Acharamati	27.16	38.89	10.90	34.21	25.18	31.55	38.33	32.13	23.40	23.20	28.50 (1)
2	Kalajeera	27.55	19.44	13.50	29.25	29.63	31.11	37.50	27.60	27.40	17.90	26.09 (4)
3	Neelabati	31.21	20.83	15.50	23.68	31.11	45.11	35.00	31.05	23.80	12.22	26.95 (2)
4	Gangaballi	19.06	15.28	11.30	27.85	29.63	47.22	30.00	27.77	21.90	13.10	24.31 (10)
5	Badshabhog	17.28	13.89	14.10	27.36	28.15	46.00	39.00	27.43	24.80	7.30	24.53 (9)
6	Jaiphulla	25.68	29.17	12.60	31.14	28.89	41.67	30.83	24.10	23.30	16.50	26.39 (3)
7	Thakurasuna	18.07	27.08	11.35	30.87	27.78	35.78	41.67	26.91	26.46	6.20	25.22 (6)
8	Nanu	17.18	21.53	12.29	24.78	24.07	39.44	32.05	26.00	23.80	9.40	23.05
9	Lajkulibadan	20.25	15.28	8.78	25.13	25.18	40.00	36.67	27.85	18.46	13.60	23.12
10	Khosakani	28.25	24.31	9.39	23.15	26.29	27.78	40.83	30.52	21.90	20.90	25.33 (5)
11	Heerakani	17.09	16.67	9.39	26.09	27.04	31.44	35.83	31.70	22.30	13.40	23.10
12	Pimpudibasa	18.57	22.22	11.45	30.70	22.22	41.78	29.16	27.22	30.10	17.80	25.12 (7)
13	ORS 199-5	26.37	25.69	12.69	32.01	26.67	36.22	36.00	24.00	19.90	10.20	24.98 (8)
14	Vasumati	17.68	22.22	13.60	30.43	28.89	31.78	25.50	23.00	20.00	7.60	22.07
	Env. Mean	**22.24**	**22.32**	**11.92**	**28.33**	**27.19**	**37.63**	**34.88**	**27.66**	**23.39**	**13.52**	**24.92**
			Genotype in Environment			**Environment**			**Genotype**			
	CD (5%)		**5.08**			**1.36**			**1.61**			

BBSR-Bhubaneswar, CHN-Chiplima, RAN-Ranital, JEY-Jeypore, MST-Mahisapat, SGD-Semiliguda, BHN-Bhanjanagar, BPT- Bhawanipatna, SKG- Sakhigopal, NPR-Nuapara.

Table 8. Stability parameter for plot yield (q/ha) under linear regression model in relation to environments.

Sl. no.	Genotypes	Mean	b	MS-Dev.	S^2_d	R^2 (%)
1	Acharamati	28.50	0.720±0.260	40.652	30.563**	48.89
2	Kalajeera	26.09	0.781±0.135	10.956	0.867	80.69
3	Neelabati	26.95	1.077±0.180	19.561	9.472*	81.65
4	Gangaballi	24.31	1.199±0.181	19.640	9.551*	84.59
5	Badshabhog	24.53	1.368±0.175	18.393	8.304*	88.43
6	Jaiphulla	26.39	0.909±0.142	12.171	2.082	83.58
7	Thakurasuna	25.22	1.228±0.163	16.008	5.919	87.61
8	Nanu	23.05	1.046±0.096	5.529	-4.560	93.70
9	Lajkulibadan	23.12	1.173±0.113	7.611	-2.478	93.13
10	Khosakani	25.33	0.753±0.220	29.136	19.047**	59.39
11	Heerakani	23.10	0.997±0.140	11.717	1.628	86.42
12	Pimpudibasa	25.12	0.914±0.178	19.075	8.986*	76.68
13	ORS 199-5	24.98	1.013±0.131	10.319	0.230	88.19
14	Vasumati	22.07	0.822±0.159	15.245	5.156	76.90

S_d^2: * and ** Significant > 0, at 5% and 1% levels of significance.

and assess the adaptability and requires adequate sampling of test environment under which the evaluation of genotype is sought for. The usefulness of the model for assessing stability of performance very much depends on adequate diversity in the test environments (Table 7).

The widely used method for selecting high yielding and stable genotypes is the linear regression method which was first proposed by Yates and Cochran (1938) for analyzing barely yield trial. The first systematic approach to analyze phenotypic stability of cultivars was made by Finaly and Wilkinson (1963). They used two parameters namely mean performance over environments and regression of performance in different environments over the respective environmental mean for assessing phenotypic stability. A number of workers critically assessed the usefulness of different stability parameters in varietal assessment (Wricke, 1962, Freeman and Perkins, 1971; Langer et al., 1979; Nguyen et al., 1989, Lin et al., 1986).

In 1966 Eberhart and Russell partitioned the genotype environment interaction of each variety into two parts i.e., slope of the regression line and deviation from the regression line. They concluded that the important measures of stability of production were highly correlated and thus could be considered as alternative measures for stability of performance. They defined a stable variety as one which has the above average yield over wide range of environments with a regression co-efficient of unity (b = 1) and minimum deviation from the regression line ($Sd^2_i = 0$).

Perkins and Jinks (1968) suggested a new model for measurement of phenotypic stability. They emphasized that regression of genotype x environment interaction on environmental index should be obtained rather than regression of mean performance (Y_{ij}) on the later as done in the Eberhart and Russell's model. Freeman and Perkins (1971) reported that an independent estimate of environmental index could be obtained, whereas with models of Eberhart and Russell (1966) and Perkins and Jinks (1968) where the estimation is not significant.

In general, regression model is used to partition the overall response pattern of a genotype into two components i.e. yield performance and stability. Although genotype slope is the primary stability parameter, not all stable genotypes are desirable, since mean yield is also an important parameter. Often these two parameters complicate a breeder's decision when comprising high yield, less stable genotypes with low yielding stable genotypes.

Therefore, during the present investigation, the genotypes were evaluated under 10 diverse environments, for the assessment of stability of performance of the genotypes in respect of plot yield following the regression model of Eberhart and Russell (1966). The stability parameters like mean, regression coefficient (b), deviation from regression (S^2_{di}) and the coefficient of determination (R^2) estimated for plot yield are presented in Table 8.

The experimental materials used for the computation of stability analysis consisted of 14 rice varieties including 12 indigenous short grain aromatic rice strains collected from different parts of the state along with one aromatic rice varietiy "Vasumati" and one non-aromatic rice variety "ORS 199-5" as checks. The experimental material was evaluated at ten different sites and the stability performance of different genotypes was assessed by computing stability parameters based on the regression model of Eberhart and Russell (1966).

The mean performance of genotypes over the environments and environment wise mean values for plot yield are presented in Table 7. The mean values of genotypes in different environments for plot yield ranged from 6.20 q/ha for Thakurasuna in environment-10 (Nuapara) to 47.22 q/ha for Gangaballi in environment-6 (Semiliguda). Genotype means over environment for plot yield ranged from 22.07 q/ha for Vasumati to 28.50 q/ha for Acharamati, indicating a wide range of variation among genotypes for this trait. The environmental means varied from 11.92q/ha for environment-3 (Ranital) to 37.63 q/ha for environment-6 (Semiliguda) with a general mean of 24.92 q/ha, thus indicating wide variability of test environment under study. The order of the environment mean for the trait was environment 6 > environment 7 > environment 4 > environment 8 > environment 5 > environment 9 > environment 2 > environment 1 > environment-10 > environment 3. Some of the top yielding genotypes were Acharamati, Neelabati, Jaiphulla, Kalajeera and Khosakani in that order. It was interesting to note that no single genotype maintained the relative rank order in all the ten environments. The difference in performance of genotypes in different environments indicated the presence of significant genotype-environment (G x E) interaction, for the expression of plot yield.

Adaptability and stability of performance

The environments correspond to normal sowing of selected aromatic rice genotypes at different research stations and KVKs all over Odisha. The pooled analysis of variance over environments as well as the difference of rank order of different genotypes in various environments indicating highly significant G x E interaction in respect of plot yield, warranted analysis of stability of performance of the genotypes in order to arrive at meaningful conclusions. The stability of performance of the genotypes was assessed following regression model of Eberhart and Rusell (1966). The stability parameters like mean, regression coefficient (b), deviation from regression (S^2_d) and the coefficient of determination (R^2) estimated for plot yield are presented in Table 8

The coefficient of determination (R^2) indicated regression response accounted for more than 80 per cent of total variation in case of Nanu, Lajkulibadan, Badshabhog, ORS 199-5, Thakurasuna, Heerakani, Gangaballi, Jaiphulla, Neelabati and Kalajeera. R^2 values ranging from 50-79 percent of total variation in case of Vasumati, Pimpudibasa and Khosakani, whereas the remaining variety Acharamati accounted < 50 per cent of total variation. Thus the coefficient of determination ranged from 48.89 per cent (Acharmati) to 93.70 per cent (Nanu) and therefore it indicated that the linear regression accounted for major part of the variation.

The estimates of regression coefficient (b) ranged from 0.720 in Acharamati to 1.368 in Badshabhog, indicating fluctuating response of genotypes to different environments. The genotypes namely, Gangaballi, Badshabhog and Thakurasuna exhibiting regression coefficient between 1.199 to 1.368 (b> 1) are considered of having below average stability. These genotypes are likely to be better adapted to favourable environment.

Three other genotypes namely Acharamati, Kalajeera and Khosakani with regression coefficient estimates less than unit (b < 1) ranging between 0.720 and 0.781 indicate above average stability, sacrificing higher mean yield with changes in the environment. The remaining 8 genotypes having regression coefficient estimates 0.822 to 1.173 (b=1) are considered of having average stability.

The deviation from regression (S^2_d) ranged from -4.560 to 30.563. The value was significantly different

Table 9. Classification of genotypes on the basis of b and S^2_d

Groups	Characteristics	Stability performance	Genotypes
Group I	$b > 1$, $S^2_{di} \sim 0$	Below average stability	Thakurasuna
Group II	$b < 1$, $S^2_{di} \sim 0$	Above average stability	Kalajeera
Group III	$b = 1$, $S^2_{di} \sim 0$	Average stability	Jaiphulla, Nanu, Heerakani Lajakulibadan, ORS 199-5 and Vasumati
Group IV	b = any value S^2_{di} = Significant	Unstable	Acharmati, Neelabati, Gangaballi, Badshabhog, Khosakani and Pimpudibasa.

Table 10. Salient features of the short grain aromatic rice varieties released for Odisha state.

Sl. no	Name of the variety	Culture no./ IET no.	Cross combinations	Days to maturity	Major features	Resistance	Yield (Q/ha)	Eco-System	Year of release
Developed jointly by CRRI, Cuttack and OUAT, Bhubaneswar									
1	Nua Kalajeera	Kalajeera IET 18393	Pure line selection of indigenous aromatic rice collection "Kalajeera" from Cuttack District	142	Tall height, Few tiller number, Weak straw, Black coloured hull, Purple coloured apiculus, Short bold grains, White kernel, Hulling%:75.0, Milling % : 68.0, HRR %: 62.2, Amylose content : 22.6, Strong aroma	MR:GM, SB, HispaMR: Sh.R,Sh.B, BLB, BS, LB R:RTV andNB	34.99 Average 60.26 Potential	Rainfed and irrigated shallow lowland	2008
Developed by CRRI, Cuttack									
2	Nua Dhusara CR Sugandh Dhan 3	CR 2579-1 (Dhusara) IET 18395	Pure line selection of indigenous aromatic rice collection "Dhusara" from Puri District	144	Tall height, Shy tillering, Weak straw, Straw coloured hull, with translucent Short bold grains, White kernel, Hulling%:76.1,Milling %: 68.8, HRR% 67.1, Amylose content : 22.3, Strong aroma	MR:GM, SB, MR:Sh.B, BLB, BS,LB R:RTV,NB and Sh.R	34.26 Average 60.00 Potential	Rainfed and irrigated shallow lowland	2008
3	Nua Chinikamini	CR 2580-7 (Chinikamini) IET 18394	Pure line selection of indigenous aromatic rice collection "Chinikamini" from Kendrapara District	144	Tall height, Poor tillering, Weak straw, Straw coloured hull, with translucent Short bold grains, White kernel, Hulling%:75.4,Milling %: 69.7, HRR% 66.5, Amylose content : 23.9, Strong aroma	MR:GM,SB, MR:Sh.B, BLB,BS,LB R: RTV, NB and Sh.R	36.33 Average 68.50 Potential	Rainfed and irrigated shallow lowland	2010
Developed by OUAT, Bhubaneswar									
4	Nua Acharmati	Acharamati IET 19713	Pure line selection of indigenous aromatic rice collection "Acharmati" from Bhawanipatna	134	Intermediate height, Few tiller number, with Stiff straw, Hull brown furrows on straw, SB grains, white kernel, Hulling%: 75.0, Milling %:69.3,HRR% : 68.4, Amylose content : 24.6, Mild aroma	R:,BPH,LF MR:GM,SB, WMMR: Blast, Sh.R, Sh. BR:RTV, BSBLB	41.87 Average 80.66 Potential	Rainfed and irrigated medium lands	2012

Table 11. Grain yield (kg/ha) of selected indigenous aromatic rice varieties at graded levels of nitrogen.

Nitrogen Variety	N_1 (0)	N_2 (30)	N_3 (60)	N_4 (80)	Mean
V_1 - Gopala bhog	1701	2153	2309	1735	1975
V_2 - KB-13	1337	2309	2413	1199	1815
V_3 - Nagri Dubraj	1806	2014	1615	1527	1741
V_4 - Acharmati	2326	3576	3264	2480	2912 (1)
V_5 - Kalanamak	1910	1997	2570	1216	1923
V_6 - Neelabati	2257	3004	3108	2535	2726 (3)
V_7 - ORS-199-5	2222	2465	2795	3871	2838 (2)
Mean	1937	2503	2582	2080	

Means of varieties: CV = 19.61 % CD = 364.51
Means of nitrogen level: CV: 22.43 % CD = 351

from zero in six genotypes like Acharmati, Neelabati, Gangaballi, Badshabhog, Khosakani and Pimpudibasa indicating unpredictability of stability in respect of plot yield.

The genotypes were classified into four groups based on regression coefficient (b) and deviation from regression (S^2_d) are presented in Table 9. The genotype Thakurasuna with 'b' values greater than 1 and values not significantly different from zero are considered as varieties with below average stability. Similarly, the genotypes like Kalajeera with 'b' values less than 1 and not significantly different from zero are regarded as varieties with above average stability.

Genotypes like Jaiphulla, Nanu, Lajkulibadan, Heerakani, ORS 199-5 and Vasumati with 'b' values equal to 1 and estimates not significantly different from zero are considered as varieties with average stability.

Acharmati, Neelabati, Gangaballi, Badshabhog, Khosakani and Pimpudibasa with any 'b' value and significantly different from zero are considered to be genotypes with unpredictability of stability in respect of plot yield. It is not surprising to note that these varieties have specific adaptability. For instance Acharmati in Kalahandi; Neelabati in Balasore; Gangaballi in Ganjam and Pimpudibasa in Keonjhar are most popular and mostly confined to their native areas of cultivation.

Table 12. Nitrogen response (kg of grain/kg of nitrogen).

Varieties	Levels of nitrogen		
	N_2	N_3	N_4
V_1 Gopala bhog	15.06	10.13	0.43
V_2 - KB-13	32.40	17.93	-1.73
V_3 -Nagri Dubraj	6.93	-3.18	-3.49
V_4 - Acharmati	41.67	15.63	1.93
V_5 - Kalanamak	2.90	11.00	-8.68
V_6 -Neelabati	24.90	14.18	3.48
V_7 - ORS-199-5	8.10	9.55	20.61

Genetic yield enhancement and release of short grain aromatic rice varieties for commercial planting in Odisha state

The development of improved short grain aromatic rice varieties was mostly limited to pure-line selection in indigenous tall varieties or farmers' varieties. Efforts were made both by NRRI, Cuttack and OUAT, Bhubaneswar for genetic yield enhancement of short grain aromatic rice in Odisha. Through pure-line selection, altogether 4 different rice varieties namely Nua Kalajeera, Nua Dhusura, Nua Chinikamini and Nua Acharamati were released during the period 2008-2012 for commercial planting in Odisha state. The salient features of these varieties are presented in Table 10 and Fig. 3. Besides pure line selection, attempts were also made to utilize indigenous aromatic varieties in cross breeding programs for improvement of yield and quality in rice. Such programmes yielded varieties like

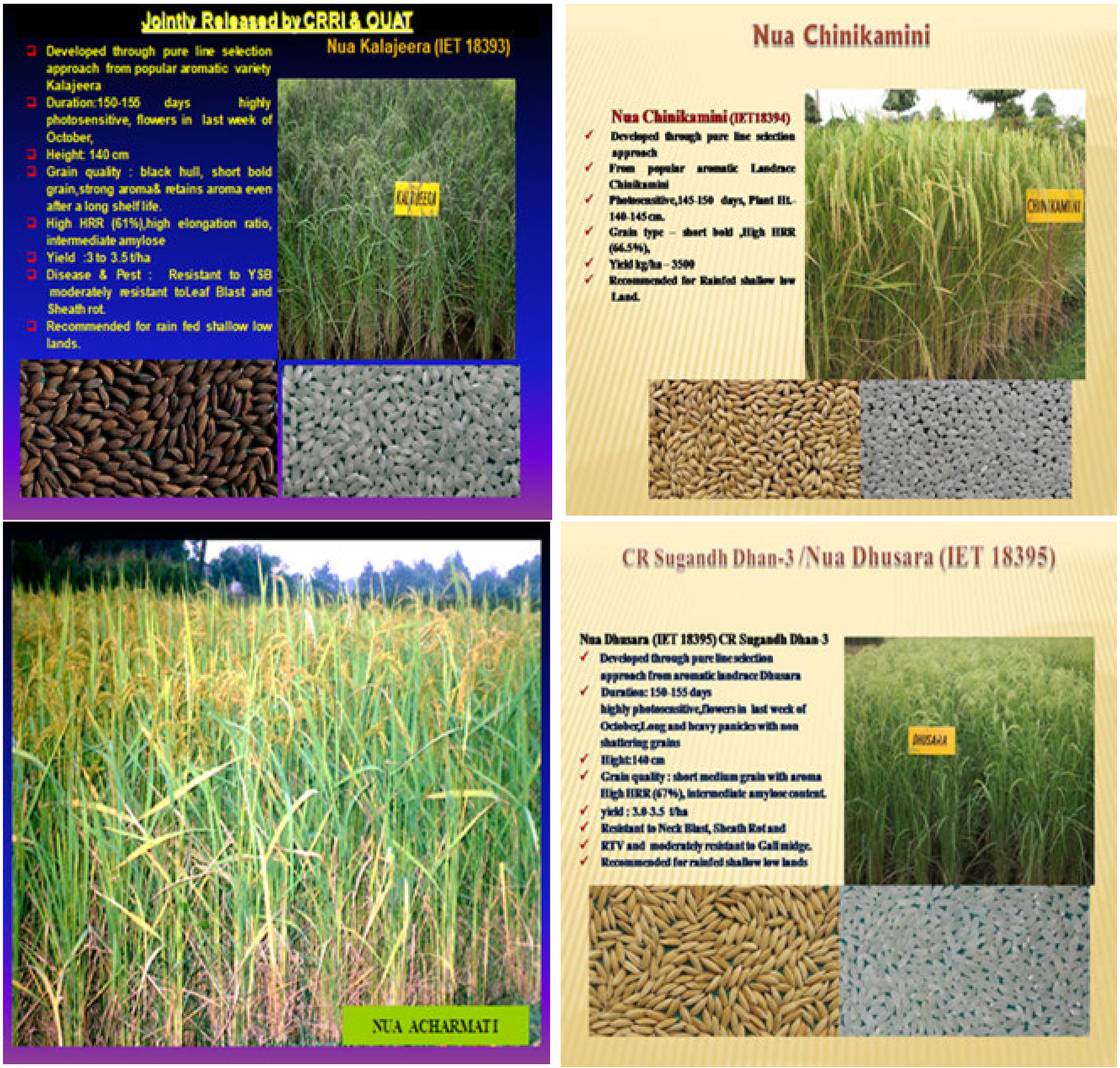
Table 13. Estimated marketable Surplus / Deficit of Rice in Odisha (Lakh Tons).

Year	Total requirement	Production	Surplus / Deficit
2000-01	53.47	46.14	-7.33
2001-02	54.40	71.49	17.09
2002-03	55.12	32.44	-22.68
2003-04	55.84	67.34	11.50
2004-05	56.57	65.37	8.80
2005-06	57.33	69.63	12.30
2006-07	58.08	69.28	11.20
2007-08	58.83	76.55	17.72
2008-09	59.61	69.16	9.55
2009-10	60.40	70.22	9.82
2010-11	61.20	69.31	8.11
2011-12	62.00	58.95	-3.05
2012-13	62.82	94.97	32.11
2013-14	63.65	76.13	18.92
2014-15	64.48	98.45	33.97
2015-16	65.43	58.75	-6.68
2016-17	66.20	97.94	31.74
2017-18	67.07	65.51	-1.56

Source: Odisha agriculture Statistics,2019-20, Government of Odisha.

Table 14. Details of cost expenses for raising 10,000 ha of non basmati scented rice.

Seed category	Area required (ha)	Production rate / ha (q)	Total Production (q)	Cost of cultivation/ha (Rs.)	Estimated cost (Rs.)	Growing season
Nucleus	0.025	10.0	0.25	25,000	625	2022 *kharif*
Breeder	1.25@ 20 kg of nucleusseed / ha	15.0	18.75	25,000	31,250	2023 *kharif*
Foundation	25.0@ 75 kg of breeder seed / ha	15.0	375.0	20,000	5,00,000	2024 *kharif*
Certified	500.0 @ 75 kg of foundation seed / ha	15.0	7,500.0	20,000	100,00,000	2025 *kharif*



Jointly Released by CRRI & OUAT

Nua Kalajeera (IET 18393)

- Developed through pure line selection approach from popular aromatic variety Kalajeera
- Duration:150-155 days highly photosensitive, flowers in last week of October,
- Height: 140 cm
- Grain quality : black hull, short bold grain,strong aroma& retains aroma even after a long shelf life.
- High HRR (61%),high elongation ratio, intermediate amylose
- Yield :3 to 3.5 t/ha
- Disease & Pest : Resistant to YSB moderately resistant toLeaf Blast and Sheath rot.
- Recommended for rain fed shallow low lands.

Nua Chinikamini

Nua Chinikamini (IET18394)

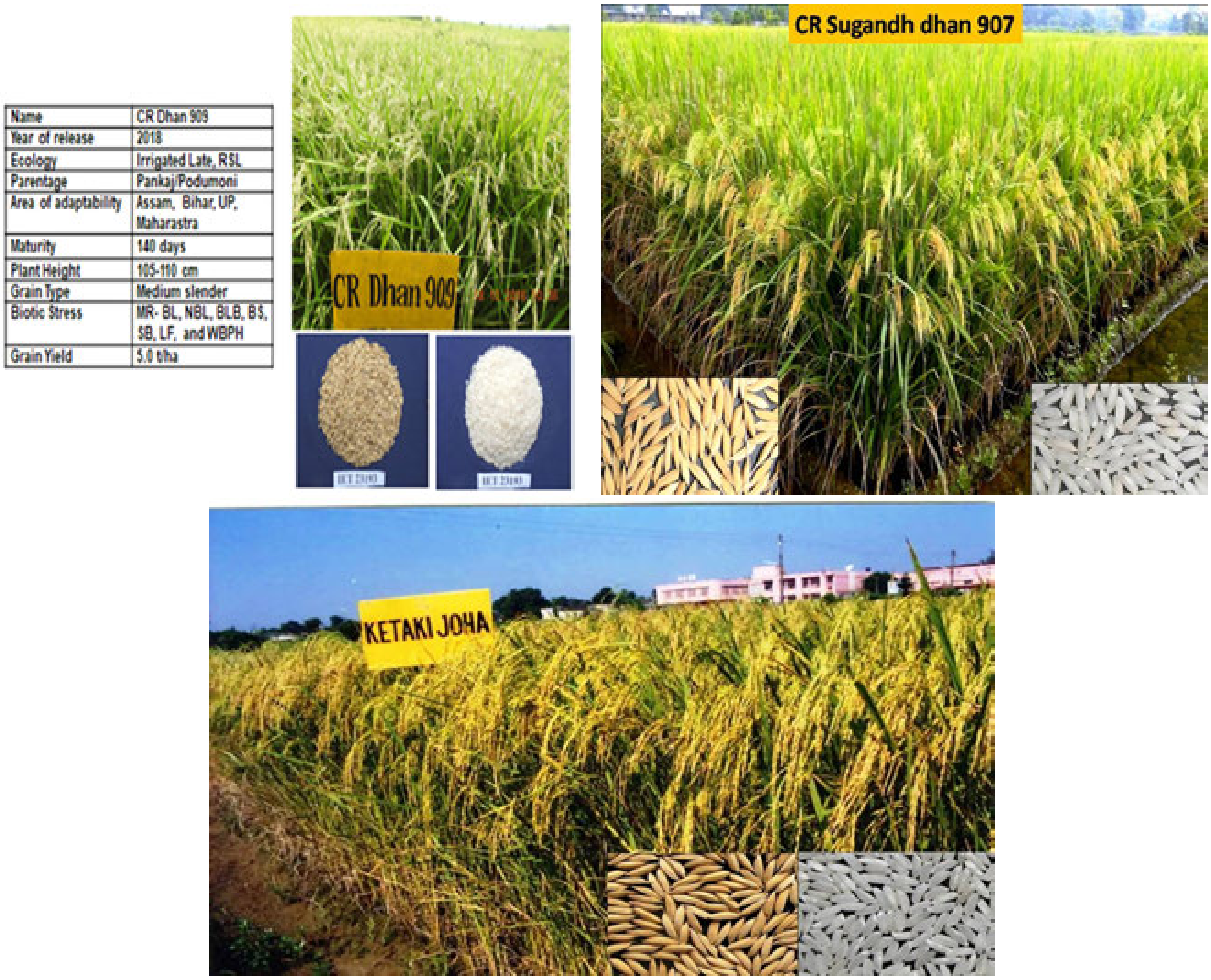
- ✓ Developed through pure line selection approach
- ✓ From popular aromatic Landrace Chinikamini
- ✓ Photosensitive,145-150 days, Plant Ht.- 140-145 cm.
- ✓ Grain type – short bold ,High HRR (66.5%),
- ✓ Yield kg/ha – 3500
- ✓ Recommended for Rainfed shallow low Land.

CR Sugandh Dhan-3 /Nua Dhusara (IET 18395)

Nua Dhusara (IET 18395) CR Sugandh Dhan-3

- ✓ Developed through pure line selection approach from aromatic landrace Dhusara
- ✓ Duration: 150-155 days highly photosensitive,flowers in last week of October,Long and heavy panicles with non shattering grains
- ✓ Hight:140 cm
- ✓ Grain quality : short medium grain with aroma High HRR (67%), intermediate amylose content.
- ✓ yield : 3.0-3.5 t/ha
- ✓ Resistant to Neck Blast, Sheath Rot and
- ✓ RTV and moderately resistant to Gall midge.
- ✓ Recommended for rainfed shallow low lands

Fig. 3. Varieties like Nua Kalajeera, Nua Chinikamini, Nua Dhusara and Nua Acharmati developed by Pure line Selection.



Name	CR Dhan 909
Year of release	2018
Ecology	Irrigated Late, RSL
Parentage	Pankaj/Podumoni
Area of adaptability	Assam, Bihar, UP, Maharastra
Maturity	140 days
Plant Height	105-110 cm
Grain Type	Medium slender
Biotic Stress	MR- BL, NBL, BLB, BS, SB, LF, and WBPH
Grain Yield	5.0 t/ha

Fig. 4. Varieties like Ketaki Joha, CR Sugandha Dhan 907 and CR Sugandha Dhan 909 developed by utilizing indigenous aromatic varieties in cross breeding.

Ketki Joha, CR Sugandh Dhan 907 and CR Sugandh Dhan 909 released during 2005, 2013 and 2018 respectively for commercial planting (Fig. 4)

Nitrogen response and N use efficiency of selected aromatic rice cultures.

Sustainability of potential productivity of crop varieties largely depends on appropriate crop management practices. It is absolutely essential to follow suitable nutrient management practices including nitrogen management for realization of higher productivity in rice. Keeping this in view an effort was made to evaluate six indigenous aromatic rice varieties namely Gopalbhog, KB-13, Nagri Dubraj, Acharmati, Kalanamak and Neelabati along with a non aromatic check variety ORS 199-5 with three graded levels of nitrogen *i.e.*, 30 kg, 60 kg, 80 kg per hectare and to study the nitrogen response and N use efficiency of selected aromatic rice cultures.(Table 11 and Table 12)

Majority of varieties although exhibited superior yield performance at N_3 level (60 kg N/ha), but the nitrogen response was higher at N_2 level (30 kg N/ha) than N_3 level (60 kg N/ha) in all the varieties except Kalanamak. However, the check variety (a semi-dwarf culture) responded linearly up to N_4 level *i.e.*, 80 kg N/ha.

Therefore, it is concluded from the studies on

Table 15. Economics of non-basmati aromatic rice seed production / ha.

Seed category	Total production/ha (Q)	Cost of cultivation / ha (Rs.)	Seed cost / kg (Rs.)	Gross income (Rs)	Net profit
Nucleus	10.0	40,000	150.0	1,50,000	1,10,000.
Breeder	15.0	50,000	150.0	2,25,000	1,75,000
Foundation	20.0	30,000	100.0	2,00,000	1,70,000
Certified	20.0	25,000	80.00	1,60,000	1,35,000

grain yield production and nitrogen response of selected short grain aromatic rice varieties under three graded levels of nitrogen that majority of short grain aromatic rice varieties respond positively between 30 to 60 kg N/ha. As these aromatic rice varieties are taller in height and lodge at higher level of nitrogen, it is therefore, recommended to use 30 kg N/ha than 60 kg N/ha for realization of higher yield in short grain aromatic rice (Kar, 2008).

Traditionally the short grain aromatic rices are grown with farm yard manure (FYM) and hardly any fertilizer is used due to their tall height, weak straw and lodging habit. Considering the lower response of nitrogen it is suggested to grow these indigenous aromatic rices organically which would fetch more price with less cost and thus enhance the profit margins of small and marginal farmers.

Seed Production of Indigenous Aromatic rice:

Estimated marketable surplus/deficit of rice for the period 2000-01 to 2010-11 in Odisha indicated that, there was surplus in rice production in most of the years (Table 13). In spite of high minimum support price, the farmers fail to recover the cost of production in the existing market infrastructure and due to poor market facilities there is distress sale of rice which creates scope for diversification of traditional to scented rice cultivation in the state. Therefore efforts should be made for promoting multiplication and distribution of promising scented rices for general cultivation. Processing and marketing of these aromatic types is likely to fetch more price and thereby increasing the socio- economic conditions of the Odisha farmers.

Success and sustenance of cultivation and marketing of indigenous aromatic rices depend on efficient and economic seed production on large scale. Efficient seed production technology is very vital for popularization as well as large scale adoption of these aromatic rices for commercial use. In order to initiate a seed production programme a scheme has been outlined, indicating the details of cost estimates and requirements of different categories of seeds for planting 10,000 hectares of non-Basmati aromatic rices in future (Table 14) and the economics of non-basmati aromatic rice seed production has been presented in Table 15.

Economics of non-Basmati Aromatic rice cultivation/ ha

I. Average Production of aromatic rice/ ha : 25 - 30 q/ha

II. Total Production cost of aromatic rice/ ha : Rs.25,000/-

III. Gross income / ha: @ Rs.2500/q : Rs.62,500-75,000/-

IV. Net profit / ha : Rs.37,500-50,000/-

Future concerns and opportunities

Although the short grain indigenous types are poor yielders, prone to lodging and susceptible to major pests and diseases, still some of them are known for their distinctive quality features. The desirable traits like kernel elongation, volume expansion and head rice recovery are more pronounced in many local types like *Acharamati, Neelabati, Jaiphula, Jubraj, Kalajeera, Tulasiphula, Badsabhog* etc. and they also combine many yield attributing traits like longer panicle length, higher grain number with improved fertility, indicating their suitability as donors for improvement of yield and quality. The entire range of quality traits in these groups of germplasms are neither exploited nor utilized for genetic enhancement of yield as well as quality. So far the efforts made in collection, maintenance and evaluation of such indigenous scented rices is very meager. Therefore, there is a need for well-organised research programmes for further collection, purification and characterization of such valuable germplasm still available with the farmers for their future use.

Majority of such scented rices are strongly aromatic and reported to retain aroma in relatively warmer climate than those of the traditional long grained Basmati types. It is indicated that the local type *Kalajira* available in many parts of Odisha can retain aroma for a longer period even under storage and therefore, has a better market demand. However, the chemical characterization and quantification of aroma has not been made so far systematically for transferring this trait successfully into high yielding genetic background. Due to complex breeding behaviour of quality traits and the role of environment in expression of characters like amylo-pectin, amylose, gelatinization temperature, translucency of grain and head rice recovery, it was not possible to combine all the desirable quality traits in a single genotypes in desired norm and direction. Therefore, there is a need for basic research on genetics and breeding behaviour of quality traits including aroma that would help in making breeding strategy more precise.

Many local scented germplasm accessions collected from different parts of the state were found to exhibit a high degree of genetic variability for several agro-morphological and quality traits. It is therefore suggested to preserve this genetic variability of the crop by in situ conservation by farmers and women groups in target villages or areas of their availability. These aromatic types also express many desirable yield related traits like longer panicles, higher panicle number, large and active sink with improved fertility and better 100-grain weight, thereby indicating their utility as potential parental sources for improvement of yield and quality in small grained aromatic rice. However, the complex breeding behaviour of quality traits, the environmental effects and inter-group sterility factors impose restrictions in bringing together the complete array of quality traits into high yielding backgrounds.

It is therefore, suggested to make use of convergent breeding techniques by utilizing diverse germplasm sources possessing genes for quality and resistance with improved agronomic base for the genetic enhancement of yield and quality in short grain aromatic rices. Further, the problems of undesirable linkage for recovery of agronomically superior recombinants associated with the use of aromatic germplasms can be overcome through many innovative breeding and selection approaches like disruptive mating, recurrent selection and population improvement, and male sterile facilitated recurrent selection to make rapid progress in yield and quality.

The distress sale of rice in many parts of the state creates scope for diversification of traditional to scented rice cultivation in the state. Therefore efforts should be made for promoting multiplication and distribution of released and notified short grain aromatic rice varieties for general cultivation. Efficient and economic seed production strategy is vital for popularization as well as large scale adoption of these aromatic rices for commercial use. Processing and marketing of these aromatic types is likely to fetch more price and thereby increasing the socio- economic conditions of the Odisha farmers.

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Oryza Vol. 60 Special Issue 2023 (45-52)
DOI https://doi.org/10.35709/ory.2023.60.0.3

Understanding the physiological, genetic and molecular basis of nitrogen deficiency tolerance and their application in rice improvement

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Received : 22 January 2023 Accepted: 04 February 2023 Published : 07 February 2023

ABSTRACT

Nitrogen (N) is a major nutrient required for growth and yield of rice plants. Several factors including plant, edapic and climate conditions influence the criticle yield response curve of the plants. Apart from breeding for N responsive rice varieties, excessive use of nitrogenous fertilizers have become a general farmers practice to boost rice productivity under intensive cropping system. Now, it is imperative to orient the crop improvement programme for sustainable crop production strategy as well as to achieve the evergreen revolution through improving nitrogen use efficiency (NUE) under global climate change condition. To develop N-efficient rice varieties under crop breeding programs, it is crucial to comprehend the physiological, genetic and molecular features associated with tolerance to nitrogen deprivation. It has always been challenging for a rice breeders to develop rice varieties with high nitrogen use efficiency (NUE), as it is highly complex physiological trait involving several component traits and its dynamic interaction with environemental factor. NUE is a polygenic traits controlled by number of quantitative trait loci's at genomic level. Till date, researchers targeted component traits for increasing NUE such as, nitrogen uptake/absorption, transport from root to shoot, assimilation, utilisation, remobilisation, reasssssmilation and partitioning /redistribution. Here, we described a short summary of the physiological, genetic and molecular underpinnings of nitrogen deficit tolerance and how these prior art information can be used for improving NUE in rice. Insight from our discussions may facilitate the breeders to improve the NUE of rice plants in future.

INTRODUCTION

More than half of the world's population primarily consumes rice, a grain crop (Lee et al., 2021). Over the past 50 years, rice yield has improved as a result of the expansion of agricultural areas, the introduction of new cultivars, and the use of chemical nitrogenous fertilizers, keeping up with the global population growth. One of the primary essential components is that rice needs are Nitrogen (N). The N content of farmland's soil, however, is insufficient to support the needs of rice's development and growth. As a result, one of the unavoidable ways to raise rice output is by the application of N fertilizer. India's total grain output more than tripled to 69.7 million tonnes annually during the previous 50 years (1961-2020).In the same period, the rate of chemical N fertilizer application nearly quadrupled, reaching 30 million tonnes of pure nitrogen per year, or about one-third of the N applied globally. (FAO,2022). The total production of Rice during 2021-22 is estimated at a record 130.29 million tonnes. It is higher by 13.85 million tonnes than the last five years' average production of 116.44 million tonnes (4th Advance estimates, 2022).

Due to inadequate N availability, nitrogen shortage is one of the most frequent issues limiting rice growth, development, and production. The most fundamental physiological processes connected to biomass production and grain yield are influenced by the availability, absorption, and usage of N. The establishment and maintenance of sink capacity (number and size of seeds), development of photosynthetic capacity and activity, maintenance of photosynthetic activity, and agricultural product quality are the four basic functions of N in the production of biomass and cereal grains. (Herrera et al., 2016). N is therefore a crucial nutrient for agriculture and the security of the world's food supply, and N fertilizers are needed to produce enough food to sustain the world's growing population (Liu et al., 2021). For reasons of productivity and quality, environmental safety, and economic issues, N must be used effectively in agricultural production. Although using N fertilizers is essential for improving agricultural yield potential, doing so has negative effects on the environment, including high energy use, greenhouse gas emissions, and eutrophication of water supplies. Rice has a very low NUE (< 33%) among cereal, because of ammonia volatilization, denitrification, surface runoff, and leaching, especially in irrigation ecologies. Hence, Understanding how growth and development of rice plants (adaptive response) happen in varied N-availability condion is essential for increasing plant NUE and optimal use of N fertilizer in agricultural practice (Gramma et al., 2020).

Physiological basis for Nitrogen deficiency tolerance

Literature suggests, researchers used the morpho-physiological, biochemical traits value differences between rice genotypes grown in N sufficient and N deficit condition to measure the plant adaptive resposes. N deficit stress impose a serious threat to life of plants as majority of N absorbed from soil is accumulated as Chlorophyll (Light harvesting pigment in photosynthetically active leaves) and Rubisco (Primary carboxylation enzyme that fixes atmospheric CO2 in to carbohydrates). The N stress affected plants are morphologically stunted, lanky, weak, chlorotic (Pale yellow in colour) leaves with erect leave position, reduced leave width, associated with less light and dark reaction efficiency, early maturity, lesser tillering habits with low biomass and growth rate to ulmately with poor grain yield. Rice growth and development depend on the timing of N availability as it affects components traits of yield, including the number of tillers, the number of productive tillers, the number of grains per ear, the weight of 1000 grains, and the N content of the grains. A typical N deficiency symptoms are first appear in old leaves, inverted "V" shaped chlorosis from leaf tip to base and eventually whole leave become chlorotic and die. Kumar et al., 2015 observed that vegetative plant development decreased at N0 levels and increased at N200 levels. Among the genotypes, Krishna Hamsa had the greatest PNUE (34.94) and subsequently the highest yield (7.15 tonnes per hectare). Other traits, including plant height, the number of productive tillers, and LAI, also showed greater values for Krishna Hamsa. Breeders can use these traits as physiological indicators/markers and superior donors to breed N efficient rice cultivars.

Ten rice genotypes were tested by Swamy et al.,2015 in a treatment cultivated in the field at the Indian Institute of Rice Research (IIRR), Hyderabad, with recommended nitrogen rates (100 kg N ha1) and inadequate nitrogen as no external nitrogen (i.e., N0). They discovered that when there was a lack of N_, root length (RL) fell by 14%. Agronomic procedures still need to be standardized to reduce N application and utilize existing N more effectively. When it comes to morpho-agronomic and physiological traits, such as plant height, tiller number, grain yield, dry weight of shoots and roots, spikelet number, number of filled grains per panicle, 1000-grain weight, the leaf colour chart (LCC), and chloroplasts in rice, nitrogen use efficiency is a complex trait that is associated with various components, such as pNUE, aNUE, and agNUE (Yogendra et al., 2017). Mu et al., 2021 described the physiological reaction of photosynthesis to N deficit in leaf structure and N distribution throughout the leaf. Photosynthesis is vital for plant growth and crop yield. Improving photosynthetic efficiency is crucial for raising agricultural yield. Among C3 species, rice has the greatest photosynthetic NUE, demonstrating that rice is the most bioactive food source, and absorbs a significant quantity of nitrogen per plant at the leaf level (Furbank et al., 2020).

Nearly all plants experience a reduction in photosynthetic rate under severe N stress. The following are the causes: (1) Reducing the stomatal conductance of mesophyll cells (gs) and bundle sheath cells (gbs), which affects intercellular CO2 concentration; (2) Reducing the content of bioenergetics and light-harvesting protein, which inhibits electron transport rate and increases the amount of light energy dissipated as heat; and (3) Reducing the content and/or activity of photosynthetic enzymes, which increases carboxylation rate. N stress during the reproductive stage causes the breakdown of N components, notably thylakoid N and photosynthetic enzymes, which lowers photosynthesis. We should select a genotype with greater N levels to maintain high grain production in low N insufficiency. In rice, the Nutrient remobilization from senescing rice leaves during the post-anthesis stages and their contribution to the rice grain nutrition has been examined quite extensively for N, but to a limited extent for the other elements. In a newly developing rice leaf, approximately half of the N accumulated comes from remobilized N from internal organs. In comparison, 70-90% of N in rice grain is contributed from the N pool deposited in the vegetative tissues before the reproductive stage, whereas the remaining depends on the post-anthesis soil uptake (Yoneyama et al., 2016). The major forms of amino acids released from senescing leaves are glutamine and asparagine. A rice mutant impaired in the ferredoxin-dependent glutamate synthase, which has been suggested to participate in the N reassimilation during the N remobilization process, showed premature leaf senescence and reduced seed setting (Zeng et al., 2017). About 50% of the total N content of rice grains is accounted for by N uptake after anthesis (Teng et al., 2022). Analyses of metabolite profiles showed that low N treatment resulted in lower concentrations of total sugars and organic acids in the leaves and higher concentrations of total sugars, organic acids, and free amino acids in the roots (Han et al., 2020).

Genetic basis of nitrogen deficiency tolerance and nitrogen use efficiency

The development of new and improved rice varieties depends on an understanding of the genetic underpinnings of the agronomic, physiological, and morphological features of rice. Recently, researchers have gained access to the tremendous online richness of genomic and plant breeding resources, including high-quality genome sequences (Du et al., 2017), dense SNP maps (Ebana et al., 2010), vast germplasm collections, and public databases of genomic data. Now, we know the braod spectrum, molecular key elements and sequence of events happen at cellular level. Among them, plants absorb N in mainly two forms such as NO3- or NH4+. NO3- under aerobic conditions or NH4+ in a flood situation are the two typical forms of N that are present in the soil. These two forms are taken up from the soil by specialized N transporters via the high-affinity transport system (HATS) and low-affinity transport system (LATS), two physiological processes. HATS uses nitrate transporter 2 (NRT2) and ammonium transporter 1 (AMT1) to take up NO_3^- and NH_4^+, respectively, under low N concentrations (250 M). While NPF (NRT1/PTR) in the LATS system works to absorb NO_3^- and NH_4^+ at high N concentrations (>250 M), (Fiaz et al., 2021). Three of the ammonium transporters (AMT) from OsAMT1 participate in high-affinity transport, while seven members of OsAMT2, OsAMT3, and OsAMT4 operate as low-affinity NH_4^+ transporters in rice. These AMT are classified into four subgroups from OsAMT1 to OsAMT4. Two isoforms of the essential enzyme GS/ GOGAT exist GS1, which is responsible for initial ammonium assimilation in roots or re-assimilation of ammonium in leaves, and GS2, which controls ammonium assimilation in chloroplasts.

N assimilation and remobilization need both isoforms. OsGS1.1 and OsGS1.2, two of the three GS members found in rice, are purportedly expressed in all organs and show a reciprocal reaction to ammonium availability in the rice roots. Ferredoxin-dependent (Fd-GOGAT) and NADH-dependent GOGAT are the two kinds of GOGAT, which differ in their preferred electron donors (NADH-GOGAT). In rice plants, one ferredoxin and two NADH-dependent enzymes have been found. Increasing the N absorption efficiency is crucial for raising a crop plant's total NUE. A significant factor in influencing grain quality is GS. A cytoplasmic isoform (GS1) and a chloroplastic isoform (GS2) are the two main categories for GS. The total protein content of grains and the GS1 and GS2 activity in flag leaves were positively linked (Hu et al., 2018). These component traits are thoroughly studied at varied tissue levels either at whole plant or leave / root; cellular level at both protein enzyme activity and gene expression at molecular level. Now, it is understood that the N deficiency tolerant genotype possess greater enzyme activity and gene functional expression level than the susceptible genotypes. Similalry, it is known that, rice plants tolerate N deficiency thorough modulating the component traits of nitrogen use efficiency (NUE). NUE is the result of N uptake efficiency (NUpE) and N utilization efficiency (NUtE). NUpE is defined as the plant N uptake divided by the N application rate.

The NUtE is calculated as the ratio of the total grain yield to the total N contents of the plant.

Forward genetic approach for improving NUE of rice plants

For sustainable rice production, it is essential to find and develop rice cultivars with high NUE for non-optimized N circumstances and N-deficit tolerance (NDT). NDT is the ability of plants to sustain normal growth and excellent output under low N content. NDT is a criterion for selection to enhance NUE. Conventionally, forward genetic approach is used to identify the QTLs/genes through phenotyping of component traits of NDT or NUE for crop improvement. Till date, several quantitative trait loci (QTL) have been discovered for NDT and NUE, utilizing populations such as backcross introgression lines, recombinant inbred lines, and chromosomal segment replacement lines under low N stress or various N levels. (Zhao et al., 2014, Anis et al., 2019). Tolerance of Nitrogen Deficiency 1 (TOND1), a significant QTL/gene that imparted NDT in the indica cultivar Teqing, was discovered by Zhang et al. in 2015. In rice cultivars lacking TOND1, overexpression of TOND1 boosted tolerance to N deprivation. The nitrate transporters OsNRT1s, OsNRT2s, and OsNAR2s, ammonium transporters OsAMTs, nitrate reductases OsNIAs, glutamine synthetases OsGS1s, and transcription factors (TFs) OsMADS, OsBT, and OsGRF4 have also been discovered as important elements in rice NDT. (Liu et al., 2017, Xuan et al., 2017, Vega et al., 2019). Large-scale datasets from their study show feature of poor N-responsiveness and offer insights into the regulatory mechanisms of N-deficiency tolerance in rice. They found 2722 differentially expressed genes in response to low N and 411 GWAS-associated genes in 5 QTL, of which 24 were found by both techniques and prioritised based on gene annotations, literature searches, gene expression, and genetic diversity analyses (Li et al., 2022).

Although the aforementioned genes involved in NDT in rice have been defined, our knowledge of the regulatory network governing N-utilization is still insufficient. In particular, when N is scarce in the soil, a greater understanding of the processes behind these features is critically required for both the selection and well-directed breeding of N-efficient rice cultivars. Genome-wide association study (GWAS) has emerged as a potential method for analyzing complicated features during the past 10 years, and it has been used to locate related loci or potential genes. (Fang et al., 2017). GWAS uses statistical methods to find associations between sequence polymorphisms and phenotypic variation among accessions. Compared with conventional QTL mapping using bi-parental populations, GWAS offers two major advantages. First, the genetic materials used for GWAS populations include more natural variation than the two parental lines used for segregation populations. Second, most GWAS can achieve relatively high mapping resolution owing to the presence of diverse historical recombination events (Wang et al., 2020). Additionally, genes in rice seedlings that are susceptible to N deficit or N supplementation have been found using genome-wide transcriptome analysis. (Hsieh et al., 2018). It is possible to combine these two methods to pinpoint the controlling factors for N-utilization in rice. Only eight of the 33 QTLs that were reported in the RIL population in response to low N treatment were consistent under low N. Four common QTLs on chromosomes 1, 3, 4, and 7 were identified after two years of QTL mapping in the RIL population for NUE and nitrogen deficit tolerance characteristics. (Wei et al., 2012).

Genome-wide association study(GWAS) revealed a change in the OsTCP19 promoter. Further research revealed that OsTCP19 controlled nitrogen absorption by controlling the expression of genes involved in nitrogen use to satisfy the needs of nitrogen growth. The OsARE promoter finds itself in a similar circumstance. After examining 2155 different rice varieties, we discovered that 18% of Indica and 48% of Japonica contained tiny insertions in the ARE1 promoter. These insertions decreased ARE1 expression, delayed senescence, and increased grain production by 10-20% when nitrogen was scarce (Wang et al., 2018). Through an association mapping technique, various agronomically significant parameters, including NUE-related traits in rice, have been studied using rice SSR markers. 12 genomic areas for yield and yield-associated characteristics under low nitrogen were found in our investigations utilizing association mapping, a marker set of 50 rice SSR markers, and 472 rice genotypes (Liu et al., 2016). A transcriptome analysis of rice accessions with varying responses to low N stress at two N levels was carried out by Li et al., 2022, employing a broad panel of 230 rice accessions in a genome-wide association study (GWAS). They discovered 411 GWAS-associated genes in 5 QTL and 2722 differentially expressed genes in response to low N, of which 24 were discovered by both techniques and rated based on gene annotations, literature searches, gene expression, and genetic diversity analysis. The large-scale datasets acquired from this work indicate low N-responsive traits and offer insights into the regulatory processes of N-deficiency tolerance in rice. Additionally, the potential genes or QTL would be useful resources for boosting rice NUE using molecular biotechnology.

Reverse genetic approach for improving NUE of rice plants

The development of rice cultivars that are resistant to pests, diseases and unfavourable environmental factors including drought, submersion, and salt stress was made possible via genetic selection and plant breeding techniques. However, a suitable genetic selection strategy is required for adapting NDT in rice crops. Modern molecular techniques that follows reverse genetic approach (Genetic engineering/transgenic approach) allow us to functionally characterise the component traits associated with NDT or NUE as well as for development of commercially viable crop varieties with improved NDT. Oflate, the inadequate recovery of N fertilizer, accompanying economic and environmental problems, and the lack of adoption of more effective N management systems demonstrate the need for superior N-efficient genotypes (Ali et al., 2018). Recently, several positive and negative genetic element associated with nitrogen absorption, transport, assmiliation and remobilisation are modulated using over expression or know down strategy to improve the rice plants.

Nitrate transporters

More than 80 NRT1 and 4 NRT2 members are found in the rice genome, however, only a few of them have been fully described (Wang et al., 2018). OsNPF6.1 was discovered to be related to enhanced plant height and effective panicle number in a recent genome-wide association study (GWAS) of rice accessions with the most N-regulated phenotypes under high as well as low N-availability. OsNAC42 controls the transcription of an elite OsNPF6.1 haplotype (OsNPF6.1HapB), which increases the NUE and associated yield in rice under low-N conditions. This plasma membrane-localized high-affinity nitrate transporter is mostly expressed in rice roots. While yield and NUE in mutant rice plants grown at low NO3 levels fell, they increased in transgenic rice plants with overexpressed OsNPF6.1HapB (Tang et al., 2019). OsNRT1.1b is a strong candidate for increasing N accumulation and enhancing growth in low-N supply environments (Fan et al., 2016). Under low-NO3 conditions, overexpressing OsNRT2.1 led to an improvement in nitrate uptake in rice, as well as an increase in total nitrogen content in transgenic plants' roots and shoots. Both of the OsNPF7.7 spliced mRNA variants OsNPF7.7-1 and OsNPF7.7-2 improved the NUtE and grain yield in rice under low and high N supplies. Surprisingly, OsNRT2.3a accounts for 74% of root-shoot NO3-transport under low-nitrate conditions (Tang et al., 2019). The growth and yield of the transgenic rice plants overexpressing OsNRT2.3b were enhanced, and the NUE was thereafter 40% better than control in both conditions of ample and insufficient N-supply. Under low NO3 availability, the co-overexpression of OsNRT2.3a and OsNAR2.1 enhanced the grain yield, N-uptake, and agricultural NUE of transgenic rice plants by 24.6%, 27.8%, and 28.6%, respectively (Chen et al., 2020).

Ammonium transporters

In rice, OsAMT1.1 overexpression boosted ammonium uptake, plant growth, grain filling, and the total number of grains per plant, particularly in low-NH4+ concentration conditions (Ranathunge et al., 2014). N-accumulation was increased in the roots and decreased in the shoots of the osamt1.1 mutant under a low ammonium supply. Their findings unequivocally show that OsAMT1.1 is not only involved in ammonium uptake by the roots but also in its distribution, which results in future plant development. Due to higher ammonium assimilation in the overexpressing lines, the simultaneous overexpression of OsAMT1.2 and OsGOGAT1 (glutamate synthase1) in rice raised plant height and improved biomass relative to WT under low-NH4 availability. Retarded growth under low and high NH4 supply was a characteristic of transgenic rice plants overexpressing OsAMT1.3 (Lee et al., 2020).

Nitrogen assimilation and remobilization in rice

Increased tolerance to nitrogen deficiency and improved ammonium absorption and N remobilization at the level of the whole plant were the results of the simultaneous activation of the OsAMT1;2 and OsGOGAT1 genes (Lee et al., 2020). According to Komarova et al. (2008), Chromatin immunoprecipitation (CHIP) and yeast-one hybrid tests revealed, that OsNLP1 may directly bind to the promoters of these genes and trigger their expression. An effective method for raising rice NUE in the future will be to increase ammonium absorption and remobilization. (Taochy et al., 2015) interestingly note that in both sufficient and low nitrogen circumstances, the overexpression of OsAMT1;2 and OsNADH-GOGAT1 in rice can boost Nitrogen deficiency tolerance in rice. Increased biomass, yield, and NUE were seen with OsATG8b and OsATG8c overexpression at low and moderate N levels. In transgenic rice plants, the overexpression of the glutamine synthetase genes GS1 and GS2 increases nitrogen-deficiency tolerance.

CONCLUSION

For sustainable, cost-effective and ecologically friendly agricultural operations, the creation of nutrient-use-efficient cultivars is essential. While various management techniques are being researched to improve the efficiency of nutrient inputs over time and space, several attempts are being made to find genotypes with varying nutrient usage efficiency for the Indian context. Developing improved/ efficient rice crop breeds is also important in the context of doubling farmers income by reducing the input cost. Additionally, a multidisciplinary effort should be made to assess reported exotic germplasm for nutrient-use efficiency and exploit the sources to create nutrient-use-efficient cultivars. In this review article, we described physiological and genetic basis of nitrogen deficiency of the rice plants. Additionally, we reviewed about how researchers used the physiological, molecular and genetic information for improving rice crop plants through traditional and modern crop improvement techniques. The same strategy can be used for improving the nitrogen deficiency tolerance of diverse crop plants in future.

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Oryza Vol. 60 Special Issue 2023 (53-62)
DOI https://doi.org/10.35709/ory.2023.60.0.4

T3SS-effectors of *Xanthomonas oryzae* pv. oryzae: The arsenal to bout rice immunity for bacterial blight development

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Received : 18 January 2023 Accepted: 25 January 2023 Published : 07 February 2023

ABSTRACT

Xanthomonas oryzae pv. oryzae (Xoo), the bacterial blight (BB) pathogen employs T3SS-effectors of two classes Xanthomonas Outer protein (Xop) and Transcriptional Activational-Like (TAL) effectors to undermine rice PTI for its limitless proliferation inside the rice during disease development. The TALEs include both complete (tTALEs) as well as incomplete or pseudo/iTALEs. Xoo mutants lacking these effectors functional genes when inoculated on rice caused significant increased expression of rice PTI genes. The both the effectors are tracked to localize to the rice plasma membrane. The effectors secreted in phase manner are targeted to nullify the innate and induced defense response in the host. The immune suppression is mediated through enzymatic and transcriptional function of these effectors. In short analysis, Xop effectors put-off of triggered immunity whereas TAL effectors ensure the supply of required nutrients for the bacteria. In vice-versa, these effectors are recognition factors for induction of defense response in non/resistant hosts which of importance in the exploitation of these factors for improving the resistance of rice against the Xoo. This advocates that Xoo T3 effectors interacts with the host interactors to accomplish its common goal of undermining the plant immunity, either through interfering physiological function or through weakening plant immune protection system. This review highlights the recent understanding into the Xoo-effectors vs rice that opened up novel rice targets and their sensible exploitation could lead to broad spectrum resistance to BB of rice.

T3SS for effector translocation

The secretion systems (SS) in bacteria helps to cope with its environment through secretion of substances across its cell wall on spatial manner either to the extracellular medium or directly into host. Among six SS found in the pathogenic bacteria, T3SS is a specialized export system to translocate type III effector (T3E) proteins directly into host cells that facilitate pathogen-mediated manipulation of plant cellular pathways and subsequent disease or trigger plant defense responses to hold the infection process and is indispensable for the pathogenesis of Xoo (Dean, 2011; Lee et al., 2013; Verma et al., 2018). The T3SS are encoded by cluster of genes in pathogenicity islands (PAIs) of chromosomes or plasmids that are designated as 'hypersensitive response and pathogenicity' (hrp) genes (Hu et al, 2017). Hrp genes are categorized into ''hrp-conserved' and 'hrp-associated'. Structurally, T3SS is syringe like, so called injectisome, made of 20 gene products of repeated copies. Xanthomonas harbours Hrp2 family of T3SS and composed of sorting platform, export apparatus and needle-complex of Hrp pilus forming a transport system of greater length with multimeric ring structure made of translocon that form pores on the host cell membrane (Buttner and Bonas, 2002; Buttner et al., 2009). T3SS in Xoo transverse two kinds of proteins, major share of T3 effectors that are injected straight into the host cytosol and harpins (Hpa1) which are extracellular accessory proteins (Wen et al., 2003; Zou et al., 2006; Kay and Bonas, 2009)

T3SS-effectors of Xoo:

Xanthomonas oryzae pv *oryzae* use type three effectors (T3Es) secreted through T3SS to compromise rice immunity response and obtain nutrients. The targets of T3Es are pathogen triggered immunity (PTI) responses incited by pathogen associated molecular pattern (PAMPs) and/or damage associated molecular pattern (DAMPs) and their suppression is essential for the colonization and spread within the host (White et al., 2009; Ji et al., 2018). These T3Es also function as avirulence factors by recognition by the host receptors followed by defence elicitation. The T3Es as individual or in combination with other, determines the virulence of the pathogen as proven with limited spread and reduced symptom in the respective mutant strains (Yang and White, 2004). Each strain of Xoo houses about 35 T3 effectors of varying numbers as in the case of a virulent Xoo strain (race 4) from India possess 21 Xop and 18 TAL effectors (Long et al., 2018; Mondal et al. 2014) whereas PXO99A strain from Philippines found to have 19 TALEs (Salzberg et al., 2008), 18 TALEs in African Xoo strain K74 (Yu et al., 2015), 6 in strains KACC10331 and 16 TAL genes in strain MAFF311018; 19 in strain PXO99A Xoo (Lee et al., 2005, Ochiai et al., 2005).

Classes of T3SS effectors:

The bacterial effectors are of two types, namely

a) Xanthomonas Outer Protein (Xop) Effectors: This group are very often referred to as non-TAL effectors.

b)Transcription Activational-Like Effector (TALEs): TALEs resembles the transcriptional factors of eukaryotic system and target genes favouring bacterial growth in susceptible hosts or defense genes in resistance hosts (Mondal et al., 2021).

Structural features of T3SS effectors:

a) Xop protein structure: Xop effectors targets host physiological function through enzymatic and non-enzymatic actions. These effectors are grouped into 40 multimembered groups. These Xop family members share similar N and C terminal regions required for T3 secretion and translocation which are basis for the categorization of these effectors (White et al., 2009). The region of variation are the domains meant for different catalytic activity and organelle targeting where these effectors act that may be membrane, cytoplasm or different organelles (The different catalytic activity includes ubiquitination, phosphorylation, G protein regulatory domains and actin-nucleation (Dean et al., 2011)

b) TALE protein structure: TALE protein contains a conserved N-terminal type III secretion signal for directing TALE into the host cell, a central repeat region (CRR) that binds specifically to its corresponding SWEET EBE in the host, a nuclear localization signal (NLS) that permits TALE inside nucleus, and a C-terminal transcriptional acidic activation domain (AD) that activates TALE function. The CRR provides specificity to TALE, comprising of variable numbers (from 1.5 up to over 30) of tandem 33-34 amino acid repeats and variation in the 12-13 amino acids of each repeat that uniquely target the EBE nucleotide sequence and are called as TALE-repeat variable di-residue (TALE-RVDs) (Streubel et al., 2013; Oliva et al., 2019; Yu et al., 2015; Mucke et al., 2019). TALEs are a trans-kingdom transcription factor enabling a TALE-RVD amino acid interaction with the DNA sequence of the UPT/EBE in the SWEET promotors. Mostly a common set of amino acid di-residues in the TALE-CRR form the RVDs - HD, NG, HG, NN, NS, NI and 'N*', its arrangement pattern in each repeat that gives identity to a TALE. The RVD amino acids complementarity with the (EBE) DNA nucleotide precisely (for e.g., 'HD' to cytosine, 'NG' or 'HG' to thymine, NN to purine ring) indicate mimicking like the transcription factor for SWEET genes, involving in modified expression. In vitro crystal structure studies designated each CRR repeat curl into left-handed 2 helix structure and further a right-handed super helix, the 12-13 are connectors of the 2 helices forming the end of each loop, such that the 13th residue helps form contact with EBE by H_2 bonding to the atoms on the single stranded DNA major groove nucleotide bases. Mostly Asparagine (N)/ Histidine (H), the 12th residue forms a directional H-Bond between the 12th amino acid R group to the 8th residual amino acid C=O of the 1st helix backbone (in aldehydes RCHO/Ketone R_2CO), conforming an optimized entropy. Artificially synthesized TALE studies inferred HD/NN and NI as strongest and weakest contributor of TALEs selectivity and affinity (Mak et al., 2013).

Target and site of action of T3SS effectors:

a) Xop targets:

XopP targets OsPUB44 U-box and inhibits rice immunity (Ishikawa et al., 2014). XopY (Xoo1488) inhibits rice immunity by suppressing OsCERK1-mediated phosphorylation of OsRLCK185 (Yamaguchi et al., 2013) ubiquitination was shown to be utilized by pathogen effectors to gain a competitive edge (Ustun, and Bornke 2014; Pruneda et al. 2016; Lin and Machner 2017). Ubiquitination alters the fate of a target protein, often tagging it for subsequent degradation by the 26S proteasome. A number of Xanthomonas T3Es interact or modulate the host ubiquitin-proteasome system including XopJ, XopD, XopK, XopAE, and XopL (Singer et al., 2013; Ustun and Bornke, 2014; Pruneda et al., 2016; Popov et al., 2018; Qin et al., 2018). XopL was shown to catalyze the ubiquitination of NbFd, which led to subsequent degradation of NbFd in planta and increased levels of reactive oxygen species and defense genes (Ma et al., 2020).

Despite the fact that a virulence function was shown only for a few effector proteins from plant pathogenic bacteria, accumulating experimental evidence suggests that individual effector proteins counteract the plant innate immune response that is triggered upon recognition of conserved pathogen-associated molecular patterns (PAMPs) such as flagellin, cell wall degradation products or LPS (Espinosa & Alfano, 2004; Keshavarzi et al., 2004; Grant et al., 2006; Jones and Dangl, 2006; Jha et al., 2007). Suppression of PAMP-triggered immunity by type III effectors might therefore be a major requirement for the successful establishment and multiplication of bacteria in the plant tissue.

b) TALE Targets:

SWEET proteins, popularly known as sugar transporter, play significant contribution through supplying the sugar molecules to different plant parts for their normal physiological processes. Xoo hijack the regulation system of the SWEETs genes from plant to ensure the sugar requirement for its own (bacterial) growth and multiplication and hence, are a major study focus to combat the disease (Chen, 2014; Chen et al., 2010). Xoo modulates the rice SWEET expression, by injecting TALEs. The TALEs have a very targeted approach towards manipulating only a few selected rice SWEETs for the pathogen to sustain and cause the disease. Mostly conserved TALEs differ in their RVD domains, which decide its specificity towards the susceptible rice SWEETs. The targets

of different TE effectors of Xoo are given in Table.1.

Table 1. T3SS effectors and target.

S. no.	T3SS- effectors/strains	Target or host interactors	Reference
1.	PthXo2 (JXO1 and MAFF 311018)	SWEET13	Zhou et al., 2015
2.	AvrXa7 (PXO86)	Xa7 resistance gene SWEET14	Yang et al., 2000 Antony et al., 2010
3.	PthXo1 (PXO99A)	Os8N3	Yang et al., 2006,
4.	XopR (Indian race 4)	Suppression of PTI responses through receptor-like cytoplasmic kinases	Verma et al., 2019
5.	XopL (PXO99A)	E3 ubiquitin ligase activity mediated degradation Ferredoxin (Fd) and mediated immune response	Ma et al., 2020
6.	XopN (KXO85)	♦ Tomato Atypical Receptor-like Kinase1 (TARK1) and four Tomato Fourteen-Three-Three isoforms (TFT1, TFT3, TFT5, and TFT6). ♦ Two rice proteins, OsVOZ2 and a putative thiamine synthase (OsXNP)	Kim et al., 2009; Taylor et al., 2012 Cheong et al., 2012
7.	Xop Z, Xop N, Xop V (PXO99A)	Peptidoglycan-triggered MAPK activation mediated suppression of immune response	Long et al., 2018
8.	XopP	Rice ubiquitin E3 ligase-OsPUB44 with U-box	Ishikawa et al., 2014
9.	XopQ (BXO43)	Rice 14-3-3 proteins, Gf14f and Gf14g; nucleoside hydrolase (NH) activity	Deb et al., 2019
10.	XopY	Rice receptor-like cytoplasmic kinase, OsRLCK185	Yamaguchi et al., 2013
11.	XopV MAFF 311018)	Inhibits flg22-triggered immunity	Popov et al., 2016
12.	XopK ((PXO99A)	Rice somatic embryogenic receptor kinase 2 (OsSERK2)	Qin et al., 2018
13.	XopZ (PXO99 strains)	Oxysterol-binding related protein, ORP1C	Ji et al., 2022

Deciphering the functional role of Xop effectors in disease development:

The composition and functional role of Xoo TAL effectors are well investigated in some strains. Though the non-TAL or Xop effectors of Xoo were shown to play as major virulence determinants but are less extensively studied (Kim et al., 2008; White et al., 2009; Kumar and Mondal, 2013; Mondal, 2017). The functions of some effectors, such as XopN, XopD, XopJ, XopZ, XopR in Xoo were predicted based on similarities with their know motifs or sequences as reported in other Xanthomonads (Kim et al., 2009; Bartetzko et al., 2009; Song and Yang, 2010; Akimoto-Tomiyama et al., 2012; Kumar and Mondal, 2013). XopN from *X. campestris* pv. vesicatoria had been demonstrated to suppress PTI by interacting with tomato atypical receptor-like kinase 1 (TARK1) and four tomato 14-3-3 isoforms (Kim et al., 2009). XopD from X. campestris pv. vesicatoria is predicted to function in the "de-SUMOlyzation" of plant proteins (Kim et al., 2008). XopJ from *X. campestris* pv. *vesicatoria* being structurally similar to the C55 group of cysteine protease was proposed to be involved in the ubiquitin/proteasome system and thus capable of removing SUMO proteins, resulting in the destabilization or inactivation of SUMOlyated proteins (Bartetzko et al., 2009). XopZ from Xoo Philippine strain PXO99A had been demonstrated to be involved in the suppression of PTI in rice (Song and Yang, 2010). Interestingly, two identical copies of XopZPXO99A were shown to be essential for full virulence of the strain PXO99A. Akimoto-Tomiyama et al. (2012) suggested XopR from Xoo Japanese strain, MAFF311018 functions as a repressor of MAMP-induced plant innate immune responses.

The detailed characterization of Xoo race 4 revealed the presence of 21 Xop- and 15 TAL-type III effector family (Mondal et al., 2014). Among TALEs, both complete (tTALEs) as well as incomplete/pseudo/iTALEs are identified (Mondal et al., 2020). The functional analysis based on loss-and-gain of effector revealed that two namely, XopF (Mondal et al., 2016) and XopR (Verma et al., 2018, 2019) contribute immensely during BB development. Xoo mutants (Xoo ΔxopF or Xoo ΔxopR) showed significantly reduced ability for in planta colonization, BB intensity but induced more callose deposition. Xoo mutants caused significant fold increase in rice PTI marker transcripts. The both the effectors localize to plasma membrane. Recently, two rice interactors for XopF, namely photosystem-I reaction subunit V (PSI-G) and cyclophilin II were identified (Fig. 1).

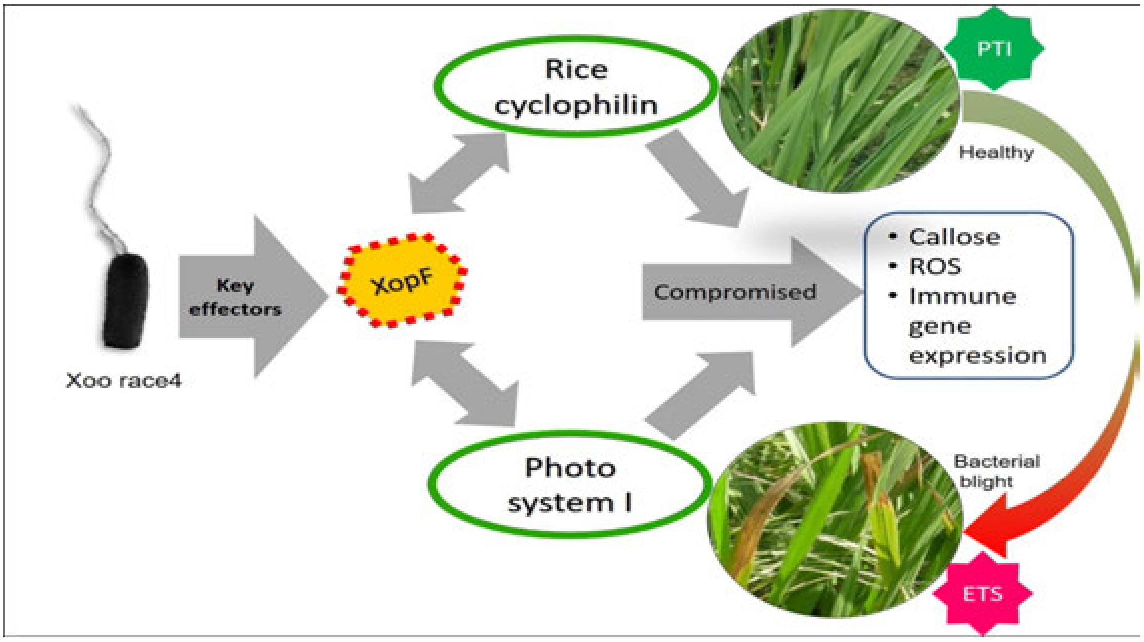

Fig. 1. Schematic presentation of the underlying interaction between XopF T3SS- effector of Xoo and rice proteins leading to modulation of PTI to ETS via compromised plant defense.

PSI-G interacts with many proteins of photosystem I, while cyclophilin II associates with proteins involved in protein-folding, signal transduction and ubiquitination. This suggests that XopF interacts with the two interactors to fulfil its common goal of subverting the plant immunity, either through interfering photosystem I or through destabilising plant immune protection system like cyclophilin. Altogether, this insight into the Xoo-effectors vs rice exposes novel target gene(s) in rice for their sensible exploitation in BB resistance programme.

Type III deficient mutant of Xoo can induce a basal plant defense response like callose deposition and thereby immunize rice against subsequent Xoo infection. A T2S- T3S- double mutant exhibited a substantial reduction in the ability to evoke these responses (Jha et al., 2007).

Deciphering the functional role of TALE effectors in disease development:

The T3SS pathway is majorly guided by 2 set of proteins translated by the *Hrp* genes (Hypersensitive response and pathogenicity genes) and *hrc* (HR and conserved) genes in bacteria. Mainly hrc genes are involved in directing the proteins to translocate into the host cytoplasm by forming a syringe like transport system called as T3SS through the bacterial envelope and *hrp* genes are involved in translocating the produced bacterial weapons like effectors, required for host pathogenicity through the host cell barrier (Alfano and Collmer, 2004). Xoo harbours 10-100 different TALEs depending on the strain. Major TALEs characterized in Xoo are AvrXa7, PthXa1, PthXa2, PthXa3, Tal5, TalC, among these Avrxa7 and pthxa1 interact with EBE of SWEET 11, PthXa2 interact with EBE of SWEET 13, pthxa3, Tal5, TalC interact with EBE of SWEET 14 (Tran et al., 2018; Oliva et al., 2019).

The promoter region of the SWEET gene comprises of UPT (upregulated by TAL effectors) boxes, also called the EBE (Effector Binding Element) to which the corresponding injected Xoo-TALE proteins selectively binds transcriptionally activating SWEET gene expression. TALEs of different Xoo strains induce the expression of anyone or a combination of the 3 SWEETs for rice pathogenicity. Therefore, studying Xoo TALE and its interacting rice SWEETs helps to identify gaps in the susceptible cultivar (Yuan et al., 2014).

iTALEs or truncated TALEs that suppresses E genes to favour pathogen:

Rice possesses several resistance (R) genes or so-called executor (E) genes that are dependent on pathogen's TALE for transcription and thereby provide resistance to the plant. The *E* genes are thus not only important for instigating host immunity like conventional *R* genes but are also required to curb the host susceptibility resulting from the loss of effector interaction. Thus, E genes hinder sucrose-accumulation by the pathogen leading to starvation of invaded pathogen in its niche. The *R* gene, *Xa1* offer resistance to rice in response to most of the typical TALEs (tTALEs). Recent analysis on Xoo genome deciphered that Xoo evolved incomplete or truncated TALES (iTALEs) that lack 58 amino acids sequence of the otherwise conserved TALE N terminal and the TALE activation domain (AD). However, it contains the NLS that directs its binding to the host R genes. Functional studies revealed that iTALEs hinder R gene (or E gene) activation through competing with the tTALE binding site. Xa1 mediated resistance of rice is compromised by iTALEs (often referred to as pseudoTALEs) like Tal2h, Tal3a, Tal3b of the Philippines Xoo strain Px099a. These truncTALEs or pseudoTALEs thus may contribute in the suppressing or masking the host immunity which may otherwise be stimulated by tTALEs (Ji et al., 2016, 2018; Xu et al., 2017).

Scope of utilizing the interaction between rice-Receptors and Xoo-Xop towards disease resistance:

A virulent Xoo strain (race 4) from India was reported to possess 21 Xop effectors (Mondal et al., 2014). Subsequent studies on these effectors revealed that T3SS-effector-like XopR plays a crucial role during blight induction. XopR was shown to be essential for in planta bacterial growth and virulence as well as for the suppression of plant defense responses including callose deposition and ROS production (Verma et al., 2018).

Scope of utilizing the interaction between rice-SWEETs and Xoo-TALEs towards disease

resistance:

The underlying interaction between rice-SWEETs and Xoo-TALEs have opened up sensible scope for targeting broad spectrum resistance to Xoo. As we know SWEET's EBE sites are primary target for induction of susceptibility genes by the bacterial blight pathogen in rice for their proliferation in the host. Over a period of time, host develop natural resistance against these pathogens by altering the EBE sequence so that pathogen will not be able to recognize and complement the EBE, failing to induce susceptibility and fulfilling their nutrition uptake. In nature, three recessive forms of susceptibility genes, namely xa13, xa25 and xa41 are found that provide resistance to bacterial blight. In these naturally resistant plants, mutation happened in the promoter regions resulting in non-activation of the SWEET genes, OsSWEET11, OsSWEET13, and OsSWEET14 (Hutin et al., 2015;Zhou et al., 2015; Eom et al., 2019; Zaka et al., 2018; Antony et al., 2010; Tian et al., 2019). So this mechanism of resistance can be engineered in desirable rice cultivar for developing resistance towards BB using genome editing tools like Mega nucleases, Zinc Finger nucleases, TALEN'S, CRISPR-CAS9 etc. The introduction of multiple edited EBEs (that will no longer be available for Xoo TALE binding) would lead to non-race-speci?c durable resistance to BB. Thus, modulating the regulation of S genes becomes an interesting alternative to R genes in today's breeding program. In this direction, the crop scientists have initiated efforts towards developing resistance in rice for BB exploiting the edited EBEs. Recently rice lines with multiple edited EBEs for Xoo TALEs has shown great promise in reducing the BB infection (Oliva et al, 2019).

Way forward & Summary:

The bacterial blight pathogen, Xoo-rice interaction is an example of the ongoing evolutionary battle between plants and pathogens. Several hrp/hrp-associated gene products are to be identifies and characterized and their role in the composition and function of T3SS is to elucidated (Cui et al., 2018). Inactivation of individual effector genes often does not significantly affect bacterial virulence, presumably due to functional redundancies among effector proteins (Vivian and Arnold, 2000; Noel et al., 2003; Roden et al., 2004). While effectors can contribute to the colonization of eukaryotic hosts by bacterial symbionts and pathogens, they can also elicit host immune responses that restrict bacterial growth. These opposing selective pressures have shaped the evolution of effector families and may be responsible for their incredible diversity in biochemical function, mechanism of action, and taxonomic distribution (Bastedo et al., 2020). In summary, the present review brought an insight into the Xoo T3SS effectors and their functional role in BB development. This detailed information would certainly helpful for the researchers, students and educationists in understanding the Xoo mediated blight pathogenesis and to formulate strategies towards developing resistance to bacterial blight pathogen.

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Oryza Vol. 60 Special Issue 2023 (63-70)
DOI https://doi.org/10.35709/ory.2023.60.0.5

Energy efficient farm mechanization for small and marginal farmers

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Received : 01 January 2023 Accepted: 16 January 2023 Published : 07 February 2023

ABSTRACT

Rice is one of the important crops and staple food for millions of people in India and world. In India, it is cultivated in 45.07 million ha which is largest area under rice cultivation in the world. However, the productivity of rice in India is less in comparison to Egypt and China. Rice crop is cultivated by conventional practices in India. These practices require high inputs which adversely affects the natural resources i.e. soil, water and climate in the form of soil degradation, ground water depletion and air pollution. Rice farming is negatively affected by these environmental degenerative factors. The development and adoption of new technologies are imperative to reduce these environmental degenerative factors of rice farming. These technologies enhance the production by efficient and precise application of inputs such as seed, fertilizer, chemicals and irrigation water. It ultimately lowers the cost of production. The aim of this paper is to provide information about available improved machineries and technologies for pre-harvest operations of rice crop. The high capacity machinery such as rice transplanters, combines, etc are to be used on custom hiring and for contractual field operations. There is a need for assured mechanised services to farmers and guaranteed business to service providers for paddy nursery raising, mechanised transplanting and combine harvesting.

Key word: *Rice mechanization, puddling, direct seeding of rice, straw management*

INTRODUCTION

Rice is cultivated in 45.07 million ha in India and is the largest area in the world. The production of rice has increased from 20.58 million tonne during 1950-51 to 122.27 million tonne in 2020-21 (Anonymous, 2021). The area under rice increased by 1.4 times while the production increased by over six times. The productivity has been increased to 2.7 t/ha from 0.7 t/ha for the same duration. This increase in rice production has been achieved due to high yielding varieties, irrigation facilities and optimised use of critical inputs. Agricultural mechanization is one of the critical inputs which not only facilitates timely completion of operations and thereby increases the production, labour saving, energy efficiency, productivity and profitability (Singh et al., 2005).

Rice cultivation is done in upland, lowland, deep water, irrigated and coastal saline conditions. It can be sown in dry seedbed, wet seedbed or can be transplanted in puddled field. It is a labour intensive crop and requires about 800-900 man-h/ha. Puddling, transplanting, weeding, harvesting and threshing operations consume 11, 38, 19, 20 and 12% man-hours, respectively (Singh et al., 2005). Small and scattered land holdings especially with rice farmers in India create bottleneck in introducing mechanization with high capacity machines. Poor investment capacity of rice farmers is the inherent constraint for adoption of mechanization technology. Investment requirement in machinery for small farms is high and therefore most of rice farmers give low priority to machinery as compared to other inputs. On the other hand, high labour demand during peak periods adversely affects timeliness of operations, thereby reducing the crop yield. Because of drudgery and mindset that the farm operations are below dignity, labour availability has decreased considerably for farm operations during last a few years. In order to solve these problems and make rice cultivation profitable, selective mechanization is need of the hour.

Mechanization in Production of Rice

The mechanization levels in different farm operations such as seedbed preparation, sowing/transplanting, weeding/interculture/plant protection and harvesting & threshing for rice crop production system in India were 70, 20, 30 and 60%, respectively (Mehta et al., 2019). This indicates that the seedbed preparation and harvesting & threshing operations for rice are highly mechanized as compared to the other field operations.

Seedbed preparation

The objective of seedbed preparation is to create favorable soil conditions for better growth of crop to get maximum crop yield with minimum amount of energy consumption. Seedbed preparation for rice cultivation includes ploughing and puddling operations. Ploughing/tillage is the first field operation to control weeds, insects, pests and diseases due to exposure to sunlight in summer. Dry seeding of rice requires well pulverized seedbed, hence the field is initially prepared by primary tillage implements followed by secondary tillage implements to break the big clods and then level. Mould board (MB) plough, disc plough, rotavators and their modified versions for different power sources such as animal, power tiller and tractors have been used for first ploughing. Animal drawn disc harrow, spike harrow, spring tyne harrow, blade harrow, zigzag harrow, cultivators, clod crushers, chisel ploughs, subsoilers, scraper, bund former and wooden leveler are also used for seedbed preparation. The tractor operated cultivators, disc harrows and rotavators are also used for dry seedbed preparation. Single operation with rotavator covers primary as well as secondary tillage operation and saves 60-70% operation time and 55-65% fuel consumption as compared to conventional method.

Wet seeding or transplanting of rice requires one summer ploughing followed by two puddling operations after rain water or irrigation water application. Puddling incorporates the weeds and manures inside the soil and churns the soil. For puddling operation, puddlers of different designs, cage wheels with tractors and power tillers, hydro-tillers and puddling rakes are used. The animal drawn puddler can cover 0.07 to 0.11 ha area in an hour, while 0.33 ha area can be covered by using tractor operated rotary puddler developed by CIAE, Bhopal (Das, 2012). The power tiller operated puddlers are suitable to operate in hilly terrain and small farms as compared to the tractors. IRRI has designed hydro-tillers which can be used for very soft soil. The similar machine has been designed by PJTSAU, Hyderabad which saves 76% labour, 87% operating time and 47% cost of operation as compared to country plough and covers 0.15 ha area in an hour. The cage wheels mounted on tractor and power tillers can also be used for puddling operation. One hectare land can be puddled in a day with tractor drawn cage wheel while power tiller operated cage wheels cover 0.44 ha. PAU, Ludhiana developed a pulverizing roller attachment to a tyned cultivator for puddling operation. It covers 0.62-0.75 ha area in an hour, saves 20% cost of operation, 40-50% labour and operating time as compared to the tractor operated cultivator. The single operation of rotavator can also give good quality puddling along with 21% saving in fuel as well as time as compared to tractor drawn puddler. The fuel

Fig. 1. Animal drawn patela puddler.

Fig. 2. Power tiller operated rotary tiller.

Fig. 3. Tractor operated rotary tiller.

Fig. 4. Laser land leveller.

consumption by rotavator was 2.25 times higher than disc harrow but the seedbed quality was far superior (Badhe et al., 2004). Custom hiring played a significant role among the small farmer to utilize these tractor and power tiller operated tillage/puddling machinery to increase productivity and reduce cost of production.

The seed bed will become more effective after proper levelling. The leveling can improve efficiency of irrigation, efficiency of various crop inputs, crop establishment and uniformity of crop maturity. Bullock drawn implements like scoop, buck scraper and power tiller as well as tractor operated wooden planker can be used for levelling the dry seed bed. For wet seed bed, animal drawn float leveler, power tiller operated leveler and tractor drawn leveler have been developed. Also, PJTSAU developed a tractor mounted wet land leveler for puddled bed transplanting. It levels 0.4 ha puddled land in an hour (Das, 2012). Precise laser land levellers are also used for dry as well as wet land levelling. It can be manual, semi-automatic and automatic laser leveller. Laser land leveling can reduce 20-30% water use and increase crop yields by 10-20%. Along with these benefits it can also increase 3-5% cultivable area, up to 50% water application efficiency, 40% cropping intensity and up to 50% productivity (Jat et al., 2005).

Sowing / Transplanting

Rice grows in a diverse environment from low elevation to high altitudes. According to the surrounding environment, it can be sown in dry seed bed, wet seed bed or transplanted in puddled field.

Direct sowing of rice in dry field is the most cost effective and less laborious sowing method as compared to wet seeding as well as transplanting (Guru et al., 2022). However, the labour required in manual transplanting is 25-50 times higher than the broadcasting. Various types of seeders are available for direct seeding of rice. It can be sown with manual seed drill, animal drawn seed drills, self-propelled hill seeder and seeders operated by power tillers and tractors in plain terrain. However, manual, animal drawn and power tiller operated seed drills can also be used for hilly terrain. The seed cum fertilizer drills with 9 and 11 rows developed by CIAE, GBPUAT, PAU and TNAU are commercially available and can also be used for rice sowing and fertilizer application simultaneously. These seed cum fertilizer drill covers from 0.4 to 0.6 hectare area in an hour (Verma and Guru, 2015). Though the cost of seed cum fertilizer drill is more, the yield of 2.5-3.5 t/ha could be obtained as compared to 1.0-1.5 t/ha by broadcasting method (Das, 2012). In addition, the puddling operation has been avoided and crop inputs i.e. seed and fertilizer have been used precisely and placed uniformly by using seed cum fertilizer drills. The self-propelled direct seeded three row rice planter with fertilizer drilling attachment was also developed. This planter places the seed at 25-40 mm depth and maintain SRI recommended hill to hill spacing. It covers 0.12 ha/h at 69% less operational cost than manual transplanting with at par yield (Bangale et al., 2019).

Wet seeding with drum seeder is the most prominent and adopted technology. It is suitable for lowland rice and can be easily adopted in hilly region due to its light weight. The manual 2, 3, 4, 5 and 6 rows drum seeders are light in weight and can be operated easily by farm women in lowland area and are commercially available with 200 mm row to row spacing (Din et al., 2014). A four row manual pre-germinated seeder was developed at IARI, New Delhi, while a 8 row drum seeder with four separate cylindrical seed boxes was developed at IRRI, Philippines. TNAU, Coimbatore developed an eight-row drum seeder which covers from 0.08 to 0.14 ha/h, while a six row CRRI design drum seeder covers 0.09 to 0.1 ha/h. The labour requirement was reduced by 90% with this technology as compared to manual transplanting with 15.4% higher net profit (Das, 2012).

Transplanting of rice seedling by hand is the traditional practice in India. Nearly 250-300 man-hour are required to transplant one-hectare area by using root wash nursery. Many types of mechanical rice transplanters were developed to mechanize this laborious and difficult operation. A manually hand cranking type two row root wash nursery based transplanters has been developed by Dr. BSKKV, Dapoli and commercially available. The field capacity and cost of transplanting operation are 0.03 ha/h and Rs. 2600/ha, respectively. The mat type nursery based transplanters have been mostly used in India. PAU, Ludhiana developed a tractor operated seeder for raising mat type rice nursery to reduce the labour requirement. This machine prepares a nursery for about 75 ha area in a day and saves in 64.3-67.9% in cost and 93.8-94.4% labour as compared to traditional method (Anonymous, 2022). This machine is commercially available in India.

IRRI, Philippines designed and developed 5 and 6 rows manual transplanters and CRRI Cuttack developed two and four row manual rice transplanters which saves about 30-40% labour and 40% in cost of operation. Chinese VST-Yanji Shakti 8 row self-propelled rice transplanters are also commercially available in India and used by the farmers. There was 81.3% labour saving and 47.3% cost saving with 8 row self-propelled rice transplanters as compared to manual transplanting. The PAU, Ludhiana and PJTSAU, Hyderabad have developed a tractor operated six rows rice transplanter which transplants 0.4 ha area in an hour and saves 72% labour (Anonymous, 2000). Different types of self-propelled, walking type and riding type transplanters were developed and tested in India and are being used in custom hiring mode due to their high initial cost. Many farmers from rice growing states are now using rice transplanters to mitigate the labour scarcity and higher labour wages.

Weeding / Interculture / Plant protection

Weeds are the foremost problem in rice crop. These

Fig.5. PAU design tractor drawn seed drill.

Fig. 6. TNAU drum seeder.

Fig. 7. TNAU drum seeder.

Fig. 8. Walk behind four row rice transplanter.

Fig. 9. Tractor operated seeder for mat type rice.

Fig. 10. Self-propelled ride on type rice transplanter.

are controlled by using chemical as well as mechanical methods. Number of weeders designed for rice crop are commercially available and adopted by the farmers. Finger weeder by CRRI, single row manual cono weeder by IRRI, star cono weeder by CRRI and TNAU, finger wheel hoe by CIAE, rake and blade weeder are most commonly used manual weeders for both lowland and upland rice. Star cono weeder performs cutting, churning and mulching of weeds in wetland. The cono weeder and its local designs become popular amongst the farmers of rice growing states. These weeders saves 60% time and 60% cost as compared to manual weeding (Das, 2012). Animal drawn, power tiller operated and self-propelled weeders are used for upland rice cultivation and these can be used at hilly terrain with minor modifications. A two row self-propelled SRI power weeder has been developed at TNAU, Coimbatore in collaboration with M/s Premier Power Equipment & Product Pvt. Ltd., Coimbatore. It is suitable for timely weeding operation under all soil conditions in line sown and SRI paddy. TNAU has also developed a multi-row rotary weeder attachment to ride on rice transplanter. This weeder saves 90% time and 77% cost as compared to manual weeding and 70% time and 68% cost as compared to SRI power weeder (Anonymous, 2022).

The chemical application can be done by using sprayers and dusters to control weed, pest and diseases. These can be operated manually, or by engine, power tiller, tractor or battery. Hand compression sprayer, knapsack sprayers, power sprayers, tractor mounted sprayer and dusters are commercially available. Nowadays, drones are also being popularized by various state and central government agencies for spraying operation in rice crop.

Fig. 11. Cono weeder.

Fig. 12. SRI power weeder.

Fig. 13. Multi-row rotary weeder.

Fig. 14. Automatic irrigation system for rice at ICAR-CIAE, Bhopal

Irrigation

Rice is a water intensive crop, which requires about 2500 litres of water to produce 1 kg of rough rice. It remains under water ponding condition for 80% of cropping duration. To increase the water use efficiency for the rice crop, CIAE studied the drip irrigation system in rice cultivation under system of rice intensification (SRI) technique and observed 33% increase in yield over traditional method. Also, CIAE developed an automatic irrigation system for alternate wetting and drying method of irrigation for rice crop. The sensors and micro-controllers used in this system detect the water level in the field and give the signals to put-on and put-off the pump and maintain the required water level during different stages of crop growth.

Harvesting

Harvesting of the rice crop is time and labour consuming and needs to be done on time. Traditionally it is done by sickles and takes about 170-200 man-hours to harvest one hectare and involves drudgery. The improved sickles such as Vaibhav, Naveen, MAIDC are light in weight and have better grip to improve operators' comfort. These sickles harvest about 17% more area as compared to traditional sickles and are commercially available (Singh et al., 2005). Self-propelled and tractor operated vertical conveyor reaper (VCR) windrower are used for harvesting of rice crop at ground level. PAU, Ludhiana has developed animal drawn, engine operated and tractor operated reapers. During 1980, CIAE developed a tractor front mounted VCR. The field capacity of VCR developed by different centres of AICRP on FIM are in the range from 0.12 to 0.27 ha/h for harvesting of rice and wheat crop (Anonymous, 2000). Self-propelled and tractor operated reaper binders are also used for harvesting and bundle making of rice crop. The average field capacity of reaper binder is 0.35 ha/h with 91% field efficiency (Din et al., 2014). Self-propelled as well as tractor-on-top combine harvesters can also be used to harvest, thresh, winnow and collect the grain in single operation. The tractor operated combine harvests 0.8 ha/h and saves 80-90% labour and 33% cost of operation as compared to traditional method. The whole straw rice combine harvests rice without damaging the straw and covers about 0.25-0.38 ha area in an hour.

Threshing

Conventionally, rice being threshed by bullock treading, trampling, beating crop with flail and beating shelves of rice. All these methods are time consuming and involve drudgery. Olpad thresher operated by animal

Fig. 15. Naveen sickle.

Fig. 16. Reaper binder.

Fig. 17. Whole straw rice combine harvester.

can reduce the drudgery and give comparatively higher output (Din et al., 2014). Pedal operated thresher is also suitable for rice threshing. It saves 20% labour and 40% operating time as compared to conventional method (Singh et al., 2005). Axial flow paddy thresher (CIAE, PAU, TNAU, ANGRAU designs), TNAU multi-crop thresher, CIAE semi-axial flow multi-crop thresher, rice thresher have been also developed to thresh the rice effectively and are commercially available in India. In addition to this, axial flow thresher with 1.5 kW motor was developed particularly for hilly region.

Straw Management

Burning of the rice straw is a major problem in rice producing states of India and causes environment pollution. It is preferred by most of the farmers due to less time availability after harvesting of rice for sowing of wheat crop. To overcome these issues, different straw management machineries have been developed by different state agriculture universities, government institutes and private institutes. PAU, Ludhiana has developed straw collector which collects straw from 0.3 ha area in an hour. Commercially available baler can also be used to collect and bale the rice straw in combine harvested fields with 0.36-0.39 ha/h field capacity. Paddy straw chopper cum spreader plays very efficient role in the incorporation of paddy straw in the soil. It is commercially available and recommended by PAU Ludhiana for paddy straw. Happy seeder or turbo happy seeder, double disc strip till seeder and zero till seed cum fertilizer drill are used to sow the wheat seeds in combine harvested paddy field without burning or removing the straw. Also, a bruiser type straw management system (Super SMS) has been developed

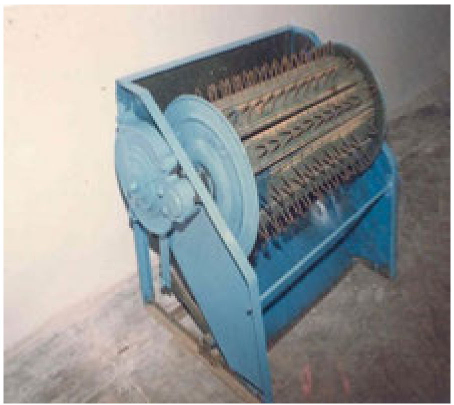

Fig. 18. Pedal operated paddy thresher.

Fig. 19. Paddy thresher (PAU design).

Fig. 20. CIAE semi-axial flow multi-crop thresher.

by PAU Ludhiana to chop and spread the loose straw along with combine harvesting in single pass for smooth operation of Happy seeder.

CONCLUSION

In Indian condition, introduction of mechanization in various crop production operations surely benefit the rice growing farmers. Economical viability of rice crop for the farmers mainly depends on timely field operations with reduced cultivation cost. This can be achieved with the proper use of improved machinery. Research organizations, State Agricultural Universities and Non-government organizations played a key role in developing as well as transferring improved technologies amongst the farmers. Seedbed preparation is the highly mechanized operation for the rice crop as the rice growers adopted the improved machineries for this operation. On the other hand, sowing/transplanting and weeding/interculture are done manually or by using conventional practices. The mechanization level for these operations is very low. The labour scarcity and increased wages are gradually affecting these operations during peak period and eventually making rice farming less profitable. Mechanization of these traditional rice practices can help in drudgery and operating cost reduction. There is need to popularize the improved technologies/machineries such as transplanters, mechanical weeders, straw management machineries etc. amongst the farmers to enhance the mechanization of rice cultivation. Agricultural co-operatives on the model of Japan may be established to cater the need of farmers for mat type rice seedlings. Government needs to create confidence in the minds of farmers about the availability of the service and reliability of the concept through wide and sustained publicity. There is a need to strengthen training facilities for rural youth and village artisans in repair and maintenance of paddy production machinery.

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Oryza Vol. 60 Special Issue 2023 (71-77)
DOI https://doi.org/10.35709/ory.2023.60.0.6

ICT application for promotion of integrated farming system

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Received : 25 January 2023 Accepted: 31 January 2023 Published : 07 February 2023

ABSTRACT

ICT is an umbrella term that includes communication devices like computer, mobile phone, radio, television, network hardware, satellite system etc. as well as services like audio and video call, text and multimedia messages. During first decade of twenty- first century, there had been spurt in experimentation of ICT in agriculture by the government, private, co-operative and non-government organizations (NGOs). The initiatives gave mixed result of success and failures. The initial challenges like lack of power back up, poor connectivity, high cost, lack of computer literacy and absence of digital content are disappearing at a faster rate. The growth in network infrastructure, cloud computing, decreasing price of computer and mobile phone and digital literacy have increased the internet access. The present-day initiatives involve multiple channels like web, mobile app, SMS and IVR in multiple languages. At the same time the gamut of information has been increasing from crop specific information to value chain information. The emergence of social media has opened new vista for agricultural extension through which two-way information in multimedia format can be exchanged at virtually no cost. These technologies can effectively be used for promotion of IFS. However, the response of research and extension system is not very encouraging. The extension professionals should gear up to develop technical competence and exposure so that content could be developed as per channel and in local language of the clients. The frontier technologies like sensor based diagnostic equipments, remote sensing and GIS, GPS technology as well as robotics and drone in agriculture are poised to change the landscape of agricultural extension.

What is Integrated Farming System (IFS)?

A judicious combination of two or more components using cardinal principles of minimum competition and maximum complementarity with advanced agronomic management tools aiming for sustainable and environment friendly improvement of farm income, family nutrition and ecosystem services is called as integrated farming system. Preservation of agro biodiversity, diversification of cropping/ farming system and maximum recycling is at the base of success of the farming system approach. ICAR - Indian Institute of Farming System Research, Modipuram has identified 51 IFS models which are suitable for marginal and small farm holders. A recent study conducted in Jharkhand has identified 15 Integrated Farming System (IFS) models in which Rice+ Dairy+ Goatry + Poultry +Vegetable model has been found dominant.

IT and ICT

Technology paves the way for development and information technology with its pervading features has been positively affecting almost all sectors of the society. The term 'Information Technology (IT)' was first used in the early 1980s to indicate the convergence of computer technology and communication technology. It is an organisation's collection of information resources, their users, and the management that oversees them; includes the IT infrastructure and all other information systems in the organisation (Turban et al., 2005). Information and communications technology (ICT) is an extension term for information technology (IT) which stresses the role of unified communications and the integration of telecommunications (telephone lines and wireless signals), computers as well as necessary enterprise software, middleware, storage, and audio-visual systems, which enable users to access, store, transmit, and manipulate information (Murray, James). The term "information and communication technologies" has been used by academic researchers since the 1980s (Melody et al., 1986; Silverstone et al., 1991) and the abbreviation ICT became popular after it was used in a report to the UK government by Dennis Stevenson in 1997. In Australasia, the term IT & T (Information Technology and Telecommunication) is also used instead of ICT. Singapore uses the term z, Infocomm for ICT. It is often used in a particular context, such as ICT in education, health care, or libraries. The term is somewhat more common outside of the United States (Whatis.com). It is the study or business of developing and using technology to process information and aid communications (webopedia.com). ICT (information and communications technology - or technologies) is an umbrella term that includes any communication device or application, encompassing: radio, television, cellular phones, computer and network hardware and software, satellite systems and so on, as well as the various services and applications associated with them, such as videoconferencing and distance learning.

ICT in agriculture

It has been stated that modern ICTs play a key role in communicating knowledge and information to rural agricultural communities (Richardson, 1997; Harris, 2004; Kweku, 2006). ICTs are considered drivers of change for rural and agricultural development. They are efficient tools for reaching rural and remote communities and improving agricultural productivity (Richardson, 1997). ICTs can speed up the extension of development services in areas such as healthcare, education and agriculture (Van Audenhove, 2003). Further, they help strengthen partnerships and provide a framework for shared learning, and have led to increased use of networked information environment and development of platforms for better sharing and exchange of information and knowledge. This has helped to achieve competitiveness (Benkler, 2006). ICTs are being used for accessing agricultural information, financial information, market information, surveys and agribusiness (Akiiki, 2006). Maru (2004) pointed out that the use of ICTs is ubiquitous in national agricultural research systems, while Grimshaw (2005) observed that there was consensus that ICTs play an important role in development by linking users to up-to-date information, skills and markets. Stiglitz (1999) concluded that ICTs had improved access to explicit knowledge. ICTs are used to disseminate local agricultural information and knowledge to small-scale farmers (Munyua and Adupa, 2002; Akiiki, 2006).

Status of ICT use in Agricultural Organizations

With expanding network infrastructure, reducing price of hardware and software and policy support, the agricultural organizations are using various ICT applications which are summarized in Table 1.

To achieve the objective of doubling farmer income, the roles of extension professionals have been increased manifold. How these roles can be effectively performed by the extension professionals with application of ICTs are presented in Table 2.

Table 1. ICT Practices adopted by Agricultural Organizations.

Activity	Organization	ICT
Teaching	Agricultural Universities/ Some ICAR Institutes	Website/App/social media
Research		Web site
Extension Education		Website/App/social media/Radio/IVR/SMS/ TV/CRS
Extension Services (Advisory and Information Services/ Training/ Demonstration)	Ministry/Department of Agriculture/ NGOs/Input Companies	Website/App/social media/Radio/TV/ IVR/SMS/CRS
Input Management		Website/App
Input Supply and Services	Input Companies	Website/App

Table 2. Expanding roles of extension professionals and use of ICT.

Roles	Use of ICT
Providing information on going schemes and programs in agriculture & allied sectors	Website/App/SMS/IVRS/social media
Capacity building	Social Media/ Google Meet/ Webex
Skilling in emerging areas	Social Media/ Google Meet/Webex
Advocacy on farmers' interests	Social Media
Counselling for farmers' well-being	Website/Portal/social media
Credit facilitation	Online information
Critical assistance in risk management including climate change, crop insurance etc	Website/App/SMS/IVRS/social media
Documentation and Reporting roles	Computer/Email
Enforcement of Farmers' Charters	
Issuing Advisories on soil health management, water conservation, pest management etc.	Website/App/SMS/IVRS/social media
Facilitating access to production and postproduction inputs & data	Website/App/SMS/IVRS/social media
Facilitation & feedback	Website/App/SMS/IVRS/social media
Friend, philosopher and guide to farmers	Social Media
Engaging in research planning	Google Meet/Webex
Promoting projectised mode of extension delivery	MS Project
ICT enabled services	Bunch of application
Intermediation	Google Meet/Webex
Linking farmers to markets	Website/App/SMS/IVRS/social media
Building managerial competence	Google Meet/Webex
Linking various support & service networks	Website/App/SMS/IVRS/social media
Organizing user/producer groups	Website/App/SMS/IVRS/social media
Planning, Monitoring and Evaluation	Google Meet/Webex
PPP Promotion	Google Meet/Webex
Promoter of farmer led innovations	Social Media
Redressal of grievances	Google Meet/Webex/social media
Technology selection, etc	Google Meet/Webex
Feedback to research system	Google Meet/Webex/Email/social media

ICT initiatives worldwide

Depending upon strength, interest and support, different organizations at national and international levels have taken initiative to conceive, develop and apply ICT applications for the development of farmers. The initiatives have been classified based on the media used which are presented as hereunder:

Recent policy interventions for promotion of drone

Drone policy (2021) banned import of drone except for research purpose. This facilitated the upsurge of more than 200 start-ups. Ministry of Agriculture and Farmers' Welfare, Government of India has prepared standard operating procedure (SOP) for application of insecticides through drone. State Agricultural Universities and ICAR institutes are being encouraged to purchase and undertake research on drone technology.

ICT Application for Promotion of IFS

The objective behind application of ICT is to facilitate integration of component enterprises and help farmers to access information and take appropriate decision. The intervention could be in the form of:

i. Expert system comprising comprehensive knowledge base

ii. Decision Support System

iii. Dissemination of information through portal, App and IVR and social media

Video based agricultural extension.

Name of initiative	Country	Feature and achievements
Digital Green	Ethiopia, Kenya, Ghana, India, Niger, Afghanistan	♦ Agricultural extension through participatory video production ♦ Hub and spoke model ♦ Partnership with Government and NGOs. ♦ Produced more than 3 000 videos in more than 20 languages ♦ Reached more than 300 000 farmers across more than 3 900 villages across India, Ethiopia and Ghana.
Access Agriculture	Global	♦ Online Training videos in multiple languages (http://www. accessagriculture.org/)

IVR based Agricultural Extension.

GoviMithuru	Sri Lanka	♦ GoviMithuru is an IVR-based agriculture information service, where farmers can register with relevant information and then get periodical push information (alerts) or can dial the IVR to listen to current advisories on agriculture, nutrition and preventive health care, tailor-made to their profiles.
80-28 hotline	Ethiopia	♦ IVR-based agronomic advice and info hotline. ♦ The hotline received more than 7.5 million calls since its' start mid 2014. (http://www. ata.gov.et/highlighteddeliverables/ 8028-agriculturalhotline

Web based Agricultural Extension.

Toto	Global	♦ Online dashboard ♦ database of databases (agriculture content, weather, prices) http://www.totoagriculture.org
NeGP-A	India	♦ This is one of the Nission Mode Project under National e-Governance Plan (NeGP). Twelve clusters of services have been deployed down to the Block level across country.
Rural Universe Network (RuN)	Global	♦ Rural Universe Network (RUNetwork) started in 2000 in Uganda and is currently covering most of Sub- Saharan countries, Jamaica and Iran.
FAO-Virtual Extension and Research Communication Network	Global	♦ VERCON aims to harness the potential of the Internet and apply it to strengthening and enabling linkages among the research and extension components of the national agricultural knowledge and information system (http://km.fao.org/ vercon/).
FAO Food Price Monitoring and Analysis tool	Global	♦ FAO Price Tool is a database that currently includes over 1000 monthly domestic retail and/or wholesale price series of major foods consumed in 78 countries and 11 international cereal export price series, covering a total of 20 different food commodity categories. (http://www.fao.org/giews/pricetool/).
AGMarknet	India	♦ AGMARKNET is an agricultural marketing Information system network initiated by the Union Ministry of Agriculture in India (http://agmarknet.dac.gov.in/).

Mobile based Agricultural Extension.

Mobile GAP Assessment System	Thialand	♦ The software and application for the Mobile GAP Assessment System was developed by National Electronics and Computer Technology Center (NECTEC) (www.gapthailand.in.th)
Progressive Rural Integrated Digital Enterprise (PRIDE) Model by mKRISHI	India	♦ It is a patented mobile-based personalized services delivery platform that enables two-way data and information exchange between the end-users such as farmers and field agents and repositories of knowledge such as virtual knowledge banks and agriculture experts and procurement officers.
SAWBO	Global	♦ Mobile app with instructional animations (http://sawboillinois4.org/)

Web-based and Mobile-based Agricultural Extension.

IRRI Rice Knowledge Bank	Asia and Africa	♦ In 2002, IRRI's RKB project worked with national agricultural research and extension (NARES) partners to introduce good rice knowledge management. ♦ Over the years IRRI has been upgrading technology. Rice Doctor was developed using Robohelp software (2002), open source content management system (2008) and mobile app (2014).
e-Krishok	Bangladesh	♦ 360-degree solutions covering preproduction, production and postproduction phases,i.e. from extension to market linkage ♦ Information portal www.ekrishok.com ♦ Short code-based Help Line 16250 ♦ SMS-based advisory services

Web-based and Mobile-based Agricultural Extension.

Africa Fertilizer	Africa	♦ The web- and mobile phone-based AMITSA system utilizes both private and public sector agro-input stakeholders to collect and process market data and information,.
Jharkhand weather	India	♦ The system provides village Panchayat level weather forecast on daily (14 parameters and hourly (six parameters) in Jharkhand state of India. (http://www.bau-eagriculture.com/ weather/faces / index.jsp). It is web and mobile app-based.
FarmForce of Syngenta Foundation	Ghana	♦ Farmforce is a web /mobile application that is used to manage out grower schemes and large farmers remotely.
Agrinet	Uganda	♦ Agrinets products and service include agricultural market intelligence, transaction security service, product marketing, agro-processing and value addition. This is web-based and SMS based system(.http://www.agrinetug.net/)

Multiple channel based agricultural extension.

Umang	India	♦ UMANG service is available on multiple channels like mobile application, web, IVR and SMS which can be accessed through smartphones, feature phones, tablets and desktops. ♦ Besides other services, it also provides agricultural services (https://web.umang.gov.in/web/#/).

ICT initiative of Birsa Agricultural University, Ranchi.

Sl. no.	Name of Application	URL
Web Application		
1.	Multilingual Agriculture portal	http://bau-eagriculture.com/submit/main_servdis
2.	Multilingual Livestock portal	http://bau-eagriculture.com/PlayerWEAAI/faces/weaai.jsp?form1:hyperlink2_submittedLink=form1:hyperlink2
3.	Multilingual Forestry portal	http://bau-eagriculture.com/PlayerWEAAI/faces/weaai.jsp?form1:hyperlink3_submittedLink=form1:hyperlink3
4.	Multilingual Weather Portal	http://bau-eagriculture.com/Weather/
5.	Birsa Kisan e-Diary in Nagpuri	http://bau-eagriculture.com/birsakisandiary/
Social Media		
6.	BAU EXTENSION	https://www.youtube.com/channel/UCQCOvp-BuLr8NZeimufNKZg
Mobile Application		
7.	Birsa Weather Forecast	Google Play Store

CONCLUSION

ICTs are considered drivers of change for agriculture and rural development. Passing through the initial phase of experimentation, it has reached the stage of consolidation. This has been facilitated by efficient and cost-effective hardware, growth in network infrastructure, increase in bandwidth and encouraging government policy. Single channel and English dominated applications are giving way to multiple channels and multiple language applications. The ever-increasing internet access gives a cue that ICT is poised to revolutionize the agriculture. The same technology can be effectively used for promotion of IFS. But there has not been encouraging response from research and extension system. The onus lies on the shoulder of extension professionals to develop and customize the content in local language of the client which could be delivered through multiple channels. The development taking place in frontier technologies like sensing technology, robotics and drone in agriculture, big data analytics and IoTs is going to change the landscape of agriculture.

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Oryza Vol. 60 Special Issue 2023 (78-90)
DOI https://doi.org/10.35709/ory.2023.60.0.7

Performance and macro-economic scenarios of rice market outlook in India

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Received : 31 January 2023 Accepted: 03 February 2023 Published : 07 February 2023

ABSTRACT

The study looks into past trends and volatility in the demand and supply components of the last 50 years (1970 to 2019) besides assessing the reliability of macro-economic scenarios of rice by 2020 to 2030 published by OECD and NITI Aayog. The study infers the growth in the area under rice cultivation is 0.30 per cent per annum but yield growth is 1.79 per cent per annum. Yield growth rather than area growth would drive future increases in rice production. Scanning of scenarios of reduced rice land revealed that India would need to boost its rice yield by a maximum of one tonne per hectare to maintain future output levels. The reliability of the projection of rice by OECD and NITI Aayog is very high since the mean absolute percentage error of demand is below 2 per cent and of supply is below 16 per cent. Discussion on future outlook suggests that India needs to either boost up its agri-infrastructure or free up some of its rice area in favour of resource conservation and crop diversification. The outlook for rice throws light on upcoming possibilities and challenges and suggests recommendations for alternative policy options to address the dynamics in the rice sector.

Keywords: *Rice, market outlook, crop diversification, resource conservation and area reduction*

INTRODUCTION

Attaining self-sufficiency in food grain production is one of the greatest accomplishments of Indian agriculture in its independent history. It recognized the importance of grains to help India in achieving self-sufficiency and also the potential capacity of inorganic inputs, infrastructure (irrigation infrastructure in particular), technologies, markets, institutions etc. Despite this massive success, growing shreds of evidence identify some of the grey areas of this voyage. Consequently, Indian agriculture is experiencing the heat of global warming, resource degradation and depletion (Kumar and Joshi, 2016) and frequent occurrence of biotic and abiotic stresses. Additionally, the growing population, urban expansion, unviable land holdings (Chand, 2007) and technology obsoletion are a few of the socio-economic factors which constrain the Indian food production system. Therefore, questions about the future agricultural situations are of particular concern for India as it has to feed about 37 per cent of global cattle (Sonavale et al., 2020) and 18 per cent of global humans (World Population Review) with its meagre four per cent of water (The World Bank, 2022) and 2.4 per cent of land resources (Kumar, __).

In this paper, we look into the past 50-year performance of the Indian rice market. We considered rice because the crop is at the fulcrum of global food security (Ngyuyen, 2002; Ghosh et al., 2013; Bandumula, 2018) and is evident from the fact that a typical Indian household spends more than half of its cereal expenditure on rice consumption alone (NSSO, 2011-12), it's an important constituent of Indian dietary system. Additionally, the paper assessed the reliability of macro-economic scenarios of rice from 2020 to 2030 published by OECD and NITI Aayog, Government of India. The manuscript also throws light on upcoming possibilities and challenges and suggests recommendations for alternative policy options to address the dynamics in the rice sector.

Data and methodology

The paper made use of secondary data on elements of demand and supply of rice crops. Computation of aggregate or domestic supply of rice in the economy is based on commodity flow which includes all the incoming flow of the commodity in the domestic market to calculate aggregated supply and clubbed all the outflows of the commodity to compute the aggregate demand (Fig. 1). Thereby, the aggregated supply in an economy consists of total domestic production, stocks variation minus net trade which is depicted through the expression given below-

$$Agg\_Sup_{it} = Prod_{it} + (Stock_{it} - Stock_{it-1}) - (Exp_{it} - Imp_{it}) \qquad \text{---(1)}$$

Where,

Agg_Sup_{it} = Aggregate Supply of the commodity i at a time t

$Prod_{it}$ = Domestic production of the commodity i at a time t

$Stock_{it}$ = Stocks of the commodity i at a time t

$Stock_{it-1}$ = Lagged stock of commodity i at a time t-1

Exp_{it} = Export of the commodity i at a time t

Imp_{it} = Import of the commodity i at a time t

While the aggregated or domestic demand of a food commodity is represented by the total food demand for household consumption, total feed demand, total industrial demand and other indirect consumption demand like seeds, and supply chain wastage demand. Although wastage is not demanded as every stakeholder in the supply chain would like to minimize it, it is unavoidable with the current state of infrastructure and technologies in the country. Therefore, the aggregated demand is given by the following equations-

$$Agg\_Dem_{it} = FCD_{it} + FeeD_{it} + IUD_{it} + SWD_{it} \qquad \text{---(2)}$$

Where,

Agg_Dem_{it} = Aggregate demand of the commodity i at a time t

FCD_{it} = Food consumption demand of the commodity i at a time t

$FeeD_{it}$ = Feed demand of the commodity i at a time t

IUD_{it} = Industrial use demand the commodity i at a time t

SWD_{it} = Seed and wastage demand of the commodity i at a time t

For the computation of aggregate demand and supply, the food balance sheet (FBS) data of the Food and Agricultural Organization (FAO) was used. However, there is a limitation with this data set that it doesn't provide insights into the future trends and patterns as it is based on a historical perspective. Therefore, we took future projections of rice demand and supply from the "Working Group on Demand and Supply Projections Towards 2033, NITI Aayog (2018)" and OECD-FAO which provide a projection for the period of 2021-22 to 2030-31. Projections from these

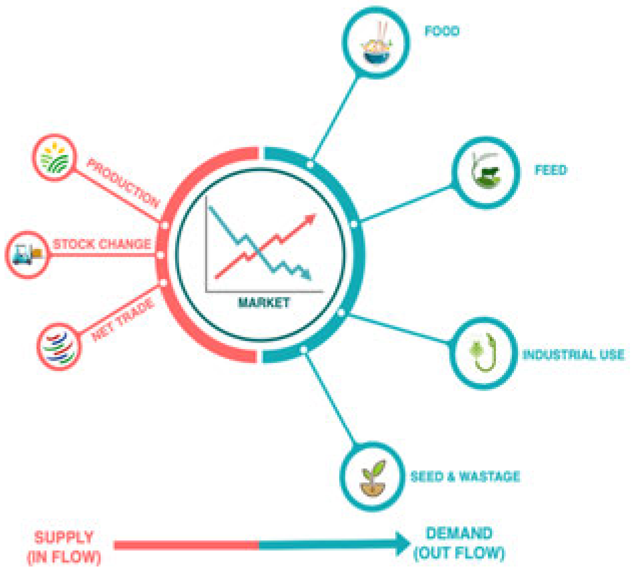

Fig. 1. Commodity flow concept of aggregate demand and supply.

two agencies are included in this paper as they used robust methodology to arrive at the projection values. NITI Aayog used a simultaneous equation model to generate the supply outlook while for the demand outlook generation, it used simplistic, normative, and behaviouralist methods. The simplistic approach assumes the short-term, static behaviour of the consumers. The behaviouralist approach, however, assumes medium to long-term household consumption behaviour and is based on the population increase and changing consumer behaviour due to changing per capita income in a growing economy. In contrast, the normative approach calculates household demand using the Indian Council of Medical Research's (ICMR) prescribed amount for per capita direct consumption. The outlook produced by the normative approach was ignored since it was provided for cereal as a whole rather than for the individual crops that made up cereal. On the other hand, the OECD-FAO employs the Aglink-Cosimo model, a recursive dynamic partial equilibrium model based on a set of simultaneous structural equations, to generate demand and supply outlooks. Market prices are produced by equating the equations for supply and demand.

Furthermore, we used mean absolute percentage error (MAPE) to compare projections for the supply and demand of rice by the two agencies which are calculated as-

$$\text{Mean absolute percentage error} = \frac{1}{n}\sum_{i-1}^{n}\left|\frac{\text{At-Ft}}{\text{At}}\right|$$

Where,

At = Actual/True Value

Ft = Predicted value

n = Number of times the summation iteration happen

Additionally, we delineated the country into six zones to get insights into the spatial trends and patterns in the supply of rice. The six zones include- East (*Assam, Bihar, Jharkhand, Odisha and West Bengal*), West (*Chhattisgarh, Gujarat, Madhya Pradesh, Maharashtra and Rajasthan*), North (*Haryana, Punjab, Uttar Pradesh and Uttarakhand*), South (*Andhra Pradesh, Karnataka, Kerala, Tamil Nadu and Telangana*), Hills (*Himachal Pradesh and Jammu and Kashmir*) and North-Eastern (*Arunachal Pradesh, Manipur, Meghalaya, Mizoram, Nagaland, Sikkim and Tripura*).

The paper also makes use of NSSO's state-level consumption data of rice and its products to analyze the spatial and temporal patterns in rice consumption in the country.

Performance of rice market in past 50 years

Trends and patterns in the area, production and yield

The transition from traditional farming to modern agriculture in the past 50 years has had a substantial effect on India's capacity to feed its people through diversified foods all the time in a year. As a consequence of the increased productivity of farmland, food availability has also increased. In the last 50 years, the cumulative area under rice cultivation has increased compound annually at the rate of 0.30 per cent while the average yield of rice has increased at the growth rate of 1.79 per cent per annum. The diminishing area growth, which fell from 0.47 per cent (during 1970-79) to 0.18 per cent (during 2010-19) over each decade, also complemented the slower area expansion. During the same period, the decadal growth in rice productivity increased from -0.44 per cent (1970-79) to 1.97 per cent (2010-19) (Table 1) indicating yield as the potential driver for production growth. The instability in the

Table 1. Trends in APY of rice and their growth and instability.

Period	Mean			CAGR (per cent)			Instability		
	A (m ha)	P (m t)	Y (t ha^{-1})	A	P	Y	A	P	Y
1970-71 to 1979-80	38.65	44.76	1.16	0.47	0.02	-0.44	3.36	10.49	8.57
1980-81 to 1989-90	40.66	59.78	1.47	0.49	3.22	2.72	2.96	8.15	5.64
1990-91 to 1999-2000	43.22	80.10	1.85	0.57	1.90	1.32	1.35	3.11	2.58
2000-01 to 2009-10	43.41	89.19	2.05	-0.64	0.47	1.12	3.55	7.93	5.22
2010-11 to 2019-20	43.68	108.10	2.47	0.18	2.16	1.97	1.01	2.66	2.55

A: Area; P: Production and Y: Yield

Table 2. Spatial and temporal pattern in the share of area (%) and production of rice in India.

Zones	East	West	North	South	Hilly	N-East
			AREA			
1970-79	44.14	17.16	14.84	21.04	0.88	1.93
1980-89	42.09	17.49	18.37	19.10	0.89	2.05
1990-99	41.37	17.58	20.10	18.16	0.82	1.97
2000-09	40.47	17.81	22.32	16.63	0.77	2.00
2010-19	37.69	18.93	23.73	16.65	0.80	2.20
CAGR (%)	-0.32	0.20	0.94	-0.47	-0.20	0.26
			PRODUCTION			
1970-79	38.32	12.63	14.21	31.78	1.22	1.84
1980-89	34.27	12.21	22.60	28.00	1.12	1.81
1990-99	34.49	11.58	25.89	25.52	0.80	1.71
2000-09	35.18	10.62	28.27	23.35	0.69	1.89
2010-19	34.18	13.77	27.98	21.41	0.67	1.99
CAGR (%)	-0.23	0.17	1.36	-0.79	-1.18	0.16

production of rice, which increased to 10.49 from 7.37 during the first three decades after Indian independence witnessed a decline to 2.66 at the end of the decade 2019-20 indicating the resilience of the Indian rice production system to smaller production shocks. Further, the decadal variation in yield instability as evident from the given table can be attributed to production shocks to the food production system either due to biotic or abiotic or a combination of both stresses.

Spatial pattern in rice area and production indicates that during 1970-79, eastern, southern and western zones had a cumulative share of 82.34 per cent in total rice area which after five decades declined to 73.27 per cent. The period of 1970-2019 saw a spatial change in the zonal share in rice area as the share of the southern zone declined from 21.04 per cent to16.65 per cent while the northern zone gained about 10 million hectares of rice area. On the production side, eastern, southern and northern zones, maintained their contribution to the tune of 80-85 per cent to the central production pool during all the decades between 1970-2019. However, these three zones witnessed a reallocation of production share among themselves as the contribution of southern and eastern zones declined by about 14 million tonnes which were gained by the northern zone during the same period. Further, the growth in area and production of rice among different zones reveals that northern, north-eastern and western zones have witnessed positive growth in both are and production in the last 50 years, unlike the other zones which registered negative growth in area and production during the same period (Table 2).

The spatial and temporal pattern of yield growth confirms the positive trends in the yield of rice across all the zones indicating the growth in total factor productivity in the rice sector. Among all the zones, the Southern (1.96%) North East (1.63%) and Hilly zones (1.50%) registered highest yield growth (Fig. 2).

Indian India yield of rice crop also grew at the rate of 1.54 per cent per annum in the past 50 years from 1.15 t ha^{-1} to 2.47 t ha^{-1}. The yield growth of southern, north-eastern, westerns zones was higher than the national growth in yield of rice during the same period.

Trends in stock variation and net trade

For an economy, its trade and food management policies are crucial to influencing the domestic supply of a food commodity. Trade policy does this job by governing exports and imports operations while the food management policy does it by regulating procurement and offtake operations. Stocks increases when procurement exceeds offtake; it decline when offtake exceeds procurement, and it remains same when procurement and offtake are equal (Fig. 3).

Assessment of past half a century of stock variation of rice demonstrate lack of any specific

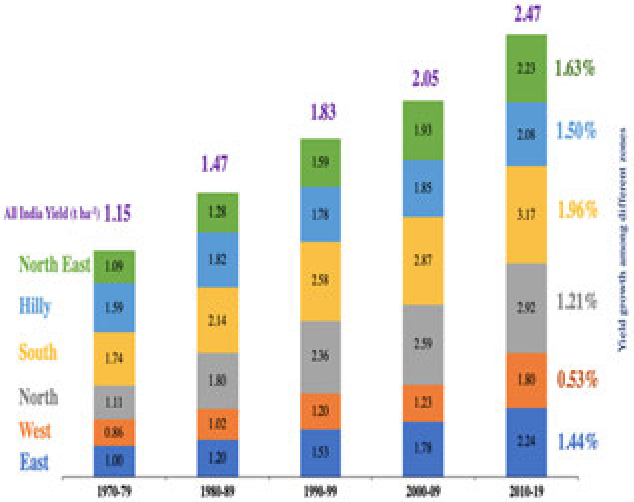

Fig. 2. Spatial and temporal pattern in yield of rice in India in the last 50 years.

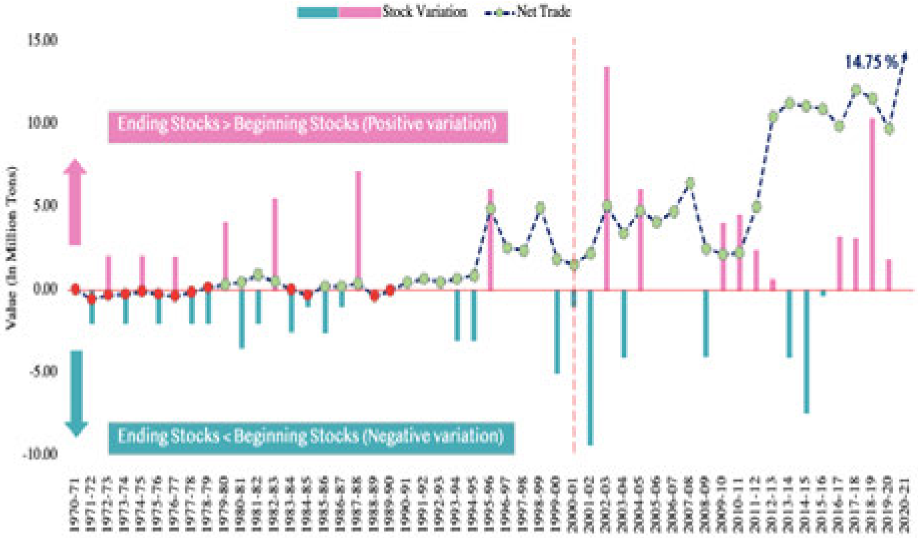

Fig. 3. Trends in net trade and stock variation of rice during 1970-71 to 2020-21.

pattern in it. Few years, witnessed positive stock variations indicating liberal procurement and tight offtake of grains while others experienced negative variations suggesting tight procurement and liberal offtake. The period prior to the year 2000 reports higher incidences of negative stock variations indicating liberal offtake policies, while the higher positive stock variations after year 2000 suggests liberal procurement policies. Further, the elevated peaks in stock variations after the year 2000 also points towards increased volume of operations. The trends in the net trade of rice in past 50 years suggests that after 1970-71, net trade had grown at the rate of about 14.75 per cent per annum, which reach to the volume of 10 million tons in 2019-20 which is almost thousand times its initial volume. Also, the volume of net trade in rice was very frequently hovering in the positive as well as negative territories prior to 1995-96.

However, after 1995-96 rice trade had never slipped in the negative territory. Further, the beginning of world trade organization (WTO) in 1995-96 provided Indian rice a greater market access into the global market as a result India experienced an increase in the volume of net trade after the year 1995-96. Further, the net trade of rice has witnessed increased volatility after 1995-96 which hints towards transmission of shocks from global to Indian market as result of integration of Indian and global rice markets.

Pattern of consumption of rice as a food

Past studies have attributed several factors to the decline in the consumption of cereals. Kumar (1998); Murthy (2000) and Radhakrishna (2005) attributed diversification of food production, easy access of high value commodities, changed tastes and preferences and reduction in relative prices of cereals to other food commodities as the factors contributing to change in consumption of cereals. While, Radhakrishna and Ravi (1992); Kumar (1997); Rao (2000) attributed economic growth, rise in per capita income, urbanisation, changing tastes and preferences, market integration, etc, as the dominating factors for the change in the per capita consumption of cereals. Kumar and Mathur, (1996) suggested factors closely linked with per capita income such as differences in urban and rural lifestyles, the development of more advanced marketing systems and occupational changes as the factors affecting the cereal consumption.

We took per capita consumption data of rice from different rounds of Household consumption expenditure survey by conducted NSSO to access the pattern of consumption. On plotting the per capita income (at 2011-12 price) against the annual per capita consumption of rice over the years for the country as a whole, we could find the similar trends as reported by previous studies . We also found that, the annual per capita consumption (PCC) of rice decreased from 69

Table 3. Growth and instability among different demand components of rice in past.

Period	Export	Feed	Seed	Losses	Processing	Food
			Percentage growth			
1970-79	28.33	0.00	0.02	0.00	0.93	0.81
1980-89	-1.23	3.23	3.21	0.00	3.37	4.21
1990-99	14.15	1.89	0.47	1.89	1.93	1.10
2000-09	3.52	0.63	-0.46	0.63	2.05	1.21
2010-19	15.89	28.99	1.10	0.24	4.11	1.78
1970-71 to 2019-20	13.41 (10.88)	6.60 (4.21)	0.29 (-1.96)	2.58 (0.28)	4.31 (1.98)	2.00 (-0.28)
			Absolute growth			
1970-71 to 2019-20	539.63	23.38	0.15	2.57	7.26	1.69
			Instability			
1970-71 to 2019-20	85.60	41.92	22.06	26.01	40.14	4.76

**Instability of ≤ 15: Low instability; CDVI between 15-30: Medium instability and CDVI of ≥30: High instability.*
Note: Figure in parenthesis indicates growth in share of usage of rice.

kg year^{-1} to 66 kg year^{-1} between 1972-1973 and 2011-2012. Similar trends were also observed in the rural and urban areas as they recorded a decline from 79 to 74 kg year^{-1} and from 59 to 56 kg year^{-1} respectively, during the same period (Fig. 4).

Additionally, the Indian market for rice consumption is highly diverse due to regional differences in taste and preferences of the consumers. We used state level per capita consumption data to trace out regional variations in consumption of rice over the period. We found that, the cumulative annual per capita consumption (kg) of rice in the Eastern, Southern, and North-Eastern (ESNE) regions is three to four times higher than the Western, Northern, and Hilly (WNH) regions throughout the period (Fig. 5). However, between the 38th and 68th rounds of the NSSO's Household Consumption Expenditure Survey, PCC of rice in the northern, western, north-eastern and eastern zones registered a positive growth of 2.56, 1.34, 1.14 and 0.25 per cent per annum respectively. Contrary to which, the southern and hilly zones registered a negative growth of 0.74 and 0.11 per cent respectively during the same period (Fig. 6).

Although, the per capita consumption figures

Table 4. Market outlook: Demand and supply outlook of rice grains for India (in million tonnes).

Period	Total Demand				Total Supply						
	SA	BA @ GDP Growth rate of		OECD-FAO	Based on all India growth trends		Based on state level growth trends		Based on three stage least square (All India)		OECD-FAO
		6 per cent	8 per cent		10 Year EGR	15 Year EGR	25 Year EGR	35 Year EGR	EGR of Pre-Lib	EGR of Po-Lib	
2021-22	111	90.51	89.28	109.60	120.12	120.71	119.46	122.44	123.6	126.8	173.77
2028-29	119-120	94.98	92.83	118.97	135.62	137.23	134.14	142.36	142.4	149.7	175.57
2032-33	125	97.67	94.96	-	145.36	147.66	143.5	155.36	154.1	164.2	-
2033-34	126	98.35	95.5	-	-	-	-	-	-	-	-

SA: Simplistic Approach; BA: Behaviouralist Approach; EGR: Exponential Growth Rate: Pre-Lib: Pre-Liberalization; Po-Lib: Post-Liberalization
NOTE:
1) Projections other than OECD-FAO are bases on Working Group on Demand and Supply Projections Towards 2033, NITI Aayog (2018).
2) Estimates of average SFW and other demand of rice for first and second half of 2020-30 period is 18.01 and 19.21 MT while for period of 2031-34, it is 20.22 MT (Based on Working Group on Demand and Supply Projections Towards 2033, NITI Aayog, 2018).

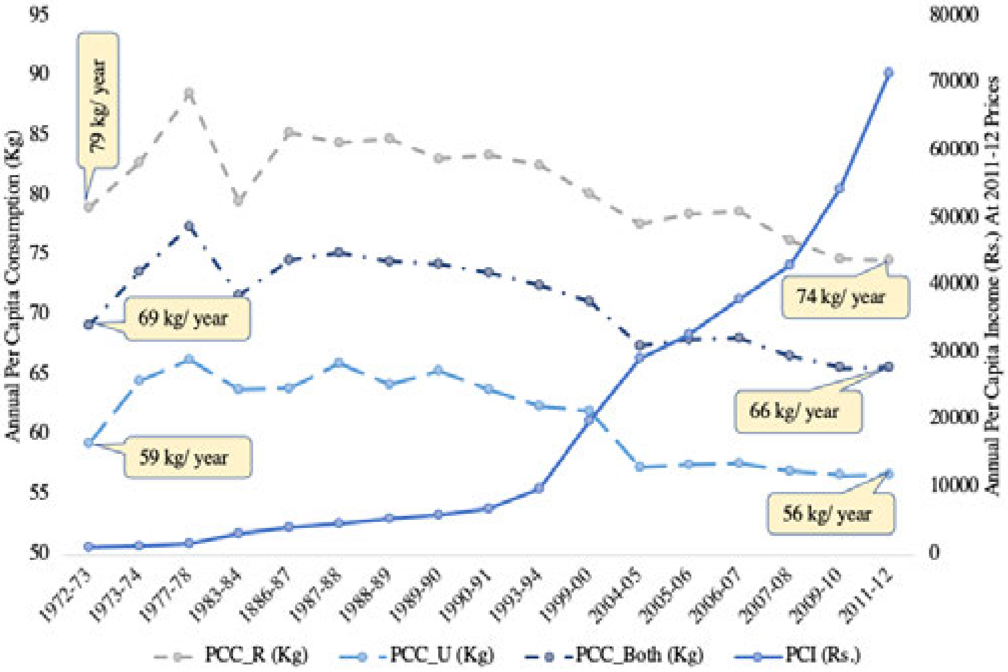

Fig. 4. Nexus of per capita income and per capita consumption of rice in India.

gives the idea of food demand, they may prove to be misleading in presenting the aggregate demand in an economy. We therefore analysed the historical trends in the other components of demand in the next section.

Demand of rice among different usages

In India, rice grains are demanded for various uses like food, animal feed, planting material (seed), and have several industrial applications too. Analysis of historical data on the demand of rice grains among different usage in India suggests that, the major demand of rice in the market comes for the consumption as a food (average 85 %). The remaining market demand of rice comes from crop production sector as a seed; from industrial sector as a raw material (beverages, starch industry, cosmetics etc.) and due to the unavoidable supply chain wastage at the current state of infrastructure and technologies. We also found that, in the past 50 years, the share of food demand of rice registered a declining share from 85 to 75 per cent while the share of export demand has registered a CAGR of 11 per cent. Interestingly, the growth in the seed demand of rice

Table 5. Market outlook: Demand and supply balance of rice (based on NITI Aayog's outlook).

Supply scenarios	Demand scenarios								
	D_1			D_2			D_3		
	2021-22	2028-29	2032-33	2021-22	2028-29	2032-33	2021-22	2028-29	2032-33
S_1	9.12	16.12	20.36	29.61	40.64	47.69	30.84	42.79	50.40
S_2	9.71	17.73	22.66	30.20	42.25	49.99	31.43	44.40	52.70
S_3	8.46	14.64	18.50	28.95	39.16	45.83	30.18	41.31	48.54
S_4	11.44	22.86	30.36	31.93	47.38	57.69	33.16	49.53	60.40
S_5	12.6	22.90	29.10	33.09	47.42	56.43	34.32	49.57	59.14
S_6	15.8	30.20	39.20	36.29	54.72	66.53	37.52	56.87	69.24

**Supply projections based on three stage least square estimates; #Approaches for demand projections: EGR:Exponential Growth rate.*

Note: Additional surplus under the behaviouralist approach is because the demand is exclusive of seed, feed, wastage (SFW) and other use demand.

Source: Author's calculation based on NITI Aayog's projections.

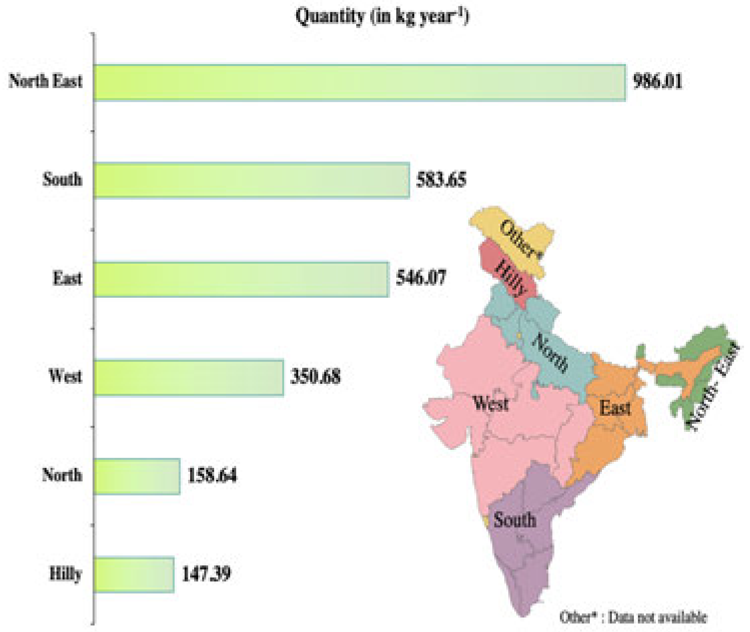

Fig. 5. Spatial differences in per capita consumption of rice in India.
(*East: Assam, Bihar, Jharkhand, Odisha and West Bengal; West: Chhattisgarh, Gujarat, Madhya Pradesh, Maharashtra and Rajasthan; North: Haryana, Punjab, Uttarakhand and Uttar Pradesh; South: Andhra Pradesh, Karnataka, Kerala, Tamil Nadu and Telangana; Hilly: Himachal Pradesh and Jammu and Kashmir and North East: Arunachal Pradesh, Manipur, Meghalaya, Mizoram, Nagaland, Sikkim and Tripura*)
Source: Based on the 68th round of NSSO's Household Consumption Expenditure Survey.

grains was the least (0.29 per cent per annum) among all the usages and its share in total demand of rice grain also declined at the rate of two per cent per annum. The average CAGR in the food demand of rice grains over the past 50 years has been two per cent, while the average CAGRs for the processing, feed, and export demand has been 4.31, 6.60, and 13.41 per cent, respectively. In terms of absolute growth, export demand of rice has witnessed more than 500 times increase while the feed, seed, supply chain losses, processing and food demand have grown by 22.38, 0.15,

Table 6. Comparison of OECD-FAO and NITI Aayog's outlook for rice crop.

Coinciding years of projections	Mean absolute percentage error in	
	Demand	Supply
2021-22	0.28	16.37
2028-29	2.09	10.67
2029-30	2.04	10.68

Table 7. Required rice yield under different scenarios of area liberation from rice crop.

Period	Production outlook (in mt)	Actual yield and required yield gain (tonnes ha^{-1}) under				
		Base area	SIM1	SIM2	SIM3	SIM4
2020-21*	118.52	2.63	2.70 (-0.01)	2.77 (0.06)	2.84 (0.13)	2.92 (0.21)
2021-22	120.71	2.68	2.75 (0.04)	2.82 (0.11)	2.89 (0.18)	2.97 (0.26)
2028-29	137.23	3.04	3.12 (0.41)	3.20 (0.49)	3.29 (0.58)	3.38 (0.67)
2029-30	139.76	3.10	3.18 (0.47)	3.26 (0.55)	3.35 (0.64)	3.44 (0.73)
2032-33	147.66	3.27	3.36 (0.65)	3.45 (0.74)	3.54 (0.83)	3.64 (0.93)

**Base period; Base area: 45.1 Mha; Parenthesis value indicates the required yield gain over base yield.*
Source: Working Group for Demand and Supply Projections Towards 2033 (for Prod. Outlook).

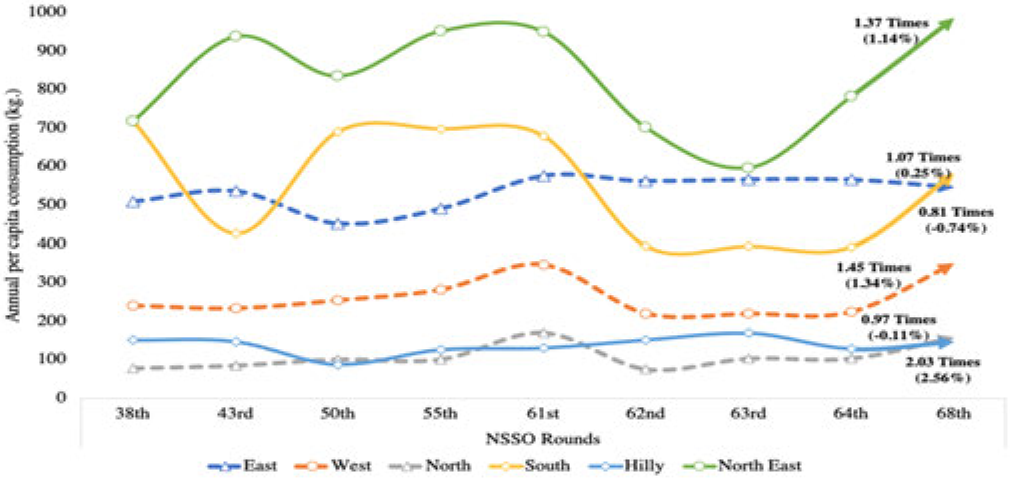

Fig. 6. Temporal variation in per capita rice consumption (kg year^{-1}) across different zones.

2.57, 7.26 and 1.69 times its value in 1970-71. Further, the food demand remained most stable component of aggregate demand with the Cuddy Della Valle Index of 4.76 while the seed, supply chain losses and industrial usage demand showed medium instability and the export, processing and feed demand components exhibited high instability (Table 3).

Market outlook for rice

Here we used two projections to discuss the medium term market outlook of rice for India. NITI Aayog (NA) provides the market outlook of demand and supply of rice under different scenarios of demand and supply. On supply side projections, NA projects future supply based on three methods which are-i) based on all India growth trends; ii) based on state level growth trends and iii) based on all India growth using three stage least square method. Under each methods, NA used different growth scenarios to project future supply. The scenarios are- S1: 10 year exponential growth rate in All India Supply; S2: 15 year exponential growth rate in All India Supply; S3: 25 years exponential growth rate in state level supply; S4: 35 year exponential growth rate in state level supply; S5: Supply trends in exponential growth rate of pre-liberalization period and S6: Supply trends in exponential growth rate of post-liberalization period. Similarly, the four demand scenarios are- D_1: simplistic approach; D_2: six per cent growth of GDP and behaviouralist approach; D_3: eight per cent growth of GDP and behaviouralist approach.

According to NA's demand projection, the aggregate rice demand under simplistic approach would be about 126 mt by the year 2033-34, while it would be about 98.35 and 95.50 mt under six and eight per cent GDP growth assumptions by the year 2033-34. On the other hand, OF projects demand of 118.97 mt by the year 2029-30. The supply projections by NA using different methods and assumptions projects rice supply in the range of 143.5 to 162.2 mt by the year 2032-33. While OF projects rice supply to be 175.57 mt by the year 2029-30 (Table 4).

Based on the above projections of demand and supply by NA and OF, we derived the market situation for the same period by estimating the demand and supply balance. The market situation in the medium term future made us to believe that, under the different assumptions of demand and supply projections used by NA, India would have a surplus of rice between 8.46 to 39.20 mt from 2021-2022 to 2032-2033 based on the simplistic demand projections approach. However, using the behaviouralist approach with an assumption of an eight percent growth in Indian GDP, the rice surplus would range between 30.18 to 69.24 mt under various supply projections. This surplus would range between 28.95 to 66.53 mt under the behaviouralist approach's assumption of a six percent growth in GDP for the same period (Table 5). Likewise, the OF's demand and supply outlook suggest that over the decade, the surplus rice output in the Indian market would decline from 33.60 mt to 24.04 mt (Fig. 7).

However, the projections of NA and OF portrays wide variations in demand-supply balance of rice in the Indian market. Therefore, we compared both the outlooks using MAPE to find their reliability. Based on the MAPE for the coinciding years of projections between NA and OF, we found that the mean absolute percentage error between the two outlooks for the demand projection ranges below three percent. However, the MAPE value for supply predictions ranges from 10 per cent to 16 per cent (Table 6) which indicates closeness in accuracy among the outlook of both the organizations.

Area and yield outlook

Using Aglink-Cosimo model, OECD-FAO also projects acreage and yield of the crop along with demand and supply outlooks. According to projections for rice yield and area, India's rice area may decline over the next ten years, albeit only slightly. However, under the assumptions of model, the yield of rice would be expected to increase by 12.94 per cent during the projection period from 2.78 to 3.14 tha^{-1}. (Fig. 8).

However, the Aglink-cosimo model in estimating crop area and yield does not account for the horizontal expansion of urban areas as it bases its calculations on the net returns per hectare from the crops only. Thus, the area equation under the Aglink-cosimo model assumes area to vary based on the endogenous factors only however in reality exogenous factors do affect the crop area. Therefore, the model overestimated the area under the rice crop in the future.

Implications of outlook for India

The market outlook of rice places India in a safe position as far as feeding its expanding population is concerned. The surplus grains increases the possibility of higher availability of grains in the market however its access is subjected to allocative efficiency of the market, distribution policies of the government and the economic well-being of the consumers. Another view on the growing surplus suggests for an increase in the economic accessibility of the grains as the surplus supply over demand has the potential to pull down the market prices. Additionally, under the assumption of growth of food processing industries in India due to current infrastructural and institutional push from the government, surplus grains indicates a gain in consumer welfare due to increased consumption choices for the consumers.

The surplus production on one hand indicates the efficiency of our food production system, but it has some environmental concerns too. Assuming 2500 litre of water use for production of one kg of rice as suggested by Surendran et al., 2021, the surplus rice production would use 5015.29 to 1,73,100 billion gallon of water under different scenarios of demand and supply between 2021-22 to 2030-31. Therefore, from the resource conservation perspective, surplus rice opens up the possibility of diverting a proportion of surplus

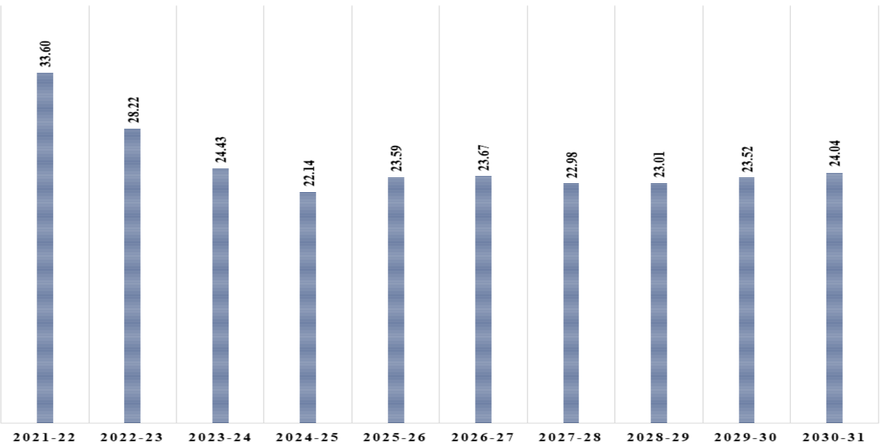

Fig. 7. Market outlook: Demand-Supply balance of rice (based on OECD-FAO).

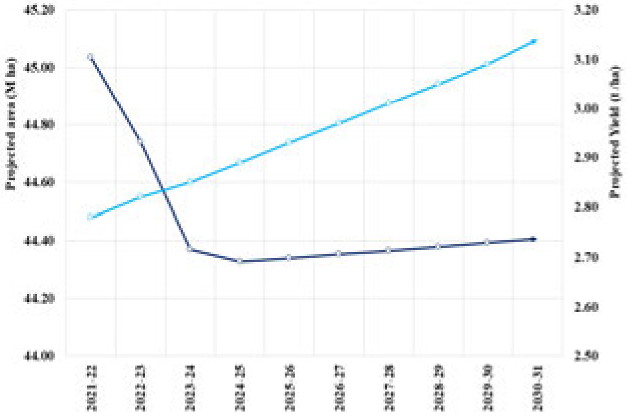

Fig. 8. Outlook of cropped area and yield of rice crop for 2021-22 to 2030-31.

area in favour of less water intensive crops like pulses and oilseeds which constitutes a sizeable proportion of Indian agricultural imports. Additionally, the decision to free some of the rice area would be a much needed choice to address the emission from the paddy fields as well as residue burning, if it happen in the north-western parts of India. In this context, we ran four simulations to find out the yield gain required in rice crop to address food security concerns if a portion of rice area can be diverted in favour of other crops. For this we used the rice area for the years 2020-21 as the baseline.

These simulations were- SIM1: 2.5 per cent diversion in rice area; SIM2: 5 per cent diversion in rice area; SIM3: 7.5 per cent diversion in rice area and SIM4: 10 per cent diversion in rice area. Results of simulation exercise suggest that, under different simulation scenarios, India need to increase the rice yield by .65 t ha^{-1}, 0.74 t ha^{-1}, 0.83 t ha^{-1}, and 0.93 t ha^{-1}, respectively (Table 7).

For the producers, the market outlook indicates that the surplus supply over demand might bring down its price in future. Therefore, the producers would need to look towards extra production instead of relying on price of output alone to sustain their revenue and income. In Indian context, this situation may hint towards two alternatives such as increased price bargaining between the producers and the government or increased demand of quality seeds and inputs. If the first alternative prevails, government need to invest more on food grain management and logistical infrastructure along with increased allocation for food subsidy. If the second alternative prevails, government would require to increase investments on research and development and transfer of technologies to boost total factor productivity (TFP) of the crop. However, higher price of output as a source of producer revenue is not a sustainable alternative. Therefore, the producer would have two obvious choices, either to source their income from higher production by enhancing TFP of their farms, or the second choice would be to allocate the arable land resources among different enterprises and opt for either the crop or enterprise diversification in future. The Doubling Farmer's Income Committee had also suggested the shifting in some area from staple cereals to high value products can lead to a sizable increase in the returns to farmers (GoI, 2021).

Further, owing to the challenges of managing surplus grains and their losses from the food grain management system, government of India allowed conversion of surplus stocks of rice for ethanol production. In this context, the surplus supply of rice may provoke the market and institutions to divert more of the surplus grains into ethanol production in future. It raises a very important question that- would our food production system will have new responsibility to produce to supplement our energy needs? However, we argue that the diversion of rice for the biofuel production may prove to be a potential huddle for achieving crop diversification and resource conservation as it would create additional market opportunities for the rice producers. The decision to convert future rice production if any into ethanol should be based on long term cost-benefit analysis from the resource conservation point of view.

Future strategies

Based on the market outlook and its future implications, we suggest following strategies to address the multiple goals ranging from food security to resource conservation-

Reduction in rice area from the unsuitable ecologies and allocating the free up area for less water intensive crops like pulses and oilseeds,

Although its politically sensitive to discontinuing price supports and subsides to the crop, but to free up unsuitable areas from rice crop, country can learn from the experience of Chhattisgarh state which incentivised its farmers for not taking up paddy on their fields,

Due to its dominance in the Indian dietary system, rice can prove to supplement nutritional security along with providing food security. The centrally sponsored pilot scheme on "Fortification of Rice & its Distribution under Public Distribution System" is a novel initiative in this direction and the lessons learnt from it, if replicable, may prove to address sustainable development goal 2.

Concluding remarks

The cornerstone of human welfare is a sufficient food supply, and a lack of food is tragic since it not only causes misery and loss of life but also leads to inhuman behaviour, political instability, and conflict (Borlaug, 1970). On the other hand, sustained losses due to failure to dispose of surplus production, puts the stability of producers' price in peril. (Popping, 1962). The market outlook of rice for the decade 2021-2030 suggests surplus rice supply in India. The study discussed the prospects and challenges of surplus grains and suggests crop diversification to save on the long run environmental cost of surplus production and stabilize farmers income. The study makes recommendations on how India might strike a balance between resource conservation and guaranteeing the population's access to enough food and nutrition. Under the growing constraints on the horizontal expansion of land, the paper suggest investments on research and development, infrastructure and transfer of technologies to enhance productivity of rice.

Declaration of conflicting interests

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Oryza Vol. 60 Special Issue 2023 (91-96)
DOI https://doi.org/10.35709/ory.2023.60.0.8

Community based extension approaches for sustainable production of rice

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Received : 03 February 2023 Accepted: 06 February 2023 Published : 07 February 2023

ABSTRACT

Rice plays very important role in food and nutritional security in the developing world. Although India is the second largest producer (113 mt) next to China with 44 mha area under rice, its average yield (~2.6 t/ha) is far below both that of China (>6 t/ha) and the global average of ~4 t/ha. Hence, along with genetic enhancement and advance crop protective measures, innovative extension approaches with agro-ecological importance, geo-political, socio-economic can support to improve the rice productivity levels with climate resilience and effective natural resources management perspectives. Moreover, the agricultural extension paradigm shift from National demonstration in 1960's to Training and visit system in 1970's to pluralistic extension approaches in 1990's has enhanced the rice production from 34.5 million tonnes in 1960-1961 to 117.5 million tonnes in 2020-2021. Still there is a huge potential to transform the rice production systems of the country through adoption of bottom-up innovative extension approaches with information and communication connectivity. Approaches like social learning, community engagement and ICT support have proven effective in dissemination and adoption of improved varieties and practices of paddy cultivation.

Keywords: *Social learning, community engagement, convergence based extension*

INTRODUCTION

Rice is grown under diverse climatic and soil conditions with largest water requirements. Rice is planted on about one-tenth of the Earth's arable land in ~114 countries across the globe, occupying ~150 m ha. Rice plays very important role in food and nutritional security in the developing world. It is also responsible for enormous greenhouse gas (GHG) emissions, particularly methane and nitrous oxide that cause global warming and emerging climate change impacts (Muralikrishnan et al., 2022). Although India is the second largest producer (113 mt) next to China with 44 mha area under rice, its average yield (~2.6 t/ha) is far below both that of China (>6 t/ha) and the global average of ~4 t/ha (Reshmita et al., 2015). Further, changing climatic variations resulting in more persistent droughts, cyclones and floods affect soil biodiversity, water-logging, groundwater depletion, micronutrient deficiencies (Zinc and Sulphur), emerging pests and diseases, excessive use of fertilizers and pesticides, etc. are the emerging challenges in rice-producing regions (Vanaja et al 2019). Hence, along with genetic enhancement and advance crop protective measures, innovative extension approaches with agro-ecological importance, geo-political, socio-economic can support to improve the rice productivity levels with climate resilience and effective natural resources management perspectives (Malhi et al., 2021). The agricultural extension paradigm shift from National demonstration in 1960's to Training and visit system in 1970's to pluralistic extension approaches in 1990's has enhanced the rice production from 34.5 million tonnes in 1960-1961 to 117.5 million tonnes in 2020-2021(Jagriti, 2017). However, still there is huge potential to transform the rice production systems of the country through adoption of bottom-up innovative extension approaches with Information and communication connectivity (Ambali et al., 2021). Thus, there is an urgent need to encourage farmers through various innovative extension approaches such as social learning, community engagement and ICT enabled system, convergence based, and farmers' participatory extension to address the UN's Sustainable Development Goals (SDGs) through sustainable agriculture and rice led food systems. Cultivation of rice will continue to be the integral element of cropping system due to food choice, livelihood option, trade dividend, and socio-cultural context. However, the declining ground water availability as well as the variability and deficit in amount and duration of rainfall have necessitated eschewing transplanted system and opt for alternative water efficient ways of rice cultivation like direct seeded rice (DSR).

MATERIALS AND METHODS

The study was conducted in Punjab, Haryana, Uttar Pradesh, Chhattisgarh and Bihar. The on-farm trials were conducted in the villages and were monitored for plants and weeds observation at different stages. The farmers were supported with technical advice and inputs such as seed, pre-emergence and post emergence herbicide for direct seeded rice. The extent of knowledge about direct seeded rice was assessed through field survey and direct interviews with 35 farmers each of participant and non-participant groups in on-farm trials. A knowledge test was developed to measure change in knowledge as result of interventions. Factor analysis was performed to identify the typologies of farmers with respect to natural resource management. With use of the statistical tests of significance, difference between the social learning and individual learning was analysed. Logistic regression was used to identify the influence of explanatory variables on adoption decision of the farmers for direct seeded rice cultivation system.

RESULT AND DISCUSSION

Promotion of direct seeded rice through Community based extension approach: Factor analysis revealed five different typologies of farmers *viz*., skeptical, pragmatic, disengaged, conservation stewards, and ambitious with respect to their approach towards natural resource management (Table 1).

It showed that scepticism orientation had the predominance among the farmers. It could be due to vagaries of monsoon and other abiotic and biotic stresses impacting production of crops. Farmers' disengagement in conservation processes was also revealed as one of the behaviours. However, there were silver lines in augmentation of effective natural resource conservation activities as presence of pragmatism, conservation stewardship, and ambitious behaviours mong the farmers were also reflected by the analysis. Considering the existing typologies of the farmers, extension interventions were made to encourage, motivate, and facilitate community engagement for promotion of direct seeded rice (DSR). As a result of interventions of community engagement, it was found that DSR practicing farmers of Haryana had more favourable environmental attitude than the conventional farmers (Table 2). They expressed affirmation to statements related to importance of environmental issues, climate change, and pubic responsibility to conserve resources for future generation.

With community engagement, caapcity building, on-fram trials and demonstrations to promote DSR were conducted in Punjab, Haryana, Uttar Pradesh, Chhattisgarh and Bihar. Assessment of knowledge about direct seeded rice was conducted with sample of 35 farmesr each from Punjab, Haryana, Uttar Pradesh, Chhattisgarh and Bihar. It was obsevred that the farmers in Punjab, Haryana, Uttar Pradesh and Bihar had average knowledge score below 4 out of maximum score of 8 with respect to 8 components of DSR technology (land preparartion and sowing, seed rate, depth of sowing, management of pre and post emergence weeds, irrigation, management of iron

Table 1. Farmers' typologies with respect to natural resource management.

Farmers' typology	Initial eigen values			Rotation sums of squared loadings		
	Total	% of Variance	Cumulative %	Total	% of Variance	Cumulative %
Skeptical	4.569	26.879	26.879	2.724	16.023	16.023
Pragmatic	2.433	14.310	41.189	2.637	15.512	31.535
Disengaged	2.131	12.535	53.724	2.444	14.374	45.909
Conservation stewards	1.869	10.996	64.720	2.372	13.952	59.861
Ambitious	1.511	8.891	73.610	2.337	13.749	73.610

Table 2. Environmental attitude of DSR and conventional farmers of Haryana.

S.N.	Statements	DRS farmers (n=35)					Conventional farmers (n=35				
		SA(%)	A(%)	UD(%)	DA (%)	SDA (%)	SA (%)	A (%)	UD(%)	DA (%)	SDA (%)
i.	I think environmental issues are extremely important	62.86	0.00	37.14	0.00	0.00	45.71	37.14	17.14	0.00	0.00
ii.	When I see or hear a story about an environmental issue, I pay particular attention to that story	45.71	48.57	5.71	0.00	0.00	11.43	60.00	28.57	0.00	0.00
iii.	It bothers me that the world's natural environment is changing so quickly	37.14	57.14	5.71	0.00	0.00	8.57	45.71	37.14	8.57	0.00
iv.	The public should not worry about climate change	14.29	40.00	5.71	40.00	0.00	8.57	25.71	45.71	20.00	0.00
v.	The public has responsibility to conserve resources for future generations	65.71	34.29	0.00	0.00	0.00	28.57	62.86	8.57	0.00	0.00
vi.	My individual actions will not make a difference regarding global climate change	5.71	2.86	14.29	74.29	2.86	0.00	25.71	37.14	31.43	5.71
vii.	It is the governments duty to protect environment	77.14	22.86	0.00	0.00	0.00	22.86	42.86	34.29	0.00	0.00

deficiency, and management of termite); while the farmers of Chhattisgarh had aveage knowledge score below 3 (Fig. 1). However, after the training, on-fram trials and demonstrations there was significant increase in knowleldge. The percentage change in knowledge ranged from 79 to 124. The highest change in knowledge was among the farmers of Chhattisgarh (Fig. 1).

Community engagement also accelerated the social learning system, where-in the farmers not only learnt about the technologies of DSR but also overcame the apprehensions about the risks associated with it through interactions with fellow farmers (Table 3). There was significant difference (P<0.01) between the farmers under social learning system and those under individual learning system in areas of understanding about technology, perceived risk of technology, and reduction in time of learning. However, there was not significant difference with respect to enhancement in willingness to experiment. Experimentation is generally undertaken by innovative farmers, however, due to homophily under social learning system. the degree to which they could take experimentation was also better among this group.

The farmer field schools (FFS) is also an important platform for promotion of social learning. It can support and engage rice farmers to get group based participatory learning about rice crop protection and crop improvement through hands on trainings and capacity building activities (Singh et al., 2020). The

Table 3. Perceived advantages of social learning systems.

Attributes	Mean perception score		t-test
	Farmers under social learning system (n=30)	Farmers under individual learning system (n=30)	
Detailed understanding about technology	4.35	2.70	6.338**
Decreased perceived risk of technology	4.50	2.80	7.134**
Less time in learning	4.20	2.50	7.458**
Reduction in decision making time	4.55	3.30	6.432**
Enhancement in willingness to experiment	4.05	4.30	-.946
Better performance of technology	4.75	3.40	7.438**
Higher return from technology use	4.85	2.70	13.622**

Table 4. Factors influencing adoption decision towards direct seeded rice technology.

Factors	B	S.E.	Wald	df	Sig.	Exp(B)
Training	2.318	.458	25.616	1	.000	10.160
Size of holding	.064	.021	9.394	1	.002	1.066
Size of family	-.040	.058	.463	1	.496	.961
Age	-.014	.015	.841	1	.359	.986
Perceived usefulness of technology	.377	.061	37.722	1	.000	1.458
Awareness	.013	.041	.108	1	.742	1.013
Perceived Risk	-.193	.071	7.305	1	.007	.825
Risk Attitude	-.385	.079	23.983	1	.000	.681
Constant	-.044	1.866	.001	1	.981	.957

groups meet regularly throughout the production cycle to test, validate and adapt new practices. The FFS enable the members to build their skills and confidence and contribute in the community development. In group, they may discuss the problems each other and with experts and build their capability to analyze and solve them. From each group a facilitator can be selected who takes lead in organizing frequent meetings to in the field with the support of master trainers from agriculture departments, state agriculture universities and research institutions (Hoffecker et al., 2018). The rice multidisciplinary team of ICAR-National Centre for Integrated Pest Management organized Rice -FFS at Nidana village of Rohtak district of Haryana for enhancing farmers income through Integrated Pest Management practices with IPM validation form 300 acres with 25 farmers supportive FFS based farmers participatory extension efforts (Anand et al., 2014; ICAR-NCIPM, 2022). Similarly, the Farmer Producer Company based extension approach is also useful in harnessing the social capital and technology diffusion and adoption. The farmer producer company supportive social capital based agri-preneurship organize, create and manage a venture to make social change in rural settings and double the farmers income (MOA, 2021). Farmer producer organizations build and strengthen the business capacities of small farmers through organized marketing structures. The collectivism, establishment of the linkages, collective risk taking and market information-based decision-making process are the important advantages of the social capital-based farmers producer organizations.

Factors associated with adoption of direct seeded rice technology

Logistic regression was used to identify the influence of explanatory variables on adoption decision of the

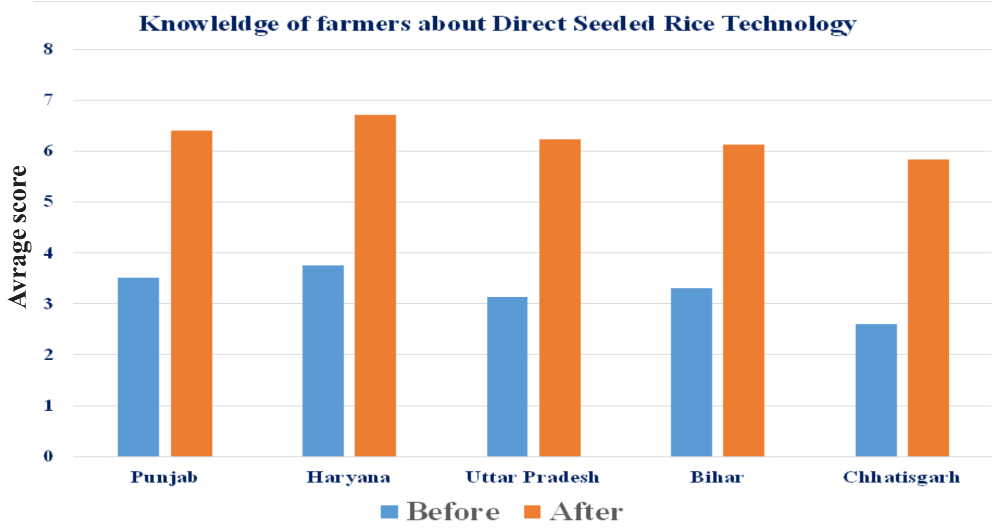

Fig. 1. Knowledge of farmers about direct seeded rice.

farmers. Cox & Snell R Square value indicated that the model was able to explain about 37% variance. The variables such as training, size of holding, and perceived usefulness of technology had positively significant β_i (the original coefficient), whereas perceived risk and risk attitude had negatively significant β_i (the original coefficient). The positively significant coefficients of explanatory variables indicate their positive influence on adoption decision of farmers towards direct seeded rice technology. If β_i (the original coefficient) is positive, its transformation (the exponentiated coefficient) will be greater than 1, meaning that the odds of an event happening will increase for any positive change in the independent variable. It is evident from Table 4 that with one unit increase in training, size of holding, and perceived usefulness of technology, the odds of decision to adopt direct seeded rice technology will increase by 10, 1.07 and 1.5, respectively. While the odds of decision to adopt direct seeded rice technology will decrease by 0.83 and 0.68 with one unit increase in the perceived risk of the technology and risk attitude.

CONCLUSION

Community based extension is an emerging approach to develop participatory methodologies, raise awareness on climate change, mobilize the community and foster adaptive capacity. Community based extension recognizes existing environmental knowledge base, perceptions of the community members, adaptation strategies against vulnerability embedded in societies and cultures. It empowers communities to take action based on their own decision-making processes and play a central role in the planning and decision making processes. Social learning is another advantage of community engagement. Essence of social learning has been harnessed in many societal domains such as sustainability of natural resources. A key element of social learning is the interaction and co-learning among of the farmers through processing of information and knowledge, discussion, examination, interpretation, and systematization as well as internalization and application of new knowledge and practices. New approaches of extension should be devised, tested and promoted with respect to the emerging innovative technologies for rice based sustainable agriculture production systems.

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Oryza Vol. 60 Special Issue 2023 (97-104)
DOI https://doi.org/10.35709/ory.2023.60.0.9

Insights into the recent approaches for rice (*Oryza sativa* L.) biofortification

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Received : 05 February 2023 Accepted: 06 February 2023 Published : 07 February 2023

ABSTRACT

Rice is the most essential source of calories for humans among the cereals and over half of the world's population is fed on rice. As part of a complete food systems approach, biofortification is an effective technique for nutrition enrichment which refers to the development of micronutrient-rich diet by utilising traditional breeding practises and sophisticated biotechnological tools. To enhance the profile of rice grain for biofortification-related properties, researchers must first understand the genetics of critical biofortification characteristics. Significant increases in micronutrients like iron and zinc, as well as many other important minerals and provitamins are acquired in rice grain using the biofortification strategies. Most indica and japonica rice types have been biofortified over the world, giving them the titles of high iron rice, low phytate rice, high zinc rice, and high carotenoid rice or golden rice. Some of the recent approaches towards rice biofortification, as well as their effects, have been explored in this article.

Keywords: *Rice, biofortification, golden rice, thiamine and Zn biofortified rice*

1. INTRODUCTION

As a result of increase in population, rising per capita incomes, and urbanisation, global agricultural production is increasing rapidly, and food demand is expected to continue rising over several decades. More than 2 billion of them suffer from 'hidden hunger,' meaning they do not consume enough nutrients or micronutrients in their regular diet and suffer from malnutrition (Saini et al., 2020). Approximately 60% of total calories consumed in developing countries come straight from cereals, with values reaching 80% in the developing countries (Parashar et al., 2023). Under nutritional deficiencies, iron deficiency, zinc deficiency, vitamin-A deficiency, iodine deficiencies and selenium deficiencies are widespread and cause serious consequences (Das et al., 2019; Parashar et al., 2023).

Oryza sativa L., commonly known as rice, is found as the most demanding crop all over the world as a staple food (Panda et al., 2009). Enriching it with essential nutrients, which are otherwise absent, would solve nutrient deficiencies to a great extent (Parashar et al., 2023). To achieve successful biofortification, the mechanism of the particular nutrient uptake and the genes involved has to be elucidated and studied. Essentially those varieties are targeted for biofortification with highly dense micronutrient rich traits which already have highly preferable agronomic traits in the genomic background. Supplements or industrially fortified food has the ability to deliver a high level of the essential micronutrients to our body. Even if the biofortified rice cannot suddenly increase the concentration in our body, it can definitely increase our daily sufficiency of micronutrient absorption throughout our life cycle (Bouis et al., 2011; Parashar et al., 2023; Herrington et al., 2023). China assembled parboiled rice about 148.5 million metric tonnes in the 2018-2019 crop year, more than almost any other country. In that crop year, by producing 116.42 million metric tonnes of parboiled rice India came second. In the 2018-2019 total production of parboiled rice in volume was 495.9 million metric tonnes worldwide (Kong et al., 2022; Peramaiyan et al., 2022). The largest rice consuming countries are China, India and Indonesia respectively.

On the other hand, white rice grains are preferred by the average consumer because of its softness, lightness, ease of digestion, better having properties and less time for cooking (Monica et al., 2020; Panda et al., 2018; Mishra et al., 2022). The bran layer, as well as the substrate, embryo and a small part of the endosperm, are removed from polished (milled) white rice (Champagne et al., 2004). Milled rice has poor in comparison than the brown rice on the aspects of nutritional quality, with the reduced iron content lower by 2.14 times (8.8 to 4.1 parts per million) to 4.75 (19 to 4 parts per million), and the zinc content lower by 1.83 times (33 to 18 parts per million), and essential minerals, fats, fibres, proteins and vitamins lowered by 1.83 times (from 33 to 18 ppm) (Masuda et al., 2009). However, the amounts of mineral reductions can vary between rice varieties and grain polishing processes. While greater awareness and education have improved in consumption of brown rice, the major rice consumers still prefer polished white rice, by considering the white polished rice developed as nutritionally improved through biofortification (specific endosperm) leaving scientists to reconsider. The improvement of essential nutrients bioavailable in the edible parts of staple foods through conventional breeding, biotechnology techniques or agricultural strategies, can help alleviate deprivation in places where staple foods are the main source of micronutrients and calories (Bouis and Saltzman, 2017). Consumption of rice in 2018- 2019 of China was 143.79 million metric tons and per capita intake in the world has remained remarkably stable since 2000, averaging about 53.9 kg per year. (Rice- Exports: https://www.statista.com/statistics/255945/top-countries-of-destination-for -us -rice-export-2011/) (Fig. 1). Developing countries face a major crisis in terms of mineral deficiency lacking in availability of fresh and hygienic foods (Gómez-Galera et al., 2010). However, lacking nutrient like calcium is a common health concern even in the developed world. Providing access to a more nutrient rich and diverse diet is a challenging task in the developing and less developed countries. Therefore, biofortification can be a sustainable way to eliminate deficiency diseases in these countries (Bouis and Saltzman, 2017).

2.RECENT APPROACHES FOR BIOFORTIFICATION

2.1 *Transgenic efforts for the development of Golden rice*

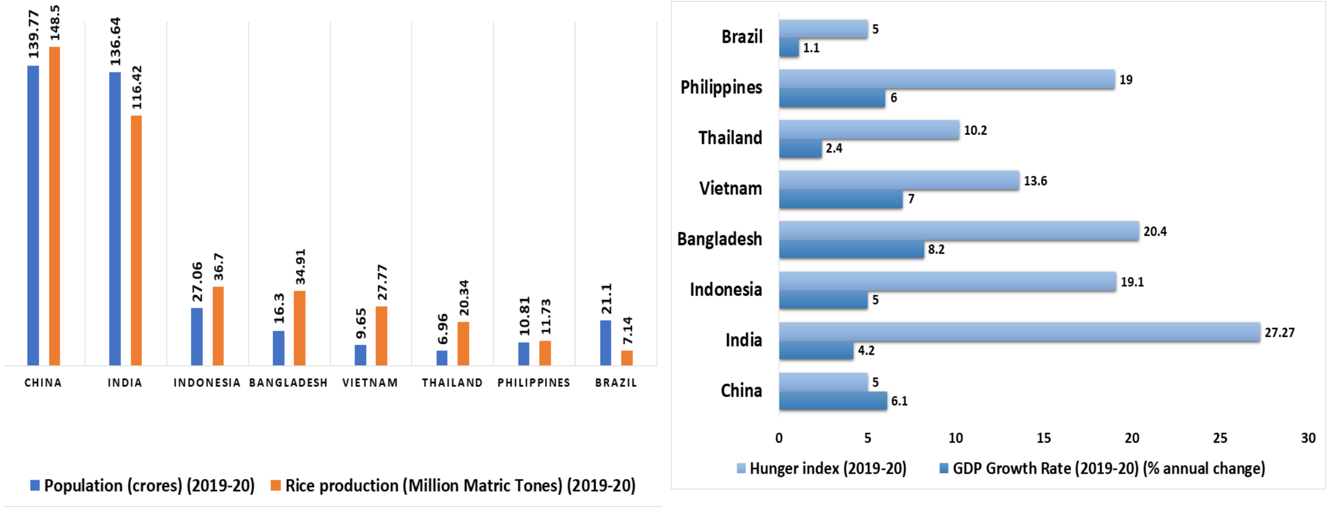
Children suffering from blindness have been a result of severe vitamin D deficiency. Developing countries faces deficiency diseases due to the lack of proper nutrients in their diet. Physiological traits such as cellular differentiation, growth, reproduction and vision, to name a few, depends on the role played by carotenoids (Wurtzel et al., 2012) as they are known to help tackle several ROS-generated diseases namely cancers, neurological and cardiovascular diseases along with eye disorders (Bai et al., 2011). β-carotene biosynthetic pathways in rice have been the target for the creation of "Golden rice". Golden rice, enriched with β-carotene was formulated in supplementing provitamin A naturally enhances immortality caused due to VAD. Phytoene synthase (psy) of daffodil (Narcissus pseudonarcissus) and phytoenedesaturase (crtI) of pathogenic bacteria (Erwiniauredovora) was chosen to be introduced and expressed in endosperm of IR64 and BR29, which are Asian rice varieties under the promoter(endosperm specific) (Datta et al., 2006) to produce Golden rice. β-carotene synthesis pathway is already present in Rice.

2.1.1 *Golden Rice: First Attempt*

Ye et al. (2000) proved in the early development years that rice grains can produce β-carotene. It has been quite evident that there was need for only transgenes (PSY and CRTI) for β-carotene production. There was, however, no need for lycopene synthase. Although initial studies were carried out in japonica cultivar, indica varieties were also included later on (Hoa et al., 2003). Many ways were developed in rice seeds to improvise with the production of carotenoids to the permissible levels. The first generation of Golden rice or GR1 was transformed with two transgenes (from daffodils and bacteria) and placed under endosperm-specific gt1 promoter. Field carotenoid levels amounted to four times to that of the proposed model.

2.1.2 *Golden Rice 2*

Golden rice 1 gave us the possibility to produce β-carotene in rice endosperm. It also helped us see that



(a)

(b)

Fig. 1. Details of economic status and hunger index of major rice growing countries worldwide (Source - https://www.statista.com/statistics/255945/top-countries-of-destination-for-us-rice-exports-2011/ and https://www.globalhungerindex.org/ranking.html)

to tackle vitamin A deficiency β-carotene should be produced in higher amounts. Since only two transgenes have been involved in the production of β-carotene, it was simple to understand that by manipulating the enzymatic activities of the products of the two gene, one can achieve higher β-carotene. Normal pathways usually have certain rate limiting steps which controls the entire pathway. Overcoming the rate-limiting step simply by further enhancing the concentration of the rate-limiting enzyme or by shifting to a more active enzyme. Different PSY sources were examined to see that the maize and rice genes were more efficient (Paine et al., 2005). Golden rice 2 was generated to synthesize approximately 37 µg g^{-1} carotenoids. Among this, only 31 µg g-1 beta-carotene was significantly higher compared to 1.6 µg g^{-1} found in first generation golden rice (Al-Babili and Beyer, 2005).

2.2 *Thiamine Biofortification of Rice*

Three rice thiamine phosphokinase (tpk) variants were analysed in the promoter region. This was done to check if the endosperm-specific cis elements were present or absent in the promoter. Higo et al. (1999) reported that motifs such as AACA, ACGT, Prolamin and TATA box was present in a 300bp region upstream of the start site of the tpk3 promoter. CRISPR-Cas9 approach was the method of choice due to its simplicity in the gene editing scenario. The promoter region of the tpk3 gene does not reflect a very important motif, GCN4. Adding this motif can be possible if editing is done at a position of selection. A gRNA sequence of 20bp containing NGG as protospacer adjacent motif or PAM is chosen to be the target site. Heigwer et al. (2014) mentioned that this site has been specifically chosen as the target site because off-site targets are absent in this region.

Tools like E-CRISP and Cas-OFFinder has been used for this purpose. Cas9 cleaves a region in the DNA 3 to 4 nucleotides upstream of PAM. For introduction of GCN4 box at the site of editing a very stable transformation with Cas9 and gRNA is essential. Homologous recombination promoting oligonucleotide has been used for co transformation for introduction of GCN4 box. The box absence has been synonymous with expression of tpk3 in rice, which is quite negligible. With the prelude of the edited gene superior engenderment of tpk3 is soothsaid. Higher ken-how of this pathway is needed for opportune enhancing to be performed for higher thiamine manufacturing in rice. The box absence has been synonymous with negligible expression of tpk3 in rice. With the introduction of the edited gene enhanced production of tpk3 is expected. Better understanding of this pathway is needed for proper editing to be done for higher thiamine production in rice.

Table 1. Effect of Zn application on Zn concentration (mg kg?1) in grains of the tested rice cultivars.

Rice verities	Type of Experiment	Application	Time of Application	Type of fertilizer	Dose of Zn fertilizer	Zn Content Grain		Reference
						Control $\mu g \cdot kg^{-1}$	Treated $\mu g \cdot kg^{-1}$	
Gobindobhog	Field Experiment	Soil	Basal	$ZnSO_4.7H_2O$	5 kg ha^{-1}	28.1	31.1	Saha et al., 2017
Lalat	Field Experiment	Soil	Basal	$ZnSO_4.7H_2O$	5 kg ha^{-1}	18.6	23.9	
Satabdi	Field Experiment	Soil	Basal	$ZnSO_4.7H_2O$	5 kg ha^{-1}	20.8	27.1	
KRH 2	Field Experiment	Soil	Basal	$ZnSO_4.7H_2O$	5 kg ha^{-1}	19.8	25	
MTU 7029	Field Experiment	Soil	Basal	$ZnSO_4.7H_2O$	5 kg ha^{-1}	21	26.1	
GB 1	Field Experiment	Soil	Basal	$ZnSO_4.7H_2O$	5 kg ha^{-1}	20.6	29.7	
Malviyasugandh 105	Pot Experiment	Soil	Basal	$ZnSO_4.7H_2O$	5 kg ha^{-1}	25	25.6	Das et al., 2019
Arize-6444 Gold	Pot Experiment	Soil	Basal	$ZnSO_4.7H_2O$	5 kg ha^{-1}	23.1	25.2	Jatav et al., 2019
Arize® H 6444 Gold	Pot Experiment	Soil	Basal	$ZnSO_4.7H_2O$	5 kg ha^{-1}	17.5	26	Mohapatra et al., 2021
Arize® H 6444 Gold	Pot Experiment	Soil	Basal	$ZnSO_4.7H_2O$	6.25 kg ha^{-1}	17.5	28.2	
Lalat	Field Experiment	Foliar	Tillering and Flowering	$ZnSO_4.7H_2O$	0.50%	28.1	38.8	Saha et al., 2017
Satabdi	Field Experiment	Foliar	Tillering and Flowering	$ZnSO_4.7H_2O$	0.50%	20.8	42.9	
KRH 2	Field Experiment	Foliar	Tillering and Flowering	$ZnSO_4.7H_2O$	0.50%	19.8	36.5	
MTU 7029	Field Experiment	Foliar	Tillering and Flowering	$ZnSO_4.7H_2O$	0.50%	21	38.8	
GB 1	Field Experiment	Foliar	Tillering and Flowering	$ZnSO_4.7H_2O$	0.50%	20.6	40	
Gobindobhog	Field Experiment	Foliar	Tillering and Flowering	$ZnSO_4.7H_2O$	0.50%	18.6	34.8	
Malviyasugandh 105	Pot Experiment	Foliar	Tillering and Flowering	$ZnSO_4.7H_2O$	0.50%	25	42.1	Das et al., 2019
Arize-6444 Gold	Pot Experiment	Foliar	Tillering and Flowering	$ZnSO_4.7H_2O$	0.50%	23.1	40	Jatav et al., 2019
Lalat	Field Experiment	Soil+ Foliar	Basal Tillering and Flowering	$ZnSO_4.7H_2O$	5 kg ha^{-1} +0.50%	28.1	41.9	Saha et al., 2017
Satabdi	Field Experiment	Soil+ Foliar	Basal Tillering and Flowering	$ZnSO_4.7H_2O$	5 kg ha^{-1} +0.50%	20.8	41.2	
KRH 2	Field Experiment	Soil+ Foliar	Basal Tillering and Flowering	$ZnSO_4.7H_2O$	5 kg ha^{-1} +0.50%	19.8	41.7	
MTU 7029	Field Experiment	Soil+ Foliar	Basal Tillering and Flowering	$ZnSO_4.7H_2O$	5 kg ha^{-1} +0.50%	21	42	
GB 1	Field Experiment	Soil+ Foliar	Basal Tillering and Flowering	$ZnSO_4.7H_2O$	5 kg ha^{-1} +0.50%	20.6	40	
Gobindobhog	Field Experiment	Soil+ Foliar	Basal Tillering and Flowering	$ZnSO_4.7H_2O$	5 kg ha^{-1} +0.50%	18.6	37.9	
Malviyasugandh 105	Pot Experiment	Soil+ Foliar	Basal Tillering and Flowering	$ZnSO_4.7H_2O$	5 kg ha^{-1} +0.50%	25	45.6	Das et al., 2019
Arize-6444 Gold	Pot Experiment	Soil+ Foliar	Basal Tillering and Flowering	$ZnSO_4.7H_2O$	5 kg ha^{-1} +0.50%	23.1	45.8	Jatav et al., 2019

2.3 *Biofortification of high zinc rice*

For the proper absorption of iron in the body zinc is essential. Plants normally take up zinc from the soil. To increase in uptake of zinc from the rhizosphere several genetic approaches have been made in order to enrich the plants. Zinc translocation and mobilisation

Table 2. QTLs identified for biofortification traits in rice (Adopted from Sharma et al., 2020).

Purpose	Cross	Population Type	Chromosome	Number of QTLs
Amino acid	Zhenshan 97 × Nanyangzhan	RILs	1, 7	2 QTLs
	Zhenshan 97 × Minghui 63	RILs	1, 2, 3, 6, 7, 10, 11, 12 (His); 2, 3, 5, 6, 7, 10, 11, 12	10 (His) + 8 (Arg)
	Zhenshan 97 × Minghui 63	RILs	1, 11	12
	Zhenshan 97B × Delong 208	RILs	1, 7, 9	3 QTLs
	Dasanbyeo × TR22183	RILs	3	6
Proteins	Caiapo × IRGC 103544	DH	1, 2, 6, 11	4
	Gui630 × Accession 02428	DH	1, 4, 5, 6, 7	5
	V20A × Accession 103,544	BC3F1	8	1
	Moritawase × Koshihikari	RILs	2, 6, 9	3
	Kasalath × Koshihikari)	BIL	6, 10	2
	Chuan × Nanyangzhan	RIL	6, 7	2
	Xieqingzao B × Milyang 46	RILs	3, 4, 5, 6, 10	
	Zhenshan 97 × Minghui 63	RILs	2, 3, 5, 6, 7, 10, 11, 12	9
	Samgang × Nagdong	DH	1, 11	3
	Asominori) × IR24)	RILs	1, 3, 4, 6, 7, 8, 9, 10, 12	10
	Zhenshan 97B × Delong 208	RILs	1, 7	2
	Cheongcheong × Nagdong	DH	2	1
	CJ06) × TN1	DH	10	1
	Cheongcheong × Nagdong	DH	8,9,10	3
	M201 × JY293	RILs	1, 2, 3, 4	5
	Cheongcheong × Nagdong	DH	7	1
Zinc and Iron	Zhengshan 97 × Minghui 63	RILs	Zn (5, 7, 11); Fe (1, 9)	GZn-3; GFe-2
	Bala) × Azucena	RILs	Zn (6, 7, 10); Fe (1, 3, 4, 7)	GZn-4; GFe- 4
	ZYQ8 x JX17	DH	4, 6	GZn-2
	Madhukar) × Swarna	RILs	Zn (3, 7, 12); Fe (1, 5, 7, 12)	GZn-6; GFe-7

involves a lot of genes. Over expressing these genes for increased bioavailability may leads to an important way by enhancing Zn content in rice grains. In rice, over expressing NA synthase genes via the introduction of a 35S enhancer element has contributed to many folds increase. Transgenic rice harbours barley nicotianamine synthase gene HvNAS1 which showed a 3-fold higher zinc accumulation under the influence of rice actin1 promoter. OsIRT (ZIP family protein in rice) can be over expressed for higher concentration of zinc to accumulate in rice. OsZIP1, OsZIP2, OsZIP3, and OsZIP4 have been connected with Zn homeostatis (Ishimaru et al., 2007).

Lee et.al. 2009 concluded that in GE rice high amount of Fe and Zn in rice grains was a result of over expression of OsIRT and MxIRT genes. Boonyaves (2016) reported that the polished grains of GM rice accumulated at highest concentration of Fe and Zn as a group of 4 genes (AtIRT1, Pvferritin, AtNAS1, and Afphytase) was channelized to rice. Many reports have also been published where there were over expression of rice OsNAS genes that led to high accumulation of zinc in grains (Johnson, 2011).

2.4 *Agronomic strategy for Zn biofertification*

Several field experiments in rice have been carried out during the past years in India with applications of several soil and foliar applied fertilizers (Table 1). Zn concentration among the popular cultivar varied in between 25-31.1 mg kg^{-1} after soil Zn applications at the time of sowing (Saha et al., 2017; Das et al., 2019; Yatav et al., 2019 and Mohapatra et al., 2021). Foliar application of Zn at the time of tillering and flowering increased Zn concentration by 35.6 to 106.7 over control (Saha et al., 2017; Das et al., 2019; Yatav et al., 2019). Clearly, soil Zn applications at the time of sowing had little effect on the concentration of Zn in the grain under control and field conditions, where as foliar Zn sprays are very effective in improving the grain Zn. An intermediate response to foliar Zn applications in rice increases in grain Zn upto 2 times. The timing of foliar Zn fertilizer application is an important determinant of its effectiveness in terms of biofortification (Welch et al., 2013). In rice, foliar Zn applications are particularly effective in enriching the grain with Zn if they are applied at a later rather than an earlier developmental stage, preferably during grain-filling stage (Cakmak et al., 2010; Boonchuay et al., 2013; Abdoli et al., 2014). The probable explanation might be that the foliar Zn application penetrates the cuticle and the cellulose wall via limitedor free diffusion and ions are also absorbed by the stomata on the leaves, which altered sub-cellular compartmentation of Zn in the shoot. This enhances more efficient biochemical utilization of Zn in cells of the shoot while only part of the nutrient can be translocated from the shoot to the grain. Shivay et al.(2015) also observed that foliar application of Zn increased Zn content both in the grain and the vegetative parts of the plants and is more suitable than soil application. Foliar spray of Zn either alone or in combination with soil application significantly reduces the phytate: Zn molar ratios in unpolished rice grains over control. The lowest phytate: Zn molar ratio and hence a higher bioavailability of the fortified Zn is found in case of SA+FS followed by other method of fertilizer application.

2.5 *Improvement of nutraceutical properties in rice grain*

It has been very well documented in the aspects of genetic diversity found on micronutrient in rice and other food crops (Yang et al., 2007). Genetic diversity has been used as the main target for developing nutritionally superior varieties by various scientist and breeders (Zapata- Caldas et al., 2009). There are many programmes to develop superior varieties rice, wheat, potato, bean etc with a higher amount content of Fe, Zn, vitamin A etc. (Pfeiffer and McClafferty, 2007). In a programme (in search for new donors) initiated by IRRI(International Rice Research Institute) in collaboration with University of Adelaide, Australia, 7000 varieties of rice have been evaluated for zinc and iron concentration in the rice grains. Later on, Khush et al. (2012) reported rice grains with higher concentration of zinc and iron. A significant variation in iron concentration has reported for many staple crops like rice, wheat, maize, bean, casavaetc (Frossard et al., 2000). Tiwari et al. (2009) suggested for the development of nutrient rich cultivars of different crops selective breeding is used as a tool. IR 68144-3B-2-2-3 (IR72 X Zawa Bonday), is identified as a developed Indian breeding line. However, breeding techniques can only be successful if micronutrients are available in the soil for the plant to take in. A list of QTLs identified for biofortification traits in rice is indexed in Table 2.

3. CONCLUSION

Biofortification is a sustainable agricultural method being minimum cost and positive impact for ameliorating the wellbeing of the world's most sizably voluminous undernourished people. Biofortification strategies predicated on crop breeding, targeted genetic modification, and/or the application of mineral fertilisers have an abundance of promise for addressing human mineral malnutrition. Breeding approaches are generalized and easy to adopt, and have been adapted to sustainably improve victorious nutritional qualities. Molecular breeding approaches, which have much higher success rates as genetically-fortified crop plants, are facing difficulties due to consumer acceptance and the costly and high regulatory approval processes used between different countries. A desirable future will be created by the use of biofortified crops as they have the capacity to kick off the malnutrition regarding the micronutrients among the poor people whole over the world, especially people of developing countries.

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PRINTED BOOK

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An International Journal on Rice

Vol. 60 Special Issue February, 2023

Edited by Dr. Anjani Kumar. Printed and Published by Dr. Sanjoy Saha, Secretary on behalf of the Association of Rice Research Workers, National Rice Research Institute, Cuttack – 753 006 (Odisha), India. [E-mail: arrworyza@rediffmail.com]