Document on Biology of Rice (*Oryza sativa* L.) in India

National Bureau of Plant Genetic Resources
Indian Council of Agricultural Research
New Delhi

Project Coordinating and Monitoring Unit
Ministry of Environment and Forests
New Delhi

Document on Biology of Rice (*Oryza sativa* L.) in India

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MOEF GOI

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Published in 2006

Copies can be obtained from :
The Director
National Bureau of Plant Genetic Resources
Pusa Campus, New Delhi-110012, India

Printed by :
Alpha Lithographics Inc., New Delhi-110028
Ph.: 9811199620, 41495131

भारत सरकार
पर्यावरण एवं वन मंत्रालय
GOVERNMENT OF INDIA
MINISTRY OF ENVIRONMENT & FORESTS

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24th July 2006

PREFACE

India is implementing a GEF-World Bank Capacity Building Project on Biosafety. National Bureau of Plant Genetic Resources (NBPGR), which is one of the four institutions being strengthened under this project, is the nodal organization in India for exchange, quarantine, collection, conservation, evaluation and the systematic documentation of plant genetic resources, As a part of the capacity building exercises, Project Coordination and Monitoring Unit (PCMU) in association with NBPGR has brought out a document on Biology of Rice (*Oryza sativa* L.) in India. Rice (*Oryza sativa* L.) is one of the three major food crops of the world, being grown worldwide, and is the staple food for more than one and a half of the world's population. This document has information on history, economic importance, taxonomy, centre of origin/diversity, germplasm exploration and conservation of varietal diversity for useful traits in cultivated and wild rices, donor sources for biotic and abiotic stresses, priority areas for germplasm conservation along with map representation of areas of concern and weed flora in rice cultures.

I am sure, this document will be very useful in strengthening our efforts for information sharing with all the stakeholders.

(Desh Deepak Verma)

जहाँ है हरियाली।
वहाँ है खुशहाली।।

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Dr. S.K. Sharma

Director

FOREWORD

Under the GEF-World Bank funded project on Capacity Building for the Implementation of the Cartagena Protocol on Biosafety, National Bureau of Plant Genetic Resources, New Delhi in association with the Project Coordination and Monitoring Unit of Ministry of Environment and Forests, Government of India is bringing out Document on Biology of Rice (*Oryza sativa* L.) in India. This document is intended to provide an exhaustive information about the biology of rice in India, including its taxonomic status, botany, reproductive biology, cultivation, genetic diversity and pests which may be used as a tool by those tasked with assessing the environmental safety of transgenic rice that may be released into the environment.

This document will surely serve as a useful reference for an effective and systematic risk assessment of transgenic rice in Indian conditions.

SK Sharma

(S. K. Sharma)

ACKNOWLEDGEMENTS

I would like to acknowledge the valuable contributions of Dr. G. S. Khush, Adjunct Professor, University of California, Davis, USA; Dr. E. A. Siddiq, Professor, Department of Biotechnology, ANGRAU, Hyderabad; Dr. S. D. Sharma, Former Head, Genetics Division, CRRI, Cuttack and Dr. Morven, President AGBIOS, Canada for reviewing this document. The contributions of Dr. R. K. Khetarpal, Head, Plant Quarantine Division, NBPGR for the chapter VIII on "Pests of rice" are especially acknowledged. Contribution of Dr. Sanjeev Saxena, Senior Scientist, Conservation Division, NBPGR for the chapter VII "Rice genetic diversity in India" was indeed very valuable. This document would not have been possible without the consistent support and guidance of Dr. B. S. Dhillon and Dr. J. L. Karihaloo, former Directors, NBPGR and coordinators of the project, which is gratefully acknowledged. The unstinted support, guidance and encouragement of Dr. S. K. Sharma, Director, NBPGR and Coordinator of the project in bringing out of this document is especially acknowledged.

The special interest taken by Dr. Eija Pehu, Senior Adviser, Agricultural and Rural Development Department, the World Bank for bringing out this document is greatly acknowledged.

The contributions of Dr. Monika Singh and Mr. Sridhar, Research Associates, of the project for bringing out this document are also acknowledged.

I also gratefully acknowledge the financial and technical support of the GEF- World Bank and Project Coordination and Monitoring Unit of Ministry of Environment and Forests, Government of India, New Delhi, for bringing out this important document.

(Gurinder Jit Randhawa)
Project Investigator

PROJECT DETAILS

Title: GEF-World Bank aided Capacity Building Project for the Implementation of the Cartagena Protocol on Biosafety in India

Period: September 2004 to June 2007

Source of Funding: World Bank and Project Coordinating and Monitroring Unit (PCMU), Ministry of Environment and Forests, Government of India, New Delhi

Team Members:

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Dr. B. S. Dhillon, Former Director, NBPGR (upto 26th July 2005)
Dr. J. L. Karihaloo, Former Director, NBPGR (upto 31st January 2006)
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Objectives:

1. Development and standardization of diagnostic tools for detection of Living Modified Organisms (LMOs) and the traits expressed by them for the transgenic material under exchange

2. Development of biology document for rice for centres of origin/diversity, its taxonomy, genetics, description of wild and weedy relatives, pests and diseases etc.

3. Human Resource Development: To conduct training courses/workshops on Biosafety and hands on training on LMOs detection using Enzyme-linked Immunsorbent Assay (ELISA) and Polymerase Chain Reaction (PCR)-based techniques.

CONTENTS

SECTION I - RICE AS A CROP PLANT

Rice (*Oryza sativa* L.) is one of the three major food crops of the world. Being grown worldwide, it is the staple food for more than one and a half of the world's population. It is a nutritious cereal crop, provides 20 per cent of the calories and 15 per cent of protein consumed by world's population. Besides being the chief source of carbohydrate and protein in Asia, it also provides minerals and fibre. Rice straw and bran are important animal feed in many countries.

India is the largest rice growing country accounting for about one-third of the world acreage under the crop. It is grown in almost all the states of India, covering more than 30 per cent of the total cultivated area. Its cultivation is mostly concentrated in the river valleys, deltas and lowlying coastal areas of northeastern and southern India, especially in the states of Andhra Pradesh, Assam, Bihar, Chhattisgarh, Karnataka, Kerala, Maharashtra, Orissa, Tamil Nadu, Uttar Pradesh and West Bengal, which together contribute about 97 per cent of the country's rice production. Contributing about 42 per cent to country's food grain production, rice not only forms the mainstay of diet for majority of its people (>55 per cent), but also is the livelihood for over 70 per cent of the population in the traditional rice growing regions (Figure 1).

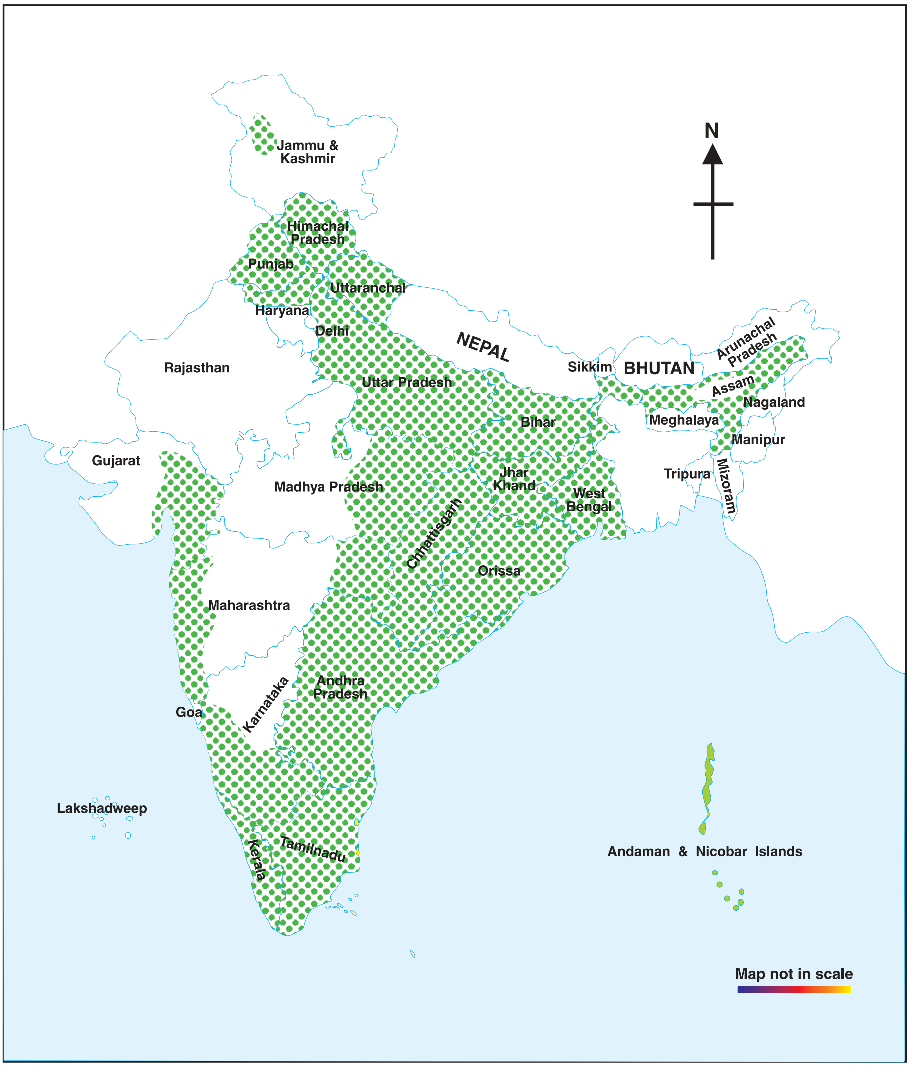

Figure 1 : Rice growing areas in India

SECTION II - TAXONOMIC STATUS

Rice belongs to the genus: *Oryza*, family: Gramineae (Poaceae) and tribe: Oryzeae. The genus *Oryza* is distributed throughout the tropics and subtropics of the world (Table1). The genus consists of 23 wild and weedy species and two cultivated species, *viz.*, the Asian *O. sativa* and the African *O. glaberrima*. *O. sativa*, domesticated in Asia has now spread to almost all the rice growing areas of the world, while *O. glaberrima*, domesticated in western tropical Africa is confined to that part of the world alone.

The basic chromosome number of the genus is n=12. The species are either diploid with 2n=24 chromosomes or tetraploids with 2n=48 chromosomes. Based on genome analysis and degree of sexual compatibility, the species have been grouped under nine distinct genomes, *viz.*, A, B, C, D, E, F, G, H and J and unclassified in five complexes, namely Sativa, Officinalis, Meyeriana, Ridleyi and Unclassified (Table 1). On the basis of crossability and ease of gene transfer, the primary genepool of rice is known to comprise the species of Sativa complex, while the species belonging to Officinalis complex constitute the secondary genepool. Crosses between *O. sativa* and the species of Officinalis complex can be accomplished through embryo rescue technique. The species belonging to Meyeriana, Ridleyi complexes and *O. schlechteri* constitute the tertiary genepool (Khush, 2000; Siddiq, 2000).

Table 1: Species complex of the genus *Oryza* and their geographical distribution

Species Complex	Chromosome Number	Genome	Geographical Distribution
I. Sativa complex			
O. sativa L.	24	AA	South & Southeast Asia
O. nivara Sharma et Shastry	24	AA	Tropical Asia
O. rufipogon Griff.	24	AA	Tropical Asia
O. meridionalis Ng	24	AA	Tropical Australia
O. glumaepetula Steud.	24	AA	Tropical America
O. glaberrima Steud.	24	AA	Tropical West Africa
O. barthii A. Chev. et Roehr.	24	AA	West Africa
O. longistaminata A. Chev. et Roehr.	24	AA	Africa
II. Officinalis Complex/ Latifolia complex			
O. punctata Kotschy ex Steud.	24	BB	Africa
O. rhizomatis Vaughan	24	CC	Sri Lanka
O. minuta J.S.Pesl. ex C.B.Presl.	48	BBCC	Philippines, New Guinea
O. malamphuzensis Krishn. et Chandr.	48	BBCC	South India (Kerala)
O. officinalis Wall. ex Watt	24	CC	Asia, New Guinea
O. eichingeri A. Peter	24	CC	East Africa & Sri Lanka
O. latifolia Desv.	48	CCDD	Central & South America
O. alta Swallen	48	CCDD	Central & South America
O. grandiglumis (Doell) Prod.	48	CCDD	South America
O. australiensis Domin.	24	EE	Northern Australia
O. schweinfurthiana Prod.	48	BBCC	Tropical Africa
III. Meyeriana Complex			
O. granulata Nees et Arn. ex Watt	24	GG	South & Southeast Asia
O. meyeriana (Zoll. et Mor. ex Steud.) Baill.	24	GG	Southeast Asia
IV. Ridleyi Complex			
O. longiglumis Jansen	48	HHJJ	Indonesia, New Guinea
O. ridleyi Hook. f.	48	HHJJ	Southeast Asia
V. Unclassified (belonging to no complex)			
O. brachyantha A. Chev. et Roehr.	24	FF	West & Central Africa
O. schlechteri Pilger	48	HHKK	Indonesia, New Guinea

Source: Brar and Khush, 2003

SECTION III - CENTRE OF ORIGIN/ DIVERSITY

Archaeological and historical evidence points to the foothills of Himalayas in the North and hills in the North-east of India to the mountain ranges of South-east Asia and South-west China as the primary centre of origin of *Oryza sativa*, and the delta of River Niger in Africa for that of *O. glaberrima*, the African rice. These areas are characterized by topological heterogeneity and are considered to be the centres of rice diversity. The diversity in these centres is being lost rapidly with many rice growers shifting to modern cultivars.

The wild progenitors of *O. sativa* are the Asian common wild rices, which show wide variation ranging in their habit from perennial to annuals. These perennial and annual forms although were treated as a single species, *viz.*, *O. rufipogon* by some biosystematists (Second, 1982; 1986). Now they are recognized as two distinct species, namely *O. rufipogon* and *O. nivara*, respectively (Chang 1985). *O. sativa* is considered to have been domesticated between 9000 and 7000 BC. Annual forms might have gradually developed in plateau regions of eastern India, South-east Asia and southern China. During the course of time, they differentiated into two ecogenetic groups: *indica* and *japonica* (temperate and tropical japonicas) (Chang, 1985). Schematic representation of evolutionary pathways of the Asian and African cultivated rices is shown in Figure 2.

The wild progenitor of the African cultivar *O. glaberrima* is *O. longistaminata* endemic to West Africa. The primary centre of diversity for *O. glaberrima* is the swampy basin of Upper Niger. Now, *O. sativa* and *O. glaberrima* are grown as mixtures of varying proportions by West African farmers (Chang, 1976; Oka *et al*., 1978; Morishima and Oka, 1979).

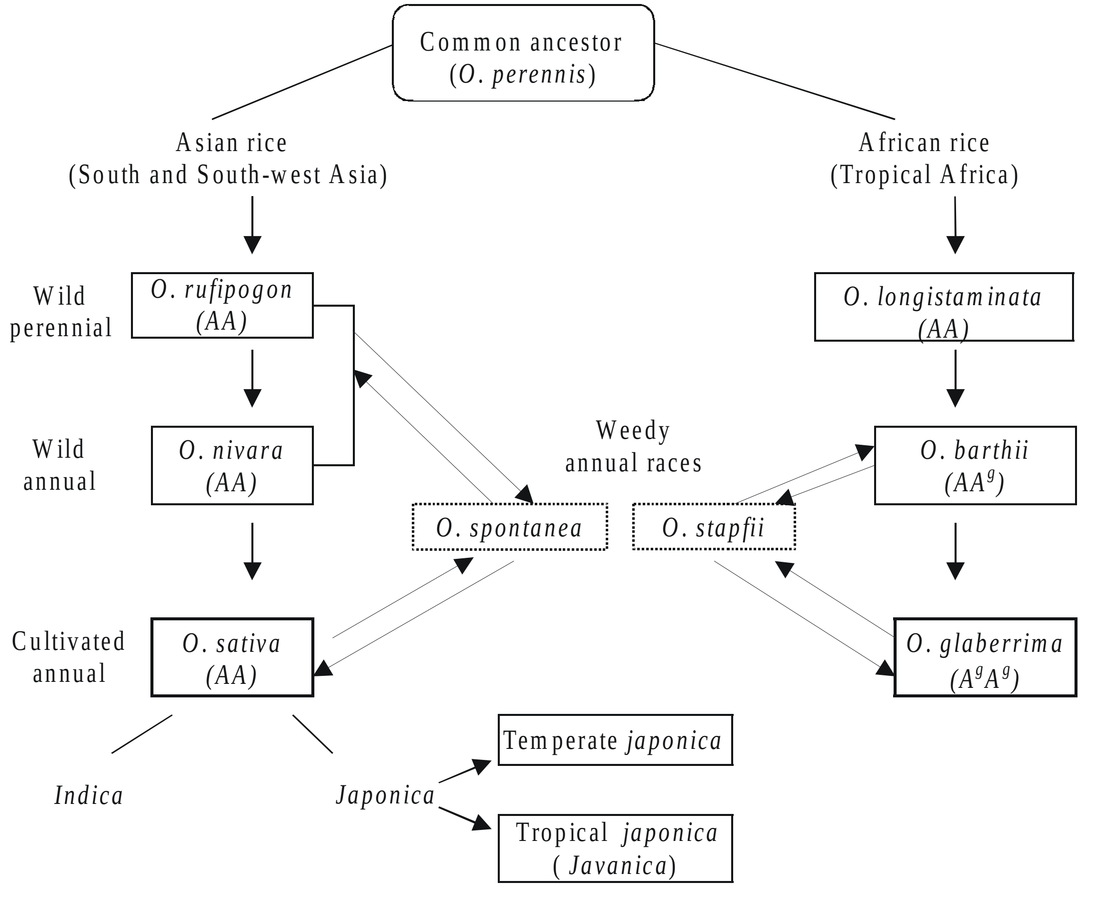

Figure 2. Schematic representation of the evolutionary pathways of Asian and African cultivated rices

SECTION IV - BOTANY OF RICE

The Asian cultivated rice (*Oryza sativa*) and its allied taxa that occur in Asia present a continuous array of morphological features, so that the whole group has been termed as *O. sativa* complex by Tateoka (1962). The updated and comprehensive botany of rice has been reviewed by Nanda and Sharma (2003).

(a) General Morphological Characteristics of Genus *Oryza*

Root system

The root system is fairly well developed in all species of rice. In perennial rices, short underground shoots densely covered with sheathed leaves are present. Annual species have long but slightly branched adventitious roots whereas a main root and subterranean shoots are completely absent.

Stalks

Stalks are erect or ascending in all rices except in *O. sativa* where they are geniculately ascending, recumbent, rooting at the nodes and sometimes producing new shoots at these points.

Leaf sheaths

Leaf sheaths are always open and glabrous along the edge. In some of the species like *O. grandiglumis*, *O. latifolia* and *O. officinalis*, leaf sheaths may possess cilia. Like stalks, leaf sheaths also have a clearly marked or ribbed venation and become keel-like by the protrudation of the midvein in the upper part of the sheath beneath the leaf lamina. The leaf sheaths of all rices are grassy, smooth and firm in species living in meadows and woods, and have air passages in that part of sheath submerged in water in species inhabiting bogs.

Auricles

In all the species of rice except *O. subulata*, the leaf sheath, where it passes into the leaf lamina, ends in a small hollow with bent neck, glabrous or ciliated edges called auricle.

Leaf lamina

All rices can be divided into 2 groups according to the shape of lamina:

- Those having linear-lanceolate leaves, i.e., in which the length of the leaf is so much greater than the width that they appear ribbon-like. e.g. *O. sativa* having long acicular linear leaves.
- Those having a lanceolate-like or elongate-lanceolate shape, e.g. *O. granulata* and *O. abromeitiana* in which base of the leaf is so constricted that it appears as if it forms a petiole.

Ligule

The ligule is oblong or blunt and 1-5 mm long in most of the species. In *O. latifolia*, the ligule is short but breaks up at the apex into a row of hard, sometimes wooly hairs.

Inflorescence

In all rices a panicle with branches that branch 1-2, or with lower branches branching once but the upper ones not branching at all that is, with an inflorescence constructed in the lower part as a panicle but in the upper part as a raceme. The shape of inflorescence also depends on the frequency of branching and for majority of rices is oblong or fusiform. In *O. brachyantha*, *O. abromeitiana* and *O. granulata*, it is almost linear with small spikelets, whereas in *O. latifolia* and *O. grandiglumis*, it is a wide panicle with many spikelets. Axis of inflorescence is ribbed in all species and appears to be composed of individual, coalescent branches. Branches of inflorescence occur on axis in 1-4 irregular whorls. Like the axis of inflorescence, the branches are also glabrous, smooth lower down but gradually become sharp scabrous in upper part.

Pedicels of spikelets and lower empty glumes

Pedicels of spikelets are short, 1-6 mm long and have distinct ridges on both sides ending in cyathiform enlargement consisting of two wide, about 0.5 mm long coalescent glumes, representing lower pair of empty glumes. Cyathiform enlargement of pedicel is mostly horizontal and attached to base of spikelet. In *O. breviligulata*, *O. sativa* and *O. stapfii*, pedicel is drawn out at its extreme apex so that the cup-shaped enlargement is placed almost vertically and attached somewhat laterally to base of the spikelet.

Articulation

Articulation is present in all rice species between lower and upper empty glumes. It is fairly distinct in most of the species because the spikelets fall easily on ripening of seeds. However, it is less distinct in the cultivated species *O. sativa* where during the ripening of fruits the spikelets do not drop off but remain on the branches.

Spikelets

Spikelets are always upright, orbicular or obliquely oblong, compressed from sides, with deep longitudinal grooves and blunt ribs. According to spikelet shapes, all rices can be divided into 3 groups:

- Rice with narrow spikelets, i.e., those in which the length is more than three times the breadth as in *O. brachyantha*, *O. breviligulata*, *O. longistaminata*, *O. ridleyi*, *O. stapffi*, *O. subulata* and *O. coarctata*.
- Rice with orbicular spikelet, i.e., those in which the length is 2-2.5 times the breadth as in *O. australiensis*, *O. glaberrima*, *O. latifolia, O. officinalis, O. punctata* and *O. sativa*.
- Rice with broad spikelets, i.e., those in which the length although greater than width is less than twice width, as in *O. grandiglumis*, *O. minuta* and *O. schlechteri*.

Upper empty glumes

Upper empty glumes are almost always distinct. They are:

- linear or linear-lanceolate as in most rice species
- subulate or setaceous as in *O. brachyantha*, *O. coarctata*, *O. granulata, O. ridleyi, O. schelechteri* and keel-shaped as in *O. grandiglumis*.
- cyathiform as in *O. subulata*.

Flowering glumes

Flowering glumes are always leathery or hard-leathery with small traversely intersecting rows of small tubercles over entire surface. In all species, lower flowering glumes are compressed from the side, keel-shaped with 5 veins, in upper part terminating along the external edge in small beak, which is generally extended into a small point or long awn. Upper flowering glume is always considerably lower than one, with 3 veins.

Awn

According to its length, the awn of all species of rice can be divided into:

- awnless: *O. abromeitiana*, *O. glaberrima*, *O. granulata and O. schlechteri*
- short awn in which the awn is shorter than the glume itself: *O. coarctata* and *O. ridleyi*
- moderately long awn, which is longer than the glume but not longer than 60 mm: *O. australiensis*, *O. latifolia*, *O. longistaminata*, *O. minuta*, *O. punctata* and *O. subulata*.
- very long awn 60-200 mm: *O. brachyantha, O. breviligulata* and *O. stapfii*.

The awns of rice are usually filiform or setaceous, i.e., in cross-section, they are orbicular and tapering only lightly at the apex.

Lodicules

In all species, lodicules are uniform, ovate-circular or orbicular, glabrous.

Stamens

The stamens have about 2-2.5 mm long linear-oblong anthers. The anthers dehisce through a longitudinal slit.

Stigmas

Stigmas are uniform, feathery and dark-violet or almost black.

Fruits

Fruits are small, compressed from sides, 1-8 mm long, oblong, elliptical or orbicular, depending on shape and size of the spikelet. Small fruits of rice are initially yellowish, then turn dark brown.

(b) Subdivision of Genus *Oryza* on the Basis of Morphological Characters

Based on morphological characters and geographical distribution of different species, the following sections may be established within the genus *Oryza*.

(i) *Sativa* Roshev.

The most widespread group, embracing the whole area of distribution of the genus; flowering glumes with distinctly crosswise intersecting rows of small tubercles; linear or linear-lanceolate upper empty glumes; annuals and perennials.

To this section belong: *O. sativa* L., *O. longistaminata* A. Cheval. et Roehr., *O. grandiglumis* Prod., *O. punctata* Kotschy, *O. stapfii* Roshev., *O. breviligulata* A. Cheval. et Roehr., *O. australiensis* Dom., *O. glaberrima* Steud., *O. latifolia* Desv., Cheval. et Roehr., Prod., *O. officinalis* Wall., and *O. minuta* Presl.

(ii) *Granulata* Roshev.

Found only in South-east Asia; perennials; flowering glumes with minute tuberculate-corrugated or verrucose surface; awl-shaped or bristle-shaped upper empty glumes; lanceolate or narrowly lanceolate spikelets.

To this section belong: *O. granulata* Nees and *O. abromeitiana* Prod.

(iii) *Coarctata* Roshev.

Embraces South-east Asia and northern Australia; perennials or less frequently annuals; flowering glumes showing an almost smooth surface with minute, longitudinal dotted stripes; awl or bristle-shaped upper empty glumes.

To this section belong: *O. schlechteriana* Pilger, *O. ridleyi* Hook. f., *O. coarctata* Roxb. and *O. brachyantha* A. Cheval. et Roehr.

(iv) *Rhynchoryza* Roshev.

Occurs only in South America; perennial; comparatively large oblong spikelets drawn out at the apex into a long cone filled with spongy tissue, passing over into an awn; cyathiform upper empty glumes, with 3-5 veins.

This section comprises only one species, *O. subulata* Nees.

SECTION V - REPRODUCTIVE BIOLOGY

(a) Sexual Reproduction

Oryza sativa is basically an autogamous plant propagating through seeds produced by self-pollination. Fertilization occurs in a spikelet, which has six anthers with more than 1,000 pollen grains in each, and an ovule with a branched stigma. Immediately after the spikelet opens at flowering, pollen disperses and germinates on the surface of the stigma. Only one pollen tube reaches the ovule to initiate double fertilization.

Maturation of pollen in an anther is synchronized with maturation of ovule within the same spikelet. Germinability of pollen lasts only for a few minutes after being shed from anther under favourable temperature and moisture conditions, while ovules keep their viability to receive pollen for several days after maturation. The pollen of cultivated rice loses its viability within three to five minutes while that of wild rice remain viable up to nine minutes (Koga *et al.*, 1971; Oka and Morishima, 1967). Most of the wild species have larger and longer stigma, which protrudes well outside the spikelet, facilitating increased percentage of outcrossing (Parmar *et al*., 1979; Virmani and Edwards, 1983).

Outcrossing is several times higher in the wild species as compared to cultivars under the 'A' genome itself. Among the ecotypes of *O. sativa*, percentage outcrossing is generally higher in *indicas* than in *japonicas* (Table 2) (Oka, 1988). Nevertheless, cross-pollination between annual/perennial species and cultivars in natural habitats where they grow side by side leading to hybrid swarms (*O. spontanea* in Asia and *O. stapfii* in Africa) is not uncommon.

(i) Outcrossing rates

Although *O. sativa* is basically self-pollinated, natural outcrossing can occur at a rate of up to 0.5% (Oka, 1988) (Table 2). When different cultivars of the same maturity group are planted side by side in a field or in adjacent fields, natural outcrossing can occur between them. Outcrossing in such cases can be avoided by planting cultivars with sufficiently different duration in adjacent fields or by time isolation by adopting sufficiently different dates of planting.

F_1 plants of crosses within the *indica* or *japonica* groups generally show high fertility and seedset. Crosses between the two groups show, however, lower fertility and seedset, the range being quite wide and varied depending on the parental choice. The F_1 fertility, according to it, cannot be the criterion for classifying Asian cultivars into *indica* and *japonica* groups (Oka, 1988; Pham, 1991). Constellation of a set of traits characteristic to them besides F_1 semisterility has justified them to consider now as subspecies or geographical groups under *O. sativa*.

The barrier of hybrid sterility in *indica/japonica* crosses has been intensively studied since early fifties and genic and chromosomal models have been proposed to explain the sterility. With the discovery of wide compatibility gene (s) in some of the varieties, which are compatible with both *japonica* and *indica* varieties, the sterility problem, has been overcome resulting in more productive varieties and hybrids of *indica/japonica* background.

(ii) Interspecific crosses

O. sativa and *O. glaberrima* are often grown as mixtures in various proportions in West African rice fields (Chu *et al*., 1969). The two species resemble each other, perhaps due to co-evolution from a common progenitor *O. perennis*, but natural hybrids between them are rare, even though experimental hybridisation is easy. The F_1 plants are highly pollen-sterile, but about one-thirds of the F_1 embryo sacs are normal and functional. Backcrosses can be made with pollen of either of the parents. The gene loci that have been examined are identical in the two species (Sano, 1988). Most natural hybrids incompatible due to genetic and physiological differences, hardly survive to facilitate gene flow between the two species.

In nature, *O. rufipogon* and *O. nivara* (the progenitor species) cross with *O. sativa* and produce hybrid swarms. The hybrids show partial sterility (Sharma and Shastry, 1965). *O. glaberrima* and its wild progenitor O. *brevigulata* similarly cross under natural environment resulting in hybrid swarms, which are fertile. They are of annual growth habit and resemble each other in most of the botanical characters (Oka, 1991).

The wild rices with AA genome are distributed throughout the humid tropics such as Asian *(O. nivara* and *O. rufipogon)*, African *(O. barthii* and *O. longistaminata)*, American *(O. glumaepatula)* and Oceanian *(O. meriodinalis)* species.

The relatively high percentage seed sets (9-73%) can however be obtained through artificial hybridization of *O. sativa* with these AA genome wild species (Sitch *et al.*, 1989). *O. nivara* and *O. rufipogon* have been extensively used as donor sources for many valuable traits of value which included resistance to grassy stunt virus, blast and bacterial leaf blight besides cytoplasmic male sterility (Khush and Ling, 1974).

Species belonging to BB, BBCC, CC, or CCDD genomes are relatively more crossable with *O. sativa* (0-30% seedset) than the more distantly related EE and FF genome species. The hybrids in both cases, however, are highly male and female sterile (Sitch, 1990). Desired gene transfer has been achieved through a series of backcrosses. For instance, resistance to brown planthopper *(Nilaparvata lugens)* and white-backed planthopper *(Sogatella furcifera)* from *O. officinalis* (Jena and Khush, 1990) and to blast and bacterial blight from *O. minuta* (Amante-Bordeos *et al*., 1992) have been transferred by repeated backcrossing with *O. sativa*. Artificial crosses between *O. sativa* and more distantly related species such as *O. ridleyi* and *O. meyeriana* although have also been reported, success rate was very low (Katayama and Onizuka, 1979; Sitch *et al.*, 1989). In such cases, embryo rescue is the approach to obtain F_1 hybrids and first backcross progenies.

(b) Asexual Reproduction

O. sativa, although is an annual and propagated by seed, can be maintained vegetatively as a perennial under favourable water and temperature conditions. The perennial character in *O. sativa* is considered to have been inherited from its ancestral species *O. rufipogon* (Morishima *et al*., 1963).

Under natural conditions, tiller buds on the basal nodes start to re-grow after harvest. These new tillers, called “ratoon” grow best under long-day conditions. In some countries/situations, farmers grow rice as a ratoon crop to obtain a second harvest in a short period.

Cell/ tissue culture techniques can be used to propagate calli and reproduce tissues or plants asexually under appropriate cultural conditions. Haploid plants are easily obtained through anther culture. They become diploid spontaneously or when artificially treated with polyploidizing agents (Niizeki and Oono, 1968). Anther culture is widely used as a rapid breeding method in rice, while doubled haploids serve as material for basic research in molecular mapping and tagging of genes of interest.

(c) Reproductive Barriers

Viable hybrids between *O. sativa* and distantly related species are difficult to achieve. The post-fertilization barriers are of four types, *viz*., F_1 inviability (early embryo abortion), F_1 weakness, F_1 sterility and hybrid breakdown (Oka, 1988). All these phenomena have been found in crosses of cultivated rice and its wild relatives, although F_1 plants, whose parents have AA genome in common show no significant disturbances in meiotic chromosome pairing (Chu *et al*., 1969).

In many cases, hybrid inviability is due to failure of development of F_1 zygotes, particularly development of endosperm. The African perennial species *O. longistaminata* shows a stronger crossing barrier with *O. glabberima* and *O. breviligulata* than with *O. sativa* and *O. rufipogon* (Chu *et al*., 1969).

F_1 weakness is controlled by complementary weakness-dominant genes (Chu and Oka, 1972), which disturb tissue differentiation or chlorophyll formation. It is rare in crosses between *O. sativa* cultivars (Amemiya and Akemine, 1963). Among strains of *O. glabberima* and *O. breviligulata* about one-fourth of the crosses examined show F_1 weakness (Chu and Oka, 1972). F_1 weakness was found also in crosses between *O. longistaminata* and *O. glabberima* or between *O. breviligulata,* and the American form of *O. perennis,* and between the Asian and Oceanian forms of *O. perennis* complex (Oka, 1988).

F_1 hybrid sterility is a common feature in crosses of cultivated rice with their wild relatives. Failure of male and female gametes to develop normally is largely due to meiotic anomalies arising from either no or partial pairing of chromosomes. Cytoplasmic sterility factor found in wild species also in some combinations manifest F_1 sterility.

Partial F_1 hybrid sterility is characteristic to intervarietal group cross with *O. sativa* especially in *indica/ japonica* combination. The sterility persisting beyond F_1, in the F_2 and subsequent generations has been explained at genic and chromosomal levels (Kitamura 1962; Oka 1964). At generic level, it is attributed to a series of duplicate recessive genes while at chromosomal level as due to cryptic structural differences in the chromosome complements of the two geographic races.

The weakness and sterility occurring in the F_2 and later segregating generations are referred to as hybrid breakdown. It is reported to be controlled by a set of complementary recessive weakness genes (Oka, 1957; Okuno, 1986). Genes for F_2 weakness seem to be distributed occasionally in cultivated and wild rice species.

Table 2: Estimated outcrossing rates in wild and cultivated rice species by different methods

Taxa/ Type	Origin	Method	No. of Populations	Outcrossing (%)	Reference
Asian *perennis*					
Perennial	Taiwan	Marker gene	1	30.7	Oka, 1957
Thailand	Marker gene		1	44.0	Oka and Chang, 1961
Thailand	Isozyme markers		1	50.6	Barbier, 1987
Intermediate	India	Variance ratio	1	37.4	Oka and Chang, 1959
Perennial	Sri Lanka	Variance ratio	2	22.4-26.5	Sakai and Narise, 1959
Annual	India	Variance ratio	1	21.7	Oka and Chang, 1959
	India	Variance ratio	3	16.6-33.9	Sakai and Narise, 1960
	India	Marker gene	1	7.9	Roy, 1921
	Thailand	Isozyme markers	1	7.2	Barbier, 1987
Weedy	India	Variance ratio	2	17.3-20.6	Oka and Chang, 1959
Breviligulata	Africa	Variance ratio	2	3.2-19.7	Morishima *et al.*, 1963
Sativa					
Indica	Taiwan	Marker gene	4	0.1-0.3	Oka, 1988
	Sri Lanka	Variance ratio	1	3.6	Sakai and Narise, 1960
Japonica	Taiwan	Marker gene	5	0.6-3.9	Oka, 1988

Source: Oka, 1988

SECTION VI – CULTIVATION OF RICE IN INDIA

(a) Rice Growing Regions

Rice is grown under diverse soil and climatic conditions. It is said that there is hardly any type of soil in which it cannot be grown including alkaline and acidic soils. Because of its wide adaptability, it is grown from below sea level in Kuttanad area of Kerala to an altitude of 2000 metres above sea level in Jammu & Kashmir, hills of Uttaranchal, Himachal Pradesh and Northeastern hills (NEH) areas.

The rice growing areas in the country may be broadly grouped into the following five regions:

(i) North-eastern region

This region comprises Assam and North-eastern states. In Assam, rice is grown in the basin of river Brahmaputra. The region receives very heavy rainfall and hence, rice is grown under rainfed conditions.

(ii) Eastern region

It comprises Bihar, Chhattisgarh, Madhya Pradesh, Orissa, eastern Uttar Pradesh and West Bengal. In this region, rice is grown in the basins of the rivers Ganga and Mahanadi. It has the highest intensity of rice cultivation in the country. The region receives heavy rainfall and hence, rice is grown mainly under rainfed conditions.

(iii) Northern region

Haryana, Himachal Pradesh, Jammu & Kashmir, Punjab, western Uttar Pradesh and Uttranchal constitute this region. Mainly as the irrigated crop, rice is grown from May/July to September/ December.

(iv) Western region

This region comprises Gujarat, Maharashtra and Rajasthan. Rice is largely grown under rainfed conditions during June/ August–October/ December.

(v) Southern region

This region comprises Andhra Pradesh, Karnataka, Kerala, Tamil Nadu and Pondicherry. Rice is mainly grown as irrigated crop in the deltas of the rivers Godavari, Krishna and Cauvery. In the non-deltaic areas, rice is grown as rainfed crop.

(b) Rice Ecosystems

Rice is grown under varied ecosystems on a variety of soils under varying climatic and hydrological conditions ranging from waterlogged and poorly drained to well-drained situations as briefly discussed below:

(i) Irrigated rice

The total area under irrigated rice is about 22.0 million hectares, which accounts for about 46 per cent of the total area under rice crop in the country. In Andhra Pradesh, Gujarat, Haryana, Himachal Pradesh, Jammu & Kashmir, Karnataka, Punjab, Sikkim, Tamil Nadu and Uttar Pradesh, rice is grown as irrigated crop.

(ii) Rainfed rice

The rainfed ecosystem may be broadly categorized into upland and lowland ecologies.

- Upland rice: Upland rice areas lie in the eastern zone comprising Assam, Bihar, Chhattisgarh, Orissa, eastern Uttar Pradesh, West Bengal and North-eastern Hill region. In the rainfed upland rice, there is no standing water in the field after few hours of cessation of rain. Because of uneven topography, the upland rice accounts for about 6.0 million ha (13.5 per cent of the total rice area). Productivity of upland rice is very low and stagnant for long. As against the present national average productivity of about 1.9 tonnes per ha., the average yield of upland rice is only 0.90 tonnes per ha.
- Lowland rice: Lowland rice area is mostly located in the eastern region comprising Assam, Bihar, Chhattisgarh, Orissa, eastern Uttar Pradesh and West Bengal. Lowland rice area is about 14.4 million ha., which accounts for 32.4 per cent of the total area under rice. The average productivity of lowland rice ranges from 1.0 to 1.2 tonnes per ha. as against the national average of 1.9 tonnes per ha.

The lowland rice ecology depending on the water regimes may be further categorized into three subecologies as detailed below:

- Shallow lowland rice: water depth below 50 cm.
- Semi-deepwater rice: water depth between 50-100 cm.
- Deepwater rice: water depth more than 100 cm in the field. The soil of this subecology is poor in nitrogen, phosphorus and organic matter but is rich in potassium. Deepwater rice areas are prone to seasonal floods and duration of which varies from year to year.

(iii) Coastal saline rice

Rice areas close to east and west coasts suffer from salinity. Andhra Pradesh, Kerala, Orissa, Tamil Nadu and West Bengal on the east coast and Gujarat and Maharashtra on the west coast have sizeable saline rice areas. Total rice area under coastal salinity rice is estimated to be about 1 million ha, which accounts for 2.3% of area under rice cultivation. The coastal saline soils often show deficiency of iron and zinc, which cause chlorosis and reduced tillering. Average yield in coastal saline area is about 1 tonne as against the average national yield of 1.9 tonnes per ha.

(iv) Cold/ hill rice

Such rice areas lie in the hill regions comprising Jammu and Kashmir, Uttranchal and North-eastern hill states. Area under rice in cold/ hill region is about 1 million ha which accounts for 2.3% of total area under rice. Average yield is about 1.1 tonnes per ha as against the average national yield of 1.9 tonnes per ha. Major productivity constraints of these areas are low temperature, blast, drought spell and very short span of cropping season. Because of the rolling topography in these areas, bench terracing is being followed, which limits the use of fertilizers and improved agronomical practices. In these areas the crop is invariably affected by low temperature in the early stage and sometimes at the flowering stage resulting in sterility and hence, reduced yields.

(c) Cropping Patterns

India has a wide range of soil and climatic conditions and accordingly cropping patterns vary widely from region to region and to a lesser extent from year to year. For devising meaningful cropping patterns, it is necessary to divide the country into homogeneous regions based on physical, climatological or agronomic features. Soil and the climate being the important factors for developing region specific cropping patterns and can be taken as the criteria for crop zoning.

The cropping pattern in different agroclimatic zones has been devised and adopted by farmers based on their long experience, suitability of soil, profitability, availability of market and industrial infrastructure and period of water available. Cropping patterns include broadly relay/sequential cropping, inter cropping and mixed cropping. With the introduction of early maturing and high yielding varieties of rice, intensification and diversification of cropping around rice could be substantially increased in the irrigated ecology as well as shallowland and rainfed ecologies. While improving the productivity, such efforts have helped in increasing the farm income as well.

In the rainfed upland and other moisture limiting/excess ecologies aimed at risk distribution and income enhancement intercropping of rice with appropriate companion crops has helped the farmers to improve the productivity. Some of the rice-based cropping patterns being followed in different rice ecologies as under:

(i) Rice-rice: This cropping pattern is practiced in the traditional rice growing areas having high rainfall and assured irrigation in summer months, particularly, in soils, which have high water holding capacity and low rate of infiltration. In some canal-irrigated areas of Tamil Nadu, a cropping pattern of 300% intensity is followed. Choice of medium early and early maturing photoinsensitive varieties makes such intensification possible.

(ii) Rice-cereals (other than rice): This cropping pattern is being followed in areas where water is not adequate for taking the third rice crop in summer. Instead of rice, early maturing and less water requiring ragi, maize or jowar is chosen.

(iii) Rice-pulses/oilseeds: In the areas where, there is water scarcity, instead of a cereal crop in summer, short duration pulse crop like blackgram or greengram is preferred. Depending on the water availability, whereas rice followed by either chickpea or mustard is the pattern in the north, rice followed by blackgram (as in Krishna district at Andhra Pradesh) in south is the practice.

(iv) Rice-groundnut: Andhra Pradesh, Tamil Nadu and Kerala are following this cropping pattern. After harvesting rice crop, groundnut is planted in summer.

(v) Rice-wheat: It is the predominant cropping pattern in north and north-western (Indogangetic plains) parts of the country. Over 9 million hectares is under this cropping pattern.

(vi) Rice-wheat-pulses: This cropping pattern is being followed in the alluvial soil belt of northern states. After harvesting of wheat, greengram and cowpea are grown as fodder. Besides, cowpea is grown in red and yellow soils of Orissa and blackgram is grown in the black soils.

(vii) Rice-toria-wheat: This cropping pattern is commonly followed in northern parts of the country. This is possible because of very early maturing toria varieties adapted to late sown conditions.

(viii) Rice-fish farming system: Fields with sufficient water retaining capacity for a long period and areas free from heavy flooding are suitable for rice-fish farming system. Small and marginal farmers in rainfed lowland rice areas in the eastern states are following this system. They raise a modest crop of traditional low yielding rice varieties during rainy (*kharif*) season along with fish. In order to improve the economic conditions of these farmers, the Central Rice Research Institute, Cuttack has developed productive rice+fish farming system. There are two farming systems involving rice and fish. They are rice+fish farming system, which is generally followed in the semideep water and deep-water ecologies in the eastern states and fish after rice (rice-fish) in coastal Kerala, West Bengal etc. Steps have already been taken to popularize rice-fish farming system in low land areas to increase the production and productivity of crops and thereby improving the economic conditions of the resource poor farmers of these areas.

SECTION VII - RICE GENETIC DIVERSITY IN INDIA

India is rich in rice diversity by virtue of its north-eastern region being on the periphery of the centre of origin of rice on one hand and having many centres of diversity (secondary centres) on the other. It exists in terms of thousands of landraces of Asian cultivar at the centre of origin/ centres of diversity; hundreds of improved cultivars adapted to varied agro-ecologies and closely related wild/weedy species constituting rice germplasm in India. Natural and human selection of cultivars over centuries for varied agro-ecological conditions; *viz*., altitude, temperature, rainfall, soil type etc. have substantially contributed to the diversity.

It is estimated that number of landraces of rice cultivars available in the country is between 75,000 and 1,00,000. Some of these landraces were introduced since mid sixties. Most of these accessions have either already been collected and conserved in gene banks or have been discarded by farmers in preference to improved varieties. All the collections now in the gene banks are not unique. It is believed that 30 to 40 per cent of these may be duplicates.

With the establishment of the ICAR in 1929, systematic research was initiated for rice improvement. Rice research stations were established in all the agro-climatic zones of the country. These rice research stations collected local varieties and improved some of them mostly through pureline selection and a few through hybridization. The improvement was for higher yield, desired maturity and grain quality, and adaptation to various ecologies and resistance to biotic stresses. Varieties like GEB24 (yield, quality), T141 (yield), SR26B (salinity resistant), FR13A & FR43B (flood resistant), Chinguru Boro (deepwater), Basmati370 (quality) etc. are outcome of such early efforts.

Due to increased population pressure mainly after the World War II coupled with limitation of available land, production efforts have to be accelerated through yield increase in Asia, where rice is the staple food for 90 per cent of the population The availability of chemical fertilizers and their successful application to rice crop in Japan prompted FAO (Food and Agriculture Organization) to launch *japonica* x *indica* hybridization project for south and Southeast Asia in the fifties. It was not, however, successful because of the problem of hybrid sterility characteristic to inter-subspecific crosses.

The discovery of the semidwarf mutant, *viz.*, Dee-geo-woo-gen and development of high yielding first semidwarf variety (Taichung Native-1) using it as source of short stature became a landmark in rice improvement in south and South-east Asia including India. IR8 was bred at IRRI and many semidwarf rice varieties have been bred in India utilising developing gene sources like DGWG as parents. More than 600 high yielding dwarf rice varieties have been released in India during 1965-2000.

These short statured varieties are responding well to higher doses of fertiliser application and have helped in raising the genetic yield level and thereby production of rice. These varieties are photoinsensitive and hence, are adapted to all the rice seasons. The whole day neutral nature of these varieties enables 2 or 3 crops of rice in a year and hence high productivity/unit area/year. Presence of rice crop round the year has facilitated increased pest/disease incidence; resulting in recurrent crop losses. In breeding efforts to contain the pests, though helped greatly, selection pressure prompted coevolution of them as well resulting in many virulent races/biotypes.

(a) Aromatic Rice Germplasm

India is also known for its quality rices, like Basmati and other fine grain aromatic types grown in north-west regions of the country, which have been enjoying patronage although as evident from various ancient texts and historical accounts including in the old Indian scriptures like *Krishi Sukt* and *Sushrta* (400 BC), *Ain-e-Akbari* (1590 AD) and *Heer Rabjha* (1725 to 1798) (Table 3).

Table 3: Indigenous high quality non-aromatic and aromatic rice (landraces or pure line selection from landraces) types in India

State	Non-aromatic	Aromatic
Andhra Pradesh	Aswani Karthi Vadlu, Atragada, Kichidi Sannalu, Krishna Katakalu, Maharajabhogam, Punasa Akkullu	Kaki Rekhalu (HR59), Sukhdas (HR47)
Assam	Aijani (Mahsuri), Guniribora (Glutinous), Kakua Bao, Lalahu, Manoharsali, Rangaduria	Badshahbhog, Malbhog, Prasadbhog
Bihar	Black Gora, BR13, BR14, BR34, Brown Gora, Kessore, Kolaba, T141, NP130	Badshahbhog, BR8, Mohanbhog, NP49, NP114, Ram Tulsi, Tulsimanjari
Gujarat	Kolamba 42, Sathe 34-36, Sukhvel 20, Zeerasal 280, Zinya 31	Kalhapur scented, Kamod 118, Pankhari 203, Zeerasal
Haryana	Jhona 221, Jhona 349	Basmati 370, Taraori Basmati
Himachal Pradesh	Dundar 43, Lalnakanda, Phulpattas 72, Ramjawain 100	Desi Basmati 23
Jammu and Kashmir	CH988, CH1039, Niver, Siga, T137, T138	Basmati 370, Muskh Budgi, Ranbir Basmati
Karnataka	Allur Sanna, Antersal, Bangarutheega, Dodda byra, Kare kagga, S1092, SR26B	Kagasali, Sindigi local
Kerala	Cheruvirippu, Pokkali, Ptb2, Ptb12, Ptb15, Ptb18, Ptb21, Ptb33, Red Triveni, Vytilla	Jeerakasala, Gandhkasala
Madhya Pradesh	Nungi, Pandhri Luchai 16, Safari 17, Sariya, Laloo 14	Baspatri, Chattri, Chinoor, Dubraj, Gopalbhog, Hansraj, Kali Kamod
Maharashtra	Bhura rata, Chimansel, Kala rata, Kolam, Kolamba 184, Kolipi, Zinya 149	Ambemohar 102, Ambemohar 157, Ambemohar 159, Jirasel, Kamod, Krishnasal, Pankhari 203
Orissa	Bahyayahuynda, FR13A, FR43B, Nonabokra, Rangolata, Ratnachudi, T90 (Machha Kanta), T141 (Soruch Inamali)	Badshahbhog, Sel T812

Punjab	Jhona 349, Lalnakanda, Phulpattas	Basmati 217, Basmati 370
Rajasthan	Batika, Dhaniasal, Pathria, Segra, Sutar, Tukri	Kala Badal, Kamod, Nawabi kolam
Tamil Nadu	Adt8, Adt10, Anaikomban, Co25, GEB24, Kar Samba, Katti Samba, Kichdi Samba, TKM6	Jeeraga Samba
Uttar Pradesh /Uttaranchal	Adamchini, Anjee, Bambasa, Bansi, Dehula, Jaisuria, Jalamagna, N22, NP130, Tapachini, T100, T136	Badshapasand, Basmati (Type 3), Basmati 370, Bindli, Duniapet, Hansraj, Kalanamak, Kalasukhdas, Lalmati, Sakkarchini, Tilakchandan, Vishnuparag
West Bengal	Badkalamkati, Bhasmanik, Charnock, Churnakati, Dhairal, Dular, Latisail, MC282, Nonabokra, Nonarasmsail, Nizersail, Patnai 23, Seetasail	Badshah pasand, Badshahbhog, Basmati, Gopalbhog, Govindabhog, Kaminibhog, Kataribhog, Randhunipagal, Sitabhog

Source: Siddiq *et al.*, 2005; Sharma and Rao, 2004

Note: For the detailed description of different rice varieties released in different states of India, refer Sharma and Rao, 2004

(b) Rice Germplasm with Medicinal Value

Earliest Indian records also list many rice cultivars like *Kalavarihi* (nourishing rice) and *Kalama, Pundarika, Panduka, Shakunahrit, Sugandhaka, Kardamaka, Kanchanaka, Mahasali, Mahishamastaka* and *Lodhrapurshpaka* (medicinal value) (Chunekar and Pandey, 1986). Ayurvedic treatise (Indian Materia Medica) also speaks of varieties like 'Njavara' and 'Gathuhan' for treatment of arthritis. Rice collection service done in Chhattisgarh area led to the identification of many varieties of curative value popular among folklore (Table 4).

Table 4: Rice varieties of Chattisgarh region reported to possess medicinal and health value

Variety	Medicinal Value
Alcha	Curing pimples, curing small boils of infants (by feeding the lactating mother with cooked rice)
Laicha	Preventing unborn children from contracting (by feeding the pregnant woman with cooked rice)
Gathuhan	Treatment of rheumatism
Karhani	Treatment of paralysis
Bassior	Relief to headache (by inhalation of fumes of rice bran); epilepsy
Nagkesar	Cure to lung disease
Kalimooch	Relief to skin problems (external application of plant extract)
Regbhaddar	Treatment of gastric ailments
Serei	Tonic for general weakness
Meharaji	Tonic for women after delivery

Source: Das and Oudhia, 2001; Siddiq and Shobharani, 1998

Boluses of cooked Njavara rice are used for '*Navarakizhi*', treatment of all skeletal and muscular diseases, paralysis, seiatica etc. in Kerala.

(c) Hybrid Rice Cultivars

Hybridization is one of the most commonly used breeding methods for improvement mainly of open pollinated and often cross pollinated crops. Rice, a strictly self-pollinated one, has been the first crop, where hybrid technology could be successfully developed and commercially exploited. The phenomenon of heterosis was first reported by Jones (1926). But it took almost five decades for its commercial exploitation. China is the first country to capitalize on hybrid rice technology. In China the first hybrid rice was released for the commercial cultivation in 1976 (Yuan, 1994). Hybrid rice technology following plant type-based high yielding varieties helped to raise the genetic yield level by 15 to 20 per cent, beyond what is achievable in semi-dwarf inbred varieties (Bharaj *et al.*, 1996).

Though sources of male sterility and fertility restoration could be found, commercial hybrid seed production posed problems because of very low percentage outcrossing. This limitation could be overcome by manipulation of pollination control mechanisms resulting in enhanced cross-pollination. Unlike in normal rice varieties, stigma in male sterile lines remains receptive relatively for long hours to receive pollen. This physiological adaptation of male sterile plants has also helped; besides supplementary pollination methods realize high percentage seed setting.

Research to develop hybrid technology in rice in India although was initiated during 1970s. It could be intensified since 1989 with the launching of a mission mode project, sponsored by ICAR. Now the project "Development and use of hybrid rice technology" operates as a national research network involving 12 centres all over the country, coordinated by Directorate of Rice Research, Hyderabad (Siddiq *et al.*, 1994; Krishnaiah and Shobharani, 1997). With the concerted research work, the country developed a dozen rice hybrids each from public and private sectors within a short period. The salient features of some of these hybrids released are given in the Table 5.

Table 5: Hybrid rice varieties released in different states of India

No	Hybrid Variety	Year of Release	Parentage	Recommended for the State	Duration (Days)	Yield (T/Ha)	Characteristics
1.	APHR-1	1994	IR-58025A/ Vajram	Andhra Pradesh	130-135	7.14	Suitable for uplands of coastal Andhra Pradesh.
2.	APHR-2	1994	IR-62829A/ MTU-9992	Andhra Pradesh	120-125	7.52	Grains are LS.
3.	CORH-1	1994	IR-62829A/ IR-10198	Tamil Nadu	110-115	6.08	Grains are MS, resistant to the pest gall midge.
4.	KRH-1	1994	IR-58025A/ IR-9761	Karnataka	120-125	6.02	Suitable for irrigated areas.
5.	CNRH-3	1995	IR-2829A/ Ajaya	West Bengal	125-130	7.49	Grains are LB, suitable for Boro season.
6.	DRRH-1	1996	IR-58025A/ IR-40750	Andhra Pradesh	125-130	7.30	Grains are LS, mild aromatic and resistant to blast disease.

7.	KRH-2	1996	IR-58025A/ KMR-3	Karnataka	130-135	7.40	Grains are LB, resistant to the pest, BPH and blast disease, suitable for irrigated areas.
8.	Pant Sankar Dhan-1	1997	IR-58025A/ UPRI-93-133	Uttar Pradesh	115-120	6.80	—
9.	CORH-2	1998	IR-58025A/ C-20R	Tamil Nadu	120-125	6.25	Grains are MB.
10.	ADTRH-1	1998	IR-58025A/ IR-66	Tamil Nadu	115-120	7.10	Grains are LS.
11.	Sahyadri	1998	IR-8025A/ BR-827-35	Maharashtra	125-130	6.15	Grains are LS.
12.	Narendra Shankar Dhan-2	1998	IR-8025A/ NDR-3026	Uttar Pradesh	125-130	6.15	—
13.	PHB-71	1997	—	Haryana, UP, Tamil Nadu	130-135	7.86	Grains are LS, resistant to the pest, BPH.
14.	UPRH-27	1997	IR-58025A/ UPRI-92-133	Plains of Uttar Pradesh	115-120	6.80	—
15.	PA-6201	2000	—	Eastern and some parts of Southern India	125-130	6.18	Grains are LS, resistant to the pest, BPH and blast disease.
16.	Pusa RH-10	2001	Pusa- 6A/ PRR-78	Delhi, Punjab, Uttranchal	125	-	Aromatic Basmati Hybrid.
17.	Hybrid-6444	2001	6CO-2/ 6MO-5	Andhra Pradesh, Maharashtra, Uttar Pradesh, Orissa, Tripura, and Uttranchal	135-140	6 - 8	Plant height: 100-120 cms, Leaf : 24x1.5 cms, 1000 grain weight-22g Kernel : 6.21x2.06 mm,L/B ratio : 3.01, Non-Lodging, N responsive Grains : MS, suitable for well drained, irrigated condition, resistant to neck and rice tungro virus.

BPH = Brown plant hopper; LB=Long bold; LS=Long slender; MB=Medium bold; MS= Medium slender

Source: Rice Status Paper, 2005

(d) Exotic Germplasm

More than 90,000 accessions have been imported and made available to researchers and farmers in India (Singh *et al.*, 2001a). Introductions from IRRI during 1960s have led to green revolution.

The accessions introduced included high yielding dwarf varieties such as Taichung (Native)-1 and IR-8. Some important trait specific introductions are listed below (Table 6).

Table 6: Abiotic and biotic stress resistant exotic accessions

Traits	Accessions
Abiotic Stress	
Cold tolerance	EC 121003
Salinity tolerance	EC 122935 to EC 122953, EC 232900 to EC 233000
Drought tolerance	EC 201878 to EC 201975
Biotic Stress	
Green leaf hopper resistance	EC 309699
Leaf folder resistance	EC 121828 to EC 121853
Stem borer resistance	EC 121824 to EC 121825, EC 199465 to EC 199466
Blast resistance	EC 121807 to EC121815, EC 307145 to EC 307161
Sheath blight resistance	EC 199465 to EC 199466
Bacterial blight resistance	EC 121816 to EC 121823, EC 201878 to EC 201975
Tungro virus resistance	EC 161320 to EC 161346

Source: Siddiq *et al.*, 2005

(e) Germplasm Sources for Various Traits

Characterization of germplasm based on easily identifiable and stable morpho-physiological traits has enabled establishment of the identity of germplasm for economic importance. However, characterization is largely qualitative and less information is available on resistance/tolerance to biotic and abiotic stresses. Characterization of wild rice germplasm has revealed that most of the wild species could be potential donors for a range of traits (Table 7).

Table 7: Useful traits in wild species

Trait	Species
Abiotic stress	
Drought tolerance/avoidance	*O. australiensis, O. barthii, O. longistaminata*
Shade tolerance	*O. granulata, O. minuta, O. officinalis*
Adaptation to aerobic soils	*O. granulata, O. meyeriana*
Biotic stress	
Brown plant hopper resistance	*O. officinalis, O. australiensis, O. minuta, O. brachyantha, O. granulata, O. punctata, O. eichengeri*
Green leaf hopper resistance	*O. eichengeri, O. minuta, O. officinalis*
White backed plant hopper resistance	*O. eichengeri, O. minuta, O. officinalis*
Yellow stem borer resistance	*O. brachyantha, O. granulata, O. ridleyi*
Blast resistance	*O. minuta, O. ridleyi*
Sheath blight resistance	*O. barthii, O. latifolia, O. minuta, O. nivara, O. rufipogon*
Bacterial leaf blight resistance	*O. barthii, O. brachyantha, O. granulata, O. minuta, O. ridleyi*
Rice grassy stunt virus resistance	*O. nivara*
Other useful traits	
Cytoplasmic male sterility	*O. rufipogon*
High bio-mass	*O. alta, O. grandiglumis, O. latifolia*
Elongation ability	*O. meridionalis*

Source: Siddiq *et al.*, 2005

Scientists have put on their efforts to broaden the genepool of cultivated rice through introgression of genes from wild species for tolerance to major biotic and abiotic stresses and improved quality characteristics. The first example of transfer from a wild species is the introgression of a gene for *Rice grassy stunt virus* resistance from *O. nivara* to cultivated rice varieties. A summary of genes transferred from wild species to cultivated rice is given in the following table.

Table 8: Introgression of genes of wild *Oryza* species into cultivated rice (*O. sativa*)

Trait	Donor *Oryza* Species	Gene
Brown plant hopper resistance	*O. officinalis*	*bph*11(t) *bph*12(t) *Qbp*1 *Qbp*2
	O. minuta	—
	O. latifolia	—
	O. australiensis	*Bph*10
White backed plant hopper resistance	*O. officinalis*	—
Blast resistance	*O. minuta*	*Pi*9(t)
Bacterial blight resistance	*O. rufipogon*	*Xa*23(t)
	O. longistaminata	—
	O. officinalis	—
	O. minuta	—
	O. latifolia	—
	O. australiensis	—
	O. brachyantha	—
Grassy stunt resistance	*O. nivara*	—
Tungro tolerance	*O. rufipogon*	—
Cytoplasmic male sterility	*O. sativa f. spontanea*	
	O. perennis	
	O. glumaepatula	
	O. rufipogon	
	O. nivara	—
Tolerance to aluminium toxicity	*O. rufipogon*	QTL
Yield enhancing loci	*O. rufipogon*	*yld*1 *yld*2

Source: Brar and Khush, 2003

Wild species carry several useful genes for rice improvement but they are associated with several weedy traits such as grain shattering, poor plant type, poor grain characteristics and low seed yield. Besides, several incompatibility factors limit the transfer of useful genes from wild species into cultivated species. To achieve precise transfer of genes from wild to cultivated species, strategies involving combination of conventional plant breeding methods with tissue culture and molecular approaches have become important.

A systematic evaluation conducted through the efforts of Directorate of Rice Research (DRR), Hyderabad and a decade long ICAR sponsored network project for germplasm evaluation of rice facilitated multi-location and location-specific hotspot screening of rice germplasm for various biotic stresses.

Table 9: Important donors identified at Directorate of Rice Research for resistance to various insect-pests and diseases, abiotic stresses and yield supporting physiological attributes

Traits	Important Donors
Insect-pests	
Yellow stem borer	ADT2, ARC10257, ARC10598, ASD10, Ptb15, Ptb18, SLO17, TKM6
Gall midge	ARC5984, Bengle, Bhumansam, Eswarakora, Velluthachira, Leaung 152, NHTA8, Siam 29, W1263
Brown plant hopper	ARC6650, Babawee, Chemban, Co25, HR19, Mudgo, Ptb18, Ptb19, Ptb21, Ptb33, Ratu Heenati
Green leaf hopper	ADT14, ARC10313, ARC6006, ARC7012, ASD7, Co9, Pankhari 203, Ptb8, SLO4
White backed plant hopper	ARC10239, ARC11316, Chempar, HR22, Kalubmati, N22, Senawee, WC1240
Leaf folder	ARC10982, GEB24, Ptb33, TMK6
Diseases	
Blast	Carreon, Co4, Dawn, Raminad Strain 3, Tadukan, Tetep
Sheath blight	ARC10531, ARC10532, ARC10635, ARC15362, Athebu, BCP3, Buhjan, KRC355, KRC356, Laka, Nangmons 4, OS4, Phoure l, Ramadja, Saibham, Suduwee, T141, Ta-Poo-cho-z
Bacterial leaf blight	BJ1, Cemposelak, Chinsura Boro II, DV85, Java 14, Lacrose/ Zenith Nira (LZN), *O.longistaminata*, Sayaphal, Sigadis, TKM6, Wase-Aikoku
Rice tungro virus	Ambemohar 159, ARC10599, ARC11554, ARC12981, ARC14320, ARC14766, ARC15570, Kataribhog, Ptb18, Ptb21
Rice grassy stunt virus	ARC13820, ARC13901
Abiotic stresses	
Drought	ARC10372, BR23 (White gora), Brown gora, Chanda 2, DJ5, Dular, EB17, Gajgaur Dhani, Goradhan, Kinandang Patong, Lalnakanda, MAU Sd10, MAU Sel.9, N22, Nandi, Prage 147, Rdn185-2, Rikuto Norin, SLO16, Tuljapur 1, Tuljapur 28, Tuljapur 34
Low light	Ambemohar 157, Batkpahi, Gajepsali, K540, Kolapakhi, Lothabar, Malkolam, Nakarasali, Rajipsali, Z63
Salinity	Chettiviruppu, Chootupokkali, Nonasail, Patnai 23, Pokkali, SR26B
Submergence	Boku, Boyan, Bayyahunda, HbDW8
Physiological attributes	
Better photosynthetic efficiency	AC4491, Mahsuri, Ptb10.
Better photosynthetic efficiency (under low light conditions)	Mahsuri, NS1281, Pankaj, T90
Better utilization of solar energy	AC1491, BAM3, Ptb10, T141
Low photorespiration	B76, Patnai 23
High dry matter production	Intan, Manosarovar, Pankaj, Swarnaprabha
High density grain	Badshahog, Rupsail
High harvest index	T141
High fertilizer use efficiency	IR42-25323, IR29912-56-3, IR29912-56-3-1

Source: Siddiq *et al.*, 2005

The large variability in rice genetic resources has led to identification of several donor sources suited to specific and changing agro-climatic conditions, having resistance/tolerance to biotic/abiotic stresses and with enhanced yield potential. A great source of strength for rice improvement programme has been the rich germplasm collections available in the gene bank of IRRI as well as in the national gene banks of several countries, including India, China and Japan. Extensive use of diverse donor sources mostly in the improved genetic backgrounds has led to the evolution of nearly 632 high yielding varieties in India (DRR, 2001). Of these 314 varieties are suitable for irrigated ecology, 84 for rainfed uplands, 44 for rainfed lowland and deep-water ecologies, 33 for high altitudes, and 15 for saline and alkaline soils. In addition, 19 aromatic slender grain varieties have also been released. Many of these varieties combine specific and multiple resistances against major insect-pests and diseases; and tolerance to cold, drought, unfavourable soils, etc. (Table 10).

Table 10: High-yielding rice varieties resistant to various biotic and abiotic stresses

Stress	Varieties
Biotic stress	
Stem borer	ADT44, ADT(R)3, Bha Lum 2, Dandi, Leima Phou 1, Mugad Sugandha, Pantdhan 16, Rajendra Mahsuri 1, Rashmi, Ratna, Saket 4, Sasyasree, Shah Sarang 1, Swetha, Vikas
Brown plant hopper	ADT(R)45, Bharathidasan, CR1002, Cottondora Sannalu, Deepti, Gauri, Godavari, HKR120, IR36, Jawahar, Jagabandhu, Jagtial Mahsuri, Jyothi, Kanakam, Kartika, Nandyal Sannalu, Rajendra Mahsuri 1, SKL 3-11-25-30-36, Surya, Tholakari
White backed plant hopper	ADT 38, Bharathidasan, Bhudeb, Dandi, HKR120, HRI120, PR109, PMK (R)3, Sarasa, Shanthi, Swetha, Sumati, Surya, Udaya
Green leafhopper	ADT38, IR24, IR50, Samridhi, Shakti, Vikramarya
Gall midge	ADT38, Anjali, ASD18, Asha, CU44, Gauri, IR36, Jagtial Mahsuri, Jagtial Sannalu, Kakatiya, Lalat, MDU3, Oragallu, Pantdhan 16, Phalguna, PKV Makarand, Pothana, PY6, Rajendradhan 202, Rashmi, Ratnagiri 1, Ratnagiri 2, Samlei, Sarathi, SKL8, Sumati, Surekha, Varalu, Sagarsamba, Pelavadlu
Blast	Apporva, Bamaleswari, Bha Lum 1, Bha Lum 2, Bharani, Bhudeb, Birsa vikas dhan 110, Birsamati, BR2656-9-3-1, CO47, CSR23, Dandi, Dhanrasi, Harsha, IET16075, Jagabandhu, Jagtial Mahsuri, KHP5, Kohshar, KRH2, Krishna Hamsa, Leima phou 1, Mugad Sugandha, PA102, Palamdhan 957, Pant sugandha dhan 115, Pantdhan 16, Pinakini, PKV Makarand, PNR519, Pusa Sugandha 3, Rajarajan, Rashmi, Rasi, Rasmi, Shah Sarang 1, Sharavati, SKL30-11-25-30-36, SKL8, Somasila, Sravani, Sukardhan1, Sumati, Swetha, Tikkana, Vandana, Vasumati, Vedagiri, Vivekdhan 82, VL Dhan 8, Yamini
Bacterial leaf blight	ADT39, Ajaya, Bamaleswari, Bapatla Sannalu, Bhudeb, Birsa vikas dhan 109, Birsa vikas dhan 110, CR1002, CSR23, Dandi, Dhansari,Godavari, HKR120, IET16075, IR36, Jagabandhu, Jagtial Mahsuri, Karjat 1, Krand, Narendra 2, Narendra Usar 3, PR110, PR111, PR113, PR114, PR115, PR116, PR4141, Pusa 1121, Rajendra Mahsuri 1, Ramakrishna, SKL3-11-25-30-36, Swetha, Tholakari, Vandana
Rice tungro virus	ASD15, Bhudeb, Dhanrasi, IR34, IR50, Jagabandhu, Pusa RH10, Ratna, Saket 4, Srinivas, Swetha

Sheath blight	ADT39, ASD18, Asha, Bhanja, Ratnagiri13, Salivahana, TKM 9
Multiple resistance	ADT38, Ananga, ASD18, Asha, Bha Lum 2, Bhudeb, Birsa vikas dhan 110, Dandi, Dhansari, Godavari, IET16075, IR36, Jagabandhu, Jagtial Mahsuri, Kshira, Lalat, Narendra 2, Pantdhan 10, Pantdhan 16, Rajendra, Rashmi, Shaktiman, SKL8, SKL30-11-25-30-36, Sumati, Suraksha, Swetha
Abiotic stress	
Salinity/ Alkalinity	Bhavani , CSR6, CSR10, CSR27, CST1, CST23, Dandi, Narendra 1, Narendra Usar 3, Panvel 1, Panvel 2, Panvel 3, SLR51214, Sumati, TRY(R)2, Vikas, Vytilla 2, Vytilla 4, Yamini
Low temperature	Barkat, Himalaya 741, Himdhan, Pantdhan 957, Surarandhan 1, Tawi, Himalaya 1, Vivekdhan 62, VL Dhan 16, VL Dhan 39, VL Dhan 163, VL Dhan 221
Drought	Aditya, Annada, Ashwini, Bha Lum 1, Bha Lum 2, Birsa vikas dhan 108, Birsa vikas dhan 109, Birsa vikas dhan 110, Chingam, Danteswari, GAUR1, Govind, GR2, GR3, GR5, GR8, Harsha, Heera, Kshira, Narendra 80, PMK(R)3, Purva, Rashmi, Rasi, Ratnagiri 71-1, Ratnagiri 73-1-1, Ravi, Sabari, Sakoli 6, Sarjoo 49, Sarjoo 50, Somasila, Vandana, Varalu

Source: Siddiq *et al.*, 2005

Strategic research towards changing plant architecture and, thereby, enhancing the physiological efficiency was initiated with search for sources potential enough to enhance genetic yield level. Evaluation of genetic resources, available with the national and international institutions, aimed at identifying sources for various traits needed for development of 'new plant type'. This has resulted in the isolation of several *indica/ japonica* cultivars of promise as listed in Table 11.

Table 11: Donors for various traits being used for developing new plant type

Trait	*Indica/ japonica* Cultivars
Heavy panicle	Darinagan, Djawa serang, G1291, G1298, Ketan gebat,
High density grains	Badshabhog, Roupsail
High harvest index	T141, Vijaya
Low photorespiration	B76, Patnai 23
High photosynthetic efficiency	AC4491, Bam 3, Mahsuri, NS1281, Ptb10, T141, T90
Prolonged grain filling	BG380, BG90-2, Darinagan, IR65601-10-1-2,IR 65740-ACI-3
Short stature	IR5, MD2, Shend Nung 889-366
Slow leaf senescence	G110, Pusa 1021, Pusa 1266, indica x japonica derivatives
Sturdy stem	Gharbaran, Pusa 44-37, Sengkeu, Sipapak, Sirah Barch
High translocation efficiency	Ptb10

Source: Swaminathan, 2002

The rice improvement research operating in the country has generated many materials, which give good performance but do not show the required superiority to get released as cultivars. In addition, there are germplasm, developed and/or identified by scientists with one or more outstanding traits such as new sources of resistance to biotic and abiotic stresses, unique quality features, male sterility, induced mutants, cytogenetic stocks, etc. These germplasm may serve as genetic stocks in crop improvement programmes or are of academic importance. The ICAR has developed a system of germplasm registration with NBPGR as the nodal institute to recognize the accomplishments and efforts of scientists who identified or developed them, and to encourage the sharing of such germplasm with other rice researchers.

(f) Indian Rice Varieties Released in Other Countries

There had been a liberal, exchange of genetic material among rice researchers around the globe particularly facilitated by the IRRI coordinated INGER programme. Many India bred varieties tested in the INGER nurseries have been directly released for general cultivation in other countries (Table 12). In all 33 elite breeding lines developed in India have been released as 46 varieties around the world. They include 25 in Sub-Saharan Africa, 10 in South Asia, 5 in Latin America and the Caribbean islands, 3 in South-East Asia, 2 in West and North Africa and one variety in East Africa. In addition, several elite breeding lines generated in India and identified to be promising in the AICRIP have also been used in many countries as donor parents for traits like insect-pest resistance, yield and quality. Global adoption of so many varieties of Indian origin gives a true measure of strength of Indian rice breeding programme.

Table 12: Rice cultivars developed in India and released in other countries

Country of Release	Name/ Designation	Parentage	Name Given	Year of Release	Ecosystem
Afghanistan	CR 44-11	TKM6 x IR8	-	1975	Irrigated
Afghanistan	Cauvery	TKM 6 x TN1	-	1975	Upland
Afghanistan	Padma	T141 x TN1	-	1975	Irrigated
Benin	CO38	IR8 x CO25	-	-	Irrigated
Benin	RAU4072-13	IR1833-208-6-3 x Mahsuri	RAU 407	1991	Upland
Bhutan	Barkat	Shinei x China 971	Barkat	1992	Irrigated
Brazil	Seshu	IR24 x T141	-	1984	Upland
Burkina Faso	Vikram	IR8 x Siam 29	-	1979	Irrigated
Burkina Faso	RP4-2	T90 x IR8	-	1985	Irrigated
Burkina Faso	Vijaya	T90 x IR8	-	1997	Rainfed
Burundi	Savithri	Pankaj x Jagannath	-	-	Irrigated
Cambodia	OR 142-99	Pankaj x Sigadis	Sante-pheap 3	1992	Rainfed
Cameroon	Jaya	TN1 x T141	-	1977	Irrigated
China P.R.	M 114	Mahsuri mutant 3628	8085	1981	Irrigated
Cote d'Ivoire (Ivory coast)	Jaya	TN1 x T141	-	-	Irrigated
Dominican Republic	IR2153-276-1-10-PR-509	IR1541-102-6-3 x IR24*4//*O.nivara*	Juma 62	1986	Irrigated
Ghana	Vikram	IR8 x Siam 29	Afife/GR 17	1982	Irrigated
Iran	Sona	GEB24 x TN1	Amol 3	1982	Irrigated
Iraq	RP 2095-5-8-31	Vikram x Andrewsali	-	-	Rainfed

Kenya	AD9246	ADT31 x AD198	-	-	Lowland
Malawai	Kitish	BU1 x CR115	Senga	1993	Irrigated
Mali	Rasi	TN1 x CO29	IET 1444	1984	Rainfed
Mali	Jaya	TN1 x T141	-	-	Irrigated
Mali	Vijaya	T90 x IR8	-	1978	Irrigated
Mauritiana	Jaya	TN1 x T141	-	-	Irrigated
Myanmar	Mahsuri mutant	-	Ma Naw Thu Kha	1977	Irrigated
Nepal	CR 123-23	Dunghansali x Jayanti	Durga	1978	Upland
Nepal	Rasi	TN1 x CO29	Bindeswari	1981	Upland
Nepal	K39-96-1-1-1-2	CH1039 x IR580-19-2-3-3	Khumal 3	-	Irrigated
Nepal	IR 2298-PLPB-3-2-1-1B	CICA4 x KULU	Himali	1982	Irrigated
Nepal	IR 3941-4-PLP2B	CR126-42-5 x IR2061213	Kanchen	1982	Irrigated
Pakistan	Kitish	BU1 x CR115	DR 82	1984	Irrigated
Paraguay	Kitish	BU1 x CR115	CEA 1	1989	Irrigated
Paraguay	R22-2-10-1	IR22 x Sigadis	CEA 3	1989	Irrigated
Senegal	Rasi	TN1 x CO29	-	1981	Upland
Senegal	Jaya	TN1 x T141	Jaya	-	Irrigated
Tanzania	BIET360	IR8 x CH45	-	1986	Irrigated
Tanzania	Rasi	TN1 x CO29	-	1984	Upland
Tanzania	RP 143-4	IR8 x HR 19/ IR 8	Katrain 1	1984	Rainfed lowland
Tanzania	L 5P23	GEB24 x T(N)1	-	-	Irrigated
Tanzania	Sabarmati (BC5/55)	TN1 x Bas370// Bas370	Subamati	-	Irrigated
Togo	Rasi	TN1 x CO29	-	1978	Upland
Venezuela	PR 106	IR8 x Peta 5// Belle Patna	Araure 3	1984	Irrigated
Vietnam	Jaya	TN1 x T141	-	-	Irrigated
Zambia	RTN 500-5-1	IR8 x RTN24	-	-	Irrigated

Source: Prasad *et al.*, 2001

(g) Dominant Weed Flora in Rice Fields in India

Rice is grown under different agro-climatic and management conditions. The weed flora also varies accordingly. The dominant weed species found in upland rice culture are listed in table below.

Table 13 a: Dominant weed species found in upland rice culture

State	Dominant Weed Species
Andhra Pradesh	*Amaranthus spinosus, Celosia argentea, Euphorbia heterophylla, Panicum* sp.
Bihar	*Alternifollia* sp., *Caesulia axillaris, Digeria* sp., *Physalis minima, Rungia repens*
Delhi	*Alternaria sessilis, Amaranthus gracilis, Cyperus diformis, Digeria arvensis, Justica* sp., *Leptochloa chinensis*
Karnataka	*Dinebera retroflexa, Paspalum conjugatum, Portulaca oleracea, Spilanthus alba*
N. E. Region	*Amaranthus spinosus, Bidens pilosa, Boerhaavia hispida, Eichornia colonum, Eupatorium odoratum, Galinsoga parviflora, Mimosa pudica, Phyllanthus niruri, Setaria pumila*
Tamil Nadu	*Chloris barbata, Croton balpandianum, C. sparciflorus, Dinebera arabica*
West Bengal	*Digitaria longifolia, Elytrophorus arteculata, Eragrostis interrupta, Setaria glauca*

Table 13 b: Dominant weeds found in puddled direct seeded and transplanted rice

States	Dominant Weeds
Andhra Pradesh	*Cyperus difformis, Fimbristylis miliacea, Jussia suffructicosa, Marsilia minuta, Panicum* sp.
Assam	*Cuphea balsamona, Fissendocarpa linifolia, Hydrolea zeylanica, Panicum colonum, Paspalum conjugatum, Rotala indica*
Bihar	*Caesulia axillaris, Cyperus* sp., *Dactyloctenium aegypticum, Eclipta alba, E. hirta, Panicum repens, Rungia repense*
Gujarat	*Ammania baccifera, Caesulia axillaris, Cynotis sp. Ludwigia octovalvis, Panicum colonum, Sporobolus indicus*
Himachal Pradesh	*Ageratum conyzoides, Panicum elatum, Setaria glauca*
Karnataka	*Cyperus difformis, Lindernia parviflora, Panicum repens*
Madhya Pradesh	*Ammania baccifera, Caesulia axillaris, Cephalandra indica, Chloris barbata, Commelina benghalensis, Cynodon dactylon, Cynotis axillaris, Cyperus* sp., *Dinebra arabica, Elusine indica, Euphorbia* sp., *Lagasca mollis, Paspalum distichum*
New Delhi	*Commelina benghalensis, Eclipta alba, Leptochloa chinensis*
Orissa	*Aeschynomene americana, Commelina benghalensis, Cynodon dactylon, Cyperus esculentus, Ipomea aquatica, Marselia quadrifoliata, Oxalis corniculata*
Punjab	*Caesulia axillaris, Ischaemum rugosum*
Tamil Nadu	*Ammania baccifera, Cyperus difformis, C. iria, Digitaria sanguinalis, Eclipta prostrata, Fimbristylis* sp., *Marsilea minuta, Paspalum distictium*
Uttar Pradesh	*Fimbrisyilis* sp., *Lippia nodiflora, Paspalum fasciculatum, Phyllanthus niruri*
West Bengal	*Eichornia colonum, Ludwigia parviflora, Monochoria vaginalis, Oldenlandia dichotoma, Paspalum scorbiculatum, Sphenocdlea zeylanica*

Table 13 c: Weed species commonly found in rainfed lowland rice

Assam	*Echinochloa crusgalli, Fimbristylis miliacea, Jussia sufforocticosa, Ludwigia octovalvis, Monochoria vaginalis, Scirpus* sp.
Bihar	*Chara* sp., *Cyperus difformis, Echinochloa, E. crusgalli, Ipomea reptants, Paspalum scorbiculatum, Spirogyra* sp.
Himachal Pradesh	*Cyperus rotundus, Eichornia colonum, Panicum* sp., *Paspalum parapalodes, Setaria glauca*
Tamil Nadu	*Ammanea baccifera, Cyperus iria, C. difformis, Echornia colonum, Eclipta alba, Fimbristylis miliacea, Marsilea quadrifoliata, Monochoria vaginalis, Scirpus mucronatus, Sphaeranllus indicus*
Uttar Pradesh	*Chara zeylanica, Cyperus difformis, C. iria, Cyanodon dactylon, Eleocharia dulcis, Hydrilla verticilliata, Nymphaea stellata, Potamogeton* sp., *Salvania* sp., *Typha* sp.

SECTION VIII – PESTS OF RICE

Rice is the staple food for more than one and a half of the world population and accounts for more than 42% of food production. Thus the increased and sustained production of rice is fundamental to food security in India. The production advance in rice in the recent years has enabled self-sufficiency despite increase in population. In India, rice is grown in 43 million hectares in four major ecosystems: irrigated (19m ha), rainfed lowlands (14 m ha), flood prone (3 m ha) and rainfed upland (6 m ha). No other country in the world has such diversity in rice ecosystem.

One of the important constraints in achieving higher rice yields is losses caused by pests. The common pests of rice are insects, nematodes, fungi, bacteria, viruses, phytoplasma etc. Cultivation of high yielding dwarf rice cultivars since mid sixties, that necessitated the high input use including excess nitrogenous fertilizers and consequent microclimate increased the pest problems. The extent of losses due to these pests fluctuates widely depending upon the prevailing factors of abundance of these pests in a particular year/ season and the local agroclimatic conditions. Losses of about 30% average cumulative were reported.

The Natural Resources Institute (NRI) London has developed a methodology for ranking different pests and diseases affecting agricultural crops (Geddes and Lles, 1991). NRI carried out a study of pre-harvest pests in South Asia and the relative importance of pests was assessed in 30 cropping systems zone. The NRI ranking of pests affecting rice is given below.

Pest	Rank
Rice blast	1
Yellow stem borer	2
Bacterial leaf blight	3
Brown plant hopper	4
Root nematode	5
Gall midge	6
Green leaf hopper/ *Rice tungro virus*	7
Leaf folder	8
White backed plant hopper	9
Rice hispa	10
Sheath blight	11

Source: Geddes and Lles (1991)

The knowledge of rice pests has been greatly expanded during the last few decades. A brief summary of the important pests, their hosts/ vectors, geographical distribution, yield losses, variability, natural enemies/ biocontrol agents is given in Tables 15, 16 and 17.

Table 15: Important insect pests of rice in India

Insect Scientific Name Common Name Order: Family	Hosts (Major)	Distribution in India	Natural Enemies (Parasites/ Parasitoids, Predators, Pathogens) Affecting Different Stages of Insect	Remarks
Field Pests				
Brevennia rehi (Lindinger) Rice mealy bug Hemiptera: Pseudococcidae	*Oryza sativa*, *Saccharum officinarum*, *Sorghum bicolor*	Andhra Pradesh, Bihar, Karnataka, Kerala, Maharashtra, Orissa, Tamil Nadu, West Bengal (*CIE, 1979*)	**Parasites/ parasitoids** affecting: Eggs, nymphs, adults *Rhopus fullawayi* **Predators** affecting: Eggs, nymphs, adults: *Anatrichus pygmaeus*, *Domomyza perspicax*, *Leucopis luteicornis* (CAB International, 2005)	It may have serious effects during drought years and in sandy soils. Moderately high temperature is the key factor in stimulating an outbreak. Often found associated with *Rice chlorotic streak virus*.
Chilo suppressalis (Walker) Striped rice stem borer Lepidoptera: Pyralidae	*Oryza sativa*, *Sorghum bicolor*, *Zea mays*	Andhra Pradesh, Bihar, Gujarat, Karnataka, Kerala, Maharashtra, Orissa, Punjab, Rajasthan, Tamil Nadu, Uttar Pradesh (including Uttranchal) (CAB International, 2005)	**Parasites/ parasitoids** affecting: Eggs: *Anagrus optabilis*, *Telenomus dignus*, *Tetrastichus schoenobii*, *Trichogrammatoidea australicum*, *T. chilonis*, *T. dendrolimi*, *T. japonicum;* Eggs, larvae: *Chelonus munakatae*, Larvae: *Cotesia chilonis*, *C. flavipes*, *C. schoenobii*, *Eriborus sinicus*, *Stenobracon deesae*, *Sturmiopsis inferens*, *Temelucha biguttula;* Larvae, pupae: *Myosoma chinensis*, *Tetrastichus howardi*, *Tropobracon schoenobii* Pupae: *Trathala flavoorbitalis*, *Xanthopimpla punctata*, *X. stemmator* **Predator** affecting: Adults: *Argiope catenulate* **Pathogens** affecting: Larvae**:** *Beauveria bassiana*, Nucleopolyhedrosis virus, *Paecilomyces farinosus*	It is one of the most serious pests of rice in the Far East for many years. During the vegetative stage, larval feeding causes dead heart. The plants recover by growing new tillers. At the reproductive stage, feeding causes whitehead. The damage could reach 100%.

Insect Scientific Name Common Name Order: Family	Hosts (Major)	Distribution in India	Natural Enemies (Parasites/ Parasitoids, Predators, Pathogens) Affecting Different Stages of Insect	Remarks
Cnaphalocrocis medinalis (Guenée) Rice leaf folder Lepidoptera: Pyralidae	*Oryza sativa*, *Sorghum bicolor*, *Triticum* spp., *T. aestivum*, *Zea mays*	Andhra Pradesh, Assam, Delhi, Haryana, Karnataka, Kerala, Madhya Pradesh, Maharashtra, Orissa, Punjab, Tamil Nadu, Uttar Pradesh (including Uttranchal) (Rajamma and Das, 1969; Gargar and Katiyar, 1971; Khaire and Bhapkar, 1971; Yadava *et al.*, 1972; Ramasubbaiah *et al.*, 1980; Chaturvedi and Mathur, 1981; Kushwaha and Sharma, 1981; Garg and Tandon, 1982; APPPC, 1987; CAB International, 2005)	**Parasites/ parasitoids** affecting: Eggs: *Copidosoma, Copidosomopsis nacoleiae, Telenomus dignus* Larvae: *Apanteles angaleti, A. angustibasis, A. cypris, A. opacus, A. syleptae, Aphanogmus fijiensis, Cotesia flavipes, C. ruficrus, Barylypa apicala, Bracon gelechiae, B. hebetor, B. ricinicola, Cardiochiles philippinensis, Chaetexorista javana, Chelonus munakatae, Diatora lissonata, Elasmus brevicornis, E. claripennis, E. philippinensis, Goniozus indicus, G. triangulifer, G. triangulus, Leptobatopsis indica, Megaselia scalaris, Meteorus bacoorensis, Nemorilla floralis maculosa, Temelucha basimacula, T. biguttula, T. philippinensis, T. stangli, Tetrastichus schoenobii* Larvae, pupae: *Brachymeria excarinata, Eriborus argenteopilosus, E. sinicus, Ischnojoppa luteator, Trathala flavoorbitalis* Pupae: *Brachymeria lasus, B. tachardiae, Tetrastichus howardi, T. israelensis, Trichospilus pupivora, Xanthopimpla flavolineata* **Pathogens** affecting**:** Larvae: *Bacillus thuringiensis* (Bt), *Beauveria bassiana* (white muscardine fungus)	Outbreaks were reported in India, Bangladesh, China, Fiji, Japan, Korea, Malaysia, Nepal, Philippines, Sri Lanka and Vietnam, (Pathak and Khan, 1994). In all the cases, yield losses were reported.

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			Predators affecting: Adults: *Argiope catenulata* Eggs: Carabidae (ground beetles) Different stages: *Chlaenius bioculatus*, *Cyrtorhinus lividipennis*, *Harmonia octomaculata* (ladybird, maculate), *Lycosa pseudoannulata*, *Solenopsis geminata* (tropical fire ant)	
Dicladispa armigera (Olivier) Rice hispa, Paddy hispa Coleoptera: Chrysomelidae	*Oryza sativa*	Andaman and Nicobar Islands, Andhra Pradesh, Assam, Bihar, Haryana, Himachal Pradesh, Jammu and Kashmir, Kerala, Madhya Pradesh, Maharashtra, Manipur, Orissa, Punjab, Rajasthan, Tamil Nadu, Tripura, Uttar Pradesh (including Uttranchal), West Bengal (CIE, 1966; Acharya, 1967; Thakur *et al*., 1979; Pasalu and Tewari, 1989; CAB International, 2005)	**Parasites/ parasitoids** affecting: Eggs: *Trichogramma* Larvae: *Bracon, B. hispae, Campyloneurus* sp., *Closterocerus cardigaster, Pediobius* Pupae: *Trichomalopsis apanteloctena*, **Predators** affecting: Adults: *Lycosa pseudoannulata*, *Rhignochoris fuscipes*, *Rhynocoris fuscipes* **Pathogens** affecting: Adults: *Aspergillus flavus*, *Beauveria bassiana* (CAB International, 2005) Infection of hispa eggs by *B. bassiana* also observed in field in India (Hazarika *et al*., 1998).	It has been a perpetual problem in Bangladesh and parts of India. In India, both rice crops, kharif and rabi, are subjected to sporadic outbreaks of *D. armigera* and may be severely attacked. Actual yield losses, have not yet been quantified. Annual yield loss estimates of 20% in Andhra Pradesh, 17-20% in West Bengal, India (Pasalu and Tewari, 1989) have been reported.

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Hieroglyphus banian (Fabricius) Rice grasshopper Orthoptera: Acrididae	*Oryza sativa, Panicum miliaceum, Saccharum officinarum, Sorghum bicolor, Zea mays*	Andaman and Nicobar Islands, Bihar, Delhi, Gujarat, Haryana, Himachal Pradesh, Karnataka, Madhya Pradesh, Maharashtra, Orissa, Punjab, Rajasthan, Tamil Nadu, Uttar Pradesh (including Uttranchal), West Bengal (Bhatia, 1949; Diwakar 1972; Garg and Chaudhary, 1979; Chatterjee and Debgoswami, 1981; Pradhan, 1983; Ahmad and Gangwar, 1984; Bhowmik and Haldar, 1984; Shah and Garg, 1986; Nayak and Gandhi, 1990; Mohan *et al.*, 1991.	**Parasites/parasitoids** affecting: Eggs, larvae, nymphs, pupae, adults: *Eutrombidium trigonum* (grasshopper, mite, red) Eggs: *Scelio hieroglyphi* **Predator:** *Mylabris pustulata* (blister beetle, arhap) **Pathogens** affecting**:** Nymphs, adults: *Beauveria bassiana, Entomophaga grylli* (CAB International, 2005).	Outbreaks of *H. banian* in India have occurred on sugarcane in Gujarat (Vyas and Butani, 1985), on sorghum in Madhya Pradesh (Vyas *et al.*, 1983) and on rice in West Bengal (Chatterjee and Debgoswami, 1981). In recent years this pest has generally been kept well under its economic injury level in India, hence no more recent loss estimates are available. It is involved in the mechanical transmission of *Xanthomonas campestris* pv. *Oryzae*, the causal agent of bacterial blight of rice.
Hydrellia philippina Ferino Rice whorl maggot Diptera: Ephydridae	*Oryza sativa*	Widespread throughout India (Thomas *et al.*, 1971; CAB International, 2005)	**Parasites/ parasitoids** affecting: Eggs: *Trichogramma*, *T. chilonis* Larvae : *Tetrastichus* sp. **Predators** affecting**:** Adults: *Lycosa pseudoannulata, Neoscona theisi , Oxyopes javanus* **Pathogen:** *Beauveria bassiana*	In south India, yield losses ranging from 20-30% have been reported on the first crop from April to September. However, infestation was less in the second crop (Thomas *et al.*, 1971).

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			*Entomophthora grylli (*CAB International, 2005).The nematodes, *Gordius* sp. and *Mermis nigrescens*, also parasitize *H. banian* (Nayar *et al*., 1976).	
Leptocorisa acuta Thunberg Rice seed bug Hemiptera:Coreidae	*Oryza sativa*	Assam, Bihar, Delhi, Himachal Pradesh, Karnataka, Kerala, Madhya Pradesh, Orissa, Punjab, Rajasthan, Tripura, Tamil Nadu, Uttar Pradesh (including Uttranchal), West Bengal (CAB International, 2005)	**Parasite/ parasitoid** affecting: Eggs: *Ooencyrtus papilionis* **Predator** affecting: Eggs: *Homorocoryphus longipennis* Nymphs, adults: *Micraspis discolor, Neoscona theisi* **Pathogen** affecting: Nymphs, adults: *Beauveria bassiana* (CAB International, 2005). An unnamed tachinid parasitoid parasitizes *L. acuta* in Andaman and Nicobar Islands, India (Ansari and Jacob, 1997). Field studies indicated that it could provide a high level of control and thus could be exploited as a potential biological control agent against *L. acuta* in other areas.	Rice attacked by these bugs is reported to have unpleasant odour even after cooking. Yield losses upto 40% have been recorded. It is a mechanical vector of *Xanthomonas oryzae* pv. *oryzae*, which causes bacterial leaf blight in India. Also involved in the transmission of sheath rot disease (Lakshmanan *et al*., 1992).
Leucopholis lepidophora Blanchard White grub Coleoptera: Scarabaeidae	*Arachis hypogaea*, *Areca catechu*, *Oryza sativa*, *Saccharum officinarum*, *Zea mays*	Karnataka, Maharashtra (Veeresh *et al*., 1982; Adsule and Patil, 1990, 1994)	In laboratory pathogenicity tests, the entomophilic nematodes *Heterorhabditis indicus, Steinernema glaseri* and *S. feltiae* were observed infecting *L. lepidophora* larvae (Poinar *et al*., 1992). *Bacillus popilliae* may cause 70.8% mortality in Larvae.	Surveys in Maharashtra, India (1986-89) indicated that *L. lepidophora* caused damage to 25-100% of sugarcane, rice, maize, groundnuts and vegetables (Adsule and Patil, 1990).

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Lissorhoptrus oryzophilus Kuschel Rice water weevil Coleoptera: Curculionidae	*Oryza sativa*	Present, introduced (CAB International, 2005)	**Predator** affecting: Larvae: *Pantala flavescens* **Pathogens** affecting: Adults: *Beauveria bassiana* (white muscardine fungus), *Metarhizium anisopliae* (green muscardine fungus)	Causes serious rice yield losses throughout its geographic range. It has spread throughout the Japan, with yield losses of 41 to 60%. From 1988 to 1992, it has occupied more than 50% of the total rice acreage in Korea Republic and has been predicted to spread throughout all of the rice-growing areas.
Melanitis leda ismene Cramer Rice butterfly Lepidoptera: Nymphalidae	*Oryza sativa*	Arunachal Pradesh, Karnataka, Kerala, Maharashtra, Manipur, Orissa, Uttar Pradesh (including Uttranchal), West Bengal (Katiyar *et al.*, 1976; Rai, 1978; Singh and Singh, 1979; Singh, 1983; APPPC, 1987; Jana and Ghosh, 1994; Padmanaban *et al.*, 1990; CAB International, 2005)	**Parasite/ parasitoid** affecting: Pupae: *Trichospilus diatraeae* **Predators** affecting: Larvae : *Amyotea malabarica*, *Andrallus spinidens*, *Eocanthecona furcellata* **Pathogen** affecting: Larvae, pupae: *Beauveria velata*, *Fusarium oxysporum*, *Serratia marcescens* (Srivastava and Nayak, 1978; CAB International, 2005).	Generally does not cause appreciable damage. However, occasional high populations have been reported in Kanpur, Uttar Pradesh (Katiyar *et al.*, 1976); Manipur, India (Singh and Singh, 1979).
Mythimna separata Walker	Wide host range	Andhra Pradesh, Assam, Bihar, Delhi, Gujarat, Haryana, Himachal Pradesh,	**Parasites/ parasitoids** affecting**:** Larvae, pupae: *Barichneumon solitarius*, *Brachymeria lasus*, *Carcelia prima*, *Charops bicolor*, *Cuphocera iavana*, *Dolicholon*	It causes the greatest damage to the rice panicles. In cases of severe infestation, damage may be upto 60% or more (Dale, 1994). However, its

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Rice armyworm Lepidoptera: Noctuidae		Jammu and Kashmir, Karnataka, Kerala, Madhya Pradesh, Maharashtra, Manipur, Orissa, Punjab, Rajasthan, Sikkim, Tamil Nadu, Uttar Pradesh (including Uttranchal), West Bengal (CIE, 1983; Thakur, 1984; Shukla *et al*., 1986; Greathead and Greathead, 1992; Patel and Patel, 1993)	*parasoxum, Drino inconspicua, Exorista fallax, E. xanthaspis, Metopius rufus, Palexorista solennis, Pseudogonia rufifrons, Pseudoperichaeta anomala, Theocarcelia oculata, Turanogonia chinensis* Larvae: *Compsilura, Cotesia parbhanii, C. ruficrus, Ovomermis albicans, Steinernema glaseri* Eggs: *Tetrastichus* sp. **Predators** affecting: Larvae: *Calosoma indicum,Carabidae* (ground beetles), *Chlaenius bioculatus, Eocanthecona furcellata* **Pathogens** affecting: Larvae: *Granulosis virus, Nucleopolyhedrosis virus* (CAB International, 2005).	incidence has declined to some extent during the past 30-40 years because of the expansion of irrigated rice cultivation.
Nephotettix nigropictus (Stål) Rice green leafhopper Hemiptera: Cicadellidae	*Cyperus* spp., *Oryza sativa, Panicum* spp., *Poa* spp.	Andaman and Nicobar Islands, Andhra Pradesh, Assam, Bihar, Goa, Gujarat, Haryana, Himachal Pradesh, Karnataka, Kerala, Madhya Pradesh, Maharashtra, Manipur, Meghalaya, Orissa, Punjab, Tamil Nadu, Uttar Pradesh (including Uttranchal), West	**Parasites/ parasitoids** affecting: Eggs: *Anagrus flaveolus, Oligosita aesopi, O. naias* Nymphs, adults: *Ecthrodelphax fairchildii, Halictophagus bipunctatus, Pipunculus mutillatus, Tomosvaryella oryzaetora, T. subvirescens* **Predators** affecting: Eggs, nymphs, adults: *Amphiareus constrictus, Coccinella transversalis, Cyrtorhinus lividipennis, Cheilomenes sexmaculata, Harmonia octomaculata, Tytthus parviceps*	A vector for Rice tungro bacilliform virus (RTBV) and Rice tungro spherical virus (RTSV). Maintains epidemiological cycle between rice seasons by transmitting RTBV and RTSV particles to alternative weed hosts, which grow throughout the year.

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		Bengal (Pawar and Bhalla, 1974; Dhawan and Sajjan, 1977; Rao, 1980; Ghose *et al.*, 1987; Balasubramanian *et al.*, 1988; CAB International, 2005)	Nymphs, adults: *Argiope catenulate, Casnoidea indica, Microvelia douglasi atrolineata, Stenonabis tagalicus* **Pathogens** affecting**:** Nymphs, adults: *Beauveria bassiana, Metarhizium anisopliae* (Manjunath *et al.*,1978; Misra ,1980; Gupta and Pawar, 1989; CAB International, 2005)	
Nephotettix virescens (Distant) Green rice leaf hopper Hemiptera: Cicadellidae	Oryza sativa	Widespread in India (CIE 1971; CAB International, 2005)	**Parasites/ parasitoids** affecting: Eggs:*Anagrus flaveolus, Oligosita* sp., *Paracentrobia andoi* Nymphs: *Ecthrodelphax fairchildii, Tomosvaryella oryzaetora, T. subvirescens,* Nymphs, adults: *Halictophagus bipunctatus* **Predators** affecting: Eggs : *Microvelia douglasi, Tetragnatha* spp., beetles, dragonflies and spiders. Two *Gonatocerus* sp. and a species of *Paracentrobia* Nymphs, adults : *Argiope catenulata* Eggs, nymphs, adults: *Cyrtorhinus lividipennis* **Pathogens** affecting: Nymphs, Adults: *Beauveria bassiana* (CAB Abstracts 1973-98; Gupta and Pawar, 1989; Das *et al*., 1990).	It is amongst the most widespread and abundant pest of irrigated rice. About 17-23 kg/ ha of grain yield was lost in five states of southern India during 1990-1991 and an additional 15 to 24 kg/ha to tungro (Ramasamy *et al*., 1996). It transmits *Rice tungro virus* (RTV). Annual economic losses due to tungro throughout Asia are US$ 1500 million (Herdt, 1988). Also transmits Rice yellow dwarf phytoplasma, Rice bunchy stunt virus, Rice gall virus and Rice transitory yellowing virus (CAB International, 2005).

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Nezara viridula (Linnaeus) Green shield bug, Green stink bug Hemiptera: Pentatomidae	Wide host range	Andhra Pradesh, Arunachal Pradesh, Assam, Bihar, Delhi, Gujarat, Haryana, Karnataka, Madhya Pradesh, Maharashtra, Orissa, Sikkim, Tamil Nadu, Uttar Pradesh (including Uttranchal), West Bengal (Datta and Chakravarty, 1977; Singh *et al.*, 1977; Saha and Saharia, 1983; Dhamdhere *et al.*, 1984; Bhalani and Bharodia, 1988; CAB International, 2005)	**Parasites/ parasitoids** affecting: <u>Eggs</u>: *Psix striaticeps, Ooencyrtus papilionis* **Predators:** *Nabis capsiformis*, *Oecophylla smaragdina*, *Sycanus collaris* **Pathogens:** *Bacillus thuringiensis*, *Beauveria bassiana* A considerable diversity of natural enemies attack *N. viridula* in various stages of its development. No product has been developed for field use (CAB International, 2005).	Blemishes reduce quality and marketability of the crop. It is known to carry spores of fungal diseases from plant to plant, and can also transfer plant pathogens mechanically during feeding. It transmits spores of fungal species of *Nematospora*, which causes internal rots.
Nilaparvata lugens Stål Brown planthopper (BPH) Hemiptera: Fulgoroidea	*Oryza* spp., *O. sativa*, *Zizania*	Andaman and Nicobar Islands, Andhra Pradesh, Arunachal Pradesh, Assam, Bihar, Haryana, Himachal Pradesh, Punjab, Karnataka, Kerala, Madhya Pradesh, Maharashtra, Meghalaya, Orissa, Tamil Nadu, Uttar	**Parasites/ parasitoids** affecting: <u>Eggs:</u> *Anagrus flaveolus, A. optabilis, A. perforator,* <u>Nymphs, Adults:</u> *Ecthrodelphax fairchildii, Elenchus japonicus, Haplogonatopus apicalis, H. orientalis, Pipunculus mutillatus, Tomosvaryella oryzaetora* **Predators** affecting: <u>Eggs, nymphs, adults:</u> *Cyrtorhinus lividipennis, Tytthus parviceps*	The most serious insect pest of rice in Asia. It was a minor rice pest until the mid-1960s (Pathak and Dhaliwal, 1981). However, it assumed the status of the most destructive pest in the 1970s (Heinrichs and Mochida, 1984), after the introduction of Taichung Native 1 in 1964 and IR8 in 1968.The yield loss in India was 1.1-32.5% (Jayaraj *et al.*, 1974). It assumed an epidemic form in India

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		Pradesh (including Uttranchal), West Bengal (Banerjee, 1971; Khaire and Bhapkar, 1971; Das *et al.*, 1972; Abraham, 1975; Bhalla and Pawar, 1975; ChannaBasavanna *et al.*, 1976; Pawar and Banerjee, 1976; Pawar and Bhalla, 1977; Chatterjee, 1978; Natarajan, 1978; Nath and Sen, 1978; Dyck and Thomas, 1979; Kalode and Krishna, 1979; Natarajan *et al.*, 1988; Rizvi and Singh, 1983; Thakur *et al.*, 1979; CAB International, 2005)	Nymphs: Carabidae (ground beetles) Nymphs, adults: *Argiope catenulata Lycosa pseudoannulata*, *Microvelia douglasi atrolineata*, *Tetragnatha mandibulata*, *T. sutherlandi* **Pathogens** affecting: Nymphs, adults: *Beauveria bassiana*, *Metarhizium anisopliae* (CAB International, 2005). Gautam (1998) also listed Parasites *Echthrodelphax* sp. (attacking all stages), *Haplogonatopus* sp. (attacking all stages), *Pseudogonatopus* sp. (attacking nymph, adult) Predators *Neoscona nautical* (attacking nymph)	in 1973 and caused extensive damage in Kerala. Following an outbreak in 1973-74, heavy losses in yields occurred, as a result of grassy stunt (reported for the first time in India). It is a vector for *Rice ragged stunt virus* and Grassy shoot virus (Rivera *et al.*, 1966).Three biotypes are known (Pasalu and Katti, 2004)
Nymphula depunctalis Guenee Rice case worm Lepidoptera:	*Oryza sativa*	Andhra Pradesh, Assam, Bihar, Karnataka, Kerala, Madhya Pradesh, Maharashtra, Manipur, Orissa, Punjab, Rajasthan,	**Parasites/ parasitoids** affecting: Eggs: *Trichogrammatoidea australicum* **Predators** affecting: Adults: *Argiope catenulata* (CAB International, 2005). The parasitic wasps *Pediobius viggianii* and *P. ni* are recorded as larval parasites in northern India	In Madhya Pradesh, India, *P. stagnalis* damaged 38 to 94% of leaves in rice fields and the combined infestation of this pest with the rice leaf folder (*Cnaphalocrocis medinalis*) caused an overall yield

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Crambidae		Tamil Nadu, Tripura, Uttar Pradesh (including Uttranchal), West Bengal (Viraktamath *et al*., 1975; CAB International, 2005)	(Khan, 1996).	loss of 80% (Patel and Khatri, 2001).
Orseolia oryzae (Wood-Mason) Mani Rice gall fly Diptera: Cecidomyiidae	*Oryza sativa*	Andaman and Nicobar Islands, Andhra Pradesh, Bihar, Karnataka, Kerala, Madhya Pradesh, Maharashtra, Manipur, Orissa, Punjab, Tamil Nadu, Uttar Pradesh (including Uttranchal), West Bengal (CAB International, 2005)	**Parasites/ parasitoids** affecting: Eggs, larvae: *Platygaster oryzae* Larvae : *Eurytoma setitibia*, *Propicroscytus mirificus*, Pupae: *Neanastatus cinctiventris*, *N. oryzae* **Predators** affecting: Larvae: Carabidae (ground beetles), *Nabis capsiformis* Larvae, pupae: *Casnoidea indica*	A major pest in Asia. Average crop losses of 50-100% over wide areas have been reported. Epidemics of this pest occurred in cycles of 3-5 years causing 100% damage of rice plants. Pathak and Dhaliwal (1981) also reported that *O. oryzae* was spreading in the Indian subcontinent and was first recorded in Uttar Pradesh in 1971. In 1989, a serious outbreak occurred in Andhra Pradesh (Rao and Rao, 1989). So far, six biotypes of gall midge have been reported throughout India (Pasalu and Katti, 2004).
Oxya chinensis (Thunberg) Rice grasshopper Orthoptera:	*Gossypium* spp., *Oryza sativa*, *Panicum miliaceum*, *Phragmites*	Karnataka, Sikkim (Thonkadarya and Devaiah, 1975; Thakur, 1984)	**Predator** affecting: Nymphs, adults: *Pantala flavescens*	In the rice field, 2-4 adults per m^2 can reduce output by 6.8-17.8%. In India, *O. chinensis* has been listed as among the five most important rice pests in the Sikkim Hills (Thakur, 1984).

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Acrididae	*australis, Sorghum bicolor, Triticum* spp., *Zea mays*			
Pelopidas mathias (Fabricius) Rice skipper Lepidoptera: Hesperiidae	*Hordeum vulgare, Oryza sativa, Saccharum officinarum, Sorghum bicolor, Triticum aestivum, Zea mays*	Andhra Pradesh, Assam, Bihar, Delhi, Goa, Jammu and Kashmir, Karnataka, Kerala, Maharashtra, Nagaland, Manipur, Orissa, Punjab, Rajasthan, Tamil Nadu, Uttar Pradesh (including Uttranchal), West Bengal (Jandu, 1943; Usman, 1954; Fawar, 1956; Sengupta, 1959; Birat, 1963; Sen and Chakravarti, 1970; Christudas *et al*., 1971; Jotwani, 1975; Maninder and Varma, 1982; APPPC, 1987; Ghose *et al*., 1987)	**Parasites/ parasitoids** affecting: <u>Larvae:</u> *Apanteles javanensis, Brachymeria lasus, Cotesia baoris, Halidaya luteicornis, Halydaia luteicornis, Trichomalopsis apanteloctena, Xanthopimpla punctata* <u>Larvae, pupae:</u> *Brachymeria, B. excarinata, Charops bicolor, Ischnojoppa luteator* <u>Eggs:</u> *Trichogramma chilonis, Trichogrammatoidea bactrae* **Predators** affecting: <u>Eggs, larvae, pupae:</u> *Amyotea malabarica, Paederus fuscipes*	A very large insect and a single larva can cause high amount of defoliation. Local outbreaks, however, are rare. Its wide host range gives it a good chance of becoming established in new areas.
Rhopalosiphum rufiabdominale (Sasaki,) Rice root aphid	*Gossypium* spp., *Hordeum vulgare, Oryza sativa, Prunus, Saccharum*	Bihar, Himachal Pradesh, Kerala, Madhya Pradesh, Maharashtra, Orissa, Punjab, Rajasthan,	**Parasite/ parasitoid** affecting: <u>Nymphs, adults:</u> *Aphelinus* (aphelinid) **Pathogens** affecting: <u>Nymphs, adults:</u> *Lecanicillium lecanii*	It is an economic pest of upland rice, particularly in Japan, but is not a pest of irrigated rice anywhere in the world. Singh (1977) presented evidence of *R. rufiabdominalis* being

Insect Scientific Name Common Name Order: Family	Hosts (Major)	Distribution in India	Natural Enemies (Parasites/ Parasitoids, Predators, Pathogens) Affecting Different Stages of Insect	Remarks
Hemiptera: Aphididae	*officinarum*, *Solanum melongena*, *Triticum* spp.	Uttar Pradesh (including Uttranchal), West Bengal (CAB International, 2005)	Meagre information is available concerning natural enemies of this aphid, largely due to its subterranean habitat (CAB International, 2005). Ding (1985) found 57.4-100% parasitism by a braconid parasite, *Aphidius* sp., in a study of upland rice in China.	a vector of *Maize mosaic virus* in India.
Scirpophaga incertulas Walker Yellow rice stemborer Lepidoptera: Pyralidae	*Oryza sativa*	Andhra Pradesh, Assam, Bihar, Himachal Pradesh, Jammu and Kashmir, Karnataka, Kerala, Madhya Pradesh, Maharashtra, Orissa, Punjab, Sikkim, Tamil Nadu, Uttar Pradesh (including Uttranchal), West Bengal (CAB International, 2005)	**Parasites/ parasitoids** affecting: Larvae, pupae: *Amauromorpha accepta accepta*, *A. accepta schoenobii*, *Eriborus sinicus*, *Ischnojoppa luteator*, *Rhaconotus schoenobivorus*, *Temelucha philippinensis*, *T. stangli*, *Tetrastichus howardi*, *Xanthopimpla stemmator* Larvae: *Chelonus munakatae*, *Cotesia chilonis*, *C. flavipes*, *Elasmus albopictus*, *Exoryza schoenobii*, *Myosoma chinensis*, *Stenobracon nicevillei*, *Tropobracon schoenobii* Eggs: *Telenomus dignoides*, *T. dignus*, *T. rowani*, *Tetrastichus schoenobii*, *Trichogramma chilonis*, *T. exiguum*, *T. japonicum* **Predators** affecting: Eggs: *Cyrtorhinus lividipennis*, *Harmonia octomaculata*, *Homorocoryphus longipennis* Adults: *Argiope catenulate*, *Lycosa pseudoannulata*, *Oxyopes javanus*, *O. pandae* **Pathogens** affecting: Larvae, pupae: *Beauveria bassiana*	It is one of the most destructive pests of rice in India. The larval feeding at vegetative stage causes the death of a central leaf whorl, the deadheart and at the reproductive stage may cause death of the emerging panicle the whitehead. *S. incertulas* has a high potential to cause significant yield losses (Islam, 1990; Islam and Karim, 1999). The reported yield losses in different areas of India vary from 3 to 95%.

Insect Scientific Name Common Name Order: Family	Hosts (Major)	Distribution in India	Natural Enemies (Parasites/ Parasitoids, Predators, Pathogens) Affecting Different Stages of Insect	Remarks
Sogatella furcifera (Horváth) White-backed rice planthopper Hemiptera: Delphacidae	*Oryza sativa*	Andhra Pradesh, Assam, Bihar, Delhi, Gujarat, Haryana, Himachal Pradesh, Karnataka, Kerala, Madhya Pradesh, Maharashtra, Orissa, Punjab, Tamil Nadu, Uttar Pradesh (including Uttranchal), West Bengal (Fletcher, 1916, 1917; Berg, 1960; Atwal *et al*., 1967; Chatterjee, 1971; Pawar and Bhalla, 1974; Chhabra *et al*., 1976; Kushwaha and Singh, 1986; Saha, 1986; Gubbaiah *et al*., 1987; Panda and Shi, 1988; Chakraborty *et al*., 1990; Krishnaiah *et al*., 1996; Ambikadevi *et al*., 1998; CAB International, 2005)	**Parasites/ parasitoids** affecting: Eggs: *Anagrus flaveolus, A. frequens, A. optabilis, A. perforator, Oligosita naias* (Prakasarao, 1969) Nymphs, adults: *Ecthrodelphax fairchildii, Elenchus japonicus,Haplogonatopus apicalis, H. orientalis* **Predators** affecting: Eggs, nymphs: Carabidae (ground beetles) Nymphs, Adults: *Argiope catenulate, Microvelia douglasi atrolineata, Paederus fuscipes* Eggs, nymphs, adults: *Cyrtorhinus lividipennis* Different Stages: *Casnoidea indica, Cheilomenes sexmaculata, Clubiona abbottii, C. drassodes, Marpissa mandali, Micraspis discolor, Tytthus chinensis* **Pathogens:** *Beauveria bassiana* (CAB International, 2005). Gautam (1998) has also listed parasites *Echthrodelphax* sp. (all stages) *Haplogonatopus* sp. (all stages) *Pseudogonatopus* sp. (nymph, adult)	A major pest of rice in tropics and subtropics in Asia. Under favourable conditions, it produces several generations causing 'hopperburn'. A serious outbreak was reported in Pakistan in 1978, in the northwest of West Malaysia in May 1979, and in India in 1982 (Khan and Kushwaha, 1991). In May-June 1985, it severely damaged rice for the first time in Assam, India, where heavily infested fields were hopperburned.
Spodoptera mauritia	*Gossypium* spp., *Oryza sativa*,	Andman and Nicobar Islands, Arunachal	**Parasites/ parasitoids** affecting: Eggs: *Telenomus remus, Tetrastichus*	Its sudden outbreaks can result in serious damage, sometimes with the

Insect Scientific Name Common Name Order: Family	Hosts (Major)	Distribution in India	Natural Enemies (Parasites/ Parasitoids, Predators, Pathogens) Affecting Different Stages of Insect	Remarks
Boisduval Paddy armyworm, Paddy swarming caterpillar Lepidoptera: Noctuidae	*Saccharum officinarum*, *Zea mays* and also number of hosts belonging to family Brassicaceae and Poaceae	Pradesh, Andhra Pradesh, Assam, Bihar, Haryana, Himachal Pradesh, Karnataka, Kerala, Maharashtra, Orissa, Sikkim, Tamil Nadu, Uttar Pradesh (including Uttranchal), West Bengal (CAB Abstracts, 1973-1998; CAB International, 2005)	*schoenobii*, *Trichogramma chilonis* Larvae: *Chelonus insularis, Cotesia flavipes, C. marginiventris, C. ruficrus, Cuphocera iavana, Lespesia archippivora, Peribaea orbata, Pseudogonia rufifrons* **Predator** *Andrallus spinidens* **Pathogen** Nucleopolyhedrosis virus	loss of the entire paddy crop. Few major outbreaks have been recorded in equatorial South-East Asia (Rothschild, 1969). According to Dale (1994), this insect is a sporadic pest causing upto 20% loss in rice yield.
Storage Pests				
Corcyra cephalonica (Stainton) Rice meal moth, Rice moth Lepidoptera: Pyralidae	*Manihot esculenta*, *Myristica fragrans*, *Oryza sativa*, *Panicum miliaceum* *Pennisetum glaucum* , *Sorghum bicolor*, *Triticum* spp., *T. aestivum*, *Zea mays*, stored products	Andman and Nicobar Islands, Andhra Pradesh, Assam, Bihar, Chandigarh, Delhi, Gujrat, Haryana, Himachal Pradesh, Karnataka, Kerala, Maharashtra, Manipur, Orissa, Punjab, Meghalaya, Uttar Pradesh (including Uttranchal), West	**Parasites/ parasitoids** affecting: Eggs: *Trichogrammatoidea australicum, T. chilonis* Larvae: *Bracon brevicornis, B. hebetor* **Predators** affecting: Eggs, larvae: *Acaropsellina docta, Blattisocius keegani, B. tarsalis* Larvae: *Amphibolus venator, Sycanus affinis* (CAB International, 2005). A technique of using gelatin capsules containing eggs of *C. cephalonica* parasitized by *T. chilonis* for the release of adult trichogrammatids has been developed in India (Maninder *et al*., 1998).	The larval feeding causes the formation of webs in the material. The webbing formed by the larvae is noticeably more dense and tough. In cases of heavy infestation the food material becomes tightly matted together with webbing, cocoons, cast skins and frass. Such contamination of food may be of greater economic importance than larval feeding. It is used as a substitute host for breeding parasitoids.

Insect Scientific Name Common Name Order: Family	Hosts (Major)	Distribution in India	Natural Enemies (Parasites/ Parasitoids, Predators, Pathogens) Affecting Different Stages of Insect	Remarks
		Bengal (CAB International, 2005)		
Rhizopertha dominica (Fabricius) Lesser grain borer Coleoptera: Bostrichidae	*Avena sativa*, *Hordeum vulgare*, *Oryza sativa*, *Panicum* spp., *Pennisetum* spp., *Sorghum bicolor*, *Triticum* spp., *T. aestivum*, *T. turgidum*, *Zea mays*, stored products	Widespread (Sinha and Sinha, 1990; CAB International, 2005)	**Parasites/ parasitoids** affecting: Eggs: *Pyemotes tritici* Larvae: *Anisopteromalus calandrae* **Predators** affecting: Eggs: *Acaropsellina docta*, *Tenebroides mauritanicus* Eggs, larvae, nymphs pupae, adults: *Xylocoris flavipes* *R. dominica* is very susceptible to *B. thuringiensis* var. *tenebrionis* with over 75% mortality (CAB International, 2005).	The larvae and adults consume the seed and cause both quantitative and qualitative losses.
Sitophilus oryzae (Linnaeus) Rice weevil Coleoptera: Dryophthoridae	*Manihot esculenta*, *Oryza sativa*, *Sorghum bicolor, Triticum* spp., *T. aestivum*, *T. spelta*, *Zea mays*, stored products	Present in India, found in all warm and tropical parts of the world, but it may also be found in temperate climates (CAB International, 2005)	**Parasites/ parasitoids** affecting: Larvae, pupae: *Anisopteromalus calandrae* **Predator** affecting: Larvae, pupae: *Acaropsellina docta*	One of the most destructive primary pests of stored cereals. It can attack cereal plants in the fields. Feeding results both in quantitative and qualitative losses. The maximum weight loss caused to single kernels of rice by individual larvae was 57%. Weight losses up to 30-40% may occur in storage.
Sitotroga cerealella (Olivier) Angoumois grain	*Avena sativa*, *Hordeum vulgare*, *Oryza* spp., *O. sativa*, *Pennisetum glaucum, Secale*	Andaman and Nicobar Islands, Assam, Bihar, Delhi, Gujarat, Karnataka, Kerala, Maharashtra,	**Parasites/ parasitoids** affecting: Eggs: *Trichogramma* spp., *T. evanescens, T. maidis, T. minutum, T. pretiosum, T. semblidis, T. telengai*	It attacks grain in the field as well as in storage, causing an estimated overall yield loss of upto 30% (Singh and Benazet, 1975). Stored rice (unhusked) revealed infestation level

Insect Scientific Name Common Name Order: Family	Hosts (Major)	Distribution in India	Natural Enemies (Parasites/ Parasitoids, Predators, Pathogens) Affecting Different Stages of Insect	Remarks
moth, Rice grain moth Lepidoptera: Gelechiidae	*cereale*, *Sorghum bicolor*, *Triticum* spp., *T. aestivum*, *T. spelta*, *Zea mays*, *Zizania palustris*	Manipur, Orissa, Punjab, Tamil Nadu, Uttar Pradesh (including Uttranchal), West Bengal (Girish *et al*., 1974; Bhardwaj *et al*., 1977; Champ and Dyte, 1977; Upadhyay *et al*., 1979; Borah and Mohon, 1982; Prakash and Kauraw, 1982; Gupta, 1983; Ilyasa *et al*., 1983; Pande and Singh, 1983; Pajni and Mehta, 1986; Padwal-Desai *et al*., 1987; Dhaliwal *et al*., 1989; Ramashrit and Mishra, 1989; Sinha and Sinha, 1992)	Larvae: *Bracon hebetor* Eggs, larvae, nymphs, pupae, adults: *Pyemotes tritici* (CAB International, 2005).	upto 88%. The eggs of *S. cerealella* have been used extensively to rear the predatory chrysopid for biologica1 control of other pests.

Table 16: Important nematode pests of rice in India

Nematode Scientific Name Common name Family	Hosts (Major)	Distribution	Natural Enemies (Parasites/ parasitoids/ predators, pathogens) Affecting the Nematode	Remarks
Aphelenchoides besseyii Christie White tip nematode of rice Aphelenchoididae	*Fragaria ananassa*, *Oryza* sp., *O. glaberrima*, *O. sativa*	Andhra Pradesh, Assam, Bihar, Delhi, Gujarat, Haryana, Punjab, Kerala, Madhya Pradesh, Maharashtra, Meghalaya, Orissa, Tamil Nadu, Tripura, Uttar Pradesh (including Uttranchal), West Bengal (Prasad *et. al*., 1987; CAB International, 2005)	*Arachnula impatiens*, *Vampyrella vorax*	Economically very important and seed-transmitted. More than 20 races known world over. Severe symptoms reported in field but accurate yield losses lacking. Computed losses of 0.2-10% reported. It has been reported in 12.8% of rice seed lots with infection levels ranging from 2-82% within lots. However, losses of upto 50% have been reported in upland rice in Brazil (CAB International, 2005).
Ditylenchus angustus Filipjev Rice stem nematode ufra disease Anguinidae	*Oryza* (generic level), *O. sativa*	Assam, Maharashtra, Orissa, Uttar Pradesh (including Uttranchal), West Bengal (Chatterjee 1984; Ray *et al*., 1987; Roy, 1987; Patil, 1998; CAB International, 2005)	Not reported	In India, yield losses in rice have been estimated to range from 10 to 15% in West Bengal and 30% in Assam, 50% in Uttar Pradesh (Rao *et al*., 1986; Prasad *et al*., 1987). It occurs in 20-80% of rice in West Bengal (Chakrabarti *et al*., 1985). Not a seed borne disease. Its distribution is becoming more restricted (Prot, 1993).
Heterodera oryzae Luc & Berdon Brizuela,	*Oryza sativa*	Assam, Kerala, Orissa (Rao and Jayaprakash, 1977)	**Pathogens** *Myrothecium verrucaria (myrothecium blotch)*	The incidence of cyst nematode results in a general decline in plant growth and vigour. The cysts remain in the field

Nematode Scientific Name Common name Family	Hosts (Major)	Distribution	Natural Enemies (Parasites/ parasitoids/ predators, pathogens) Affecting the Nematode	Remarks
Rice cyst nematode Heteroderidae				and liberate the larvae in the soil for multiplication. Eggs may hatch from egg masses after 9 months and form cysts after 2 years. Once hatched, juveniles can only survive in the soil for about 3 weeks, slightly longer in anaerobic conditions. The economic impact of *H. oryzae* has not been assessed.
Heterodera oryzicola Rao & Jayaprakash Rice cyst Heteroderidae	*Oryza sativa*	Goa, Haryana, Kerala, Madhya Pradesh, Orissa, Tamil Nadu, West Bengal (Koshy *et al*., 1987; Prasad *et al*., 1987; CAB International, 2005)	Not reported	Yield losses are not well documented as the nematode generally occurs in association with other species. The nematode caused upto 56% reduction in the growth of rice plants grown in pots. Yield losses are not documented as it occurs in association with other species.
Hirschmanniella oryzae (van Breda de Haan) Luc & Goodey Rice root nematode Pratylenchidae	*Oryza sativa*	Andhra Pradesh, Assam, Bihar, Haryana, Himachal Pradesh, Jammu and Kashmir, Kerala, Madhya Pradesh, Maharashtra, Orissa, Punjab, Tamil Nadu, Uttar Pradesh (including Uttranchal), West	**Predators:** *Mononchoides fortidens, Mononchoides longicaudatus* (Greathead and Greathead, 1992)	*Hirschmanniella* spp. infest 58% of the world's rice fields, causing 25% yield losses. However, there are discrepancies in yield loss estimates as it is not always solely attributable to the nematodes and also influenced by soil fertility, age of the plant, number of crops and by flooding, and climatic conditions. The root harbour large number of nematodes. The rice plants are stunted with fewer tillers and poor grain filling

Nematode Scientific Name Common name Family	Hosts (Major)	Distribution	Natural Enemies (Parasites/ parasitoids/ predators, pathogens) Affecting the Nematode	Remarks
		Bengal (Mathur and Prasad, 1971; CAB International, 2005)		may cause 10-36% yield loss. It survives in moist as well as dry soil.
Hoplolaimus indicus Sher Lance nematode Hoplolaimidae	*Oryza sativa*	Assam, Bihar, Delhi, Gujrat, Haryana, Himachal Pradesh, Jammu and Kashmir, Kerala, Karnataka, Madhya Pradesh, Maharashtra, Manipur, Orissa, Punjab, Rajasthan, Sikkim, Tamil Nadu, Tripura, Uttar Pradesh (including Uttranchal), West Bengal (Birat, 1965; Banerji and Banerji, 1966; Gupta and Gupta, 1967; Das *et al*., 1970; Khan and Chawla, 1975; Hasan *et al*., 1976; Krishnappa *et al*., 1980; Phukan and Sanwal, 1980; Zoological Survey of India, 1983; Anonymous, 1984; Darekar *et al*., 1992; Sharma and Ali, 1993;	**Pathogen** *Catenaria anguillula* (Greathead and Greathead, 1992)	Reduction in rice yield is upto 25% and decrease in protein content of grain by 2.9% reported. The nematode survives in soil and root debris. The phytosanitary risk is low, with the most likely mode of spread being through infected plant roots/ soil.

Nematode Scientific Name Common name Family	Hosts (Major)	Distribution	Natural Enemies (Parasites/ parasitoids/ predators, pathogens) Affecting the Nematode	Remarks
		Sundararaj and Mehta, 1993; Hazarika, 1994; Nath *et al*., 1995)		
Meloidogyne graminicola Golden & Birchfield Rice root knot nematode Meloidogynidae	*Oryza sativa*	Assam, Delhi, Haryana, Punjab, Madhya Pradesh, Orissa, Tripura, Uttar Pradesh (including Uttranchal), West Bengal (CAB International, 2005)	**Pathogen** *Myrothecium verrucaria* (myrothecium blotch).	In upland rice, there is an estimated reduction of 2.6% in grain yield for every 1000 nematodes present around young seedlings. The losses are highly significant in case of infection of young crop. Upto 16 % loss has been reported. With every increase of a thousand larvae of the nematode in the inoculum, the grain yield was reduced by 2.6%. Soil temperature of 23.5°C and below are favourable to the formation of root knots and to the production of egg masses. Nematode activity is more pronounced in soils with acidic pH.
Meloidogyne incognita (Kofoid & White) Root-knot nematode Meloidogynidae	*Abelmoschus esculentus*, *Capsicum annuum*, *Carica papaya*, *Coffea*, *C. arabica*, *Hibiscus cannabinus*, *Lactuca sativa*, *Lycopersicon esculentum*, *Mangifera indica*,	Andman and Nicobar Islands, Andhra Pradesh, Arunachal Pradesh, Assam, Bihar, Chandigarh, Delhi, Gujarat, Haryana, Himachal Pradesh, Punjab, Jammu and Kashmir, Karnataka, Kerala, Madhya Pradesh, Maharashtra,	**Pathogens** *Aspergillus niger* (collar rot), *Aureobasidium pullulans* (blue stain: wood), *Cochliobolus lunatus* (head mould of grasses, rice and sorghum), *Corticium rolfsii*, *Fusarium oxysporum*,*F.oxysporum* f.sp. *ciceris* (Fusarium wilt of chickpea), *Nectria haematococca* (dry rot of potato), *Myrothecium verrucaria* (myrothecium blotch), *Paecilomyces lilacinus* (biocontrol: nematodes), *Pasteuria penetrans*,	Most widespread and probably the most serious plant parasitic nematode pest of tropical and subtropical regions throughout the world. It is widely endemic in subtropical and tropical regions.

Nematode Scientific Name Common name Family	Hosts (Major)	Distribution	Natural Enemies (Parasites/ parasitoids/ predators, pathogens) Affecting the Nematode	Remarks
	Medicago sativa, *Oryza sativa*, *Phaseolus* spp. , *P. vulgaris*, and number of hosts belonging to families Cucurbitaceae, Fabaceae, Solanaceae	Manipur, Meghalaya, Orissa, Rajasthan, Sikkim, Tripura, Tamil Nadu, Uttar Pradesh (including Uttranchal), West Bengal (Mathur *et al*., 1970; Raveendran and Nadakal, 1975; Sen and Das Gupta, 1976; Haryana Agricultural University, 1980; Tiwari and Dave, 1985; Prasad, 1986; Mathur and Khera, 1991; Salam, 1991; Bhat and Kaul, 1994)	*Thanatephorus cucumeris*, *Serratia marcescens*, *Trichoderma viride*, *Verticillium chlamydosporium*	
Pratylenchus indicus Das Root lesion nematode Pratylenchidae	*Arachis hypogaea*, *Capsicum annuum*, *Feijoa sellowiana*, *Nicotiana tabacum*, *Oryza sativa*, *Psidium guajava*, *Saccharum officinarum*, *Sorghum bicolor*, *Zea mays* and number of hosts belonging to Solanaceae.	Andhra Pradesh, Bihar, Delhi, Gujarat, Haryana, Himachal Pradesh, Punjab, Karnataka, Kerala, Madhya Pradesh, Maharashtra, Orissa, Rajasthan, Tamil Nadu, Uttar Pradesh (including Uttranchal), West Bengal (CAB International, 2005)	Not reported	A migratory endoparasite of the root cortex. All stages are found in the outer parenchyma cells and never in the vascular tissues. Crop losses upto 48.5 % in grain yield have been reported. These nematodes survive in soil and root debris. Control measures may result in 13-55% increase in yield.

Table 17: Important diseases of rice in India

Pathogen Common Name	Transmission	Geographical Distribution	Host Range	Remarks
Viruses				
Rice tungro bacilliform virus (RTBV) Tungro	*Nephotettix virescens* (synonym *N. impicticeps*); *N. cincticeps*, *N. nigropictus*, *N. malayanus* and *Recilia dorsalis*	Andhra Pradesh, Assam, Bihar, Delhi, Karnataka, Kerala, Madhya Pradesh, Manipur, Orissa, Punjab, Tamil Nadu, Tripura, Uttar Pradesh (including Uttaranchal), West Bengal (Mishra, 1977; Anjaneyulu, 1986; CAB International, 2005)	*Cyperus rotundus*, *Echinochloa colona*, *E. crus-galli*, *E. glabescens*, *Eleusine indica*, *Leersia hexandra*, *Leptochloa chinensis*, *Oryza sativa*, *Panicum repens*	Tungro reached an epidemic level in West Bengal, Bihar and Uttar Pradesh in 1969, and in Kerala in 1973-1974 and in Andhra Pradesh, Orissa and West Bengal 90,000 ha of land was affected (Anjaneyulu *et al*., 1994). In 1984-1985, a tungro outbreak in Tamil Nadu and Andhra Pradesh led to an estimated yield loss of 20,000 t in Tamil Nadu, and 49,000 ha in Andhra Pradesh. In 1998, an outbreak of tungro-like yellow stunt syndrome occurred in Punjab where yield losses were estimated at 30-100% (Azzam *et al*., 1999). Four biological variants of RTBV (L, G1, G2 and Ic) have been described based on their characteristic symptoms in rice cultivars FK 135 and TN1 (Cabauatan *et al*., 1995). RTBV isolates from South Asia (India, Sri Lanka and Bangladesh) differ in sequence from those from South-East Asia (Fan *et al*., 1996; Druka and Hull, 1998). There is microvariation in the sequences of isolates from the Philippines and other countries (Azzam *et al*., 2000a).

Pathogen Common Name	Transmission	Geographical Distribution	Host Range	Remarks
Rice tungro spherical virus (RTSV) Tungro	*Nephotettix virescens (synonym N. impicticeps), N. cincticeps, N. nigropictus, N. malayanus* and *Recilia dorsalis*	Andhra Pradesh, Assam, Bihar, Delhi, Karnataka, Kerala, Madhya Pradesh, Manipur, Orissa, Punjab, Tamil Nadu, Tripura, Uttar Pradesh (including Uttaranchal), West Bengal (Mishra, 1977; Anjaneyulu, 1986)	*Cyperus rotundus, Echinochloa colona*, *E. crus-galli*, *E. glabescens, Leersia hexandra*, *Leptochloa chinensis*, *Oryza sativa*, *Panicum repens*	In south and southeast Asia, tungro, a composite disease caused by RTSV and RTBV, is a major threat to stable rice production in irrigated areas (Hibino, 1989a). Several serological variants of RTSV have been reported (Druka *et al*., 1996; Druka & Hull, 1998). The electrophoretic mobility of RTSV CP3 of Indian isolate differed from that of Southeast Asian isolates (Druka *et al*., 1996). Molecular techniques reveal much microvariation in the sequences encoding CP1 and CP2 (Azzam *et al.*, 2000b).
Rice grassy stunt virus (RGSV) Grassy stunt	*Nilaparvata lugens, N. bakeri* and *N. muiri*	Kerala, Tamil Nadu (Ghosh and Venkataraman, 1994; CAB International, 2005)	*Oryza glaberrima, O. rufipogon, O. sativa*	RGSV incidence was high during 1973-74 and in 1981 in Kerala; in 1972 and 1984 in Tamil Nadu. Since 1984, the incidence has been generally low in Asia. In Kerala, 15,000 ha were affected by RGSV (Gopalakrishnan *et al.*, 1973; Anjaneyulu, 1974; Kulshrestha *et al*., 1974; Santhakumari *et al*., 1982) and yield losses due to the virus and plant hoppers were estimated to be $20 million (Dyck and Thomas, 1979). Different strains of RGSV viz., GSV1 and GSV2 in the Philippines, wilted stunt virus (GSW), grassy stunt B (GSB), grassy stunt Y (GSY) isolates in Taiwan, GSV 2-like strains in India, Indonesia and Thailand are reported

Pathogen Common Name	Transmission	Geographical Distribution	Host Range	Remarks
				(Hibino, 1989b). Serologically, a Japanese isolate was indistinguishable from strains 1 and 2 (Hibino *et al*., 1985) and closely related to severe strains from India (Mariappan *et al.*, 1984) and Thailand (Chettanachit *et al.*, 1985), and to GSB and GSW isolates from Taiwan (Hibino, 1986). Different variants of RGSV were observed in the Philippines. Their relationship with existing strains and the Taiwan isolates has not been determined (Miranda *et al*., 1991).
Rice ragged stunt virus (RRSV) Ragged stunt	*Nilaparvata lugens*	Orissa, Tamil Nadu, West Bengal (Heinrichs, 1978; Ghosh *et al*., 1979; Mishra, 1979; Narayanasamy and Baskaran, 1980; CAB International, 2005)	*Oryza latifolia, O. nivara, O. sativa*	RRSV is sporadically a very serious problem of rice in Thailand, Malaysia, the Philippines, India and Indonesia where yields can be reduced by 50-100% (CAB International, 2005). No strains reported.
Phytoplasma				
Rice yellow dwarf phytoplasma Yellow dwarf	*Nephotettix cincticeps, N. nigropictus, N. virescens, N. malayanus* and *N. parvus*	Andhra Pradesh, Assam, Bihar, Delhi, Karnataka, Kerala, Manipur, Orissa, Tamil Nadu (Arjunan *et al.*, 1985; Singh, 1987; Muniyappa *et al*., 1988; Pun and	*Oryza sativa*	In Karnataka, rice yellow dwarf was more severe in the ratoon than the main crop (Muniyappa *et al*., 1988). Reddy and Jeyarajan (1990) screened 36 cultivars for resistance and suggested the presence of different strains of the pathogen in Tamil Nadu.

Pathogen Common Name	Transmission	Geographical Distribution	Host Range	Remarks
		Das, 1992; CAB International, 2005)		
Bacteria				
Acidovorax avenae subsp. *avenae* (Manns) Willems Bacterial brown stripe	Seed	Bihar, Delhi, Maharashtra, Punjab, Tamil Nadu, Uttar Pradesh (including Uttaranchal) (CAB International, 2005)	*Oryza sativa*, *Saccharum officinarum*, *Sorghum bicolor*, *Zea mays*	Bacterial brown stripe is frequently detected in rice-growing countries (Shakya *et al*., 1985), but the disease is considered to have low epidemic potential (Cottyn *et al*., 1994). Losses are related to the inhibition of seed germination and to seedling damage in nursery boxes adapted to mechanized transplanters (Goto *et al*., 1988).
Xanthomonas oryzae pv. *oryzae* (Ishiyama) Swings *et al.* Bacterial leaf blight	Seed	Andaman and Nicobar Islands, Andhra Pradesh, Arunachal Pradesh, Assam, Bihar, Delhi, Goa, Gujarat, Haryana, Jammu and Kashmir, Karnataka, Kerala, Madhya Pradesh, Maharashtra, Manipur, Meghalaya, Mizoram, Nagaland, Orissa, Punjab, Sikkim, Tamil Nadu, Tripura, Uttar Pradesh (including Uttaranchal), West	*Leptochloa chinensis*, *Oryza sativa*	In *Kharif* 1999, bacterial leaf blight (BLB) appeared in epidemic form in districts of Punjab where rice cv. Pusa-44 was predominant and suffered about 30% yield loss (http://www.tifac.org.in/itsap/disease.htm). The dominant strains in Madhya Pradesh belong to the pathotype 1 group (Sahu and Sahu, 1988). Pathogenic variability was noted among all the 24 isolates tested at CRRI, Cuttack (Tembhurnikar, 1989). At CRRI, Cuttack, using differential hosts, BLB isolates were grouped into six pathotypes. Pathotyping of 241 isolates collected from four different states in eastern India revealed the

Pathogen Common Name	Transmission	Geographical Distribution	Host Range	Remarks
		Bengal (Bradbury, 1986; Ghose *et al*., 1987; Gupta and Choudhury, 1988; Tikoo *et al*., 1987; Reddy and Reddy, 1987; CAB International, 2005)		existence of 20 different pathotypes. Also, pathogen diversity was clearly partitioned according to the site of collection using DNA markers. A total of 15 lineages were detected. The populations examined from Orissa and Raipur were much diverse as they consisted of 8 and 7 out of 15 lineages, respectively, as compared to those from Uttar Pradesh. Collections from a given site tended to consist of related haplotypes (http://crri.nic.in/ Pathology.htm).Natural enemy reported is *Pseudomonas fluorescens* (CAB International, 2005).
Xanthomonas oryzae pv. *oryzicola* (Fang *et al.*) Swings *et al.* Bacterial leaf streak	Seed	Bihar, Karnataka, Madhya Pradesh, Maharashtra, Uttar Pradesh (including Uttaranchal), West Bengal (CAB International, 2005)	*Oryza sativa*	Bacterial leaf streak is much less important than BLB, generally occurring in some areas during very wet seasons and where high rates of nitrogen fertilizer are used. High grain losses due to the disease are therefore rare, because plants have time to recover after a disease outbreak. Losses of up to 30% have been reported in India, but losses are generally lower (Ou, 1985).
Fungi				
Cochliobolus miyabeanus (Ito &	Seed	Andaman and Nicobar Islands, Andhra	*Oryza sativa*	The disease causes blight of seedlings grown from heavily infected seeds. The

Pathogen Common Name	Transmission	Geographical Distribution	Host Range	Remarks
Kurib.) Drechsler ex Dastur Brown leaf spot		Pradesh, Arunachal Pradesh, Assam, Bihar, Chattisgarh, Haryana, Himachal Pradesh, Orissa, Madhya Pradesh, Manipur, Meghalaya, Mizoram, Nagaland, Orissa, Sikkim, Tamil Nadu, Tripura, Uttar Pradesh (including Uttaranchal), West Bengal (Saini, 1985; Reddy and Reddy, 1987; Gupta and Choudhury, 1988; Gupta *et al*., 1992; Naim Uddin and Rama Chakraverty, 1994)		disease reduced the number of tillers and inhibited root and shoot elongation and severe infection reduced both yield (20-40%) and quality (Vidyasekaran and Ramadoss, 1973). Rice isolates of *C. miyabeanus* obtained from different parts of Brazil varied in growth on culture media, incubation temperature, fungicide sensitivity and sectoring (Artigiani and Bedendo, 1996). Non-sporulating isolates grew better than the sporulating isolates in almost all media containing different sources of carbon, nitrogen and amino acids (Diaz and Bedendo, 1999). Natural enemies reported are *Arachnula impatiens*, *Bacillus megaterium*, *B. subtilis*, *Vampyrella vorax*, *Xanthomonas oryzae* pv. *oryzae* (CAB International, 2005).
Gibberella fujikuroi (Sawada) S. Ito Bakanae disease	Seed	Andaman and Nicobar Islands, Andhra Pradesh, Assam, Gujarat, Himachal Pradesh, Karnataka, Kerala, Madhya Pradesh, Maharashtra, Manipur, Meghalaya, Orissa, Punjab, Rajasthan, Uttar	*Gossypium*, *Leucaena leucocephala*, *Lycopersicon esculentum*, *Musa*, *Oryza sativa*, *Pinus*, *Saccharum officinarum*, *Sorghum bicolor*, *Vigna unguiculata*, *Zea mays*	Pavgi and Singh (1964) stated that losses of 15% occurred in eastern districts of Uttar Pradesh, India. Nisikado and Matsumoto (1933) reported that among 66 strains of *G. fujikuroi* obtained from rice and five strains of *G. moniliformis* var. *majus*, there were marked differences in pathogenicity as indicated by the degree of overgrowth. Four

Pathogen Common Name	Transmission	Geographical Distribution	Host Range	Remarks
		Pradesh (including Uttaranchal), West Bengal (Pavgi and Singh, 1964; Singh and Srivastava, 1989; CAB International, 2005)		antagonistic bacteria, designated as B-916, 91-2, A-2 and A-3, used in seed soaking gave good control of bakanae and significantly increased yield (Lu *et al*., 1999).
Magnaporthe grisea (Hebert) Barr Blast	Seed	Andaman and Nicobar Islands, Andhra Pradesh, Arunachal Pradesh, Assam, Bihar, Chattisgarh, Gujarat, Himachal Pradesh, Jammu and Kashmir, Karnataka, Kerala, Madhya Pradesh, Maharashtra, Manipur, Meghalaya, Mizoram, Nagaland, Orissa, Sikkim, Tamil Nadu, Tripura, Uttar Pradesh (including Uttaranchal), West Bengal (Reddy and Reddy, 1987)	*Oryza sativa*	Blast is one of the most destructive diseases of rice and yield loss can be as high as 50% when the disease occurs in epidemic proportions. Many physiological races were reported from each country, Japan registered 34 (Matsumoto *et al*., 1969), Taiwan 27 (Chien, 1967), USA 16 (Latterell *et al*., 1960; Atkins, 1962), India 31 (Padmanabhan, 1965), the Philippines 250 (Bandong and Ou, 1966; IRRI, 1967, 1975) and Korea 18 (Lee and Cho, 1990), each country using different cultivars for race identification. Veeraraghavan and Dath (1976) found that only the race IC-17 was prevalent in India. This was the predominant race among the 31 reported by Padmanabhan *et al*. (1970). Recent molecular genetic studies indicate that *Pyricularia grisea*, the anamorph of *Magnaporthe grisea* exists as a number of genetically

Pathogen Common Name	Transmission	Geographical Distribution	Host Range	Remarks
				distinct clonal (asexually reproducing) populations occurring as a result of strong selection to maintain host specificity and perhaps geographic isolation (Shull and Hamer, 1994). However, sexual recombination has been reported to occur in wild populations in South and South-East Asia (Zeigler, 1998) and parasexual recombination has been demonstrated in field populations (Zeigler *et al*., 1997). Examination of MGR586 DNA-fingerprint diversity of a collection of *P. grisea* from the United States identified eight lineages (Levy *et a*l., 1991; Xia *et al*., 1993). The population genetics of *M. grisea* were analyzed in a center of rice diversity (the Uttar Pradesh hills of the Indian Himalayas) using multilocus and single-, or low-copy DNA markers. It was observed that Himalayan *M. grisea* populations are diverse and dynamic and the structure of some populations may be affected to some extent by sexual recombination (Kumar *et al*., 1999).Natural enemies reported are *Acidovorax avenae* subsp. *avenae* (bacterial leaf blight), *Aspergillus niger* (Aspergillus ear rot), *Trichoderma harzianum*, *T. koningii*,

Pathogen Common Name	Transmission	Geographical Distribution	Host Range	Remarks
				T. pseudokoningii (CAB International, 2005).
Sarocladium oryzae (Sawada) W. Gams & D. Hawksw. Sheath rot	Seed	Andaman and Nicobar Islands, Andhra Pradesh, Arunachal Pradesh, Assam, Bihar, Haryana, Karnataka, Kerala, Madhya Pradesh, Manipur, Meghalaya, Mizoram, Nagaland, Orissa, Punjab, Rajasthan, Tamil Nadu, Tripura, Uttar Pradesh (including Uttaranchal), West Bengal (Reddy and Reddy 1987; CAB International, 2005)	*Oryza rufipogon*, *O. sativa*	The disease caused upto 57% loss in South India (Mohan and Subramanian, 1978) and in West Bengal, Chakravarty and Biswas (1978) reported yield losses of 10-26% (average estimate of 14%). In the Punjab, averages of 30% disease incidence and 70% disease severity, with 15-35% grain chaffiness were reported. In severe cases, 100% seed sterility and no panicle emergence were observed (Raina and Singh, 1980). In 1982, sheath rot caused losses of upto 50% (Kang and Rattan, 1983). Severe sheath rot infection was observed to affect the number of filled spikelets, the quality of rice grains, the 1000-grain weight, seed germination percentage and the protein content of grains (Vidhyasekaran *et al.*, 1984). Reduction in sheath rot disease index due to treatment with *Pseudomonas fluorescens* was reported to vary from 32 to 42% in the five rice cultivars tested, with corresponding yield increases of 3-62% (Sakthivel and Gnanamanickam, 1987). Natural enemies reported are *Bipolaris zeicola* [*Cochliobolus carbonum*] *P. fluorescens* and culture filtrates of B.

Pathogen Common Name	Transmission	Geographical Distribution	Host Range	Remarks
				zeicola [*Cochliobolus carbonum*] completely inhibited mycelial growth of *S. oryzae* (Viswanathan and Narayanasamy, 1990).
Sphaerulina oryzina Hara Narrow brown leaf spot	Seed	Karnataka, Tamil Nadu, Uttar Pradesh (including Uttaranchal) (Sanne-Gowda *et al*., 1973; Kannaiyan,1979; Singh, 1988; CAB International, 2005)	*Oryza sativa*	Narrow brown leaf spot was of significant concern in the USA in the 1930s and 1940s because of the high degree of susceptibility in some commercial cultivars (Ou, 1985). The disease may cause severe damage to susceptible varieties by reducing the green surface area of leaves, resulting in death of the leaves and sheaths (Misra *et al*., 1994). The disease has a low economic impact when resistant cultivars are used, but in the US, new cultivars become susceptible within 3-4 years of release (Groth *et al.*, 1990). Many physiological races have been identified on the basis of reactions on differential varieties of rice (Padwick, 1950; Estrada *et al*., 1981; Sah and Rush, 1988).
Thanatephorus cucumeris (Frank) Donk Sheath blight	Seed	Andaman and Nicobar Islands, Andhra Pradesh, Arunachal Pradesh, Assam, Bihar, Delhi, Gujarat, Haryana, Himachal Pradesh, Jammu and	*Arachis hypogaea*, *Beta vulgaris var. saccharifera*, *Brassica napus* var. *napus*, *B.oleracea var. botrytis*, *B. oleracea* var. *capitata*, *B. rapa* subsp. *rapa*, *Capsicum annuum, Citrus* , *Cucumis sativus*, , *Daucus carota*, *Elaeis guineensis*, *Glycine max*, *Hordeum vulgare*, *Lactuca sativa*, *Lupinus*,	Field experiments during the rainy seasons of 1986 and 1987 indicated that an increase of 1% in sheath blight incidence resulted in a 0.38% loss in grain yield (Saikia and Baruah, 1990). The losses due to sheath blight have been reported to vary from 5-13.5 %

Pathogen Common Name	Transmission	Geographical Distribution	Host Range	Remarks
		Kashmir, Karnataka, Kerala, Madhya Pradesh, Maharashtra, Manipur, Meghalaya, Nagaland, Orissa, Punjab, Rajasthan, Sikkim, Tamil Nadu, Tripura, Uttar Pradesh (including Uttaranchal), West Bengal (Reddy and Reddy, 1987; Bilgrami *et al*., 1991)	*Lycopersicon esculentum, Manihot esculenta, Medicago sativa, Oryza sativa, Oxalis tuberosa, Phaseolus, Raphanus sativus, Solanum melongena, S. tuberosum, Sorghum bicolor, Trifolium, Triticum, T. aestivum, Tulipa, Ullucus tuberosus, Vigna radiata, V. unguiculata, Zea mays*	in Punjab (http://www.tifac.org.in/itsap/disease.htm). Chien and Chung (1963) studied 300 isolates from Taiwan, inoculated on 16 rice cultivars. Based on the degree of pathogenicity, they classified the 300 isolates into 7 cultural types and 6 physiologic races. Isolates differing in virulence were also reported by Tsai (1973) among 40 single basidiospore cultures, and by Haque (1975) among 25 field isolates, but no distinct differential reaction was noticed. Although earlier studies suggested that AG-1 IA represented a homogeneous group of isolates, recent investigations support the hypothesis that the sheath blight pathogen is far more diverse than previously assumed. Knowledge of field populations of this pathogen is still scarce, particularly in tropical agroecosystems (Banniza *et al*., 1999). Natural enemies reported are protozoa, nematodes, Collembola, earthworms, mycoparasitic fungi including *Fusarium* spp., *Gliocladium* spp., *Pythium* spp., *Trichoderma* spp., *Verticillium* spp. and bacterial antagonists such as *Pseudomonas* spp., and Actinomycetes (CAB International, 2005).

Pathogen Common Name	Transmission	Geographical Distribution	Host Range	Remarks
Ustilaginoidea virens (Cke.) Tak. False smut	Seed	Andaman and Nicobar Islands, Andhra Pradesh, Assam, Bihar, Haryana, Jammu and Kashmir, Karnataka, Maharashtra, Manipur, Orissa, Punjab, Rajasthan, Tamil Nadu, Uttar Pradesh (including Uttaranchal) (Tyagi and Sharma, 1978; Singh, 1984; Sharma and Chaudhury, 1986; Reddy and Reddy, 1987)	*Oryza sativa*	False smut has been considered a minor disease, but sporadic severe incidences have been reported that cause losses because grain weight decreases as a result of the number of smutted balls that replace grains per panicle (Singh and Dube, 1978). In India, losses varied from 7 to 75% (Agarwal and Verma 1981). In Uttar Pradesh, yield losses upto 44% were observed by Singh and Dube (1978). In Punjab, yield losses upto 16.8% were reported (Dhindsa *et al*., 1991). This disease reduced the yield of the cv. Mashuri by 9.2% by increasing numbers of chaffy grains and decreasing grain weight. It may become economically important under favourable conditions (Baruah *et al*., 1992).

SECTION IX - STATUS OF TRANSGENIC RICE IN INDIA

The ever-increasing human population especially in the developing countries and various biotic and abiotic stresses has posed a challenge to boost the rice production in a limited cultivated land. Genetically engineered plants with genes expressing desirable traits can be produced in a relatively short time with more precision and can be of direct value in the agri-food industry.

More recent applications of biotechnology to rice breeding, particularly genetic transformation of rice, was started in late 1980s. Polyethylene glycol (PEG), electroporation, particle gun bombardment and *Agrobacterium* have been used to mediate gene transfer. Among these, PEG has had only limited use in recent years. Electroporation directly introduces foreign genes into the protoplasts. Improvement in efficiency and stability of regeneration from protoplasts to plantlets is another factor contributing to the development of this method. The biolistic (particle gun bombardment) method directly introduces foreign genes into regenerable plant cells such as scutellum cells. The main merit of this method is that it eliminates the problems of regeneration from protoplasts and minimizes the possibility of the occurrence of somaclonal variation during the regeneration process. *Agrobacterium*-mediated transformation in rice has also been employed successfully. Its main merit includes insertion of a more precise gene construct, including promoters and marker genes on the plasmids, which results in the improved efficiency of gene introduction as well as more stable expression and inheritance of the transgenes.

After the introduction of foreign genes into rice plant tissue, a suitable selection system is required to select plants that have been successfully transformed. In the case of rice, selectable markers usually constitute genes that confer resistance to antibiotics. Among them, kanamycin was used in early stages, but most of the recent successful results of rice transformation have been obtained using hygromycin and geneticin (G418) due to their more efficient and stable function in selection procedures.

Several agronomically important genes have been introduced into rice to improve resistance/ tolerance to biotic and abiotic stresses using various available transformation methods. Mohanty *et al.* (1999) reported *Agrobacterium*-mediated transformation of an elite indica rice variety Pusa Basmati 1 using the gene construct having *npt II* gene for hygromycin resistance and *gus* gene encoding β-D-glucuronidase. *Agrobacterium*-mediated transformation of other indica varieties is also under progress.

Two Bt rice transgenic varieties of IR64 and Pusa Basmati 1 using the gene constructs *cry* 1*Ac* have been developed by Khanna and Raina in 2002. These transgenic rice plants expressed modified endotoxin of *Bacillus thuringiensis* and showed enhanced resistance to yellow stem borer (*Scirpophaga incertulas*). The evaluation of generated rice transgenic lines, in particular the bioassays along with the field evaluations were undertaken successfully (Annual Report 2002-2003; NRC on Plant Biotechnology, Raina *et al*., 2002). It is expected that transformed rice plants with modified/desired traits will be released in near future, supported by developments both in basic genome research and in transformation technologies in India.

Carefully planned commercialization and monitoring of transgenic crops after evaluation of potential risks would be required to sustain biodiversity and to harness the benefits of these crops.

SECTION X - REFERENCES

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