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Rice (*Oryza sativa*) research in India

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ABSTRACT

In rice (*Oryza sativa* L.) varietal improvement had been largely through pureline selection before fifties. Intervarietal hybridization programme was the first serious attempt to break the yield barrier in tropical rice. A breakthrough in breeding was witnessed with the concept of semi-dwarf, non-lodging plant type. Special breeding programmes were also launched to develop varieties, suited to rainfed uplands, shallow lowlands, semi-deep and deep water areas as well as problem soils. The All-India Co-ordinated Rice Improvement Project played a key role in rapid material generation and varietal identification suitable for varied situations. The mechanism of inter-discipline-based multilocation testing facilitated development of agro-ecology-specific varietal and matching production technology. This model has helped to evolve more than 528 high-yielding, dwarf rice varieties and enabled us to achieve a record production of 82 million tonnes of milled rice during 1994–95, ensuring self-sufficiency in rice. Eleven rice hybrids have been released so far for commercial cultivation. The fine grain and aromatic rice helped increase rice export. India exported 5.5 million tonnes rice valued at Rs 30 000 million. The article deals with the present rice scenario in India.

Key words : rice, varietal improvement, hybrid, genetic resources, physiology, disease and pest management

Rice (*Oryza sativa* L.) research in India started its glorious chapter as early as 1911 with major emphasis on collection and purification of locally grown land races. This resulted in the identification of several purelines of tall *indica* varieties that suited more or less subsistence farm conditions. Realizing the importance of organized research on basic and applied aspects of rice, the Imperial Council of Agricultural Research established the Central Rice Research Institute (CRRI) at Cuttack, Orissa, in 1946 primarily for developing high-yielding rice varieties and technologies for different parts of the country (Ramaiah 1953). A review of the trends in area, production and yield of rice in India during 1934--60 shows that during this period, the increased production (annual growth rate 1.0%) had mainly achieved through the expansion of area under the crop (annual growth rate 1.2%) with negative annual growth rate of –0.2% in productivity (Parthasarathy 1972). Apparently rice breeding had no significant impact on productivity during this period despite a large number of varieties identified through pureline selection. The farmers and researchers experienced certain limitations such as excessive vegetative growth, mutual shading, low response to fertilizer and lodging when attempts were made to raise productivity of these varieties under such superior management as the Japanese method of rice culture with higher level of inputs.

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Realizing the limitations of traditional *indica* varieties, the Food and Agriculture Organization (FAO) sponsored a regional programme in 1952 on intervarietal (*indica* x *japonica*) hybridization for India and southeast Asia to help introduce high-yielding attributes of *japonica* into the background of *indica* varieties (Parthasarathy 1972). Since the impact of this programme had not readily been reflected in improving production and productivity of rice, the need was felt to understand the major production constraints in major rice-growing areas with a better co-ordination and understanding of the applied aspects of rice research at the national level. The All-India Co-ordinated Rice Improvement Project (AICRIP) was thus established in 1965 to accelerate and co-ordinate rice research at national level, for rapid generation and identification of varieties and management technologies appropriate to different agro-ecologies through multilocation testing (ICAR, New Delhi 1985, Paroda and Siddiq 1993) in partnership with state agricultural universities and departments of agriculture and central agricultural research institutes.

RESEARCH ACCOMPLISHMENTS

Varietal improvement

Before the onset of Green Revolution era, varietal improvement had largely been confined to pureline selection, resulting in identification of 445 varieties (ICAR, New Delhi 1960). Some of these varieties like 'Manoharsali', 'SR 20B', 'FR 13A' and 'Nonasali' in the fragile environments and

Table 1 Some of the popular varieties developed before 1960 in India

State	Popular variety
Andhra Pradesh	'MTU 1', 'MTU 15',' HR 19'
West Bengal	'Chinsurah 7'
Bombay	Kolamba strains
Madhya Pradesh	'Hybrid 2', 'Hybrid 18', 'Dubraj'
Tamil Nadu	'GEB 24', 'Co 2', 'Co 25', 'Co 26', 'ASD 1'
Orissa	'T 141', 'SR 26B'
Punjab	'Basmati 370'
Uttar Pradesh	'T 136', 'N 22'

'Basmati 370' and 'NP 130' in north–western India continued to be grown. Some of the most outstanding varieties of this period are given in Table 1. A large number of donors being used today for improving yield, stability and quality were pureline selections from these land races. Exotic introductions further supplemented the early efforts in identifying successful varieties for cold and hill ecology of Himachal Pradesh, Kashmir and Uttar Pradesh. All early efforts had hardly helped raise the genetic yield potential appreciably to meet the growing demand. The first serious research effort to break the yield barrier of tropical rice was made through intervarietal (*indica* x *japonica*) hybridization programme to combine fertilizer responsiveness of *japonica* varieties with adaptability and quality of *indica* ones. Although it was not that fruitful totally, this programme eventuated in the identification of 'Mahsuri' in Malaysia and 'ADT 27' in Tamil Nadu resulting in significant production advancement in India. This breeding programme convinced breeders that the key to higher yield lies in breeding for non-lodging plants.

By 1965, it was realized that plant type was the major yield barrier in rice. A major breakthrough was witnessed in the history of rice breeding in the form of 'IR 8' which bestowed practical expression to the concept of ideotype. As information on different components of plant type became available, India recognized new horizons for increasing productivity through identification of semi-dwarf varieties from introduced materials as well as selections from hybridization programmes. The co-ordinated research programme was geared up for this task to achieve the desired result at the earliest possible time, resulting in the release of 'IR 8' from the introduced material of the IRRI in 1966 and 'Jaya' from hybridization programme of the AICRIP in 1968. This was followed by the identification of several varieties which combine improved plant type with high yield for different maturity groups. The unique mechanism of multidiscipline-based multilocation testing of the AICRIP has thus facilitated rapid development of varietal and production technologies appropriate for varied agroecologies (AICRIP, Hyderabad). The model, now adopted by several countries and international institutions, helped to evolve more than 528 high-yielding varieties and enabled the country to achieve a record production of 82 million tonnes of milled rice in 1994–95 ensuring sustained self-sufficiency. Important varieties recommended for different ecosystems are listed in Table 2.

Thrust in breeding research varied with the changing needs and socio-economic compulsions. If it was for high yield and general adaptability in the first decade after introduction of dwarf varieties, stability of yield by breeding for resistance or tolerance to biotic and abiotic stresses was the priority in the following decade, and raising the genetic yield threshold and evolution of varieties suited to rainfed ecologies received increased research attention from the third decade onwards. The post-'Jaya' period of varietal development in India may broadly be grouped into 4 phases, viz. (*i*) the first decade of high-yielding varieties of different maturity periods and varied grain quality; (*ii*) the second decade of aggressive breeding for resistance to pests and diseases; (*iii*) the third decade of breeding for high-yielding varieties adapted to diverse rainfed ecologies; and lastly (*iv*) the development and use of hybrid technology.

Varietal development for yield, adoptability and quality: During the first decade (till 1979), the AICRIP, through its 3-tier system of evaluation, identified 17 centrally released and 73 state released high-yielding varieties of short and medium durations for irrigated ecosystem. Like introduction of early-maturing cotton and of mexican dwarf varieties that enabled wide adoption of wheat in north–western India, relatively early-maturing, high-yielding dwarf varieties of rice replaced huge areas under millets and oilseed crops making rice–wheat as the most productive and profitable cropping system.One of the notable achievements of Indian rice breeding programme is the successful development of quick-maturing varieties like 'Pusa 2-21', 'Pusa 33' and 'Saket 4' which are capable of yielding as high as 90% yield of medium-duration varieties under irrigated conditions. Wide adoption of these varieties which enabled farmers to fit them into varied cropping systems substantially increased the cropping intensity and thereby factor productivity. Some of the popular varieties among them were 'Jayanthi' and 'IR 20' in medium; 'Padma' and 'Ratna' in mid-early; and 'Pusa 2-21', 'Saket 4' and 'Annapurna' in early- duration groups. Varieties like 'Jagannath' and 'IR 5' ('Pankaj') with long-duration were released for rainfed lowland ecosystem. Efforts continued during the second and third phases as well lead to the identification of many more promising varieties. Keeping in view the strong and varied consumer preference, efforts were directed towards quality improvement for incorporating fine grained type, red grain type and semi-dwarf high-yielding aromatic types. 'Pusa 4-1-11' among the fine grained types and 'Annapurna' and 'TKM 9' among the red grained types were widely accepted by the consumers. As for aromatic rice, concerted efforts continued for over long period helped to develop high-yielding, dwarf aromatic varieties ('Pusa Basmati 1', 'Kasturi'), comparable with highly prized traditional basmati varieties like 'Basmati 370' and 'Taroari Basmati' in quality, aroma, elongation and texture on cooking

Table 2 Popular rice varieties for different ecosystems and rice-growing situations in India

Ecosystem or rice-growing situation	Variety
Rainfed upland	'Tulasi', 'Aditya', 'Prasanna', 'Rasi', 'Satya', 'Rudrama', 'PNR 381', 'Vandana', 'Birsadhan 101', 'Birsadhan 104', 'Birsadhan 105', 'Birsadhan 201', 'Birsadhan 202', 'Heera', 'Kanchan', 'Kalinga III', 'Annada', 'GR 2', 'GR 5', 'GR 6', 'Himdhan', 'Nagardhan', 'VLK Dhan','VL Dhan 221', 'RP 2421', 'Himalaya 741', 'Himalaya 2216', 'Amrut', 'Mukti', 'IET 7564', 'Suvarna', 'Modan', 'Onam', 'JR 75', 'Rathe','R 281-31-1', 'Tuljapur 4', 'Ratnagiri 73-1-41', 'Terna', 'Kranti', 'Ngoba', 'Parijat', 'Pathara', 'Kalyani II', 'Sattari', 'Neela', 'Rudra', 'Vanaprabha', 'Khandagiri', 'Nilagiri', 'Ghanteswari', 'Sneha', 'Patnai 23', 'Aswani', 'Renu', 'Saket 4','Narendradhan 18', 'Narendradhan 80', 'Narendradhan 97', 'Narendradhan 118', 'Khitish', 'Kiron', 'Bhupen'.
Rainfed shallow lowland	'Manasarovar','Swarnadhan', 'Phalguna', 'Mandya Vijaya', 'Nandi', 'Swarna', 'Sambamahsuri', 'Pinakini','Krishnaveni', 'Thikkana','Chaitanya','Pothana','Orugallu','Sri Ranga','Sagarasamba', 'Simhapuri', 'Laksmi','Salivahana', 'Bahadur', 'Kushal', 'Ranjit','Manoharsali', 'Mahsuri', 'Moniram Katekijoha', 'Rangili', 'Bhogali','Pankaj','Savitri', 'Sita', 'Jayashree', 'Janaki', 'Radha', 'CR 1002','Rajashree', 'Kanak', 'Vaidehi', 'Hemavathi', 'Nethravathi', 'IET 7191', 'Abhilash', 'Intan','KPH 2', 'Neerja', 'Rashmi', 'Kayamkulam', 'Shyamala', 'Safril 7', 'Kranti', 'Surekha', 'Mahamaya', 'Ratnagiri 2', 'SYE 75', 'SYE-ER-1', 'Darna', 'Ratnagiri 3', 'R 374-11', 'Jagannath', 'NEH Megha Rice 1', 'NEHMegha Rice 2', 'Rajeswari', 'Seema', 'Parijat', 'CR 1014', 'Jajati', 'Urbashi', 'Samalei', 'Pratap', 'Saradhi', 'Gauri', 'Daya', 'Mahalakshmi', 'Lakhmi', 'Savitri', 'Madhukar', 'Jayalakshmi', 'Suresh', 'Dinesh', 'Biraj', 'Bipsa', 'IR 42'
Semi-deep and water situation	'Amulya', 'Nalini', 'Jogen Sabita', 'Biraj', 'Jaladhi 1', 'Suha', 'Jaladhi 2', 'Vaidehi', 'Jalmagna', 'Rambha', 'Utkal Prabha', 'Manika', 'Mahalaxmi', 'Kanchan', 'Panidhan', 'FR 13A', 'Jallahri', 'Jalnidhi', 'Jalapriya', 'Jitendra', 'Madhukar', 'Chakia 59', 'Natina', 'Mandira', 'Matangini', 'Purendu'
Irrigated	'Rasi', 'Vikas', 'Tella Hamsa', 'Prabhat', 'Abhaya', 'Rajendra', 'Divya', 'Sasyashree', 'Bhaddrakali', 'Suraksha', 'IR 64', 'Ajaya', 'Vikramarya', 'Vibhava', 'Satya', 'Saleem', 'Surekha', 'Kavya', 'Erramallelu','Pusa 2-21', 'Pusa 44-23', 'Gautam CR 1002', 'Archana','Rajendradhan 201', 'Rajendradhan 202', 'Jaya', 'Vikram', 'Karjat 2', 'Karjat 3', 'Ratnagiri 3', 'Sugandha', 'Ambika', 'Jaya', 'Narmada', 'Ratna', 'IR 20', 'IR 36', 'GR 4', 'GR 6', 'Gaur 10', 'GR 102', 'GR 103', 'HKR 102', 'Haryana Basmati', 'Taroari Basmati', 'Basmati 370', 'Pusa 44', 'Pusa Basmati 1', 'Kasturi', 'PR 103', 'HKR 126', 'RP 732', 'Himalaya 2', 'Himalaya 732', 'Ranbir Basmati', 'Jhelum', 'K78-13', 'SKAU 23', 'SKAU 27', 'Akash','Avinash', 'Karna', 'Mahaveer', 'Prakash', 'Vikram', 'Vibhava', 'Sonasali', 'IR 30864', 'Red Annapurna', 'Mandya Vani', 'Triveni', 'Jyothi', 'Pavizham', 'Athira', 'Kartika', 'Makom','Sabari', 'Jayathi', 'Kanchana', 'Swarnaprabha', 'Aishwarya', 'Aruna', 'Remya', 'Kanakam', 'Mata Triveni','Kairali', 'Ruchi','Mahamaya', 'Patel 85', 'Madhuri', 'Pawana', 'Sugandha', 'Punshi', 'Maniphouibi 1', 'Maniphouibi 2', 'IR 8', 'PR 106', 'PR 109', 'PR 108', 'Basmati 385', 'PR 111', 'Bharatidasan', 'Jawahar', 'Aravinder', 'Punithavathi', 'Savitri', 'Puduvai Ponni', 'BK 79', 'BK 190', 'Mahisugandha', 'IR 50', 'TKM 9', 'PMK 1', 'ADT 36', 'ADT 37', 'IR 20', 'Co 41', 'Co 43', 'Co 44', 'TPS 1','MDU 2', 'MDU 3', 'ADT 39', 'ADT 42', 'JJ 92', 'ASD 17', 'White Ponni', 'Ponni', 'Paiyur 1', 'ADT 40', 'Co 42', 'Co 45', 'TRC Boro Dhan', 'Saket 4', 'Sarjoo 52', 'Narendradhan 359', 'Govind', 'Madhukar', 'Jayalakshmi', 'Suresh','Dinesh', 'Biraj', 'Bipsa', 'IR 42','Givind', 'Pantdhan 4', 'Pantdhan 6', 'Pandhan 4', 'Pantdhan 6', 'Pantdhan 10', 'Pantdhan 12', 'Manhar', 'Narendradhan 2', 'Kunti', 'Lakhmi', 'Munal',
Saline areas	'CST 7-1', 'Lunishree', 'CSR 10', 'Panvel 1', 'Panvel 2', 'Vytilla 2', 'Vytilla 3', 'Vytilla 4', 'CSR 5'
Alkaline areas	'Vikas', 'CSR 5'
Post-flood situation	'Heera', 'Luit', 'Kalinga III'
Hilly regions	'Pantdhan 1', 'Majhera 3', 'VL Dhan 39', 'VL Dhan 163', 'VL Dhan 206', 'VL Dhan 221'

besides 50–60% higher yield (Siddiq 1991). While early-maturing varieties have helped crop intensification by ideally fitting as potential crop component in varied cropping systems. the fine grained aromatic varieties have helped step up export of high-quality rice.

Hybrid rice: To break the yield barrier of popularly grown dwarf plant types, research on hybrid crops was initiated in 1989 through a research network. Efforts to develop hybrid rice technology has been successful during the last 6 years with the release of rice hybrids for commercial cultivation. Based on their performance in the multilocation tests and on-farm trials 11 hybrids ('APHR 1', 'APHR 2', 'DRRH 1' in Andhra Pradesh; 'MGR 1', 'CORH 1' and 'ADTRH 1' in Tamil Nadu; 'KRH 1', 'KRH 2' in Karnataka; 'CNRH 3' in West Bengal; 'UPHR 17' in Uttar Pradesh; and 'KJTRH 1' in Maharashtra were released by the respective states; and 'PHB 71' by the Central Variety Release Committee. These hybrids yielded about 15 % grain yield higher than the prevailing popular varieties. Package of practices for cytoplasmic male-sterile lines multiplication as well as hybrid seed production techniques were standardized to obtain seed yield of about 1.5 tonnes/ha. Some of the private companies are successfully producing and marketing their own hybrids which cover about 0.1 million ha land.

Varieties with resistance to pests and diseases: Pest-disease syndrome in rice causes 25–30% of yield loss (Krishnaiah 1996). The problem became serious with the introduction of high-yielding, semi-dwarf varieties because of the favourable host environment facilitated by the genetic homogeneity due to continuously large area planted to a few high-yielding varieties, changes in the cropping patterns, crop intensification in resource-rich areas and high input management. Appearance of new pests like bacterial leaf blight (BLB), rice tungro virus (RTV), grassy stunt virus (GSV), sheath blight, brown planthopper (BPH), green leafhopper (GLH), leaf folder and hispa in addition to the traditional ones like blast, stem-borer and gall-midge and their new strains with increased virulence. Pest resurgence and pesticide resistance have further compounded the problem and made the pest management more and more expensive and difficult. Crop losses often of high magnitude experienced in one or the other region caused wide fluctuation in the production growth. This necessitated, during the second decade, a shift in breeding emphasis for development of varieties with specific or multiple resistance to key pests and diseases. Identification of resistance sources in 'Siam 29' and 'W 1263' (a derivative of the native variety 'Eswarakora') and their use in cross breeding resulted in the development of the first gall-midge-resistant variety 'Phalguna' which was a breakthrough in resistance breeding (Shastry *et al.* 1972). Other biotype-specific gall-midge-resistant varieties like 'Surekha', 'Pothana', 'Abhaya', 'Suraksha' and 'Triguna' were followed for general cultivation. Other serious pests which required concerted breeding efforts in the seventies and eighties were BPH, BLB and RTV. Taking advantage of rich genetic resources of resistance available in Indian and exotic germplasm, a wide choice of resistant varieties could be developed against them. It was through a mosaic of resistant varieties such as 'Krishnaveni', 'Chaitanya', 'Jyothi', 'Sonasali' and 'Kanakam' with diverse gene sources that BPH could be contained effectively. Although such opportunities were available for managing BLB and RTV, only a few varieties with reasonably high level of resistance could be evolved. Among them, important ones are 'Ajaya' and 'PR 110' against BLB and 'Vikramarya' and 'Nidhi' against RTV (Siddiq 1991). Significantly, 'Ajaya' is the most reliable answer to BLB in India, while 'Vikramarya' is the first-ever released resistant variety against RTV. Thus, as many as 37 varieties are having either specific or multiple resistance (Table 3). Although varieties with stable resistance to stem-borer and blast are yet to be evolved. Many of the varieties under cultivation are relatively tolerant to them and concerted efforts are underway to evolve varieties with durable resistance. The impact of host-plant resistance is visible through the reduced crop losses, less frequent recurrence of pest epidemics, declining use of chemical pesticides and above all stable production and productivity growth in pest-endemic areas (Krishnaiah 1996).

Management of genetic resources: Genetic resources constitute primary base for varietal improvement. Through systematic explorations rice germplasm was collected from diversified ecologies and conserved at the National Bureau of Plant Genetic Resources (NBPGR), major collections from Indian explorations being 1 800 cultivars from Jeypore tract of Orissa and Madhya Pradesh; 900 from Manipur; 6 630 from northern eastern region; 19 000 from Madhya Pradesh; 1976 from eastern Uttar Pradesh; 1 247 from hilly areas of Uttar Pradesh; and 1 947 from Sikkim and Bihar (Seetharaman *et al.* 1972, Sharma 1982).

The first systematic evaluation of rice germplasm in India was attempted at the CRRI and the Directorate of Rice Research (DRR), in which about 6 000 accessions known as Assam Rice Collections (ARC) were evaluated for morphological characters and stress tolerance. Germplasm accessions 85 000 at the IRRI, 30 000 in China, 16 345 at Cuttack, 1 750 from Jeypore were screened against major biotic and abiotic stresses at the IRRI, DRR, CRRI and other state research centres, and donors for these stresses were identified which served as valuable primary donor gene pool for varietal improvement. Under the ongoing ICAR Research Network programmes, a systematic screening of rice germplasm for biotic stresses was initiated at the DRR in collaboration with the NBPGR in 1993. So far 10 577 accessions received from different centres and universities were screened under controlled conditions as well as in hot spots through multi-location testing at 16 collaborating centres. The number of germplasm accessions found promising from the germplasm evaluation scheme are given in Table 4.

Rice biotechnology: Programme is structured in nineties on deployment of cellular and molecular techniques in 2 important areas: (*i*) gene transfer (gene transformation) and (*ii*) gene characterization (DNA marker technology), wide hybridization, tissue and anther culture techniques is also being pursued with specific objectives.

Wide hybridization while identifying alternate sources of male-sterile cytoplasm from wild species led to the development of new CMS lines, possessing complete panicle exertion and desirable trait for promoting pollination.

Anther culture is being pursued to develop double haploid mapping populations. From several double haploids induced from F_1, hybrid anther culture realized 90% yield of F_1 hybrid. In the area of genetic transformation, gene transfer protocols, utilizing Biolistic and *Agrobacterium*, were developed (DRR, Hyderabad 1995–96). Genes conferring resistance to gall-midge biotype 1, viz $\mathbf{Gm_2}$ and $\mathbf{Gm_3}$ (non-allelic), have been mapped on rice chromosomes 4 and 11 respectively. To facilitate proper gene deployment in disease-endemic areas, population variability of bacterial leaf blight, blast and sheath blight was evaluated. This led to the identification of 3 distinct races in blast IC 9, IC 17, ID 1 for which many varieties possessing broad spectrum of

Table 3 Rice varieties with resistance to diseases and insect pests

Disease or pest	Variety					
Blast	'ADT 36'	'ADT 38'	'ASD 18'	'Athira'	'Amrut'	'Avinash'
	'BK 79'	'Bhadur'	'Bhagoil'	'Bhavani'	'Bharatidasan'	'Birupa'
	'Co 43'	'Co 45'	'CR 1002'	'GR 101'	'GR 102'	'GR 103'
	'Gaur 1'	'Gauri'	'Govind'	'Ghanteswari'	'Indryani'	'IR 64'
	'IET 7564'	'Janaki'	'Jaya'	'Jayasree'	'Jayanthi'	'Kairali'
	'Kanchana'	'Karjat 1'	'Karjat 2'	'Khandagiri'	'Kitish'	'Kunti'
	'Kushal'	'Laxmi'	'Manhar'	'Mandya Vijaya'	'Mahaveer'	'MTU 9993'
	'Neeraja'	'Narendra 359'	'Netravati'	'Onam'	'Palghar 1'	'Pantdhan 4'
	'Pantdhan 6'	'Pantdhan 10'	'Pantdhan 11'	'Pranava'	'Patel 85'	'Penna'
	'Pusa 169'	'Pusa 205'	'Pavizham'	'Prabhat'	'Punshi'	'Phew Oibi'
	'PR 106'	'Radha'	'Rangoli'	'Rajavadlu'	'RP 2421'	'Safri 17'
	'Sagarsamba'	'Sakoli 6'	'Salivahana'	'Sambamahsure'	'Sarjoo 52'	'Savithri'
	'SKL 47-8'	'Shaktiman'	'Sneha'	'Sonamahsuri'	'Sujatha'	'Srabani'
	'Swathi'	'Swarnadhan'	'Swarnamukhi'	'Syc 1'	'TKM 9'	'TKM 10'
	'TPS 10'	'TPS 3'	'Tulasi'	'VL Dhan 221'	'Vytilla 4'	'TRC Borodhan'
BLB	'Ajaya'	'PR 110'	'PR 111'	'Pantdhan 12'		
RTV	'Nidhi'	'Vikramarya'	'Bharani'	'Vasundhara'	'CORH 1'	
GLH	'Vikramarya'	'Lalat'				
BPH	'HKR 126'	'Nandi'	'Arvindar'	'PMK 2'	'ADT 42'	'TPS 3'
	'PKU 2'	'Kanakam'	'Chaitanya'	'Krishnaveni'	'Vajram'	'Pratibha'
	'Macom'	'Pavizahm'	'Manasarovar'	'Chandana'	'Nagarjuna'	'Sonasali'
	'Rasmi'	'Jyothi'	'Bhadra'	'Neela'	'Annanga'	'Daya'
	'Aruna'	'Remya'	'Bharathidasan'	'Karthika'	'Nandi'	'CO 46'
WBPH	'HKR 120'					
Stem-borer	'Sasyasri'	'Vikas'	'Ratna'			
Gall midge	'Phalguna'	'Surekha'	'Sneha'	'Samridhi'	'Bhuban'	'Samlei'
Biotypes 1-2	'Abhaya'	'Shakti'	'Suraksha'	'Daya'	'Pratap'	'Udaya'
	'IR 36'	'Shaktiman'	'Tara'	'Khira'	'Sarasa'	'Neela'
	'Lalat'	'Dhanyalaxmi'	'Vikram'	'Kunti'	'Karna'	
GM Bio-1	'Kakatiya'	'Erramallelu'	'Kavya'	'Vasundhara'	'Penna'	'Kesava'
	'Siva'	'Indursamba'				
GM Bio-3	'Rajendradhan 202'	'Karna'	'Ruchi'	'Divya'		
GM Bio-4	'Suraksha'	'Abhaya'				
GM Bio-5	'IET 12875' ('Triguna')					

Table 4 Germplasm accessions found promising to insect pests and diseases

Year	Accessions tested	Insect pest					Disease		
		BHP	SB	GM	LF	PH	BL	BLB	ShBl
1993–94	2 970 (CRRI, Cuttack)	6	54	69	4		18	5	7
1994–95	3 000 (Raipur)	93	20	149	4	16	65	8	3
1995–96	3 000 (Raipur)	7	11	9	22	73	30	6	6

resistance could be identified. For bacterial leaf blight 3 predominant pathotypes prevalent were recorded (DRR, Hyderabad 1995–96).

Crop physiology

Physiological studies intensified after the introduction of dwarf varieties, aimed at the characterization of morpho-physiological parameters for different ecologies and for increasing the yield potential.

In transplanted rice dry-matter production after flowering directly contributes to grain yield under optimum conditions in dry season. Major constraints in wet season are low light and high night temperatures influencing the contribution of carbohydrate reserves for grain-filling and the resultant yield. Major productivity indicators in wet season are low grain number/panicle in early, high spikelet sterility in medium- and low-panicle number in the late-duration varieties.

Studies on interrelationship between grain number and per unit area showed that maximum grain number was about 30 000 grain/m^2 with 400 panicles/m^2. For enhancing yield potential, grains/panicle are to be stabilized while increasing the panicle number per unit area. The grain size and number are negatively correlated. Early varieties generally have low grain number per unit area than the medium and late varieties. Grain yields can be improved (eg up to 30% in 'IR 8') by improving the density of filled spikelets. For increasing the number of high-density grains (weighing 20–28 mg/panicle) should be composed of mainly primary branches. Grain density seems to be a genotype character and is possible to combine the higher grain density character with any vegetative growth duration. Low temperature and high photosynthetically active radiation after flowering and higher N levels increased the number of high density grains.

Tolerance to drought in general is associated with (*i*) higher germination in polyethylene glycol, (*ii*) less starch disintegration in root and low destruction of chlorophyll, (*iii*) tillering in quick succession before the onset of drought, (*iv*) longer root length (> 25 cm), (*v*) higher leaf moisture content and greater accumulation of sugars in non-reducing form. Tolerance to waterlogging is associated with (*i*) fast, early tiller development, (*ii*) liberation of more oxygen from the root, (*iii*) moderate pectin-methyl esterase activity in the culm, and (*iv*) greater chlorophyll *b* and higher photosynthetic rate of the top leaves above water level. Important traits related to salinity, submergence, dormancy, etc were studied and donors possessing tolerance to all abiotic stresses have been identified for utilization in varietal improvement (CRRI, Cuttack 1996).

Soil and crop management

Soils and agronomy research resulted in development of several production technologies that have made significant contribution to the enhancement of yield and input-use efficiency in rice. Following are some of the salient production technologies developed during the period.

Efficient use of native soil nitrogen: Rice derives about two-thirds of its total N from native soil N pool even when recommended levels of fertilizer N are applied. A 45-cm deep soil profile generally supplies about 60 kg mineral N/ha during a crop season. Late-maturing rice uses almost entire amount of this N from surface as well as subsurface soils, while very early-maturing rice uses hardly 30 kg N/ha only from surface soil of the profile. For effective use of native soil N, one should grow late-maturing rice varieties.

Biological nitrogen fixation (BNF) by pre-rainy season legumes: It is often possible to grow a legume in rice lowland for about 8 weeks during a pre rainy season. Fast-growing legumes like *Sesbania* and *Crotalaria* often accumulate about 100 kg N/ha in their biomass during this period. It was found that 64 to 88% of this N is derived from atmosphere through BNF which may be added to soil through incorporation of the biomass before planting *kharif* rice.

Improving nitrogen-use efficiency: The N-use efficiency can be increased by:

Split application with incorporation of the basal dose into soil: Application of total N fertilizer in 2–3 splits matching N supply to plant requirements at critical stages of growth rather than in a single basal dose at planting, and incorporation of basal dose of fertilizer N into drained soil rather than in standing water increase N-use efficiency significantly.

Deep placement of nitrogen: Placement of fertilizer N in the reduced zone of soil reduces gaseous loss and improves use efficiency of the applied N. Urea supergranules (USG) developed for placement at desired depth, i e 10–15 cm, were extensively tested across the country. The field trials indicated 6 to 30% higher efficiency due to basal placement of USG over the conventional split application of prilled urea. Subsurface application of urea solution in the root zone of rice 10 days after transplanting by an indigenously fabricated applicator, was found equally effective in improving use efficiency of applied fertilizer N.

Use of coated urea materials: Coating of urea with suitable materials to control transformation of applied N in soil reduces N loss and increases its utilization by rice. Neem cake-coated urea (NCCU) applied as basal performed better than split-applied prilled urea in diverse soil types. Neem-cake possesses both urease- and nitrification-inhibition properties, and a 10–15% higher efficiency through NCCU than prilled urea is common. Basal application of gypsum-coated urea and mussoorie rockphosphate-coated urea also proved significantly superior to prilled urea applied in recommended splits.

Nitrogen management in direct-seeded rice: Direct-seeded rice requires very little or no supply of fertilizer N through the first 3–4 weeks. Much of the fertilizer N supplied through basal dose is not utilized by the crop and lost from the root zone. To realize high efficiency of fertilizer N, the major part of N needs to be applied 3–4 weeks after germination or sowing of sprouted seeds and the rest at the panicle initiation.

Efficient management of P: Phosphorus can be managed efficiently as :

Phosphorus sources: Single superphosphate (SSP) and diammonium phosphate (DAP) are the most common P sources for rice. Ammonium polyphosphate (APP), a newly developed complex P fertilizer, has recently been evaluated for its efficiency in rice. The DAP was found to be better than SSP, while APP proved superior to both DAP and SSP, especially in acidic clay-loam soils of Titabar, Assam.

Application methods: For lowland rice, surface broadcasting of fertilizer before final puddling followed by mixing is the most common method of P application. Dipping the roots of seedlings in a slurry of SSP, soil and water before transplanting proved a cost-effective method of supplying P to rice. A root dip using 10–30 kg P_2O_5/ha increased rice yield significantly and compared well with higher rates of soil applied P.

Optimum application time: Application of P at seeding or planting is the common practice for rice. Sources like rockphosphates applied 3–4 weeks before seeding of upland rice or flooding in lowland rice to provide some lead time for dissolution of P.

Efficient management of potassium (K): Generally, recommended level of fertilizer K is applied to soil in a single basal dose before transplanting of rice. In high rainfall areas with coarse-textured soils, split application of K (half at planting and half at panicle-initiation stage) gives higher efficiency. Based on the research findings, split application of K in rice has been recommended in Andhra Pradesh, Kerala, Orissa and Uttar Pradesh. Benefits of split application of K in rice have also been realized in West Bengal and north-eastern hills regions.

Phosphorus and K management in rice-based cropping system: Due to fixation in soil, often considerable part of the P and K applied to a crop remains unused and becomes available to succeeding crop. It was found that in a rice-based cropping system, application of P and K fertilizers may be skipped in rainy *(kharif)* season without any loss in yield if the winter *(rabi)* season crop received supply of the nutrients.

Zinc management in rice: Almost half of the rice-growing soils are deficient in Zn. It was found that Zn-deficiency in rice can be alleviated by 50 kg $ZnSO_4$/ha. However, the optimum rate varies with the type of soil and its deficiency status, variety, and method of Zn application. The best time of Zn application is just before transplanting. Rice yields decline appreciably with a 10–20 days delay in Zn application on Zn-deficient soils. Broadcasting and mixing of $ZnSO_4$ into soil is the most efficient method. When the deficiency is faced in the standing crop, foliar sprays of 0.5–2.0% $ZnSO_4$ solution can be done. Amelioration of Zn deficiency was also tried through soaking or coating seeds in Zn solution and dipping or soaking roots of rice seedlings in Zn solution or suspension before transplanting.

Integrated nutrient-supply systems: Use of all other sources of plant nutrients to complement and supplement mineral fertilizers is necessary for the maintenance of soil fertility, sustaining productivity and improving profitability of rice farms. Combined use of mineral fertilizers, organic manures, biofertilizers, and the inherent nutrient supplies of soils are being promoted. Inclusion of farmyard manures or green-manures in the nutrient management schedule could substitute inorganic fertilizers up to 50% at several locations. Regular use of organic manures or crop residues improved soil structure, organic matter content, and other physico-chemical and biological properties, besides supplying nutrients to the crops.

Integrated weed control: Scarcity of labour and increasing wages make the manual weeding less efficient and uneconomic. Several herbicides like butachlor, oxadiazon, anilophos and oxyflurofen were found effective in controlling common weeds in lowland rice. Recent research has shown that use of herbicide combinations like butachlor + 2,4-D Na, anilophos + 2,4-D EE, pretilachlor + 2,4-D EE, etc control wide spectrum weed flora, and is cost effective. Butachlor + safener or pretilachlor + safener gave best control of weeds in direct-sown rice under puddled conditions.

Establishment of wet-seeded rice: Rice crop established by broadcast sowing of seeds generally suffers from uneven growth and gives lower yields than a transplanted rice crop. Recent research has indicated that line sowing of sprouted seeds at 20 cm spacing with a row seeder gives excellent crop stand and similar yields to that of transplanted crop. Varieties like 'Vikas', 'IET 9994', 'IET 10402' and 'Jalapriya' performed well under direct-seeding under puddled soil conditions.

Management practices for scented rice: Planting of basmati rice during first fortnight of July gave the best results in north-western India while planting by the end of July gave better results in eastern India under rainfed lowland ecosystem. At most locations, basmati rice responded well up to 90 kg N/ha. Higher N application had a detrimental effect on yield and quality of grains.

Agrotechniques to stabilize yield of late-planted rice: In eastern states and coastal belts of the country, rice planting often gets delayed due to floods or cyclones leading to drastic fall in the productivity. In such a situation, yields can be reasonably stabilized by growing suitable varieties or manipulating plant density. Planting of overaged seedlings at closer spacing and more number of seedlings/hill to compensate for reduced tillering, and maintain normal yield level. Varieties like 'Chaitanya', 'IET 5914', 'IET 7251', 'RGL 2537', 'Neeraja' and 'Salivahana' were found suitable for late planting in coastal areas. A 3-week delay in planting did not cause significant reduction in their yields.

Pest management

Rice is essentially a crop of warm humid environments conducive to the survival and proliferation of insects. The number of insect pests that deserved attention in terms of control interventions has increased from 2 (pre-high yielding variety era) to 12 (post-high-yielding variety period). Frequent outbreaks of brown planthopper in rice-growing areas of the country, wide-spread damage due to yellow stem-borer particularly after 1980, newly emerged threats like leaf folder, rice hispa, gundhi bug, ear-cutting caterpillar show the insect pest scenario in the country. Loss in grain yield due to these pests estimated to vary 10–51% (Krishnaiah 1996). The advances made in the management of rice insect pests are summarized here:

Host plant resistance: Host plant resistance played an important role in mitigating the key-pest problems. Following concerted and accelerated efforts in the identification of sources of resistant genes and their incorporation into the cultivars with desirable agronomic and quality characteristics, large number of resistant varieties against major insect pests were developed.

Table 5 Reaction of Indian biotypes to gall-midge on rice differentials

Group	Differential	Biotype/reaction				
		1	2	3	4	5
I	W 1263 and ARC 6605	R	S	R	S	R
II	Siam 29 and ARC 5984	R	R	S	S	R
III	Velluthacheera and Aggani	R	R	S	R	S
IV	TN 1	S	S	S	S	S

Besides the DRR, major rice research centres in India were involved actively in the evaluation of rice germplasm against insect pests. Total number of resistant sources collectively identified against the key pests include 570 for BPH, 370 for WBPH, 258 for GM, 1 200 for GLH, 32 for YSB and 44 for leaf folder. When the origin of these primary donors of resistance is considered, it is strikingly apparent that Assam, Manipur, Orissa and Kerala have contributed a large share of the donors. Some of the resistant donors identified are 'ARC 6650', 'Manoharsali', 'Ptb 33', 'ARC 7080', 'Leb Muc Nahng', 'Rathu Heenati', 'Sinna Sivappu' for BPH; 'IET 6288', 'MOI', 'Anaikomban', 'Andrewsail' for WBPH; 'Eswarakora', 'Siam 29', 'Leuang 152', 'ARC 5984', 'Ptb 18', 'Ptb 21', 'Ptb 10', 'Ob 677', 'ARC 10660', 'ARC 6605' for gall-midge; 'Ptb 2', 'ADT 14', 'ARC 6606', 'ADR 52' for GLH; 'TKM 6', 'W 1263', 'ARC 5500', 'Manoharsali' for YSB; and 'Ptb 12', 'ARC 1128', 'Gorsa' and 'Darukasail' for leaf folder. Several multiple-resistant donors like 'Banglei', 'Aganni', 'T 1177', 'Velluthacheera', 'ADR 52', 'Pandi', 'Chennellu' and 'NHTA 8' were also identified (Siddiq 1998).

Matching with the genetic diversity in the host plant, insect pests also displayed a wide range of genetic variability resulting in variable reaction of certain cultivars to the pest in different geographical areas. Such variability was recorded within the country for gall-midge,which showed 5 biotypes across the country (Table 5). However, continuing efforts enabled indentification of biotype-specific resistant varieties (Table 3).

Chemical control: Insecticide application has been one of the effective and quick methods of reducing insect pest populations. More often, it forms the only solution to sudden outbreaks of insect pests.Therefore several insecticides, both granular and spray formulations, were evaluated for their effectiveness against rice insect pests to determine the dosage and spectrum of toxicity under co-ordinated and lead research programmes. The effective granular formulations include carbofuran, phorate, diazinon, mephosfolan, quinalphos, MIPC, terbufos, thiocyclam hydrogen oxalate, isofenphos, ethoprop, cartap, isazophos, etc and the spray formulations include phosalone, chlorpyriphos, dicrotophos, monocrotophos, isofenphos, carbosulfan, thiocyclam, hydrogen oxalate, carbaryl, ethofenprox and triazophos. Techniques to minimize the use of insecticides for rendering the chemical control cost effective were also developed.

Biocontrol: Biocontrol agents like predators, parasites and pathogens are silent suppression factors of insect pests in rice ecosystem. About 185 natural enemies against yellow stem-borer, 126 against planthoppers, 104 against green leafhoppers, 54 against leaf folder, 18 against gall midge, 50 against army worm and 5 against rice hispa were reported from India. Avoiding pesticide application at the time of abundance of these natural enemies, avoiding broad-spectrum insecticides, adopting of selective methods of insecticides application like seed soaking, seedling root soaking, etc are some of the methods to conserve natural enemies in the field. Inundative release of *Trichogramma chilonis* at 100 000 adults/ha, 5 times (weekly) during the crop season commencing from 30 days after planting suppressed the leaf folder effectively (DRR, Hyderabad 1995–96).

Behavioral control: Insect sex pheromones were evaluated for monitoring of yellow stem-borer and leaf folder populations as alternatives to light traps.There was a significant correlation between pheromone trap catches and light trap catches of male moths as well as damage due to yellow stem-borer in the field, revealing the utility of sex pheromones in the pest monitoring. A week days following the sudden peak catch at the pheromone trap can be reckoned as appropriate time for critically looking the field for yellow stem-borer damage. Direct control of yellow stem-borer could be effectively achieved by disrupting mating mechanism by permeating the pheromone plumes through multipoint pheromone dispensers and by annihilating the male moths attracted to the traps containing pheromone lure.

Integrated pest management: Trials conducted under co-ordinated programme in pest-endemic areas showed that cultivation of a resistant or tolerant variety against the key pests like gall-midge or brown planthopper or stem-borer coupled with need-based application of insecticides against other pests as indicated by regular surveillance was found the best strategy in deriving maximum net profit. This approach was successfully implemented on farmers' fields through Operational Research Projects in pest-prone areas of Andhra Pradesh, Kerala, West Bengal, Orissa, Maharashtra and Madhya Pradesh.

Disease management

Bacterial leaf blight, sheath blight, rice tungro virus along with blast continued to be severe in the post-Green Revolution era causing an estimated grain yield loss of 10%.

Host plant resistance: A number of resistant donors have been identified (Reddy 1992) and rice cultivars deriving their resistance from these donors are given in Table 4. For sheath blight disease, donors and varieties with high level of resistance could not be identified, hence it calls for effective disease-management practices integrating cultural practices like keeping bunds clean of grasses and timely application of fungicide to prevent vertical spread of the disease, rice tungro disease (RTD) occurring sporadically can be contained by using resistant varieties like 'Vikramarya' or 'Radha'. However, considering the complex nature of its etiology, RTD requires a suitable mix of integrating various management practices as discussed elsewhere in this article.

Among the various pathogens, *Pyricularia grisea* the blast pathogen is highly variable in its differential virulence and can break down the resistance of a host genotype within 2–3 years of its introduction.The population variability of the pathogen showed that populations of upland and irrigated ecosystems were more virulent than those of hilly regions (DRR, Hyderabad 1986) and warrants incorporation of functional resistant genes in the former 2 rice ecosystems to prevent epidemics.

Two predominant pathotypes of BLB pathogens were identified by their virulence spectrum on set of differential varieties. Pathotype I was widely prevalent in all the rice-growing states except West Bengal, Bihar and Orissa where pathotype II was prevalent. The genetic structure of BLB pathogen in the country was characterized genomic.The DNA finger printing showed that 94 isolates of X.o.o collected from 24 locations belonging to 1 lineage and most bacterial strains belong to pathotype 1b. Varieties resistant to major pathotypes have been already developed at the DRR and efforts are underway to pyramid resistant genes for other pathotypes.

Chemical control of rice diseases: Chemical control was chiefly aimed at blast and sheath blight diseases. Initial trials during seventies indicated that although copper oxychloride checked blast disease, the high-yielding varieties proved copper-shy. Hence attention was shifted to another group of topical fungicides, viz dithiocarbamates and edifenphos. The limitation with these products was their shorter residual activity. During 1974–75, the first-generation systemic fungicide benomyl, carbendazim and others were evaluated and found highly effective. Many systemic fungicides with different modes of action like anti-mitotic compounds, melanin inhibitors, ergosterol biosynthetic inhibitors and other organic compounds (EBI) were evaluated. Tricyclazole and pyroquilon as seed-dressers could protect seedlings up to 8 weeks (2 g/kg seed) after sowing. As foliar sprays also they could control effectively neck blast. Many fungicides were also evaluated against sheath blight. Among them, triazoles–propiconazole and hexaconazole–were highly effective. Chlorothalonil is effective against false-smut incidence.

In recent years efforts are underway to identify biological control for a few intractable diseases such as sheath blight (DRR, Hyderabad 1995–96).

Novel methods of control of rice diseases through genetic engineering is underway and transgenic plants developed for RTV and BLB are under various stages of testing.

IMPACT OF RESEARCH

Meticulous efforts of rice researchers over the past 50 years resulted in the release of nearly 528 high-yielding varieties and 8 hybrids suitable for diverse production envi-

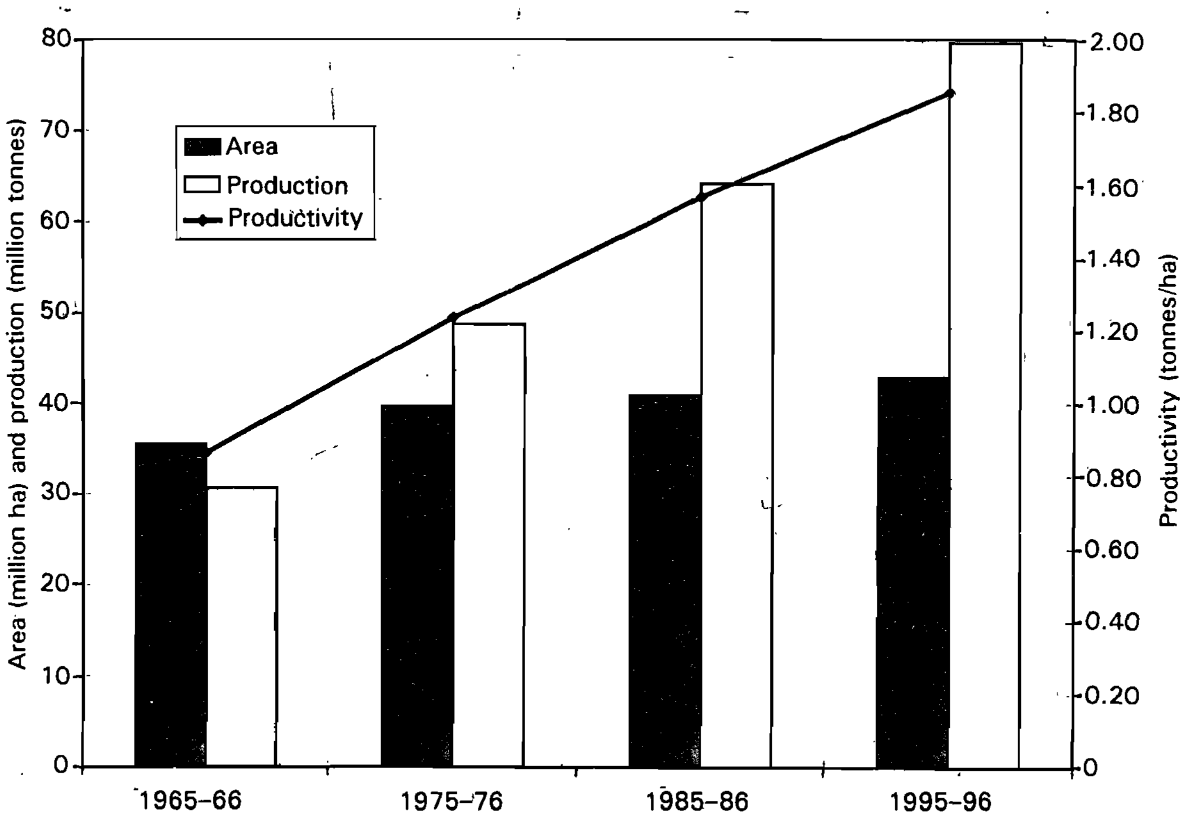

Fig 1 Area, production and productivity of rice in India

ronments. As a result, nearly 29 million ha of rice area has been covered under high-yielding varieties by 1995. These varieties along with improved production and protection technologies elevated the production from 30 to 81 million tonnes; productivity from 862 to 1 921 kg during 1965–95 (Fig 1). Increased rice production resulted in the surplus of foodgrain stocks of the country. Contribution of rice to the total buffer stocks has increased from 6.2 million tonnes in 1982 to 18.0 million tonnes in 1995. Per caput availability of rice and total foodgrains has increased from 70.3 and 171.1 kg per annum in 1971 to 86.7 and 183.2 kg per annum in 1995. This implies that the total increase in per caput availability of foodgrains, despite a decline in coarse cereals production has come mainly from rice. Modern rice technologies emerged as a result of the 50 years of vigorous research has helped sustain food security of the country not only through increase in production but also through improvement in economic accessibility to food due to price stability mechanism.

Rice cultivation, in high-productivity areas of south India is providing a gross income of Rs 25 000–30 000/ ha. Modernization of rice farming also generated huge employment opportunities and thus increasing labour earning and purchasing power.

Research efforts over the last few decades further augmented the objective of maintaining India's balance of payments at a desirable level. At the outset, rice research strategies in early sixties and seventies have transformed India's food economy from chronic food deficiency and excessive dependence on imported food to self-sufficiency by eighties. India could reduce the import bill on rice from US $ 165 million in 1965 to US $ 1.2 million in 1980 mainly owing to quantum jump in domestic production. During the same period, rice export from India also increased from 0.003 to 0.333 million tonnes worth of US $ 175 million. India's rice export was further increased as a result of development of high-quality rice through strong research strategies in the late eighties and early nineties. It is a matter of pride for rice researchers for their role in making India as the second largest rice exporter in the world. About 5.5 million tonnes of rice was exported from India in 1995 worth US $ 1.4 billion which is 15% of globally traded rice. Therefore, improvement of grain quality of rice to make them suitable for export purpose through research strategies played an important role in increasing rice exports from India.

FUTURE THRUST AREAS

Consolidation of already accomplished yield gains and searching for new yield thresholds in irrigated area and maximization and stabilization of yield levels in ecologically handicapped rainfed rice areas will continue to be our major research thrust to achieve the future rice production targets and food security.

While the irrigated rice research will concentrate on ways and means to step up realizable yield potential of existing varieties and stabilize it, further improvement in yield potential through hybrid rice technology and improved plant type will continue to receive attention. The rice crop will have to be made fairly remunerative, so as to compete with other high-value crops and thereby allowing the crop to sustain in these high-productive areas. In rainfed system major emphasis will be on extending to farmer, the technology developed during past 1 decade, so that he starts reaping the benefits. Further researches will concentrate on improving the yield potential of varieties incorporating tolerance to abiotic and biotic stresses, improving input-use efficiency, cropping intensity and augmenting farmers' income. Emphasis on integrated pest-management approach is essential, as it is environment friendly. Freeing the crop and soil health considerations should also receive high priority. Selective mechanization of rice cultivation will also be merited in view of shortage of labour during peak rice- cultivation operations.

REFERENCES

AICRIP, Hyderabad. 1970–96. *Progress Reports, 1970–96*. All-India Co-ordinated Rice Improvement Project, Hyderabad, Andhra Pradesh.

CRRI, Cuttack. 1996. *Fifty years of Research at CRRI*. Central Rice Research Institute, Cuttack, Orissa.

DRR, Hyderabad. 1986–95. *Research Highlights, 1986–96*. Directorate of Rice Research, Hyderabad, Andhra Pradesh.

DRR, Hyderabad. 1995–96. *Research Highlights*. Directorate of Rice Research, Hyderabad.

DRR, Hyderabad. 1996–97. *Annual Reports*. Directorate of Rice Research, Hyderabad, Andhra Pradesh.

Hossain M. 1996. 'Rice economy in India: achievements, challenges and implications for technology development research'. A paper presented at the IRRI-India Dialogue, held at New Delhi on 28–29 September 1996.

ICAR, New Delhi. 1985. *Rice Research in India*, 726 pp. Indian Council of Agricultural Research, New Delhi.

Krishnaiah K, Janaiah A, Kundu D K, Rao A V, and Chand, Ramesh. 1996. 'Productivity Trends of Rice in Intensively Farming Systems in India'. A paper presented at the Expert Consultation on Technology Evaluation and Impact for Sustainable Rice Production in Asia and the Pacific, Bangkok, Thailand, 29–31 October 1996.

Krishnaiah K. 1996. Changing scenario in rice insect pest problems. (*in*) *Pest and Pest Management in India–The Changing Scenario*, pp 11–8. Sharma H C and Veerabhandra Rao M (Eds). Plant Protection Association of India, Hyderabad.

Krishnaiah K, Srinivasan T E and Rao Prasada U. 1994. Identification of rice varieties/cultures resistant to virulent gallmidge biotype 4 for north coastal districts of Andhra Pradesh. *Indian Journal of Plant Protection* **20** (22) : 173–8.

Parthasarathy N. 1972. Rice breeding in tropical Asia up to 1960. (*in*) *Rice Breeding*, pp 5–30. International Rice Research Institute, Manila, Philippines.

Paroda R S and Siddiq E A. 1993. *Accomplishment of the Co-ordinated Rice Research–An Overview in New Frontiers in Rice Research*, pp 25–24. Murlidharan K and Siddiq E A (Eds). Directorate of Rice Research, Hyderabad.

Pathak M D.1991. Rice Production Trends in Selected Asian Countries. IRRI-Research paper series No. 147 International Rice Research Institute, Los Baños, Manila, Philippines.

Ramaiah. 1951. *Rice Research in India*. Hosalli Press, Bangalore, Karnataka.

Ramaiah. 1953. *Rice Research and Genetics*. Scientific Monograph No.19. Indian Council of Agricultural Research. New Delhi.

Reddy A P K. 1992. The changing scenario in rice diseases and their management. (*in*) *Pest and Pest Management in India-The Changing Scenario*, pp 121–9. Sharma H C and Veerabhandra M (Eds). Plant Protection Association of India. Hyderabad.

Roy J K, De R N, Ghorai D P and Panda A R. 1985. Collection and evaluation of genetic resources of rice in India. *Phytobreedon* **1** : 1–9.

Seetharaman R, Sharma S D, and Shastry S V S. 1972. Germplasm conservation and use in India. (*in*) *Rice Breeding*, pp 187–98. International Rice Research Institute, Los Banos, Philippines.

Shastry S V S, Freeman W H, Seshau D V, Israel P, and Roy J K. 1972. Host plant resistance in rice gall midge. *(in) Rice Breeding*, pp 353–66. International Rice Research Institute, Manila, Philippines.

Sharma S D. 1982. Collection and evaluation of rice from north-east India. *Plant Genetic Resources News Letter* **50** : 62–79.

Siddiq E A. 1991. Genes and Rice Improvement. *Oryza* (28) : 1–17.

Siddiq E A, Reddy A P K, Krishnaiah K and Bentur J S. 1998. *Genetic Improvement for Resistance to Pests and Diseases in Rice. IPM System in Agriculture*, vol 3, pp 75–103. Aditya Books (Pvt) Ltd, New Delhi.