Series of Crop Specific Biology Documents

Biology of *Oryza sativa L.* (Rice)

सत्यमेव जयते

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Biology of *Oryza sativa L.* (Rice)

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FOREWORD

India is one of the leading countries having an active agricultural biotechnology research and development programmes in diverse crops including cereals, vegetables, oilseeds etc. and traits such as insect, disease, and virus resistance, herbicide tolerance, stress tolerance etc. The successful development and commercialization of biotech derived crops also referred as genetically engineered (GE) or genetically modified (GM) crops requires a science based regulatory process to address the concerns arising out of genetic manipulation to human health and environment.

The Department of Biotechnology (DBT), as one of the implementing agencies for biosafety regulations in India has been providing science based support for evaluating the GM crops by preparing various guidance documents and disseminating information through websites. In continuation with the above efforts, a need was felt to prepare crop specific biology documents to provide relevant baseline information about various crops in a readily accessible format.

I am pleased to note that Dr. K.K. Tripathi, Advisor, DBT and Member Secretary, RCGM has put in considerable efforts in putting together a series of five crops specific biology documents on cotton, brinjal, okra, maize and rice, in association with the Ministry of Environment and Forests (MoEF). The biology documents have been put through a consultative process with various stakeholder viz. agriculture research institutions, state agricultural universities, industry etc. The views have been taken by circulating the documents to relevant institutions as well as by placing them on websites. The documents have also been reviewed by the members of RCGM and GEAC. Biotech Consortium India Limited (BCIL) provided support in compiling the baseline information, as well as the consultative process.

I believe that these crop specific biology documents would be of immense value for both the developers in planning the safety assessment of their products as also the regulators for evaluating the data submitted to them. Scientific developments being advancing at a rapid rate, I hope that these biology documents would be continuously updated from time to time.

(M.K. Bhan)

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PREFACE

Genetically engineered (GE) crops are regulated products in view of various concerns for human and animal health and environment. Extensive evaluation and regulatory approval process take place before any GE crop is introduced for cultivation. The approval for release of a GE crop is given by the Genetic Engineering Approval Committee (GEAC) functioning in the Ministry of Environment and Forests (MoEF) as per "Rules for the manufacture, use, import, export & storage of hazardous microorganisms, genetically engineered organisms or cells, 1989" notified under the Environment (Protection) Act, 1986.

So far, Bt cotton, is the only GE crop approved for commercial cultivation in India. There are several crops under various stages of research, development and field trials. The present set of crop specific biology documents has been prepared jointly by MoEF and the Department of Biotechnology (DBT) to provide scientific baseline information used for safety assessment of GE crops. These biology documents have sections on taxonomy, economic importance, centre of origin, growth and development (vegetative and reproduction biology), ecological interactions, distribution pattern in India etc.

I wish to put on record my appreciation of the sincere efforts put in by Dr. Ranjini Warrier, Director, MoEF who has worked closely with DBT and other stakeholders for this initiative and the consultative approach adopted in finalizing these documents. I also acknowledge the support of members of both GEAC and RCGM for their useful inputs during the review process. The inputs and support provided by Dr O.P. Govila, Former Professor of Genetics, Indian Agricultural Research Institute (IARI) and Dr. Vibha Ahuja, General Manager, Biotech Consortium India Limited (BCIL) has also been extremely valuable.

I am sure that these crop specific biology documents would serve as practical tools for researchers, regulators and industry.

(M.F. Farooqui)

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PROLOGUE

Modern biotechnology like any new technology has its associated benefits and risks. Accordingly products of modern biotechnology like biopharma, genetically engineered (GE) crops etc. are regulated for ensuring safety to human and animal health and environment. In case of GE crops, scientific assessments ensure food safety and environmental safety, an integral part of approval process. The whole process of safety assessment is based upon comparison between genetically engineered crop and its unmodified counterpart and thus requires a broad understanding and knowledge of various features of the crop plants. This familiarity with the crops allows both the developers and regulators to draw on previous knowledge and experience to ensure safety of the GE crops.

Keeping in view the above, the Department of Biotechnology (DBT) and the Ministry of Environment and Forests initiated the preparation of a "Series of Crop Specific Biology Documents" to provide information directly relevant to safety assessment in a readily accessible format. The objective of these documents is to make available the information about biology of the crops to applicants as information in applications to regulatory authorities; to regulators as a guide and reference source in their regulatory reviews; and for information sharing, research reference and public information. To start with, crop specific documents for five crops viz. cotton, brinjal, maize, okra and rice have been prepared. In addition to the scientific literature and references, the documents have also taken into account the information available in Consensus documents published by OECD as well as biology documents by other countries. The documents have been finalized through a consultative process with the concerned research institutions, state agricultural universities and subject experts. The documents were also placed on DBT's biosafety website for public review.

It is proposed to continue this exercise for more crops such as mustard, potato, tomato etc. that are under development. The support from various technology developers from both public and private sector, state agricultural universities, agricultural research institutions and other subject experts in providing information as well as reviewing these documents is acknowledged. We also appreciate the assistance provided by Dr. Vibha Ahuja, General Manager, Biotech Consortium India Limited, Dr. O.P. Govila, Former Professor of Genetics, Indian Agricultural Research Institute and other team members at BCIL for backend support in finalizing these documents.

Dr. Ranjini Warrier **Dr. K.K. Tripathi**

CONTENTS

BIOLOGY OF *ORYZA SATIVA L.* (RICE)

1. RICE AS A CROP PLANT

Rice (*Oryza sativa* L.) is a plant belonging to the family of grasses, Gramineae (Poaceae). It is one of the three major food crops of the world and forms the staple diet of about half of the world's population. The global production of rice has been estimated to be at the level of 650 million tones and the area under rice cultivation is estimated at 156 million hectares (FAOSTAT, 2008). Asia is the leader in rice production accounting for about 90% of the world's production. Over 75% of the world supply is consumed by people in Asian countries and thus rice is of immense importance to food security of Asia. The demand for rice is expected to increase further in view of expected increase in the population.

India has a long history of rice cultivation. Globally, it stands first in rice area and second in rice production, after China. It contributes 21.5 percent of global rice production. Within the country, rice occupies one-quarter of the total cropped area, contributes about 40 to 43 percent of total food grain production and continues to play a vital role in the national food and livelihood security system. India is one of the leading exporter of rice, particularly basmati rice.

O. sativa has many ecotypes or cultivars adopted to various environmental conditions. It is grown in all continents except Antarctica. In fact, there is hardly any crop plant that grows under as diverse agro-climatic condition as rice does (Box 1).

Box 1: Diverse growing condition of rice

Rice is now cultivated as far north as the banks of the Amur River (53° N) on the border between Russia and China, and as far south as central Argentina (40° S) (IRRI, 1985). It is grown in cool climates in the mountains of Nepal and India, and under irrigation in the hot deserts of Pakistan, Iran and Egypt. It is an upland crop in parts of Asia, Africa and Latin America. The other environmental extremes are floating rices, which thrive in seasonal deeply flooded areas such as river deltas - the Mekong in Vietnam, the Chao Phraya in Thailand, the Irrawady in Myanmar, and the Ganges-Brahmaputra in Bangladesh and eastern India etc. Rice can also be grown in saline, alkali or acidsulphate soils. Clearly, it is well adapted to diverse growing conditions.

Source: OECD, 1999

The morphology, physiology, agronomy, genetics and biochemistry of *O. sativa* have been intensely studied over a long time. More than 40,000 varieties of rice had been reported worldwide. Crop improvement research in case of rice had been started more than a century back. Extensive adoption of higher yielding varieties has enabled many countries in Asia to achieve sustained self sufficiency in food. In India rice is grown under four ecosystems: irrigated, rainfed lowland, rainfed upland and flood prone.

More than half of the rice area (55%) is rainfed and distribution wise 80% of the rainfed rice areas are in eastern India, making its cultivation vulnerable to vagaries of monsoon.

Rice is a nutritious cereal crop, used mainly for human consumption. It is the main source of energy and is an important source of protein providing substantial amounts of the recommended nutrient intake of zinc and niacin (Table 1). However, rice is very low in calcium, iron, thiamine and riboflavin and nearly devoid of beta-carotene.

Table 1: Composition per 100 g of edible portion of milled rice

Calories (kcal)	345.0	Calcium (mg)	10.0
Moisture (g)	13.7	Iron (mg)	0.7
Carbohydrates (g)	78.2	Magnesium (mg)	90.0
Protein (g)	6.8	Riboflavin (mg)	0.06
Fat (g)	0.5	Thiamine (mg)	0.06
Fibre (g)	0.2	Niacin (mg)	1.9
Phosphorus (mg)	160.0	Folic acid (mg)	8.0
Minerals (g)	0.6	Copper (mg)	0.14
Essential amino acids (mg)	1.09		

Source: Gopalan et al., 2007.

Rice protein is biologically the richest by virtue of its high true digestibility (88%) among cereal proteins and also provides minerals and fibre. Calories from rice are particularly important for the poor accounting for 50-80% of the daily caloric intake. Rice can also be used in cereals, snack foods, brewed beverages, flour, oil (rice bran oil), syrup and religious ceremonies to name a few other uses. Rice is also believed to have medicinal properties and used in many countries for the same including in India.

Rice is classified primarily based on its grain size and shape. Uniform standard grain classification is used in India for grouping the varieties into 5 groups based on the length/length-breadth ratio of the kernel. This classification has been developed by the Ramaiah Committee in 1965 which was appointed by Government of India. Similar international classification has also been developed by International Rice Research Institute (IRRI), Philippines which also takes into consideration the grain length-width (breadth) ratio. As per Indian classification, rice varieties are grouped as Long Slender and Long Bold where the length is 6 mm and above and the length-breadth ratio is either 3 and above or less than 3 respectively. Likewise the varieties which are classified as Short Slender and Short Bold where the length is less than 6 mm and the length-breadth ratio is more than 3 or less than 2.5 respectively. There is a Medium Slender category which has a grain length of less than 6 mm and the length-breadth ratio between 2.5 to 3.

Amylose content varies from 2% to more than 25% and varieties with low (2-19%), intermediate (20-25%) and high (>25%) amylose content are available in all grain types. However, only in case of japonicas, short bold or round grains in general have only low (<20%) and very low (2-8%) amylose content.

Husk, bran and broken rice are the by-products of the rice milling industries. These by-products can be used in better and profitable manner both for industrial human and animal consumption. Rice husk constitutes the largest by-product of rice milling and one fifth of the paddy by weight consists of rice husk. Rice husk has a considerable fuel value for a variety of possible industrial uses. Hence, the major use of husk at the moment is as boiler fuel. Rice husk is also a rich source of silica. Rice bran is the most valuable by-product of the rice milling industry. It is obtained from the outer layers of the brown rice during milling. Rice bran consists of pericarp, aleurone layer, germ and a part of endosperm. Rice bran can be utilized in various ways. It is a potential source of vegetable oil, feed, fertilizers etc. Rice bran oil is one of the healthiest oil for human consumption.

2. TAXONOMY, GEOGRAPHIC ORIGIN AND GENOMIC EVOLUTION

2.1 Taxonomy

Rice belongs to the genus *Oryza* and the tribe Oryzeae of the family Gramineae (Poaceae). The genus *Oryza* contains 25 recognized species, of which 23 are wild species and two, *O. sativa* and *O. glaberrima* are cultivated (Morishima, 1984; Vaughan, 1994; Brar and Khush, 2003). *O. sativa* is the most widely grown of the two cultivated species. It is grown worldwide including in Asian, North and South American, European Union, Middle Eastern and African countries. However, *O. glaberrima* is grown solely in West African countries.

Name	Rice
Kingdom	Plantae
Division	Magnoliophyta
Class	Liliopsida
Order	Poales
Family	Gramineae o Poaceae
Tribe	Oryzeae
Genus	*Oryza*
Species	*sativa*

2.2 Geographic Origin

The centre of origin and centres of diversity of two cultivated species *O. sativa* and *O. glaberrima* have been identified using genetic diversity, historical and archaeological evidences and geographical distribution. It is generally agreed that river valleys of Yangtze, Mekon rivers could be the primary centres of origin of *O. sativa* while Delta of Niger River in Africa as the primary centre of origin of *O. glaberrima* (Porteres, 1956; OECD, 1999). The foothills of the Himalayas, Chhattisgarh, Jeypore Tract of Orissa, northeastern India, northern parts of Myanmar and Thailand, Yunnan Province of China etc., are some of the centres of diversity for Asian cultigens. The Inner delta of Niger river and some areas around Guinean coast of the Africa are considered to be centre of diversity of the African species of *O. glaberrima* (Chang, 1976; Oka, 1988).

O. sativa and *O. glaberrima* are believed to have evolved independently from two different progenitors, viz. *O. nivara* and *O. barthii* and they are believed to be domesticated in South or South East Asia and tropical West Africa respectively. The progenitors of *O. sativa* are considered to be the Asian AA genome diploid species and those of *O. glaberrima* to be African AA genome diploid species *O. barthii* and *O. longistaminata* as indicated in various reviews by Chang, 1976; Siddiq and Viraktamath, 2001 and NBPGR, 2006 (Figure 1).

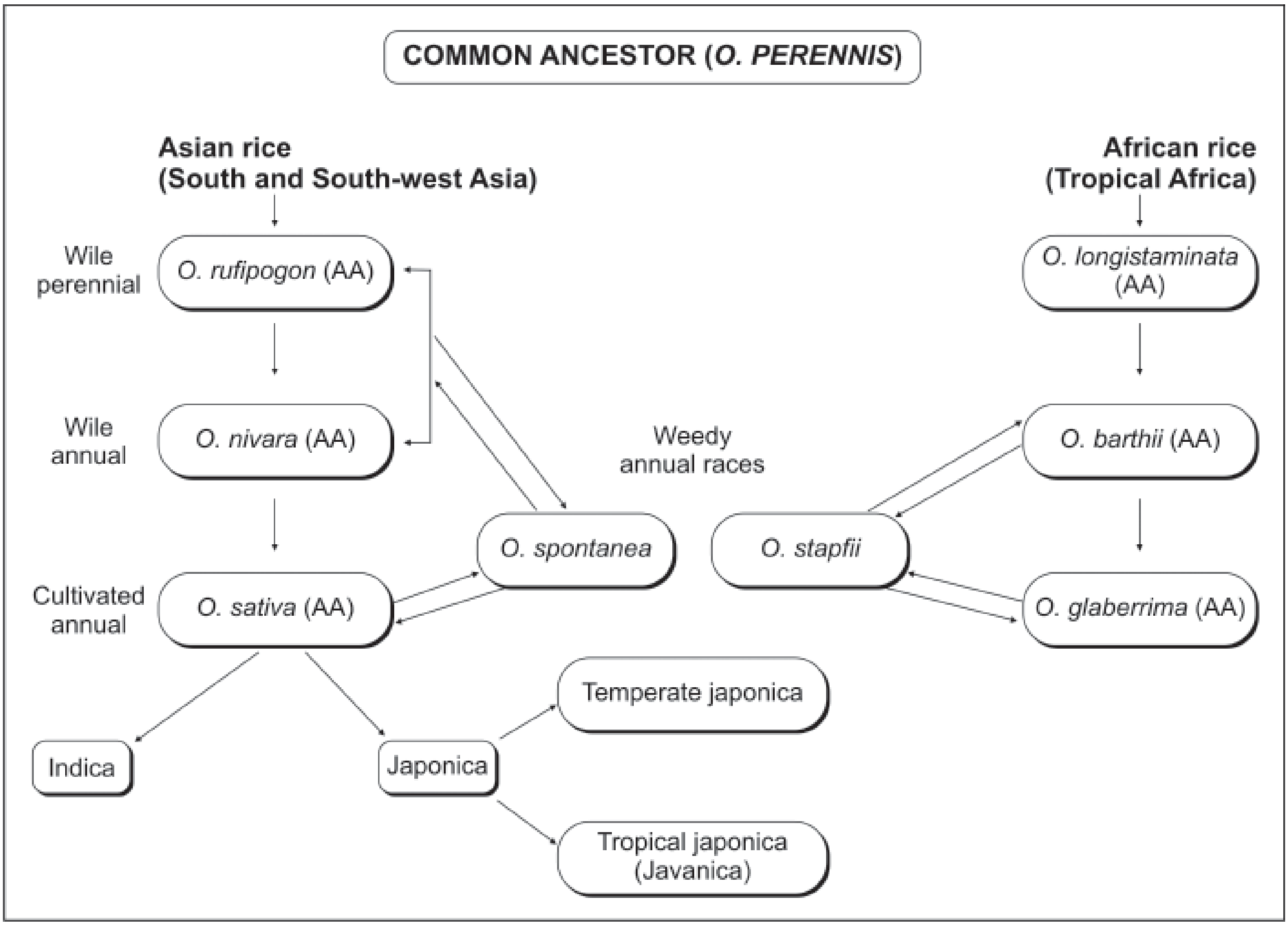


Figure 1: *Schematic representation of the evolutionary pathways of Asian and African cultivated rices*

Domestication of Asian rice, *O. sativa*, is considered to have occurred in 7,000 BC (OECD, 1999). It has spread and diversified to form two ecological groups, Indica and Japonica (Oka, 1988). There are other studies indicating that the two groups were derived independently from the domestication of two divergent wild rices in China and India, respectively (Second, 1982; 1986).

2.3 Rice Gene Pool and Species Complexes

The species of the genus *Oryza* are broadly classified into four complexes (Vaughan, 1994) viz. Sativa, Officinalis, Ridley and Meyeriana (Table 2). Of these, Sativa and Officinalis complexes are the best studied. The Sativa complex comprises the cultivated species *O. sativa* and *O. glaberrima* and their weedy/wild ancestors viz., perennial rhizomatous *O.longistaminata, O.barthii* (formerly *O. breviligulata*) and *O. rufipogon, O. nivara* and *O. sativa f. spontanea*.

Table 2: Species complexes of the genus *Oryza* and their geographical distribution

	Species Complex	Chromosome Number	Genome	Geographical Distribution
I.	**Sativa complex**			
	1. *O. sativa* L.	24	AA	Worldwide: originally South & Southeast Asia
	2. *O. nivara* Sharma et Shastry	24	AA	South & Southeast Asia
	3. *O. rufipogon* Griff.	24	AA	South & Southeast Asia, South China
	4. *O. meridionalis* Ng	24	AA	Tropical Australia
	5. *O. glumaepetula* Steud.	24	AA	Tropical America
	6. *O. glaberrima* Steud.	24	AA	Tropical West Africa
	7. *O. barthii* A. Chev. et Roehr	24	AA	West Africa
	8. *O. longistaminata* A. Chev. et Roehr.	24	AA	Tropical Africa
II.	**Officinalis Complex/ Latifolia complex**			
	9. *O. punctata* Kotschy ex Steud.	24	BB	East Africa
	10. *O. rhizomatis* Vaughan	24	CC	Sri Lanka
	11. *O. minuta* J.S.Pesl. ex C.B.Presl.	48	BBCC	Philippines, New Guinea
	12. *O. malamphuzaensis* Krishn. et Chandr.	48	BBCC	Kerala & Tamil Nadu
	13. *O. officinalis* Wall. ex Watt	24	CC	South & Southeast Asia
	14. *O. eichingeri* A. Peter	24	CC	East Africa & Sri Lanka
	15. *O. latifolia* Desv.	48	CCDD	Central & South America
	16. *O. alta* Swallen	48	CCDD	Central & South America
	17. *O. grandiglumis* (Doell) Prod.	48	CCDD	South America
	18. *O. australiensis* Domin.	24	EE	Northern Australia
	19. *O. schweinfurthiana* Prod.	48	BBCC	Tropical Africa
III.	**Meyeriana Complex**			
	20. *O. granulata* Nees et Arn. ex Watt	24	GG	South & Southeast Asia
	21. *O. meyeriana* (Zoll. et Mor. ex Steud.) Baill.	24	GG	Southeast Asia
IV.	**Ridleyi Complex**			
	22. *O. longiglumis* Jansen	48	HHJJ	Indonesia, New Guinea
	23. *O. ridleyi* Hook. f.	48	HHJJ	Southeast Asia
V.	**Unclassified (belonging to no complex)**			
	24. *O. brachyantha* A. Chev. et Roehr.	24	FF	West & Central Africa
	25. *O. schlechteri* Pilger	48	HHKK	Indonesia, New Guinea

Source: Brar and Khush, 2003

The basic chromosome number of the genus *Oryza* is 12. *O. sativa*, *O. glaberrima* and 14 wild species are diploids with 24 chromosomes, and eight wild species are tetraploids with 48 chromosomes. Genome analysis done on the basis of chromosome pairing behaviour and fertility in interspecific hybrids and degree of sexual compatability, has made possible to group them under nine distinct genomes, viz., A, B, C, D, E, F, G, H and J. On the basis of crossability and ease of gene transfer, the primary gene pool of rice is known to comprise the species of Sativa complex, while the species belonging to Officinalis complex constitute the secondary gene pool. 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 gene pool (Chang, 1964). A brief description of each of these complexes is given in Box 2.

Box 2: Species complexes of *Oryza*

- **Sativa complex:** This complex consists of two cultivated species and six wild taxa. All of them have the *AA* genome and form the primary gene pool for rice improvement. Wild species closely related to *O. sativa* have been variously named. The weedy types of rice have been given various names, such as '*fatua*' and '*spontanea*' in Asia and *Oryza stapfii* in Africa. These weedy forms usually have red endosperm – hence the common name 'red rice'. These weedy species may be more closely related to *Oryza rufipogon* and *Oryza nivara* in Asia and to *Oryza longistaminata* or *Oryza breviligulata* in Africa. One of the species, *Oryza meridionalis*, is distributed across tropical Australia. This species is often sympatric with *Oryza australiensis* in Australia.
- **Officinalis complex:** The *Officinalis* complex consists of nine species and is also called the *Oryza latifolia* complex (Tateoka, 1962a). This complex has related species groups in Asia, Africa and Latin America. The tetraploid species *Oryza minata* is sympatric with *Oryza officinalis* in the central islands of Bohol and Leyte in the Philippines. *Oryza eichingeri*, grows in forest shade in Uganda. It was found distributed in Sri Lanka (Vaughan, 1994). Two species of this complex, *Oryza punctala* and *O. eichingeri*, are distributed in Africa. Three American species of this complex, *O. latifolia*, *Oryza alta* and *Oryza grandiglumis* are tetraploid. *Oryza latifolia* is widely distributed in Central and South America, as well as in the Caribbean Islands. A diploid species *O. australiensis*, occurs in northern Australia in isolated populations.
- **Meyeriana complex:** This complex has two diploid species, *Oryza granulate* and *Oryza meyeriana*. *Oryza granulate* grows in South Asia, South-East Asia and south-west China. *Oryza meyeriana* is found in South-East Asia. Another species, *Oryza indandamanica* from the Andaman Islands (India), is a sub-species of *O. granulate*. The species of this complex have unbranched panicles with small spikelets.
- **Ridleyi complex:** This complex has two tetraploid species, *Oryza ridleyi* and *Oryza longiglumis*. Both species usually grow in shaded habitats, near rivers, streams or pools. *Oryza longiglumis* is found along the Komba River, Irian Jaya, Indonesa, and in Papua New Guinea. *Oryza ridleyi* grows across South-East Asia and as far as Papua New Guinea.
- ***Oryza brachyantha***: This species is distributed in the African continent. It grows in the Sahel zone and in East Africa, often in the laterile soils. It is often sympatric with *O. langistaminata*.
- ***Oryza schlechtri***: This is the least studied species of the genus. It was collected from north-east New Guinea. It is a tufted perennial, with 4-5 cm panicles and small, unawned spikelets. It is tetraploid, but its relationship to other species is unknown.

2.4 Sub-specific Differentiation of the Asian Cultivated Rice

The subspecies or varietal groups of *O. sativa* viz., indica, japonica and javanica (Table 3), are the result of centuries of selection by man and nature for desired quality and adaptation to new niches. Most differentiation occurred in the region extending from the southern foothills of the Himalayas to Vietnam. These can be distinguished on few key characteristics such as glume size, number of secondary panicle branches (rachii), panicle thickness etc.

Table 3: Characteristics of *Oryza sativa* varietal groups

Characteristics	Subspecies		
	Indica	Japonica	Javanica
Tillering	High	Low	Low
Height	Tall	Medium	Tall
Lodging	Easily	Not easily	Not easily
Photoperiod	Sensitive	Non-sensitive	Non-sensitive
Cool temperature	Sensitive	Tolerant	Tolerant
Grain shattering	Easily	Not easily	Not easily
Grain type	Long to medium	Short and round	Large and bold
Grain texture	Non-sticky	Sticky	Intermediate

According to Sharma *et al.* (2000), the subspecies are believed to have evolved from 3 different populations of *O. nivara* existed then in different regions. The hill rices of south east India, the japonica like types of south-west China and the hill rices of Indo-China are said to have directly evolved from the annual wild species in the respective regions. The aus ecotype of West Bengal seems to have directly evolved from the upland rices of south east India, whereas aman type from introgression of rufipogon genes into aus type somewhere in the lower Gangetic Valley. The sali type of Assam had possibly evolved from introgression of *O. rufipogon* genes into japonica like type somewhere in the Brahmaputra Valley. Migration of the hill rice of mainland Southeast Asia to Indonesia following introgression of genes from *O. rufipogon* had possibly led to the evolution of javanica type. The primary ecotypes (aus and japonica) of *O. sativa* have retained photoperiod insensitivity of annual wild species (*O. nivara*), whereas the secondary ecotypes (aman, javanica and sali) have acquired photoperiod sensitivity and adaptation to lowland ecologies.

There is variance in opinion regarding the evolution of three sub species. Londo *et al.* (2006) concluded, based on one chloroplast and two nuclear gene regions, that *Oryza sativa* rice was domesticated at least twice - indica in eastern India, Myanmar and Thailand; and japonica in southern China, although they concede that there is archaeological and genetic evidence for a single domestication of rice in the lowlands of China. Vaughan *et al.* (2008) determined that there was a single domestication event for *Oryza sativa* in the region of the Yangtze river valley, because the functional allele for non-shattering - the critical indicator of domestication in grains as well as five other single nucleotide polymorphisms, is identical in both indica and japonica.

The genetic affinity between the three subspecies as studied from chromosome pairing behaviour, F1 sterility and F2 segregation pattern reveal indica-japonica to show the least compatibility as compared to indica-javanica and javanica-japonica crosses. The genetic differences between indica and japonica have been explained through genic (Oka, 1953; 1974) and chromosomal (Sampath, 1962; Henderson *et al.*, 1959) models. With the discovery of wide compatible varieties and proposition of the concept of allelic interaction to explain hybrid sterility/fertility the whole subject of affinity between the ecotypes (issue of hybrid sterility) has changed greatly (Ikehashi and Arai, 1984; 1986 and 1987; Ikehashi *et al.*, 1991).

2.5 Important Cultivated Species/Wild Relatives in Southeast Asia

India has abundant resources of wild rices particularly *O. nivara*, *O.rufipogon*, *O.officinalis*, and *O. granulata*. The wild species of rices can be found in many different natural habitats, from shade to full sunlight, and can be either annual or perennial in nature. The habitats of *O. nivara* are ditches, water holes, and edges of ponds, whereas *O.rufipogon* is usually found in deepwater swamps. Some wild species occur as weeds in and around rice fields and even hybridize naturally with the cultivated forms. This complex association between cultivated and wild forms has also enhanced the diversity of rice crop in traditional agricultural systems.

Northeastern hills, Koraput region of Orissa, Raipur region of Chattisgarh and peninsular region of India are considered important centres of diversity based on germplasm collections. The distribution pattern of the four species in Southeast Asia is depicted in Figure 2.

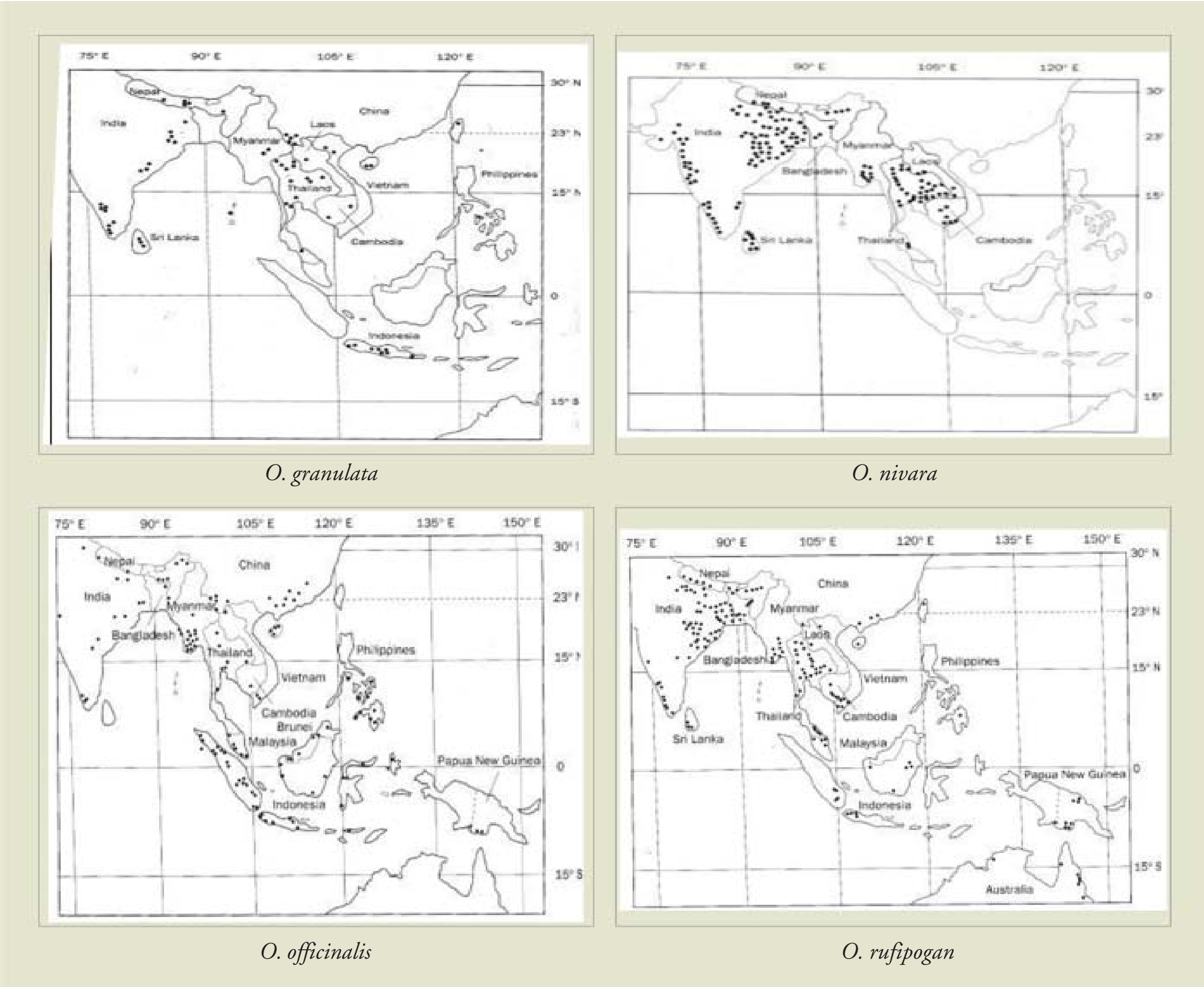


***Figure 2:** Wild Rice Distribution in Southeast Asia*
Source: *Vaughan, 1994*

The rice crop has evolved with enormous diversity over thousands of years, as the peasants and farmers selected different types to suit local cultivation practices and needs. This process of selection has led to a multiplicity of rice varieties adapted to a wide range of agro-ecological conditions. India has also seen the release of more than 850 varieties in last 50 years. The full spectrum of rice germplasm in India includes:

- Wild *Oryza species* and related genera.
- Natural hybrids between the cultigen and wild relatives and primitive cultivars of the cultigen in areas of rice diversity.

- Germplasm generated in the breeding programs including pureline or inbred selection of farmers varieties, F1 hybrids and elite varieties of hybrid origin, breeding materials, mutants, polyploids, aneuploids, intergeneric and interspecific hybrids, composites, etc.
- Commercial types, obsolete varieties, minor varieties, and special purpose types in the centers of cultivation
- Diverse ecological situations in areas of rice cultivation have given rise to the following major ecospecific rice varieties with specificity for season, situation, and system.
- **The aus group:** Early maturing, photoinsensitive types can be grown across the seasons except in the winter.
- **The aman group**: Late types mostly photoperiod sensitive and flower during specific time regardless of when they are sown or transplanted.
- **The boro group**: Perform best as a summer crop. When sown during winter they tolerate cold temperature in the early vegetative stage better than the other groups.
- **The gora group**: Short duration, can withstand a certain degree of moisture stress during its growing period.
- **The basmati group**: Specific to regions in the northern parts of Indian subcontinent, possessing extremely valuable quality traits like elongation, aroma, flavour, etc.
- Aromatic rices other than Basmati are found in different states of the country.

2.6 Germplasm Conservation

Rice germplasm comprising of over 1,50,000 genotypes and large accessions of wild species, is one of the richest among crop species. Most countries in Asia maintain their own collections of rice germplasm, and the largest are in China, India, Thailand and Japan. In Africa, there are significant collections in Nigeria and Madagascar, while in Latin America, the largest collections are in Brazil, Peru, Cuba and Ecuador. All these collections include landraces as well as breeding materials. Four centres of the Consultative Group on International Agricultural Research (CGIAR) i.e. the International Rice Research Institute (IRRI) in the Philippines, the West Africa Rice Development Association (WARDA) in Côte d'Ivoire, the International Institute for Tropical Agriculture (IITA) in Nigeria (on behalf of WARDA), and the International Centre for Tropical Agriculture (CIAT) in Colombia, also maintain rice collections. IRRI holds nearly 1,00,000 accessions. It is also the most genetically diverse and complete rice collection in the world (Table 4).

The International Rice Genebank (IRG) at IRRI was established in 1977, although shortly after its foundation in 1960 IRRI had already begun a germplasm collection to support its nascent breeding activities (Jackson, 1997). This rich biodiversity has been collected and maintained by various national agricultural research systems. The systematic collection campaign has been mainly coordinated by IRRI since 1972. The International Network for Genetic Evaluation of Rice (INGER) is the principal germplasm exchange and evaluation network worldwide.

Table 4: Origin of the accessions in the International Rice Genebank Collection at IRRI

Country	Accessions
India	16 013
Lao PDR	15 280
Indonesia	8 993
China	8 507
Thailand	5 985
Bangladesh	5 923
Philippines	5 515
Cambodia	4 908
Malaysia	4 028
Myanmar	3 335
Viet Nam	3 039
Nepal	2 545
Sri Lanka	2 123
7 countries with > 1 000 and < 2 000 accessions	10 241
105 countries < 1 000 accessions	11 821
Total	**108 256**

As one of the primary centers of origin of *O. sativa*, India has rich and diverse genetic wealth of rice. According to an estimate, about 50,000 landraces of rice are expected to exist in India. A total of 66,745 accessions have so far been collected from various parts of the country. More than 200 wild rices were collected from the primary and secondary centres of origin comprising of Jeypore - Koraput region, Eastern, North-eastern hills, Chhattisgarh and Pennisular India. Recent collections through World Bank funded National Agricultural Technology Project (NATP) from different parts of the country have added 334 wild accessions and 700 accessions of varieties to the national collection. NBPGR is the nodal agency for collection, conservation, evaluation, cataloging and exchanging of germplasm of many crops including rice. The total germplasm of rice on hand with NBPGR is estimated to be around 80,000. NBPGR has been organizing the evaluation of several hundreds of rice germplasm with the help of Directorate of Rice Research (DRR) as coordinating centre and 30 other centres located in various parts of the country through a project titled Multi-location Evaluation of Rice Germplasm since 2004. Indira Gandhi Krishi Vishwa Vidyalaya (IGKV), Raipur also holds a valuable rice germplasm collection of 22,972 accessions of which about 19,000 accessions belong to indica group which have originated in the Chhattisgarh region. The Assam hills are another invaluable source of rice germplasm known as Assam Rice collection.

India is also known for its quality rices, like basmati and other fine grain aromatic types grown in Northwest and Western Ghats region of the country (Bhat and Gowda, 2004; Hanamaratti *et al.*, 2008). The basmati rice is known globally for its special characteristics (Box 3).

Box 3: Main characteristics of Indian Basmati Rice

- **Origin**: Authentic Basmati rice is sourced from northern India at the foothills of the Himalayas. Whilst Basmati rice can be sourced from India and Pakistan, Indian Basmati is traditionally considered premium.
- **Colour**: The colour of a basmati is translucent, creamy white. Brown basmati rice is also available but the most commonly used is white Basmati.
- **Grain**: Long Grain. The grain is long (6.61 - 7.5 mm) or very long (more than 7.50 mm and 2 mm breadth).
- **Shape**: Shape or length-to-width ratio is another criteria to identify basmati rice. This needs to be over 3.0 in order to qualify as basmati.
- **Texture**: Dry, firm, separate grains. Upon cooking, the texture is firm and tender without splitting, and it is non-sticky. (This quality is derived from the amylose content in the rice. If this value is 20-22%, the cooked rice does not stick. The glutinous, sticky variety preferred by the chopsticks users has 0-19% amylose).
- **Elongation**: The rice elongates almost twice upon cooking but does not fatten much. When cooked, the grains elongate (70-120 % over the pre-cooked grain) more than other varieties.
- **Flavour**: Distinctive fragrance. The most important characteristic of them all is the aroma. Incidentally, the aroma in Basmati arises from a cocktail of 100 compounds - hydrocarbons, alcohols, aldehydes and esters. A particular molecule of note is 2-acetyl-1-pyrroline.
- **Uses**: Flavour and texture complements curries because it is a drier rice and the grains stay separate. Also suits biryani and pilaf (where saffron is added to provide extra colour and flavour). Great for Indian & Middle Eastern dishes.
- **Main benefits**: Aromatic fragrance and dry texture.

Source: *http://rice-trade.com*

There is a general notion that any aromatic rice is Basmati, however, this is not the case. No single criterion can distinguished basmati rice from other rice. A harmonious combination of minimal kernel dimension, intensity of aroma, texture of cooked rice, high volume expansion during cooking made up by linear kernel elongation with minimum breadthwise swelling, fluffiness, palatability, easy digestibility and longer shelf life qualify a rice to be Basmati in consumers' and traders' view (Singh *et al.*, 1988). Recently, the Government of India has specified the parameters to qualify the Basmati varieties.

3. REPRODUCTIVE BIOLOGY

3.1 Growth and Development

In India, most of rice cultivation is done through transplanting. The young seedlings grown in nursery beds are transplanted by hands to rice fields. However, about 28% of rice area is under cultivation through direct seed, particularly in Eastern India (Pandey and Velasco, 1999). The growth of the rice plant is divided into three phases viz. vegetative, reproductive and ripening phase (IRRI, 2002). The stages of development in each phase are further divided according to 0-9 numerical scale to identify the growth stages of a rice plant. Each number in the scale corresponds to a specific growth stage. Therefore, three growth phases consist of a series of 10 distinct stages, as indicated in Table 5. These growth stages are based on data and characteristics of IR64, a modern, high yielding, semi dwarf variety but apply generally to other rice varieties.

Table 5: Growth phases and stages of rice

Growth phase		Stage	
I.	**Vegetative (germination to panicle initiation)**	•	Stage 0 from germination to emergence
		•	Stage 1 - seedling
		•	Stage 2 - tillering
		•	Stage 3 - Stem elongation
II.	**Reproductive (panicle initiation to flowering)**	•	Stage 4 - panicle initiation to booting
		•	Stage 5 - heading or panicle exsertion
		•	Stage 6 - flowering
III.	**Ripening (flowering to mature grain)**	•	Stage 7 - milk grain stage
		•	Stage 8 - dough grain stage
		•	Stage 9 - mature grain stage

It has been indicated that in the tropical countries like India, the reproductive phase is about 30-35 days and the ripening phase is about 30 days (Figure 3). The differences in growth duration are determined by changes in the length of the vegetative phase. For example, IR64 which matures in 110-120 days has a 45-55 day vegetative phase, whereas IR8 which matures in 130 days has a 65-day vegetative phase (Figure 3). The botanical features of rice are placed at Annexure - I.

Each of the growth phases are explained as under:

i. Vegetative Growth Phase

- **Stage 0 - Germination to emergence:** Seeds are usually pre-germinated by soaking for 24 hours and incubating for another 24 hours. After pre-germination the radicle and plumule protrude through the hull. By the second or third day after seeding in the seed bed or direct seeding, the first leaf breaks through the coleoptile. The end of stage 0 shows the emerged primary leaf still curled and an elongated radicle (Figure 4a).
- **Stage 1 - Seedling:** The seedling stage starts right after emergence and lasts until just before the first tiller appears. During this stage, seminal roots and up to five leaves develop. Leaves continue to develop at the rate of 1 every 3-4 days during the early stage. Secondary adventitious roots that form the permanent fibrous root system rapidly replace the temporary radicle and seminal roots. This is an 18-day-old seedling ready for transplanting. The seedling has 5 leaves and a rapidly developing root system (Figure 4b).

Figure 3: *Growth Phases*

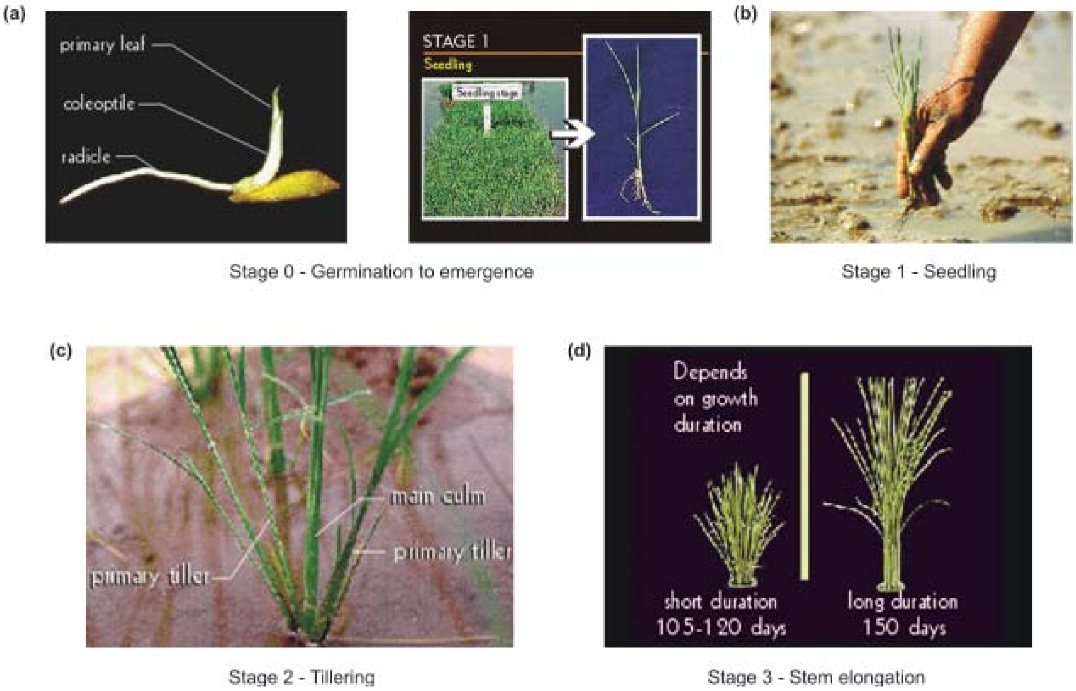


Figure 4: *Vegetative Phase*

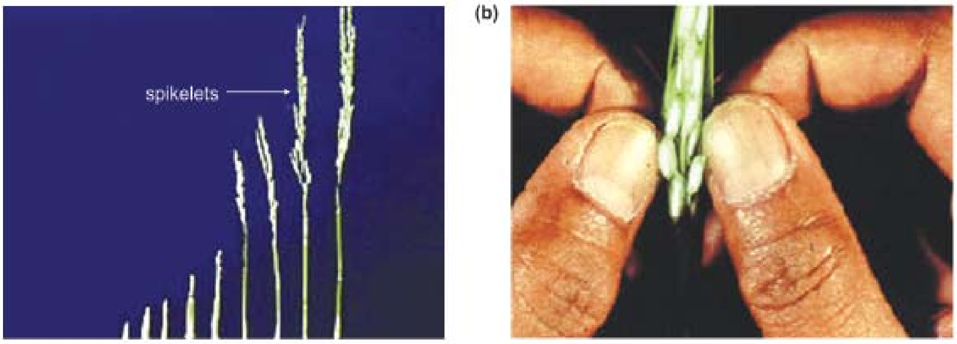
- **Stage 2 - Tillering:** This stage extends from the appearance of the first tiller until the maximum tiller number is reached. Tillers emerge from the auxiliary buds of the nodes and displace the leaf as they grow and develop. This seedling shows the position of the two primary tillers with respect to the main culm and its leaves. After emerging, the primary tillers give rise to secondary tillers. This occurs about 30 days after transplanting. The plant is now increasing in length and tillering very actively. Besides numerous primary and secondary tillers, new tertiary tillers arise from the secondary tillers as the plant grows longer and larger. By this stage, the tillers have multiplied to the point that it is difficult to pick out the main stem. Tillers continuously develop as the plant enters the next stage which is stem elongation (Figure 4c).
- **Stage 3 - Stem elongation:** This stage may begin before panicle initiation or it may occur during the latter part of the tillering stage. Thus, there may be an overlap of stages 2 and 3.The tillers continue

to increase in number and height, with no appreciable senescence of leaves noticeable. Ground cover and canopy formation by the growing plants have advanced. Growth duration is significantly related to stem elongation. Stem elongation is more in varieties with longer growth duration. In this respect, rice varieties can be categorized into two groups: the short-duration varieties which mature in 105-120 days and the long-duration varieties which mature in 150 days. In early-maturing semidwarfs like IR64, the fourth internode of the stem, below the point where the panicle emerges, elongates only from 2 to 4 cm before panicle initiation becomes visible. Maximum tillering, stem elongation, and panicle initiation occur almost simultaneously in short-duration varieties (105-120 days). In long-duration varieties (150 days), there is a so-called lag vegetative period during which maximum tillering occurs. This is followed by stem or internode elongation, and finally by panicle initiation (Figure 4d).

ii. Reproductive Phase

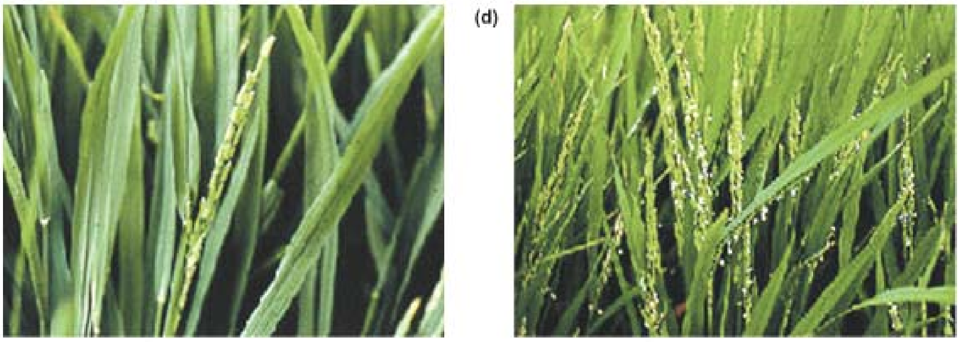
- **Stage 4 - Panicle initiation to booting:** The initiation of the panicle primordium at the tip of the growing shoot marks the start of the reproductive phase. The panicle primordium becomes visible to the naked eye about 10 days after initiation. At this stage, 3 leaves will still emerge before the panicle finally emerges. In short-duration varieties, the panicle becomes visible as a white feathery cone 1.0-1.5 mm long. It occurs first in the main culm and then in tillers where it emerges in uneven pattern. It can be seen by dissecting the stem. As the panicle continues to develop, the spikelets become distinguishable. The young panicle increases in size and its upward extension inside the flag leaf sheath causes the leaf sheath bulge. This bulging of the flag leaf sheath is called booting. Booting is most likely to occur first in the main culm. At booting, senescence (aging and dying) of leaves and nonbearing tillers are noticeable at the base of the plant (Figure 5a).
- **Stage 5 - Heading:** Heading is marked by the emergence of the panicle tip from the flag leaf sheath. The panicle continues to emerge until it partially or completely protrudes from the sheath (Figure 5b).
- **Stage 6 - Flowering:** It begins when anthers protrude from the spikelet and then fertilization takes place. At flowering, the florets open, the anthers protrude from the flower glumes because of stamen elongation, and the pollen is shed. The florets then close. The pollen falls on the pistil, thereby fertilizing the egg. The pistil is the feathery structure through which the pollen tube of the germinating pollen (round, dark structures in this illustration) will extend into the ovary. The flowering process continues until most of the spikelets in the panicle are in bloom. From left to right, this frame shows anthesis or flowering at the top of the panicle, 1st day after heading; anthesis at the middle of the panicle, 2nd day after heading; anthesis at the lower third of the panicle, 3rd day after heading.Flowering occurs a day after heading. Generally, the florets open in the morning. It takes about 7 days for all spikelets in a panicle to open. At flowering, 3-5 leaves are still active.The tillers of this rice plant have been separated at the start of flowering and grouped into bearing and nonbearing tillers (Figure 5c).

(a) (b)



Stage 4 - Panicle initiation to booting emergence

(c) (d)



Stage 5 - Heading

Stage 6 - Flowering

Figure 5: Reproductive Phase

iii. Ripening Phase

- **Stage 7. Milk grain stage:** In this stage, the grain begins to fill with a milky material.The grain starts to fill with a white, milky liquid, which can be squeezed out by pressing the grain between the fingers.The panicle looks green and starts to bend. Senescence at the base of the tillers is progressing. The flag leaves and the two lower leaves are green (Figure 6a).
- **Stage 8 - Dough grain stage:** During this stage, the milky portion of the grain first turns into soft dough and later into hard dough. The grains in the panicle begin to change from green to yellow. Senescence of tillers and leaves is noticeable. The field starts to look yellowish. As the panicle turns yellow, the last two remaining leaves of each tiller begin to dry at the tips (Figure 6b).
- **Stage 9 - Mature grain stage:** The individual grain is mature, fully developed, hard, and turns yellow and hard. The upper leaves dry rapidly although the leaves of some varieties remain green. A considerable amount of dead leaves accumulate at the base of the plant (Figure 6c).

(a) (b) (c)

Stage 7 - Milk grain stage

Stage 8 - Dough grain stage

Stage 9 - Mature grain stage

Figure 6: Ripening Phase

3.2 Floral Biology (Adopted from Siddiq and Viraktamath, 2001)

Precise knowledge of floral biology, which includes structural and functional aspects of rice flower is essential for breeders to plan and execute breeding strategies. Inflorescence of rice is a terminal panicle with single flowered spikelets. The panicle has a main axis, on which primary branches are borne. Secondary branches are borne towards the basal region of the primary branches. Tertiary branches, if any, are seen at the base of the secondary branches. Much of the variability for spikelet number is due to variation in the number of secondary branches. The spikelet consists of two short sterile lemma, a normal fertile lemma and palea. The fertile lemma is either awnless or short or long awned (Figure 7). The fertile lemma and palea enclose the sexual organs viz., six stamens arranged in whorls and a pistil at the centre. The stamen consists of bilobed anthers borne on slender filaments, while the pistil consists of ovary, style and feathery bifid stigma.

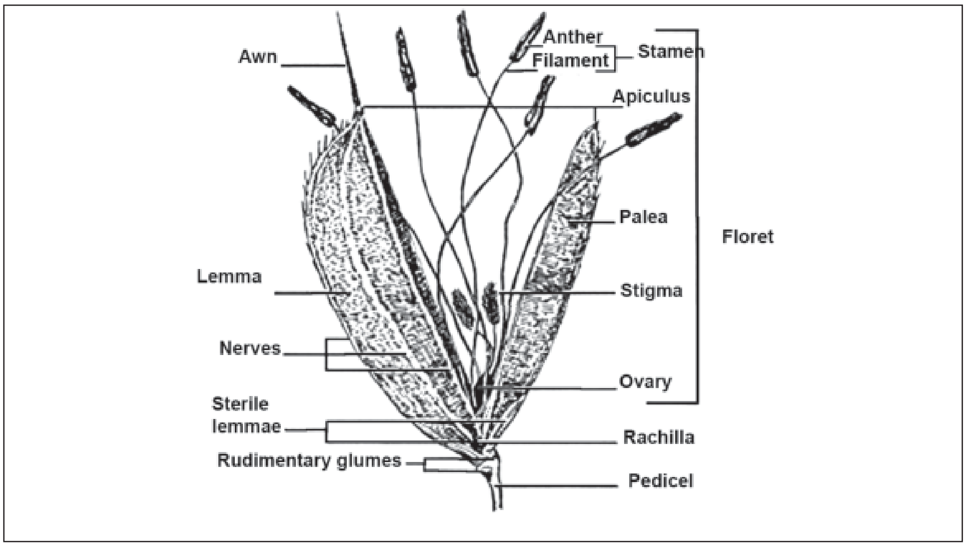


Figure 7: *Parts of spikelet (From Chang and Bardenas, 1965)*

As indicated in the previous section, reproductive phase starts with panicle initiation, which occurs about 35 days before panicle emergence. Complete emergence of panicle from flag leaf sheath takes place within a day. Days to complete heading varies with the variety, the range being between 5-15 days. Anthesis (spikelet opening and dehiscence of anther) occurring immediately after the panicle emergence, follows a specific pattern, in which spikelets on the primary branch followed by spikelets on the secondary/ tertiary branches at the corresponding position of the panicle open (Figure 8). The lower most secondary/ tertiary branches open last. Thus completion of anthesis on a panicle takes about 7 days.

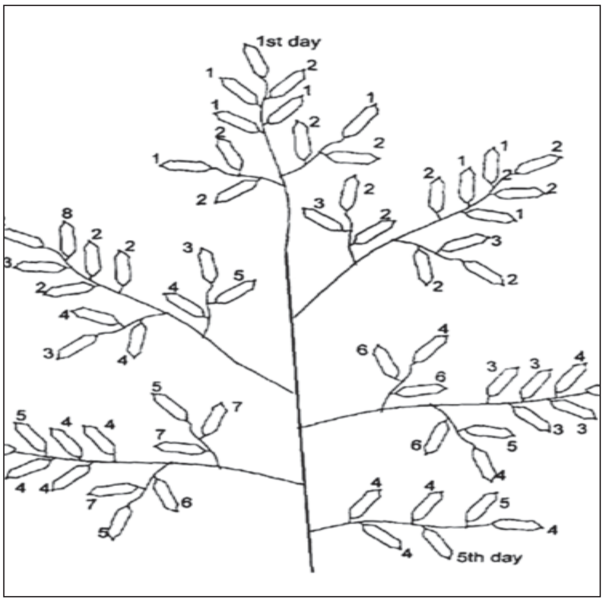


Figure 8: *Flowering order within a panicle*

The process of anthesis is greatly influenced by weather conditions. The spikelets generally open on a sunny day between 10 AM and 2 PM, the maximum blooming being between 10 and 11 AM. About six days before heading, pollen grains mature and the flag leaf swells indicating the approach of booting stage. At the time of anthesis, lemma and palea get separated, filaments of stamens elongate and protrude out and anthers dehisce releasing the pollen. Most of the pollen is shed on the protruded stigma of the same spikelet or neighbouring spikelets of the same plant, thus causing self-pollination. After 20-30 minutes of anthesis, anthers wither out and the spikelet closes leaving the stamens sticking out from the seams of lemma and palea. The pollen remain viable for not more than 3-5 minutes, while stigma is receptive for 2-3 days from the day of opening. Under tropical conditions, all the spikelets on a panicle complete flowering within 7-10 days and following fertilization, ovary starts developing into a caryopsis.

3.3 Pollination and Fertilization

O. sativa is basically a self-pollinated crop, with limited degree of outcrossing (< 0.5%). The factors limiting the receptivity of rice flowers to outcrossing include a short style and stigma (1.5 to 4 mm in combined length), short anthers, limited pollen viability and brief period between opening of florets and release of pollen (between 30 seconds and 9 minutes) (Morishima, 1984; Oka, 1988).

Immediately after the spikelet opens at flowering, pollen is shed on the protruded stigma of the same spikelet or neighboring spikelets of the same plant, thus causing self-pollination. The maturation of pollen in an anther is synchronized with the maturation of the ovule within the same spikelet.

All wild and cultivated rice can also be wind-pollinated, with a few varieties having scented flowers that attract bees (Oka, 1988). It has been reported that natural greater out-crossing is observed when honeybees are present (Gealy *et al.*, 2003). Although wind assisted pollen dispersal distances have been estimated at upto 110 metres (Song *et al.*, 2004). However, rice pollen is short-lived with most pollen grains loosing viability after approximately five minutes under typical environmental conditions (Koga *et al.*, 1969). The morphology of pollen grain also changes dramatically after shedding from the anther. Initially grains are spherical but within minutes they begin to collapse and this collapse of the pollen grains coincide with a measured loss of viability. It has been reported by Koga *et al.*,1969 that 90% of the pollen grains were found to be viable for upto four minutes in one of the studies, and the viability decreased to approximately 33% between five and eight minutes after shedding.

Although, the germinability of pollen lasts only for few minutes after being shed from anther under favourable temperature and moisture conditions, ovules keep their viability to receive pollens for several days after maturation. Fertilization is completed within six hours and occurs in the spikelet. Only one pollen tube reaches an ovule to initiate double fertilization. During fertilization rice is most sensitive to cold temperature (McDonald, 1979).

3.4 Seed Dispersal

The probability of seed dispersal from rice plants varies widely within the *O. sativa* species (OGTR, 2005). Most cultivars have limited dispersal ability, whereas in wild rices and some cultivars mature rice seeds can be shed from the plant through seed shatter. Shattered seed can either be buried in the soil for subsequent germination or be eaten/dispersed by animals. Another cultivar specific trait is the presence or absence of awns at the tip of the lemma. When present, awns can vary in their rate of development, length, diameter and bristle length. The presence or absence of awns influences the potential for seed dispersal through attachment to passing animals (Oka, 1988).

3.5 Seed Dormancy

Seed dormancy is generally weaker in cultivated rice than in wild or weedy rice (Oka, 1988; Vaughan, 1994). The longevity of rice seeds has not been well studied however,wild rice seeds are believed to be long lived (Vaughan, 1994) and may be dormant for several years (Moldenhauer and Gibbons, 2003).

It has been reported that of the three *O. sativa* ecotypes, Indica cultivars display the greatest degree of dormancy, followed by Javanica and then Japonica cultivars (Ellis *et al*., 1983). Although, dormancy is a heritable trait but the environmental conditions during seed maturation also appear to influence the degree of dormancy present in the seeds. For example, Indica cultivars have stronger dormancy after maturation in rainy weather, but drying the seeds at high temperature (40°C to 50°C for upto two weeks) after harvest removes dormancy from all rice seeds (Takahashi, 1984).

3.6 Mating Systems

O. sativa is largely an autogamous plant (self fertilizing) propagating through seeds produced by self-pollination (OECD, 1999). Cross pollination between wild species and *O. sativa* cultivars has been reported to occur in natural habitats (Oka and Chang, 1961). The degree of outcrossing has been reported to be generally higher in Indica cultivars and wild species than in Japonica cultivars (Oka, 1988).

3.7 Asexual Reproduction

Although *O. sativa* is cultivated annually, the rice plants can grow vegetatively and continuously under favourable water and temperature conditions, even after they have borne seeds (OECD, 1999). This perennial character in *O. sativa* is considered to have been inherited from the ancestral species *O. rufipogon* (Morishima *et al*., 1963).

Under natural conditions, tiller buds on the basal nodes of rice plants start to re-grow after rice grains have been harvested. These new tillers, called the ratoons, grow best under long day conditions and are used in some countries to obtain a second harvest (OECD,1999) .

Cell/tissue culture techniques can be used to propagate calli and reproduce tissues or plants asexually under the appropriate cultural conditions (OECD, 1999). Haploid plants can be easily obtained through anther culture and they become diploid spontaneously or when artificially treated with chemicals (Niizeki and Oono, 1968).

3.8 Methods of Reproductive Isolation

The commonly used method of reproductive isolation in case of rice is spatial isolation. In case of varieties, an isolation distance of 3 metres have been recommended for seed production as per the Indian Minimum Seed Certification Standards. For hybrids, the requirement of isolation distance is 200 metres (Tunwar and Singh, 1998). It has also been reported that outcorssing can be avoided by allocating cultivars with sufficiently different maturity time to adjacent fields, or by adopting sufficiently different dates of planting (OECD, 1999).

4. ECOLOGICAL INTERACTIONS

4.1 Potential for Gene Transfer

Gene transfer can occur within a species or between different species of the same, or other genera, referred to as intraspecific and interspecific gene transfer respectively. Successful gene transfer requires that the plant population must overlap spatially, temporally and be sufficiently close biologically that the resulting hybrids are able to reproduce normally (den Nijs *et al.,* 2004). The potential of gene transfer from *O. sativa* is discussed below:

4.1.1 Intraspecific Gene Transfer

O. sativa is essentially a self pollinating plant due to its flower morphology and low period of pollen viablity. However, low rates of outcrossing can occur at a rate of upto 0.5% have been reported (Oka, 1988). Natural outcrossing occurs only when plants with synchronous or overlapping flowering times grow in close proximity (Gealy *et al.*, 2003). Even if flowering periods overlap, the time of day that the flowers open is important as rice flowers often remain open for period of less than three hours (Moldenhauer & Gibbons, 2003). Summary of some of the studies performed to study the extent of outcrossing in *O. sativa* is given in Box 4. Outcrossing can be avoided by allocating cultivars with sufficiently different maturity time to adjacent fields, or by separating cultivars with same maturity time.

As regards crossability among various groups of *O. sativa*, it has been reported that F1 plants from crosses within the indica or japonica group generally show high fertility in pollen and seed set. Those from crosses between the two groups have lower pollen fertility and lower seed set, with some exceptions (Oka, 1988).

Box 4: Extent of outcrossing in *O. sativa*

- In the study by Reano & Pham (1998) to study cross-pollination between cultivars, ten varieties were grown in four different plot designs. The varieties chosen were paired in order to match, as closely as possible, plant height and flowering time. The pollen acceptor plants had various stigma lengths (ranging from 1.00 to 1.88 mm) and varying degrees of stigma exsertion (32 to 70%). In the first two plot designs, the pollen donor plants (carrying a gene for purple leaf colouration) and pollen acceptor plants were alternated within the rows, so that each acceptor was surrounded by donors. In one of these plots, the panicles of donor and acceptor plants were clipped together in pairs to ensure close contact between the flowers. In the third plot design, alternating rows of the donors and acceptors were planted. In the final plot, paired varieties were planted in adjacent blocs separated by 1.5 m. The highest rate of gene flow (hybrid progeny identified by leaf pigmentation) found was 0.9%. This occurred between clipped panicles with the pollen acceptors that had the greatest degree of stigma exsertion and the longest stigmas. No viable hybrids were found amongst the 600-900 seeds tested from the plots that were separated by 1.5 m, indicated that if gene flow was occurring it was occurring at a rate of less than 0.08%, the lowest rate detected.

- Messeguer *et al.*, 2001 reported rates of less than 1% at 1 m and less than 0.05% at 5 m in concentric circle plots. In these experiments, wind direction was important in pollen transfer at 1 m but at 5 m the more random spread of hybrids around the circular plot indicated that wind direction was no longer important. Gene flow (measured as numbers of herbicide tolerant seedlings) was greater between plants of the same cultivar than between the cultivar and red rice plants, which were taller and flowered slightly earlier, but with a 10 day overlap.

  In a study by Zhang *et al.*, 2004, three rice varieties (red seed, purple leaf and herbicide tolerant) were paired and grown in random plots in 50:50 mixes. No hybrid plants were recovered when seeds were collected from the taller red rice plants, indicating a lack of gene flow in that direction. However, hybrids were found in seeds collected from plants grown with the red rice with rates of 0.76% and 0.33% for purple rice and the herbicide tolerant rice respectively. The hybrids formed between the herbicide tolerant and red rice plants were very late in maturing and had to be removed from the field to a glasshouse at the end of the season to reach reproductive maturity. These would not have been able to set seed in the field, and in the glasshouse showed reduced fertility.

Sharma *et al.*, 2000, reviewed many studies on the intra specific differentiation of *O. sativa* (Iso, 1928; Matsuo, 1952; Waagenr *et al.*, 1952; Oka, 1958; Jennings, 1966; Morinaga, 1968; Sano *et al.*,1985; Glaszmannan and Arrandeau, 1986) and concluded that the cultivated rice of Asia has differentiated into many ecogenetic groups and when cultivars of two ecogenetic groups are crossed, their F1 hybrid often shows different degrees of sterility.

4.1.2 Interspecific Gene Transfer to other *Oryza spp.*

As mentioned in Table 2, species in the *Oryza* genus can be grouped according to the compatibility of their genomes. *O. sativa* has an AA-type genome, which means that its chromosomes can pair correctly at meiosis with other AA-type genome species. Despite this, hybrids between AA genome rice species can be difficult to obtain and have been reported to show low fertility. However, this does not prevent gene flow between these species, as backcrossing to one of the parents can stabilize the hybrids (Vaughan & Morishima, 2003). In fact successful hybrid formation has been used to transfer beneficial traits from related species to *O. sativa*. Examples includes transfer of resistance to grassy stunt virus from *O. nivara* (Khush, 1977), cytoplasmic male sterility from weedy/rice rice (*O. sativa f. spontanea* (Lin & Yuan, 1980) and resistance to bacterial blight from *O. longistaminata* (Khush *et al.*, 1990). Occurrence of gene flow has also been reported in studies conducted in India e.g. IGKV, Raipur undertook studies to assess the pollen flow between the cultivated rice i.e *O.sativa* and wild rice *O. nivara* and *O. f. spontanea* for two consecutive years (2001 and 2002) (Sidram, 2001 and Tamatwar, 2003). The study clearly indicated that significant amount of gene flow occurred from *O. sativa* to *O. nivara*, *O. sativa* to *O. spontanea*, and vice versa.

Hybridization between *O. sativa* and non AA type genome *Oryza* sp. is also possible with human assistance (Vaughan & Morishima, 2003) and has been used to introduce insect and disease resistance genes into new cultivars. However, these type of inter-specific hybridization do not occur naturally and rely on extensive embryo rescue and backcrossing efforts to obtain fertile hybrids.

The relatively high seed-sets (9-73%) can be obtained through the artificial hybridization of *O. sativa* with AA genome wild species (Sitch *et al.*, 1989). Further, species with the BB, BBCC, CC or CCDD genome are more crossable with *O. sativa* (0-30% seedset) than the more distantly related EE and FF genome species with *O. sativa* (0.2-3.8% seedset), but their hybrids are highly male and female sterile (Sitch, 1990).

As regards the crossability of *O. sativa* with wild species occurring in India, *O. nivara* is easily crossable with different *O. sativa* varieties and occurs widely as weed in and around rice fields. Infact their F1 and segregating populations create significant problems with regard to seed impurity besides yield losses. In fact efforts have been made to eradicate this problem by releasing specific marker varieties for eradication. On such example is the Shyamala variety released by IGKV, Raipur which has purple leaves. *O. rufipogon*, the wild progenitor of *O. sativa*, can also be crossed with *O. sativa* and sometimes produces hybrid swarms in the field. Their hybrids show low sterility (Oka, 1988). However, viable hybrids between rice and *O. officinalis*, as well as with *O. sativa x O. granulata* have been produced by human intervention (Brar and Khush, 2003).

In fact, relationship among different Asian AA species has been reviewed and reported by Sharma, 2000. It has been indicated that in the coastal regions of south and southeast Asia, *O. sativa* is sympatric with *O. rufipogon*. The genetic barrier between these two species is not complete and, therefore, they easily hybridize in nature and form F1 hybrids. These F1 hybrids are partially sterile and hence get backcrossed with either of the parents. As a result, various intergrades of these hybrids are found in nature. The single plant progenies of these plants segregate indicating their hybrid nature. In cultivated fields, one often comes across plants similar to *O. sativa* but with a few introgressed rufipogon characters such as presence of awn, black husk, red kernel, shattering of spikelet on maturity, etc. These plants are "wild" only in the sense that they shatter their spikelets on maturity and hence are not harvestable by the farmers. Instead, they become self-sown in the same field and germinate next year. The field thus comes up with more and more plants of these weedy spontanea rices in subsequent years. These plants compete with the cultivated rice (*O. sativa*) but, as they cannot be harvested, cause loss to the farmers. Since these weedy types resemble the cultivated rice closely in their vegetative stage, a farmer tries to weed any rice plant that appears off type at the vegetative stage. However, by such attempts, weedy types resembling cultivated varieties more and more closely have appeared (Oka and Chang, 1959).

In plateau regions of south and southeast Asia where *O. sativa* and *O. nivara* are sympatric. The genetic barrier between these two species is incomplete leading to a situation similar to that between *O. sativa* and *O. rufipogon* in the coastal region.

The natural hybrids (between *O. sativa* and *O. nivara* or between *O. sativa* and *O. rufipogon*) that get repeatedly backcrossed with the wild parent (*nivara* or *rufipogon*) acquire the characters of the wild parent and adapt more and more to the habitat of the wild parent. One, therefore, comes across forms that are similar to *O. nivara* or *O. rufipogon* but with a few sativa characters due to introgression of genes from the cultivated rice.

O. nivara is a photoperiod insensitive species whereas *O. rufipogon* is a sensitive one and hence they flower in different seasons in south and southeast Asia. The natural hybrids between *O. nivara* and *O. rufipogon* are, therefore, rare.

4.2 Gene Flow to Non-*Oryza* spp.

As evident from above, gene flow through conventional sexual hybridization is limited to *O. sativa* varieties and to the AA type genome species within this genus. Gene flow between more distantly related species, particularly those outside of the *Oryza* genus, is restricted to artificial breeding methods such as embryo rescue and somatic hybridisation (the regeneration of plants following the fusion of two protoplasts) (Liu *et al.*, 1999; Multani *et al.*, 2003).

4.3 Gene Flow to Other Organisms

The only means by which genes could be transferred from plants to non-plant organisms is by horizontal gene transfer (HGT). Such transfers have not been demonstrated under natural conditions (Nielsen *et al.*, 1997; Nielsen *et al.*, 1998; Syvanen,1999) and deliberate attempts to induce them have so far failed (Schlüter *et al.*,1995; Coghlan, 2000). Thus, gene transfer from rice to organisms other than plants is extremely unlikely.

4.4 Weediness of Rice

Rice plants (*O. sativa* or other species) that are grown unintentionally in and around rice growing areas are regarded as weeds (Vaughan & Morishima, 2003). Rice has a tendency to become weedy in areas where wild and cultivated rice plants grows sympatrically. In these areas, wild and cultivated rice plants can hybridize, producing plants that compete with the cultivars and produce inferior seed, thus decreasing the yield from the rice crop (Oka, 1988). However, weedy rice can also develop in areas without native wild rice populations (Bres-Patry *et al.*, 2001; Vaughan & Morishima, 2003).

In the case of *O. sativa,* the weeds are known as red rice due to the coloured pericarp associated with these plants. Red rice is viewed as a major economic problem when it occurs in rice fields as it causes losses in yield through competition with the cultivars as wells as decreasing the value of the harvested grain through its colour. Other *Oryza* species growing in and around rice fields are known as weedy rice and can also produce red seeds.

Characteristics of weedy rice contributing to its potential weediness include similar growth attributes with cultivars due to common progenitors, high seed shedding rate, dormancy and persistence, adoption to different habitats and relatively higher outcrossing ability. In view of the above, populations of weedy/red rice tend to be genetically diverse and highly heterogeneous and often have intermediate characteristics between wild and cultivated characteristics.

5. FREE LIVING POPULATIONS

The term "free living" is assigned to plant populations that are able to survive, without direct human assistance, over long term in competition with the native flora. This is a general ecological category that includes plants that colonize open, disturbed prime habitat that is either under human control (weedy populations) or natural disturbed areas such as river banks and sand bars (wild populations). There are no such free living populations of rice in India.

6. HUMAN HEALTH CONSIDERATIONS

There is no evidence of any toxicity or pathogenicity associated with use of rice grains as a food crop for humans. However the antinutrients including phytic acid, trypsin inhibitor, hemagglutinins (lectins) present in the bran fraction can present low levels of toxicity. Also the rice straw used as stock feed for animals in many parts of the world (Jackson, 1978; Drake *et al.*, 2002; FAO, 2004), has the potential to cause toxicity if fed in large quantities due to the high levels (1 to 2%) of oxalates present in the straw (Jackson, 1978) that can result in calcium deficiencies if supplements are not provided (FAO, 2004). In general rice is considered to be of low allergenicity (Hill *et al.*, 1997).

7. RICE CULTIVATION IN INDIA

7.1 Climate and Soil Type

Rice is grown under varied ecosystems on a variety of soils under varying climatic conditions. The climatic factors affecting the cultivation of rice are:

¬ **Rainfall:** Rainfall is the most important weather element for successful cultivation of rice. The distribution of rainfall in different regions of the country is greatly influenced by the physical features of the terrain, the situation of the mountains and plateau.

¬ **Temperature:** Temperature is another climatic factor which has a favourable and in some cases unfavourable influence on the development, growth and yield of rice. Rice being a tropical and sub-tropical plant, requires a fairly high temperature, ranging from 20° to 40°C. The optimum temperature of 30°C during day time and 20°C during night time seems to be more favourable for the development and growth of rice crop.

- **Day length or Sunshine:** Sunlight is very essential for the development and growth of the plants. In fact, sunlight is the source of energy for plant life. The yield of rice is influenced by the solar radiation particularly during the last 35 to 45 days of its ripening period. The effect of solar radiation is more profound where water, temperature and nitrogenous nutrients are not limiting factors. Bright sunshine with low temperature during ripening period of the crop helps in the development of carbohydrates in the grains.

Rice can be grown in all types of soil. However, soils capable of holding water for a longer period such as heavy neutral soils (clay, clay loam and loamy) are most suited for its cultivation. The most important group of soils for successful rice cultivation include alluvial soils, red soils, laterite soils and black soils. It is grown normally in soils with soil reaction ranging from 5 to 8 pH. Because of its better adaptation it is also grown under extreme soil conditions such as acid peaty soils of Kerala (pH 3) and highly alkaline soils (pH 10) of Punjab, Haryana and Uttar Pradesh.

7.2 Rice Ecosystems

Rice farming is practiced in several agro-ecological zones in India. No other country in the world has such diversity in rice ecosystems than India. Because cultivation is so widespread, development of four distinct types of ecosystems has occurred in India, such as irrigated rice, rainfed upland rice, rainfed lowland and flood prone as explained below:

i. **Irrigated rice ecosystem:** Rice is grown under irrigated conditions in the states of Punjab, Haryana, Uttar Pradesh, Jammu & Kashmir, Andhra Pradesh, Tamil Nadu, Sikkim, Karnataka, Himachal Pradesh and Gujarat. Irrigated rice is grown in bunded (embanked), paddy fields. The area under irrigated rice accounts for approx 50% of the total area under rice crop in the country.

ii. **Rainfed upland rice ecosystem:** Upland rice areas lies in eastern zone comprising of Assam, Bihar, Eastern M.P., Orissa, Eastern U.P., North Karnataka, West Bengal and North-Eastern Hill region. Upland rice fields are generally dry, unbunded, and directly seeded. Land utilized in upland rice production can be low lying, drought-prone, rolling, or steep sloping.

iii. **Rainfed lowland rice ecosystem:** Rainfed lowland farmers are typically challenged by poor soil quality, drought/flood conditions, and erratic yields. Production is variable because of the lack of technology used in rice production. The low land rice area accounts approx. 32% of the total area under rice crop in the country.

iv. **Flood prone rice ecosystem:** Flood prone ecosystems are characterized by periods of extreme flooding and drought. Yields are low and variable. Flooding occurs during the wet season from June to November, and rice varieties are chosen for their level of tolerance to submersion.

New systems for rice cultivation are continuously evolved for increased productivity by introducing management practices in various ecosystems. Two such examples include aerobic rice and the system of rice intensification.

Aerobic rice is a new way of cultivating rice in water short areas. It entails the growing of rice in aerobic soil, with the use of external inputs such as supplementary irrigation and fertilizers, and aiming at high yields (Huaqi *et al.*, 2002). This new way of growing rice started as early as the mid-1980s in China. Research on developing new varieties and management practices, for successful cultivation of aerobic rice is also underway in India.

The System of Rice Intensification (SRI) also is a method of increasing the rice yield, where paddy growing soil is not saturated during the vegetative growth period, some soil aeration is introduced and then continuously flooded conditions are maintained during the reproductive and grain-filling stages to promote better plant growth and increased grain yield. The practice of SRI offers rice-growing farmers increased yields and other benefits when they apply less water, provided this is done in conjunction with other changes, in terms of management of plants, soil, and nutrients.

7.3 Zonal Distribution

On the basis of above classification of ecosystems, the rice growing areas in the country have been broadly grouped into the following five regions:

(i) **North-eastern region** comprising of Assam, eastern Uttar Pradesh receives very heavy rainfall and hence rice is grown under rainfed conditions.

(ii) **Eastern region** has the highest intensity of rice cultivation in the country including the states of Bihar, Chhattisgarh, Madhya Pradesh, Orissa, eastern Uttar Pradesh and West Bengal. In this region rice is grown in the basins of Ganga and Mahanadi rivers. This region receives heavy rainfall and rice is grown mainly under rainfed conditions.

(iii) **Northern region** includes Haryana, Himachal Pradesh, Jammu & Kashmir, Punjab, western Uttar Pradesh and Uttranchal. Rice is grown mainly as an irrigated crop from May/July to September/December in these states.

(iv) **Western region** comprising of Gujarat, Maharashtra and Rajasthan have a largely grown, rainfed area.

(v) **Southern region** includes Andhra Pradesh, Karnataka, Kerala, Tamil Nadu and Pondicherry where rice is mainly grown as irrigated crop in the deltas of the rivers Godavari, Krishna, Cauvery and the non-deltaic rain fed areas of Tamil Nadu, Karnataka and Andhra Pradesh.

7.4 Rice Growing Seasons

Rice is grown under widely varying conditions of altitude and climate in the country and therefore, the rice growing seasons vary in different parts of the country, depending upon temperature, rainfall, soil types, water availability and other climatic conditions. In eastern and southern regions of the country, the mean temperature is found favourable for rice cultivation throughout the year. Hence, two or three crops of rice are grown in a year in eastern and southern states. In northern and western parts of the country, where rainfall is high and winter temperature is fairly low, only one crop of rice is grown during the month from May to November.

There are three seasons for growing rice in India. These three seasons are named according to the season of harvest of the crop.

7.5 Cropping Patterns

Rice cropping pattern in India vary widely from region to region and to a lesser extent from one year to another year depending on a wide range of soil and climatic conditions. Some of the rice based cropping patterns being followed in the country are as follows:

Autumn Rice/Pre-Kharif Rice
Summer Rice/Rabi Rice
Winter Rice/Kharif Rice

- **Rice-Rice-Rice:** This is most suitable for areas having high rainfall and assured irrigation facilities 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. In such areas three crops of rice are grown in a year.
- **Rice-Rice-Cereals (other than rice):** This cropping pattern is being followed in the areas where the water is not adequate for taking rice crop in summer. The alternate cereal crops to rice being grown are Ragi, Maize and Jowar.
- **Rice-Rice-Pulses:** In the areas where, there is a water scarcity to take up cereal crops other than rice in summer, the short duration pulse crops are being raised.
- **Rice-Groundnut:** This cropping pattern is being followed by the farmers of Andhra Pradesh, Tamil Nadu and Kerala. After harvesting of rice crop, groundnut is grown in summer.
- **Rice-Wheat:** This crop rotation has become dominant cropping pattern in the Northern parts of the country.
- **Rice-Wheat-Pulses:** In this sequence of cropping pattern, after harvesting of wheat, green gram and cowpea as fodder are grown in the alluvial soil belt of Northern states. Besides, cowpea is grown in red and yellow soils of Orissa and black gram is grown in the black soils.
- **Rice-Toria-Wheat:** Rice-toria-wheat cropping pattern is the most common and largest one. It is being practiced in the Indo-Gangetic plains of India since long time.
- **Rice-Maize:** This cropping sequence is becoming very popular in the states of Andhra Pradesh, Karnataka and Tamil Nadu.

- **Rice-Fish farming system:** The field with sufficient water retaining capacity for a long period and free from heavy flooding are suitable for rice-fish farming system. This system is being followed by the small and marginal poor farmers in rainfed lowland rice areas.

7.6 Breeding Objectives and Milestones

Rice breeding programme in India was started way back in 1911 in Bengal followed by Madras province (Tamil Nadu). Subsequently, rice research projects were initiated after the establishment of Indian Council of Agricultural Research in 1929 in various provinces. By 1950, 82 research stations in 14 provinces were established fully devoted to rice research. These research stations released 445 improved varieties mainly by pure line method of selection. These varieties were bred for various ecotypes and other traits such as earliness, deep water and flood resistant, lodging resistant, drought resistant, non-shredding of grains, dormancy of seed, control of wild rice, disease resistant and response to heavy manuring. Thus, during the pure line period of selection from 1911-1949, the advantage of natural selection have been fully exploited and there have been varieties available for every rice ecology. The Central Rice Research Institute (CRRI) was established in 1946. An inter-racial hybridization programme between japonicas and indicas was initiated during 1950-54. This programme continued in India upto 1964 without much success. The International Rice Research Institute was established in the Philippines in 1960. This Institute helped in evolving dwarf high yielding varieties based on the use of a gene from semi-dwarf varieties from Taiwan. Major breeding efforts in rice were thus initiated in the early 1960s and resulted in improved productivity, higher quality and increased tolerance to various biotic and abiotic stresses. Maximum impetus was achieved with the advent of the spontaneous mutant Dee-Geo-Woo-Gen which possessed a dwarfing gene. Dwarf, photo-insensitive and upright-effective plant types which were highly responsive to added dosages of inputs then gave new direction to the rice improvement programmes Following this plant type concept, Indian rice breeders developed many semi-dwarf rice varieties that increased the productivity of rice in the country and India became self-reliant in its rice production.

The breeding priority has changed over the decades from purification of landraces placing emphasis on early maturity , consumer preference and blast resistance to recombining of desired traits through hybridization and recombinant DNA technology giving emphasis to high yield and value addition. Other important breeding objectives include disease/ pest resistance, field resistance against rice blast, tolerance to unfavourable conditions such as drought, submergence, salinity etc. and improvement in cooking and nutritive quality.

Cytoplasmic genetic male sterility (CMS) system is being widely utilized for development of rice hybrids. The first commercially usable CMS line was developed in China in 1973 from a spontaneous male sterile plant isolated in a population of the wild rice *O. sativa f. spontanea* (Yuan, 1977) This source 'Wild Abortive' or 'WA' type is considered a landmark in the history of rice breeding. The first rice hybrid for commercial cultivation was launched by China in 1976. Efforts to develop and use of hybrid rice technology in India was initiated during 1970 but the research works were systematized and intensified since 1989 with a mission mode project and this helped India earn the distinction of being the second country after China to make hybrid technology a field reality. The first four rice hybrids were released in the country viz. APHR-1, APHR-2, MGR-1 and KRH-1 during 1994. Due to concerted efforts made both by the public and private sectors, 42 hybrids have been released so far and about 1.4 mha was covered under hybrid rice during 2008.

7.7 Varietal Testing of Rice

Indian Council of Agricultural Research (ICAR) started All-India Coordinated Rice Improvement Project (AICRIP) in 1965 at Hyderabad. The coordinated variety improvement and testing programme covers 46 funded cooperating centres in addition to 72 voluntary centres in different rice growing ecologies in the country and involves more than 300 scientists (Source: Progress Report, 2008, Vol. 1, Varietal Improvement, AICRIP, ICAR, DRR, Hyderabad, India).

Under AICRIP, the following trials are carried out at 118 locations spread across 26 Indian States and 2 Union Territories.

1.	Upland trials
2.	Lowland trials
3.	Irrigated trials
4.	Hybrid rice trials
5.	Basmati trials
6.	Slender grain trials
7.	Aromatic short grain trials
8.	Saline-alkaline tolerant trials
9.	Hill rice trials
10.	Aerobic trials
11.	Boro season trials
12.	Near isogenic trials (to test rice lines derived through marker-assisted breeding)
13.	International observational nurseries
14.	Rabi trials

The AICRIP programme helps to exchange and evaluate breeding material quickly across the country. The aim of AICRIP programme is to improve yielding ability, increase efficiency in the use of external inputs and incorporate resistance to biotic and abiotic stresses. The multi-locational testing of breeding stock developed at different research centres is organized by AICRIP. The evaluation of genotype x environment interactions in different ecosystems has been the rationale for the multidisciplinary approach to rice improvement research. Depending on genotype sensitivity to photoperiod, three to four years are needed to identify a promising superior genotype based on data from the multilocational tests.

In the first year, the newly evolved genotypes are tested in replicated local yield trials. The selected breeding lines from these experiments are included in the zonal coordinated trials called initial variety trial (or initial evaluation trial). Simultaneously, these breeding lines are also put to screening nursery tests for identifying their reaction to pests and diseases. The breeding lines that yield consistently well for two years are grouped to form advanced variety trials (or uniform variety trials) and tested for two more seasons. Agronomic data on these elite breeding lines are also generated during this period. After a careful scrutiny by different research centres, selected breeding lines are evaluated in on-farm trials for obtaining reaction of farmers and extension workers on the yield performance and acceptability. Considering yield records, agronomic data and the reaction to pests and diseases, candidate breeding lines are identified for release as varieties at the annual workshop by the coordinating unit. These are then named and released as new high yielding varieties to cultivators by the state or central variety release committee. More than 850 high yielding varieties have been released for different states through the coordinated system.

7.8 Key Insect Pests and Diseases

Insect pests and diseases take a heavy toll of rice crop and thus are one of the important constraints in achieving higher rice yields. Blast disease continues to be the major constraint particularly in rainfed uplands, rainfed lowlands and hill ecosystem. Neckblast damage on basmati varieties is getting increasingly severe. Sheath blight causes considerable damage at endemic sites. False smut and sheath rot diseases have emerged as new threats to rice production. Bacterial leaf blight occurs frequently in some location. Rice tungro virus becomes a problem at a few places along the east coast in some years (ICAR, 2006). The major insect pests, nematode pests, diseases and predators of rice crop are explained in the Annexure-II to IV.

8. STATUS OF RICE CULTIVATION

Since India attaining the independence in 1947, there has been a remarkable progress in rice production. There has been one and half times increase in the area from 30 million hectares to 44 million hectares. The productivity increased three times from 700 kg/ha to 2000 kg/ha and the total annual rice production of the country has increased more than four times from 22 million tonnes to 96 million tonnes. The impressive growth is mainly owing to wide adoption of high yielding, semi-dwarf varieties, increased use of chemical fertilizers and improved package of cultural practices (Figure 9).

Based on the current trends in population growth and per capita availability of rice (215 - 230 g/day), a requirement of 109 to 117 million tones of rice has been projected for consumption alone. At a much higher level per capita availability of 250 g/day, approximately 127 million tonnes would be required by 2025 (Directorate of Rice Research, 2007).

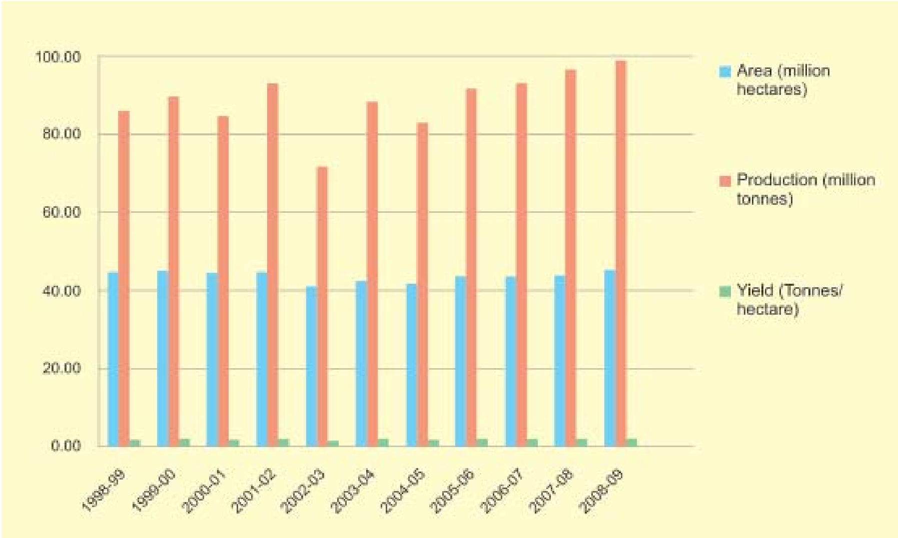


Figure 9: *Area, production and yield of rice in India*
Source: *Department of Agriculture and Cooperation, Ministry of Agriculture, Government of India (http://agricoop.nic.in/Agristatistic.htm).*

Rice is grown from Kashmir to Kanyakumari and Amritsar to Nagaland almost in every district with variations in area of cultivation. The entire country has been divided into five rice growing zones. These zones are mentioned below along with the states falling in each zone.

S. No.	Name of the Zone	Name of the States
1.	Southern zone	Andhra Pradesh, Karnataka, Kerala, Tamil Nadu, Pondicherry, Andaman & Nicobar Islands
2.	Northern zone	Haryana, Himachal Pradesh, Jammu & Kashmir, Punjab, Uttarakhand
3.	Western zone	Goa, Gujarat, Maharashtra, Rajasthan
4.	Eastern zone	Bihar, Jharkhand, Madhya Pradesh, Chhattisgarh, Orissa, Uttar Pradesh, West Bengal
5.	North-Eastern zone	Assam, Arunachal Pradesh, Manipur, Meghalaya, Mizoram, Nagaland, Sikkim, Tripura

9. BIOTECH INTERVENTIONS IN RICE

Rice is the first food crop for which complete genome sequence is available. Rice is considered as the reference genome for the grasses, including other cereals. Complete sequence is available for both japonica (Goff *et al.*, 2002) and indica (Yu *et al.*, 2002) genomes. Worldwide effort has resulted into development of gene, transcriptome, protein and metabolome databases. This offers an unprecedented opportunity to identify and functionally characterize the genes and biochemical pathways that are responsible for agronomic performance, adaptation to diverse environments, resistance to biotic stress and quality traits. The progress achieved in biotechnology applications for rice improvement is in two major areas viz. the use of molecular markers for identifying and introgressing favourable genes and gene combinations from varieties and related species, the use of transgenic technologies to incorporate genes/traits of interest. Considerable efforts have been made to identify QTLs governing several agronomic traits, resistance to biotic and abiotic stresses, and nutritional traits. This has also led to map-based cloning of genes. Such efforts have eased introgression of traits by employing marker assisted selection for rice improvement.

Among the many tools of rice biotechnology currently being applied for rice improvement, molecular markers, particularly PCR based molecular markers are one of the most important tools in rice breeding. In India, molecular markers are now routinely used for pyramiding of pest and disease resistance genes and most of the major biotic stress resistance genes have been molecularly mapped on the rice genome. Successful application of molecular markers in India include the introgression of three major bacterial blight resistance genes, Xa21, xa13 and xa5 into the genetic background of an elite fine-grained, high yielding rice variety Samba Mahsuri and two major bacterial blight resistance genes, Xa21 and xa13 into another elite Basmati variety, Pusa Basmati-1. The improved versions of the two varieties have been released recently for commercial Pusa Basmati-1. The development and release of the two improved varieties represents the first successful application of biotechnological tools in the country are the first commercial products in rice derived from application of biotechnological tools in the country. Presently efforts are on to introduce multiple biotic stress resistance genes like those conferring resistance to bacterial blight, blast, gall midge and brown plant hopper into the genetic background of elite high yielding, but biotic stress susceptible rice varieties. Efforts are also on to utilize PCR based DNA markers like SSRs and STSs for estimating seed genetic purity in rice hybrids and parental lines.

Although no transgenic rice has yet been commercialized in Asian countries, GM rice containing herbicide tolerant traits have been granted regulatory approval in the United States and also approved for food and feed use in other countries like Canada, Mexico, Australia, Colombia etc. Extensive research and development efforts are underway to develop transgenic rice broadly into herbicide tolerance, biotic-stress resistance, abiotic-stress resistance and nutritional improvement. Herbicide tolerance has been the major focus for the private sector especially in the United States. Biotic-stress tolerance, on the other hand been the primary focus for private sector as well as public sector research institutions including those in Asia. Specific traits being worked in this category include resistance to bacterial blight using Xa21 gene, rice blast, various viral diseases, the brown planthopper, and yellow stem borer, the latter-using Bt technology-being the closest to commercialization. For abiotic-stress tolerance, transgenic rice plants have been developed with tolerance to various conditions viz. drought and salinity. Regarding the nutritional traits, one of the most promising application of transgenic technology has been the development of pro-vitamin A-enriched varieties, popularly known as Golden Rice due to the slightly yellow colour conferred to the endosperm (Portrykus, 2000).

Various research institutions working in the area of GM rice in India include Directorate of Rice Research, Hyderabad; Indian Institute of Technology, Kharagpur; Bose Institute, Kolkata Central Rice Research Institute, Cuttack; Indian Agricultural Research Institute, New Delhi; University of Delhi South Campus, New Delhi; M.S. Swaminathan Research Foundation, Chennai; Tamil Nadu Agricultural University, Coimbatore; Osmania University, Hyderabad etc.

ANNEXURE-I

BOTANICAL FEATURES

Rice is a monocarpic plant that flowers once, set seeds and then die. Cultivated rice plant is an annual grass growing to 1–1.8 m with round, hallow and jointed culms, flat leaves and a terminal inflorescences, called panicle. Each culm or tiller is a shoot, which includes root, stem and leaves (Figure 10).

Root

The root system is fairly well developed in all species of rice. The root system consists of two major types: **crown roots** (the adventitious roots, including mat roots) that develop from nodes below the soil surface and the **nodal roots** that develop from nodes above the soil surface; bedsides the primary (seminal) roots. Primary root is direct prolongation of radicle that usually dies within a month. Dimorphism is a regular feature of rice roots, as originally they are thick and white with numerous root hairs on their entire surface. They become thinner, branched and brownish having hairs left only towards the root apex afterwards. Root hairs are tubular extensions of outermost layer of root and theses are generally short lived. The main rooting system of the plant develops at later stages of plant growth, when roots develop horizontally from the nodes of the stem below ground level (crown roots).

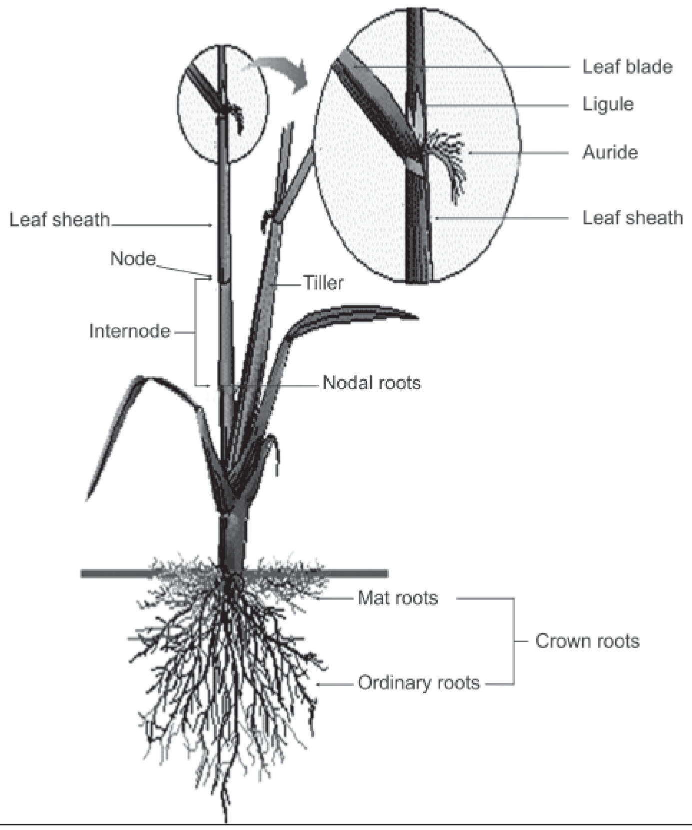


Figure 10: *Morphology of Rice Plant*
Source: *http://ikisan.com*

In the "floating rice", whorls of adventitious roots are formed from the first three very short nodes, giving rise to whorls of permanent adventitious roots. Tillers are produced at the nodes and adventitious roots are produced from lower nodes of these culms, so that the plant quickly develops a mass of adventitious roots.

Stem

The stem has 2 parts, underground and aerial. The aerial part, has well defined solid nodes and hollow internodes. Another name for the aerial part of the stem of the rice plant is the culm which consists of several nodes spaced apart by internodes. The culm is more or less erect, cylindrical, and hollow except at the nodes, and varies in thickness from about 6-8 mm. At the base of the culm is a bladeless bract called the prophyllum. The first leaves are generated at the first node. Their sheaths envelop the main culm and this is called the primary tiller. Primary tillers emerge alternatively from the main stem, projecting in upward direction. The lower point of origin on the main stem, the older is the tiller. Secondary tillers arise from the first node of the primary tiller and generally have a fewer number of leaves. At the leaf junction at the furthermost node, ligules and a pair of auricles occur. The panicle also forms at the uppermost node and gives rise to the spikelets or fruits of the rice plant.

The nodes are clearly defined by the presence of a distinct thickening, the Pulvinus, immediately above the node. The pulvinus may be coloured, varying in intensity from a "touch" of purple to a deep uniform purple. A bud may form in the axil of each leaf of the main stem, but normally only the lowermost bud from the crowded nodes at ground level develop into branches, thus a typical tillered plant develops.

Leaf

Leaves on the main stem are produced one at a time and are arranged alternatively. The number of leaves borne on an axis is equal to the number of nodes. The first leaf of the plant is the sheathing leaf or coleoptile. The second leaf emerging through the lateral sheath of the coleoptile is reduced in size and has no blade. The remaining leaves are normal, except the uppermost or "**flag**" which is slightly modified. The angle of flag leaf is oriented more vertically than of preceding leaves. The uppermost leaf or flag of the axis possesses a blade always shorter and broader than the lower leaves. As the panicle emerges from the sheath, its blade is nearly parallel to the panicle axis. After the panicle has emerged the blade falls.

The leaves are born at an angle of every node and they possess two parts viz., **leaf blade** or expanded parts and the **leaf sheath** which wraps the culms. The bud of potential tiller is enclosed in the sheath. The normal vegetative leaf has sheath, auricles and blade. The leaf sheath is an elongated, cylindrical structure that encloses and so protects the younger shoots inside of it. The leaf blade is flat, elongated, and ribbon like, the "leafy" part of the leaf, it is usually longer than the sheath, its major function is to perform photosynthesis.

Rice leaf can be distinguished from other rice like grasses by the presence of **ligule** and **auricle**. The white band at the junction of the blade and the sheath is called **collar**. The ligule is the papery scale located inside the blade and it looks like continuation of the sheath. The auricle is a pair of hairy, sickle-shaped appendages located in the junction of the collar and the sheath.

Flowers

Inflorescence of rice is a terminal panicle (compound raceme) with single flowered spikelets, born on a long peduncle, which is the last internode of the culm. Panicle formation occurs at the tip of the growing point of the shoot. The spikelet consists of two short sterile lemma, a normal fertile lemma and palea. The floral organs are present protected within the Lemma and Palea, the hardened, modified stem. When the spikelet is closed, the lemma partly encloses the palea. The flower consists of two small, oval, thick, and fleshing bodies, the lodicules situated at the base of the axis. When floral parts mature, the lodicules swell and open the spikelet to expose the mature floral parts.

The fertile lemma and palea enclose the sexual organs viz., six stamens arranged in whorls and a pistil at the centre. The stamen consists of bilobed anthers borne on slender filaments, while the pistil consists of ovary, style and feathery bifid stigma. The anther present in the stamen includes 4 elongated sacs where pollen grains are stored. The stigma is some what longer than broad, smooth and bears two styles and sometimes a short, rudimentary third.

The panicle has a main axis, known as 'primary rachis' which bears a number of secondary rachii. The secondary rachii further branch out into tertiary ones and produce in turn still smaller branches, known as 'rachilla'. Each rachilla bears a spikelet at its tip. Much of the variability for spikelet number is due to variation in the number of secondary branches.

Grain

Rice grain, a caryopsis, is a dry one seeded fruit having its pericarp fused with seed coat. The outer protective covering of grain is called the Hull which consists of a *lemma*, a *palea*, an *awn* (tail), a *rachilla* (grain stem) and two *sterile lemmas*. The hull is hard cover of seed, which accounts for 20% of total seed weight. Other parts of the grain are the pericarp, seed coat and nucellus; and embryo and endosperm. The endosperm is made of starch, protein and fat. The endosperm consists of aleurone layer that encloses the embryo and the starchy or inner endosperm. It is the storehouse of food for embryo. The food needed for germination is stored here (Figure 11).

Grain length varies with cultivar between 5 and 7 mm, and grains can be round, bold or slender.

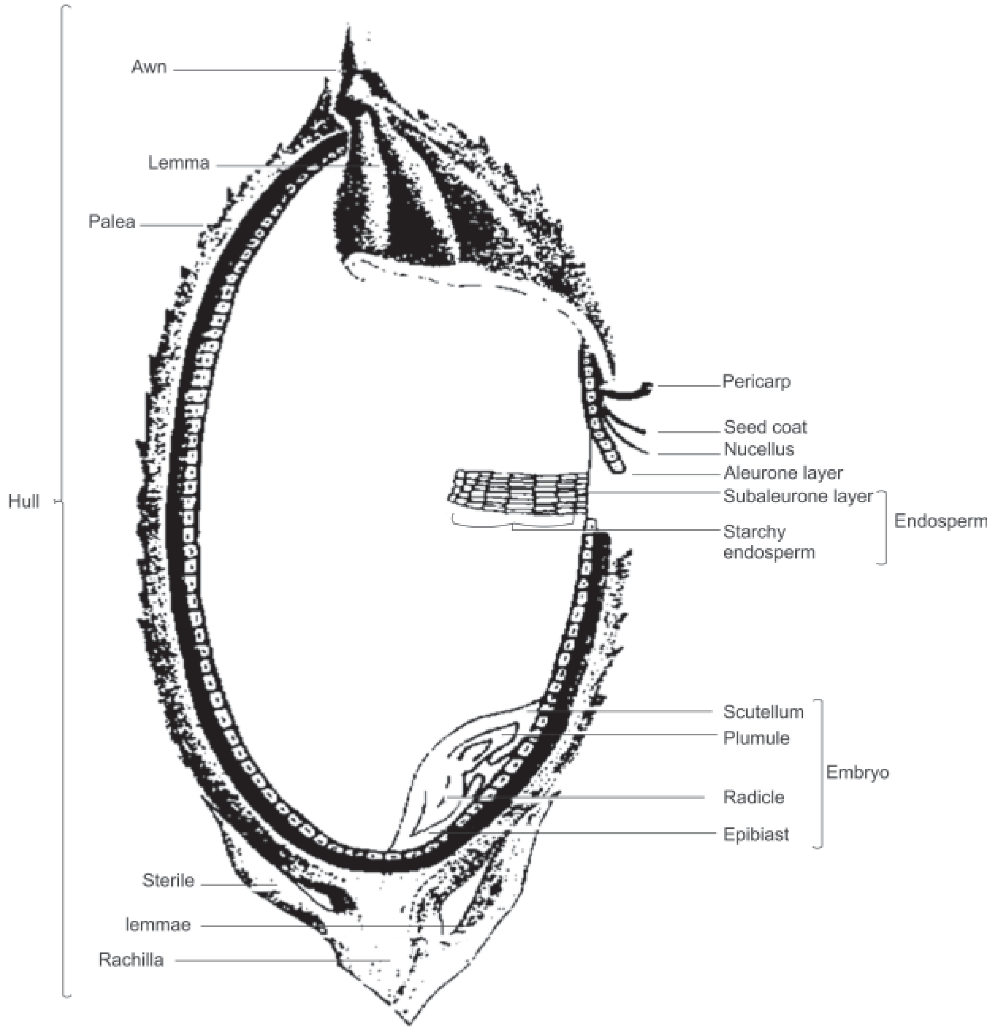


Figure 11: *Rice Grain*

ANNEXURE-II

KEY INSECT AND NEMATODE PESTS OF RICE

Insect pests are most important in rice as they are widespread, vary widely in intensity and feeding habits and are more in number making them difficult to manage in the farmers fields. The tropical warm and humid climate prevalent in the country particularly in the rice ecosystems makes their incidence, development and multiplication favourable. There are more than 70 pest species of rice of which 20 have major significance. On an average, the yield losses in the country due to insect pests are around 28%.

The major insect pests of rice in India are described below:

i) Rice Stem Borer

Yellow stem borer (**YSB**) i.e ***Scirpophaga incertulas*** is the most widespread, dominant and destructive pest regularly occuring in all parts of India both in kharif and rabi seasons. The pest affects the crop in the nursery, soon after transplanting and also in the pre-earhead stage. The caterpillars bore into stem and feed internally causing death of central shoot "dead hearts" in vegetative stage and "white earhead" at milky stage respectively. This results in chaffy grains. The larvae feed on green tissue of leaf sheath and stem. They initially mine the midrib of leaves.

Figure 12: *Yellow Stem Borer (Scirpophaga incertulas) caterpillars boring into stem of rice plant*
Source: *http://extension.entm.purdue.edu/*

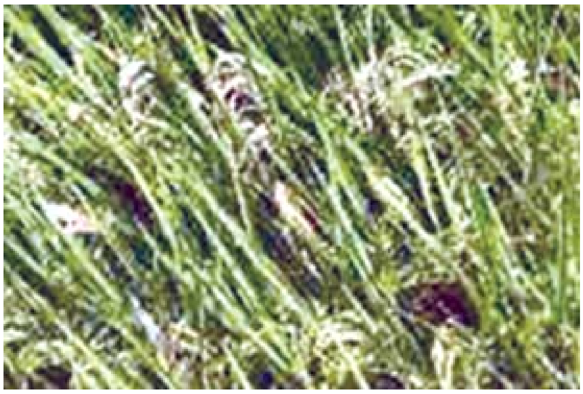


Figure 13: *White ears in paddy due to YSB*
Source: *http://image.shutterstock.com/*

The other borers are, pink stem borer, *Sesamia inferens* (Walker) occurring mostly in rice-wheat cropping systems of north-west, white borer, *Scirpophaga innotata* (Walker) common in southern region particularly in Kerala, dark headed stem borer, *Chilo polychrysus* (Meyrick) and striped stem borer, *Chilo suppressalis* (Meyrick) in states of West Bengal and Assam, respectively.

ii) Rice Gall Midge (*Orseolia oryzae*)

It is a serious pest of the rice growing countries, including India. The maggots crawl down the plant between leaf sheaths to reach the apical meristem on which they feed. The maggot feeding causes formation of a tubular sheath gall called silver shoot (Figure 14). The pest causes damage mainly during the tillering stage of the rice plant. The adult gall midge is a mosquito like insect and lays eggs singly on the under surface of the rice leaves or sometimes on the leaf sheaths. The differentiation of tiller is affected and tiller is rendered sterile.

Figure 14: Rice Gall Midge (Orseolia oryzae)
Source: http//knowledgebank.irri.org/

iii) Green Leafhoppers (*Nephotettix* spp.)

The two predominant species of green leafhoppers are *N. virescens* (Distant) and *N. nigropictus* (Distant). The leafhoppers attack all stages of the plant. Both adults and nymphs cause direct damage by sucking plant sap leading to stunted growth and reduced tillering (Figure 15). At high population levels their feeding occasionally results in the drying of the plants and the infested paddy fields appear blighted. Infestation at the time of panicle emeregence affect grain formation. Apart from direct damage, the insect also act as vectors of rice tungro virus.

Figure 15: Green Leafhopper-adults (Nephotettix spp.)
Source: http//knowledgebank.irri.org/

iv) Brown Plant Hopper (*Nilaparvata lugens*)

The brown plant hopper (BPH) is common in irrigated wetland environments especially during the reproductive stage of the rice plant. Nymphs and adults congregate at the base of plants, above water level, sucking the plant sap (Figure 16). At early stages, round yellowish patches appear which soon turn brownish due to drying up of the plants. The patches of infestation spreads in concentric circles within the field and in severe cases the affected field gives a burnt appearance, known as 'hopper burn' (Figure 17). Apart from direct damage, BPH is also a vector of grassy stunt virus.

Figure 16: Adults and eggs of BPH (Nilaparvata lugens)

Figure 17: Field showing hopper burn

Source: ikisan.com

In the recent times, white backed planthopper has emerged as a serious pest in areas particularly where rice varieties resistant to BPH are grown.

v) Leaf Folder (*Cnapholocrocis medinalis*)

In India the rice leaf folder is another serious pest. Infestation usually occurs during late growth stages of the crop. Nymphs and adults suck the sap from leaves. Infested leaves are characterized by small scratches like mark due to chlorophyll removal (Figure 18). The leaf folder larvae hatching from the flat and oval eggs laid on leaf blades, fold the leaves longitudinally and feed within resulting in a linear pale white stripe. They transmit "yellow dwarf" and "tungro virus" disease in rice.

Figure 18: *Leaf folder damage in paddy*
Source: *http://ikisan.com*

vi) Gundhi Bug (*Leptocorisa oratorius*)

Gundhi bugs also called stink bugs, are distributed in all rice growing areas in India (Figure 19a). Nymphs and adults suck the milk from the developing grains in the early stage of the sap from the grain at the milk stage by which the panicles become discoloured and the grains becomes chaffy, empty and some grains develop but break during milking. Damage by nymphs is more compared to adults (Figure 19b).

Figure 19a : *Gundhi Bug (Leptocorisa oratorius)*

Figure 19b: *Discolored panicles damaged grains due to Gundhi Bug*

Source: *http://ikisan.com*

vii) Rice Hispa (*Dicladispa armigera*)

Rice hispa is a common rice pest in wet-land environments. Damage is caused by both the grubs and adult during early vegetative stage. Grubs feed by tunneling lower and upper epidermis resulting in regular translucent white patches (Figure 20). Adults scrape chlorophyll between the veins and so white parallel streaks are visible. Feeding on veins results in the formation of blotches on the leaves (Figure 21).

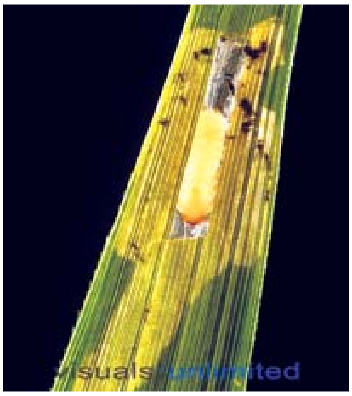


Figure 20: *Grub of Rice Hispa (Dicladispa armigera)*

Figure 21: *Rice leaves infected with Dicladispa armigera*

Source: http://c.photoshelter.com/

viii) Rice Case Worm (*Nymphula depunctalis guen*)

The rice case worm is an important pest of irrigated and rain fed wet land (Figure 22). The pest attacks the crop in the early transplanted stage. The larvae cut the leaf tips and roll by spinning both margins to make tubular case. They live inside the tube, feed on leaves, float over the water to move from plant to plant and defoliate rice plant before maximum tillering. Heavy damage can lead to patches of severe defoliation, stunted growth, skeletonization of leaves and death of plants (Figure 23).

Figure 22: Adult moth of Rice Case Worm (Nymphula depunctalis guen)

Figure 23: *Field damage due to Rice Case Worm*

Source: http://ikisan.com

ix) Rice Thrips (*Stenchaetothrips biformis*)

The pest causes damage both in nursery and main field. Both the nymphs and the adults suck the sap from the leaves (Figure 24). Initially yellow streaks appear on the leaves followed by curling of the leaves longitudinally from the margins inwards leading to sharply pointed leaf tips, resembling that of needles, which finally wither. In case of severe infestation, the plants become lanky and present a sickly appearance. Infestation at the panicle stage causes unfilled grains or spikelet sterility.

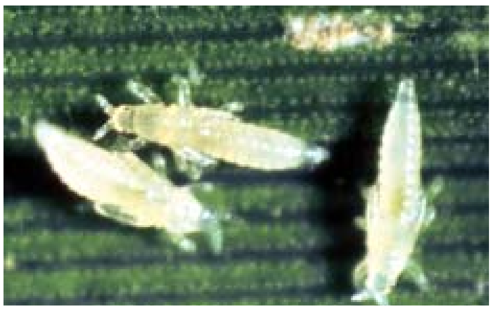


Figure 24: *Rice Thrips (Stenchaetothrips biformis)*

Source: http://www.pestalert.org/

x) Climbing Cutworm (*Mythimma separate*)

The climbing cut worm is also known as ear-cutting caterpillar. Damage by cut worms remains unnoticed in the earlier stages of pest infestation and often leads to a serious situation at the time of crop maturity. The larvae cut the earheads in addition to damaging the foliage (Figure 25). When the pest population reaches high, there is excessive feeding and complete removal of leaves and plants. The rice panicles are cut off from the base, sometimes leading to complete loss of the crop.

Figure 25: *Plant damaged by Cutworm (Mythimma separate)*
Source: *http://ikisan.com*

xi) Rice Root Aphid (*Tetrineura nigriabdominalis* Sasakii)

Rice root aphids (*Tetrineura nigriabdominalis* Sasakii) are the major pests of the upland rice. The nymphs and adults suck the sap from the tender roots (Figure 26). Ants are found frequently in association with aphids feeding on honey dew excreted by aphids. The aphids remain in the cavities made by the ants around the root system. The soil around the aphid attacked plant becomes loose and the plant appears yellowish with curled and dried up leaf tips (Figure 27).

Figure 26: *Adults and immatures of Rice Root Aphids (Tetrineura nigriabdominalis Sasakii)*

Figure 27: *Damage caused due to Root Aphid*

Source: *http://knowledgebank.irri.org/*

In addition to insect pests, the major nematodes identified as constrains for rice production are root knot, white tip, *ufra*, root and root lesion nematodes. The nematodes account for 5 to 10% of the rice yield losses.

i) Root - Knot Nematodes (*Meloidogyne graminicola* Golden and Birchfield)

The root-knot nematode is a serious pest of upland and deepwater rices (Figure 28). Root-knot nematodes affected plants show depletion in vigour, yellowing and curling of leaves. Infection by second stage juveniles in roots cause disruption and hypertrophy of cortical cells due to their secretions resulting in swellings of stele at the sites of nematode establishment. The swellings are visible to the naked eyes as knots on the roots (Figure 29). In upland rice the nematode infection leads in incomplete filling of kernals while in deepwater, infected seedlings remain stunted, unable to grow above flood water and perish due to continuous submergence.

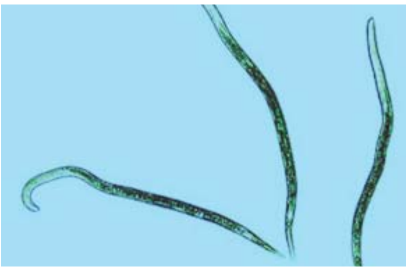


Figure 28: Second stage juveniles of Root - Knot Nematode (*Meloidogyne graminicola*)

Figure 29: Root galls on rice caused by Root - Knot Nemtodes

Source: *http://knowledgebank.irri.org/*

ii) White Tip Nematode (*Aphelenchoides besseyi* Christie)

Affected plants show white-tip or whip-like malformation of the top one-third of the leaf blade (Figure 30). In flowering tillers, chaffiness and abnormal elongation of glumes in some spikelets, rachii and rachillae are observed. Infected plants show reduced vigour, height and weight of spikelets and number of grains.

Figure 30: White Tip (*Aphelenchoides besseyi* Christie) diseased rice plants
Source: *http://knowledgebank.irri.org/*

iii) Stem or *Ufra* Nematode (*Ditylenchus angustus* Butler Filipjev)

The nematode is common in deepwater rice and causes *ufra* or *Dak pora* disease in rice. In the vegetative stage, injury due to the nematode results in yellow splash pattern in the invaded areas of leaf sheaths and the margins become contorted similar to ragged stunt virus disease of rice. During the reproductive stage of the crop, nematodes reach the space between the inner sides of imbricate whorl of leaf sheaths to feed on the ear primordial and developing earheads. As a result, earheads emerge in a twisted and crinkled manner with empty spikelets or donot emerge at all (Figure 31). The plants infested with *ufra* are also susceptible to blast, sheath rot or bacterial leaf blight.

Figure 31: Ufra disease (*Ditylenchus angustus*) damage symptoms at reproductive stage
Source: *http://knowledgebank.irri.org/*

iv) Root Nematode (*Hirschmanniella spp.* Luc and Goodey)

The root nematode occurs in irrigated and semi-deepwater rices. Besides direct feeding, the root nematode migrates intra and inter cellularly in the root cortex, causing degeneration of physiological functioning of roots. This results in growth retardation and decrease in tillering during the early growth stages. Flowering can be delayed by 14 days.

v) Root Lesion Nematode (*Pratylenchus spp.* Filipjev)

The nematode infected roots appear swollen with black nectrotic lesions on the root surface. The infested plants are stunted and even smothering resulting in patchy growth in fields. Other symptoms include chlorosis of leaves and reduction in number of earheads and grains.

ANNEXURE-III

MAJOR DISEASES OF RICE

Disease are considered major constraints in rice production. Rice diseases are mainly caused by fungi, bacteria or viruses. An over view of important fungal and bacterial diseases affecting the rice crop in India are as follows:

i) Fungal diseases of Rice

1. **Rice Blast** [*Magnaporthe grisea (Pyricularia oryzae)*]
   Blast is caused by the fungus *Magnaporthe grisea* (*Pyricularia oryzae)*. Blast fungus can infest any organ of the plant. Young seedlings, leaves, panicles and other aerial parts of the adult plant are affected and so often called as leaf blast, neck blast, or panicle blast (Figure 32). The fungus produces spots or lesions on leaves, nodes, panicles, and collar of the flag leaves. Leaf spots are of spindle-shaped with brown or reddish-brown margins, ashy centers, and pointed ends. Infection of panicle base causes rotten neck or neck rot and causes the panicle to fall off.

Figure 32: *Symptoms of Rice Blast (Pyricularia oryzae) infection*
Source: *http://knowledgebank.irri.org/*

2. **Sheath Blight** (*Rhizoctonia solani*)
   Sheath blight of another major fungal disease in rice caused by *Rhizoctonia solani*. Symptoms become apparent at tillering or flowering stage and affect all plant parts above water line. Spots or lesions first develop near the water level (in flooded fields) or soil (in upland fields) and spots initially appear on the leaf sheath. Spots may be oval or ellipsoidal and measure 1-3 cm long. Lesions on the leaf blade are usually irregular and banded with green, brown, and orange coloration (Figure 33). When several such lesions are continuous on a greenish tissue, it almost looks like a snake skin from a distance, so it is also known as snake skin disease.

Figure 33: *Symptoms of Sheath Blight (Rhizoctonia solani)*
Source: *http://knowledgebank.irri.org/*

3. **False Smut** (*Ustilaginoidea virens)*

   False smut is caused by *Ustilaginoidea virens* and is characterized by large orange to olive-green fruiting structures on one or more grains of the mature panicle (Figure 34).The symptoms of false smut are visible only after flowering. The pathogen grows in the ovary and transforms it into large, yellowish and velvety green balls, which become greatly enlarged at later stage. The spore balls are covered by a membrane in the early stages, which bursts with further growth and the loose velvety pseudomorphs become visible.

Figure 34: *False Smut (Ustilaginoidea virens) infection*
Source: *http://knowledgebank.irri.org/*

4. **Brown Spot** *(Bipolaris oryzae)*

   The disease symptoms of brown spot causes by *Bipolaris oryzae* are seen on leaves and glumes of maturing plants. Symptoms also appear on young seedlings and the panicle branches in older plants. Brown leaf spot is a seed-borne disease. The fungus causes brown, circular to oval spots on the leaves. Leaf spots may be evident shortly after seedling emergence and continue to develop until maturity (Figure 35).

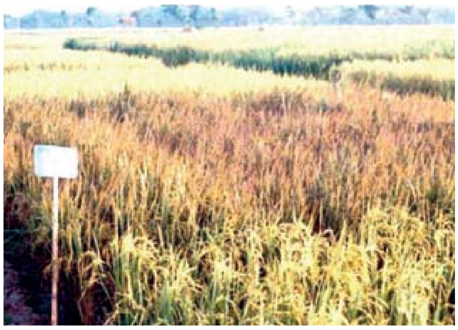


Figure 35: *Symptoms of Brown Spot (Bipolaris oryzae)*
Source: *http://knowledgebank.irri.org/*

5. **Black Sheath Rot** (*Gaeumannomyces graminis)*

   Gaeumannomyces graminis attacks the crown, lower leaf sheaths, and roots of the rice plant causing a dark brown to black discoloration of the leaf sheaths from the crown to considerably above the water line. As the discolored, infected sheaths decay, tiny, black the fungal reproductive structures (perithecia) form within the tissue (Figure 36). The disease is usually observed late in the main crop season and may cause reduced tillering, poor grain fill, and lodging.

Figure 36: *Black Sheath Rot (Gaeumannomyces graminis)*
Source: *http://msucares.com/*

6. **Bakanae Disease** (*Gibberella fujikuroi)*

   Gibberella fujikuroi causes bakanae disease in which infected plants become several inches taller than normal plants in seedbed and field. The plants become thin with yellowish green leaves and pale green flag leaves. Dying of the seedlings occur at early tillering (Figure 37). Reduced tillering and drying leaves at late infection occurs.

Figure 37: *Bakanae Disease (Gibberella fujikuroi)*
Source: *http://knowledgebank.irri.org/*

ii) Bacterial diseases of Rice

Figure 38: Small streaks caused by Bacterial Leaf Blight (Xanthomonas campestris pv. oryzae)
Source: http://knowledgebank.irri.org/

1. **Bacterial Leaf Blight** (*Xanthomonas campestris* pv. *oryzae)*
   The most serious bacterial disease is Bacterial leaf blight caused by *Xanthomonas campestris* pv. *oryzae.* The first symptom of the disease is a water soaked lesion on the edges of the leaf blades near the leaf tip. The lesions expand and turn yellowish and eventually grayish-white (Figure 38). Leaves wilt and roll up and become grayish green to yellow. Entire plant wilt completely. Seedling wilt or kresek.

2. **Bacterial Leaf Streak** (*Xanthomonas campestris* f.sp. *translucens)*
   Xanthomonas campestris f.sp. *translucens* is responsible for bacterial leaf streak in which small, dark-green and water-soaked streaks appear initially on interveins from tillering to booting stage. Streaks dark-green at first and later enlarge to become yellowish gray and translucent (Figure 39). The number of streaks is more towards the tip of the leaf which coalescens and thereby causes pre-mature drying of the leaf. Numerous small yellow beads of bacterial exudates on surface of lesions on humid conditions.

Figure 39: Bacterial Leaf Streak (Xanthomonas campestris f.sp. translucens)
Source: http://knowledgebank.irri.org/

iii) Viral Diseases of Rice

Figure 40: Leaf symptoms of Tungro
Source: http://knowledgebank.irri.org/

1. **Tungro**
   The Tungro virus is spread by green leafhoppers , *Nephotettix virescens* and *N. nigropictus* for which rice is the preferred host. The virus causes leaf discoloration, which varies from light green to orange yellow leaves, reduction in tiller number and stunted plant growth (Figure 40). The panicle emergence is delayed resulting in small and sterile panicles. In some cultivars, the panicles do not emerge at all.

2. **Grassy stunt**
   The virus is transmitted by brown planthopper, *Nilaparvata lugens*, which can transmit the virus after acquisition until its death. The symptoms include, stunting, profuse tillering, leaves with pale green or green color and usually with rusty brown spots, which spread giving a bronze color to the plants. The leaves become stiff and erect (Figure 41).

Figure 41: Rice Grassy Stunt Virus (RGSV)
Source: http://knowledgebank.irri.org/

3. **Ragged stunt**

The disease is transmitted through the brown planthopper. Symptoms of the disease are stunting, twisting and curling of the leaves especially the flag leaf with ragged or serrated margins (Figure 42). Sometimes galls are present along the leaf veins.

Figure 42: *Rice Ragged Stunt Virus (RRSV)*
Source: *http://knowledgebank.irri.org/*

ANNEXURE - IV

NATURALLY OCCURRING PREDATORS

The predominant predators that offer control of pests in rice crop are spiders, beetles, plant bug, damselfly etc as indicated below:

i) Spiders

Spiders play an important role in regulating insect pests in the agricultural ecosystem. Spiders as the wolf spiders, Lynx spider, Orb spider are known to consume a large number of prey and play an important role in reducing the densities of plant hoppers and leafhoppers in rice fields (Figure 43 - 45).

Figure 43: *Wolf Spiders (Pardosa pseudoannulata)*

Figure 44: *Orb Spider*

Figure 45: *Lynx Spider (Oxyopes javanus)*

Source: *http://knowledgebank.irri.org/*

ii) Beetles

Both the adults and nymphs prefer to prey upon various aphid, leafhopper and planthopper. In the absence of prey however they feed on the rice plant parts itself. Some e.g. are Ground beetle (*Ophionea nigrofasciata),* Rove beetle (P*aederus fuscipes).* Lady beetles are important insect predators in rice as *Micraspis crocea* (Mulsant) (Figure 46-48).

Figure 46: *Ground Beetle (Ophionea nigrofasciata)*

Figure 47: *Rove Beetle (Paederus fuscipes)*

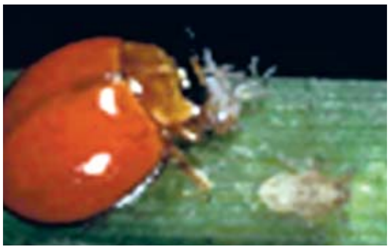


Figure 48: *Coccinellid Beetle (Micraspis sp.)*

Source: *http://knowledgebank.irri.org/*

iii) Bugs

Microvelia douglasi atrolineata a short but broad small water bug can survive for long periods even without food provided the field is saturated or flooded as in rice fields (Figure 49). Both the adults and nymphs live on the water surface and attack insects that fall onto the surface. They are more successful as predators when they attack the host in groups.

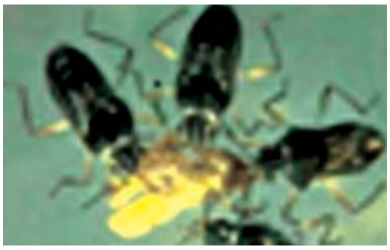


Figure 49: *Bug (Microvelia douglasi atrolineata)*
Source: *http://knowledgebank.irri.org/*

iv) Damselfy

The narrow winged damselflies are weak fliers compared with their dragonfly cousins. The yellow-green and black adults have a long slender abdomen. They feed on flying moths, butterflies, and hoppers. The following are common in rice *Agriocnemis femina femina* (Brauer), *Agriocnemis pygmaea* (Rambur) (Figure 50 - 51).

Figure 50 : *Agriocnemis femina femina (Brauer)*

Figure 51: *Agriocnemis pygmaea (Rambur)*

Source: *http://knowledgebank.irri.org/*

v) Crickets

Two species of Crickets are common predators of rice insect pests i.e. *Anaxipha longipennis* (Serville) and *Metioche vittaticollis* (Sword-tailed Cricket) (Figure 52 - 53).

Figure 52 : *Anaxipha longipennis (Serville)*

Figure 53: *Metioche vittaticollis (Sword-tailed Cricket)*

Source: *http://knowledgebank.irri.org/*

In addition, parasitoids of common rice insect pests are very important components of the natural enemy complex of insect pests and have been the most common type of natural enemy introduced for biological control of insects. The different parasitoids attacking the various growth stages i.e. egg, larvae and pupa of rice-pests are provided in the Table 6 given below:

Table 6 : Parasitoids attacking at the various stages of common rice insect pests

Parasitoides for insect pests	Egg	Larva	Pupa
Yellow stemborer Parasitoids	*Tetrastichus schoenobii* *Trichogramma japonicum* *Telenomus rowani*	*Stenobracon nicevillei* *Bracon chinensis*	*Tetrastichus ayyari*
Leaffolders Parasitoids	*Copidosomopsis nacoleiae* *Trichogramma chilonis*	Cotesia augustibasis	*Xanthopimpla* flavolineata *Tetrastichus ayyari*
Brown planthopper Parasitoids	*Oligosita yasumatsui* *Anagrus spp.*	*Pseudogonatopus spp.*	*Pseudogonatopus spp.*
Gall midge Parasitoids		*Platygaster oryzae*	

REFERENCES

Bhat, R. S. and Gowda, M. V. C. 2004. Specialty native rice (*Oryza sativa* L.) germplasm of Uttara Kannada, India. *Plant Gen. Res. Newslet*. 140: 42- 47.

Brar, D. S. and Khush, G. S. 2003. Utilization of wild species of genus *Oryza* in rice improvement. In: Nanda, J.S. and Sharma, S. D. (eds.), *Monograph on Genus Oryza,* pp. 283-309.

Bres-Patry, C., Lorieux, M., Clement, G., Bangratz, M., Ghesquiere, A. 2001. Heredity and genetic mapping of domestication-related traits in a temperate japonica weedy rice. *Theoretical and Applied Genetics*. 102: 118-126.

Chang, T. T. 1964. Present knowledge of Rice Genetics and Cytogenetics. International Rice Research Institute, Philippines. pp. 95.

Chang, T. T. 1976. The origin, evolution, cultivation, dissemination and diversification of Asian and African rices. *Euphytica,* 25 (1): 425-441.

Chang, T. T. and Bardenas, E.A. 1965. "The Morphology and Varietal Characteristics of the Rice Plant. *Technical Bulletin* (Manila, Philippines: International Rice Research Institute) nfo. 4.

Coghlan, A. 2000. So far so good: for the moment, the gene genie is staying in its bottle. *New Scientist.* 2231:4.

den Nijs, H.C.M., Bartsch, D. and Sweet, J. 2004. Introgression from genetically modified plants into wild relatives. *CAB International*, UK. Pp 1-403.

Directorate of Rice Research. 2007. DRR Perspective Plan: Vision 2025, published by Directorate of Rice Research, Hyderabad.

Drake, D.J., Nader, G. and Forero, L. 2002. Feeding rice straw to cattle. University of California, Division of Agriculture and Natural Resources. <http://agronomy.ucdavis.edu/uccerice/STRAW/pub8079.pdf>

Ellis, R.H., Hong, T.D., Roberts, E.H. 1983. Procedures for the safe removal of dormancy in rice seed. *Seed Science & Technology.* 11: 77-112.

FAO. 2004. Species description *Oryza sativa* L. <http://www.fao.org/ag/AGP/AGPC/doc/GBASE/data/pf000274.htm>

Gealy, D.R., Mitten, D.H., Rutger, J.N. 2003. Gene flow between red rice (*Oryza sativa*) and herbicide-resistant rice (*O. sativa*): Implications for weed management. *Weed Technology* 17:627-645.

Glaszmann, J.C., Arraudeau, M. 1986. Varietal diversity and reproductive barriers. I. Rice plant type variation, *japonica-javanica* relationships. *Rice Genet Newsletter.* 3:41-43.

Goff, S., Ricke, D., Lan, T., Presting, G., Wang, R., Dunn, M., Glazebrook, J., Sessions, A., Oeller, P., Varma, H., Hadley, D., Hutchison, D., Martin, C., Katagiri, F., Lange, B., Moughamer, T., Xia, Y., Budworth, P., Zhong, J., Miguel, T., Paszkowski, U., Zhang, S., Colbert, M., Sun, W., Chen, L., Cooper, B., Park, S., Wood, T., Mao, L., Quail, P., Wing, R., Dean, R., Yu, Y., Zharkikh, A., Shen, R., Sahasrabudhe, S., Thomas, A., Cannings, R., Gutin, A., Pruss, D., Reid, J., Tavtigian, S., Mitchell, J., Eldredge, G., Scholl, T., Miller, R., Bhatnagar, S., Adey, N., Rubano, T., Tusneem, N., Robinson, R., Feldhaus, J., Macalma, T., Oliphant, A. and Briggs, S. 2002. A draft sequence of the rice genome (*Oryza sativa* L. ssp. *japonica*). *Science.* 296 (5565): 92-100.

Gopalan. C., Rama Sastri. B.V. and Balasubramanian .S. 2007. Nutritive Value of Indian Foods, published by National Institute of Nutrition (NIN), ICMR.

Hanamaratti, N. G., Prashanthi, S. K., Salimath, P. M., Hanchinal, R. R., Mohankumar, H. D. and Parameshwarappa, K. G. 2008. Traditional land races of rice in Karnataka: Reservoirs of valuable traits. *Curr. Sci.* 94 (2): 242-247.

Handbook of Agriculture. 2006. pp 870-886. ICAR. New Delhi.

Huaqi, W. Bouman, B.A.M, Zhao, D., Changgui, W. and Moya, P.F. Aerobic rice in northern China: opportunities and challenges. In: Water-wise rice production. In: Bouman BAM, Hengsdijk H, Hardy B, Bindraban PS, Tuong TP, Ladha JK, editors. 2002. Water-wise rice production. International Rice Research Institute, Manila.

Henderson, M.T., Yeh, B.P. and Exner, B. 1959. Further evidence of structural differentiation in the chromosomes as a cause of sterility in intervarietal hybrids of rice, *Oryza sativa* L., *Cytologia.* 24: B 415-422.

Hill, D.J., Hosking, C.S., Zhie, C.Y., Leung, R., Baratwidjaja, K., Likura, Y., Lyngkaran, N., Gonzalez, A.A., Wah, L.B., Hsieh, K.H. 1997. The frequency of food allergy in Australia and Asia. *Environmental Toxicology and Pharmacology.* 4: 101-110.

Ikehashi, H. and Araki, H. 1984. Varietal screening for compatibility types revealed in F_1 fertility of distant crosses in rice. *Jpn. J. Breed.* 34(3):304–312.

Ikehashi, H. and Araki, H. 1986. Genetics of F_1 sterility in remote crosses of rice. Pages 119–130 in Rice genetics. International Rice Research Institute, P.O. Box 933, Manila, Philippines.

Ikehashi, H. and Araki, H. 1987. Screening and genetic analysis of wide compatibility in F_1 hybrids of distant crosses in rice, *Oryza sativa*. Tech. Bull. 22. Tropical Agriculture Research Center, Japan.

Ikehashi, H., Araki, H., and Yanagihara, S. 1991. Screening and analysis of wide compatibility loci in wide crosses of rice. Pages 33-43 in Rice genetics II. International Rice Research Institute, P.O. Box 933, Manila, Philippines.

International Rice Research Institute. 2002. Growth and Morphology of the Rice Plant. <http://www.knowledgebank.irri.org/pu_growthMorph.htm>

IRRI. 1985. International Rice Research: 25 Years of Partnership, IRRI, 188pp.

Iso, E. 1928. Studies on breeding of rice in Formosa. Agric Div Cent Institute Formosa Rep 37 (In Japanese, cited by Morinaga, T 1954).

Jackson, M.G. 1978. Rice straw as livestock feed. In: FAO, ed. Ruminant nutrition: selected articles from the World Animal Review <http://www.fao.org/DOCREP/004/X6512E/X6512E00.htm#TOC>

Jackson, M.T. 1997. Conservation of Rice Genetic Resources: the role of the international Rice Genebank at RRI, *Plant Mol. Biol.* 35: 61-67.

Jennings, P.R. 1966. Evaluation of partial sterility in indica x japonica rice hybrids. Tech Bull 5. International Rice Research Institute, Manila.

Khush, G.S. 1977. Disease and insect resistance in rice. *Advances in Agronomy*. 29: 265-341.

Khush, G.S., Bacalangco, E., Ogawa, T. 1990. A new gene for resistance to bacterial blight from *O. longistaminata. Rice Genetics newsletters.* 7:121-122.

Koga, Y., Akihama, T., Fujimaki, H. and Yokoo, M. 1969. Studies on the longevity of pollen grains of rice *Oryza sativa* L. I. Morphological changes of pollen grains after shedding. *Cytologia*, 36: 104-110.

Lin, S.C. and Yuan, L.P. 1980. Hybrid rice breeding in China. In: Innovative approaches to rice breeding. International Rice Research Institute, Manila, The Philoppines. pp 35-51.

Liu, B., Liu, Z.L. and Li, X.W. 1999. Production of a highly asymmetric somatic hybrid between rice and *Zizania latifolia* (Griseb): evidence for inter-exchange. *Theoretical and Applied Genetics*. 98: 1099-1103.

Londo, J.P., Chiang, Y.C., Hung, K.S., Chiang T.Y. and Schaal B.A. 2006. "Phylogeography of Asian wild rice, *Oryza rufipogon*, reveals multiple independent domestications of cultivated rice, *Oryza sativa*". *PNAS*. 103 (25): 9578-9583.

Matsuo, T. 1952. Genecological studies on the cultivated rice. *Bull. Natl Inst Agric Sci* (Japan), Ser D 3: 1-111. (In Japanese with English summary).

McDonald, D.J. 1979. Rice. Chapter 3. In: Australian field crops vol 2: Tropical cereals, oilseeds, grain legumes and other crops. .pp 70-94. Angus and Robertson, London.

Messeguer, J., Fogher, C., Guiderdoni, E., Marfa, V., Baldi, G., Mele, E. and Catala, M.M. 2001. Field assessments of gene flow from transgenic to cultivated rice *(Oryza sativa* L.) using a herbicide resistance gene as tracer marker. *Theoretical and Applied Genetics.* 103: 1151-1159.

Moldenhauer, K.A.K and Gibbons, J.H. 2003. Rice Morphology and Development. Chapter 2.1. In: Smith, C.W., Dilday, R.H. (eds.). Rice . Origin, History, Technology and Production. John Wiley and Sons, Inc. Hoboken, New Jersey. pp 103-127.

Morinaga, T. 1968. Origin and geographical distribution of Japanese rice. *Jap Agric Res Quarterly.* 3:1-524.

Morishima, H. 1984. Species relationships and the search for ancestors. In: Tsunoda, S. and Takahashi, N.(ed.), Biology of Rice: 3-30, Japan. Sci. Soc. Press, Tokyo/Elsevier, Amsterdam.

Morishima, H. 1984. Wild plants and domestication. In: Tsunoda, S. and Takahashi, N. (ed) Biology of rice. Elsevier, Amsterdam Page 3-30.

Morishima, H., Hinata, K. and Oka, H.I. 1963. Comparison of modes of evolution of cultivated forms from two wild rice species, *Oryza breviligulata* and *O. perennis*. *Evolution.* 17:70-181.

Multani, D.S., Khush, G.S., delos Reyes, B.G. and Brar, D.S. 2003. Alien gene introgression and development of monosomic alien addition lines from *Oryza latifolia* Desv. to rice*, Oryza sativa* L. *Theoretical and Applied Genetics.* 107: 395-405.

National Bureau of Plant Genetic Resources and Project Coordinating and Monitoring Unit, Ministry of Environment and Forests (2006). Document on Biology of Rice (*Oryza sativa* L.) in India.

Nielsen, K.M., Bones , A.M., Smalla, K., Bones, A.M., van Elsas, J.D. 1998. Horizontal gene transfer from transgenic plants to terrestrial bacteria – a rare event? *FEMS Microbiology Reviews* 22: 79-103.

Neilsen, K.M., Gebhard, F., Smalla, K., Bones, A.M., van Elsas, J.D. 1997. Evaluation of possible horizontal gene transfer from transgenic plants to the soil bacterium *Acinobactor calcoaceticus* BD 413. *Theoretical and Applied Genetics.* 95:815-821.

Niizeki, H. and Oono, K., 1968. Induction of haploid rice plant from anthor culture. *Proc. Japan. Acad.*44: 554-557.

OECD. 1999. *Consensus document on the biology of Oryza sativa (Rice)*. ENV/JM/MOMO (99) 26. Organization for Economic Co-operation and Development.

OGTR. 2005. The Biology and Ecology of Rice (*Oryza sativa* L.) in Australia published by Office of the Gene Technology Regulator, Australian Government.

Oka, H.I. 1958. Intervarietal variation and classification of cultivated rice. *Indian J Genet.* 18:79-89.

Oka, H.I. 1953. Phylogenetic differentiation of the cultivated rice plant VI. The mechanism of sterility in the intervarietal hybrid of rice. *Jpn. J. Breeding.* 2: 217-224.

Oka, H.I. 1974. Analysis of genes controlling F1 stability in rice by the use of isogenic lines. *Genetics.* 77: 521-534.

Oka, H.I. 1988. Origin of cultivated rice. Elsevier, Amsterdam.

Oka, H.I. and Chang, W.T. 1961. Hybrid swarms between wild and cultivated rice species, *Oryza perennis* and *O. sativa*. *Evolution.* 15:418-430.

Oka, H.I., Chang, W.T. 1959. The impact of cultivation on populations of wild rice, *Oryza sativa* f. *spontanea*. *Phyton*. 13: 115-117.

Pandey and Velasco. 1999. *Intl. Rice Res. Notes*. 24: 6-11.

Progress Report. 2008. All-India Coordinated Rice Improvement Project (AICRIP), Indian Council of Agricultural Research (ICAR). Directorate of Rice Research, Hydreabad.

Porteres, R. 1956. Taxonomic agrobotanique der riz cultives *O. sativa* Linne. et *O. glaberrima* Steudelo, *J. Agri. Trop. Bot. App*. 3: 341-384.

Potrykus, I. 2000. The Golden Rice ™ Tale. Agbio View : http://agbioview.listblot.com.

Reano, R. and Pham, J.L. 1998. Does cross-pollination occur during seed regeneration at the International Rice Genebank? *Internatinoal Rice Research Notes (IRRN)* 23: 5-6.

Sampath, S. 1962. The genus *Oryza*: its taxonomy and inter-relationships. O*ryza* 1: 1-29.

Sano, R., Konishi, T. and Morishima, H. 1985. An altitude cline of isozyme variation found in landrace populations of Nepalese rice. *Rice Genet Newsletter*. 2: 51-52.

Schluter, K., Futterer, J. and Potrykus, I. 1995. Horizontal gene transfer from a transgenic potato line to a bacterial pathogen (*Erwinia chrysanthemi*) occurs – if at all – at an extremely low frequency. *Bio/Technology.* 13: 1094-1098.

Second, G. 1982. Origin of the genic diversity of cultivated rice (*Oryza spp*.): study of the polymorphism scored at 40 isozyme loci. *Japan. J. Genet.* 57:25-57.

Second, G. 1986. Isozymes and phylogenetic relationships in *Oryza*. In IRRI (ed.), *Rice Genetics*, 27-39, IRRI.

Sharma, S.D., Dhua, S.R. and Agrawal, P.K. 2000. Species of genus *Oryza* and their interrelationships. In: Nanda, J.S. (ed). Rice breeding and genetics: Research priorities and challenges. pp 313-347. Oxford and IBH.

Sharma, S.D., Tripathy, S. and Biswal, J. 2000. Origin of *O. sativa* and its ecotypes. In: Nanda, J.S. (ed). Rice breeding and genetics: Research priorities and challenges. pp 349-369. Science Publishers, Enfield and Oxford and IBH, New Delhi.

Siddiq and Viraktamath, 2001. Rice. In: Chopra, V.L. (ed.), *Breeding Field Crops.* pp. 1-85. Oxford and IBH Publishing Co. Pvt. Ltd. New Delhi, India.

Sidram, S.R. 2001. Interspecific gene flow in genus *Oryza* and its consequences in development of transgenic's. Thesis no T777 Nehru Library IGKV Raipur.

Singh, V.P., Siddiq, E.A., Zaman, F.U. and Sadananda, A.R. 1988. Improved Basmati donors. *International Rice Res. Newsletter*. 13(6): 22-25.

Sitch, L.A. 1990. Incompatibility barriers operating in crosses of *Oryza sativa* with related species and genera. In: Gustafson, J.P. (ed.), Gene Manipulation in Plant Improvement II:77-93. Plenum Press, New York.

Sitch, L.A., Dalmacio, R.D. and Romero, G.O. 1989. Crossability of wild *Oryza* species and their potential use for improvement of cultivated rice. *Rice Genet. Newsl.* 6:58-60.

Song, Z.P., Lu, B.R., Chen, J.K. 2004. Pollen flow of cultivated rice measured under experimental conditions. *Biodiversity and Conservation.* 13: 579-590.

Syvanen, M. 1999. In search of horizontal gene transfer. *Nature Biotechnology.* 17: 833.

Takahashi, N. 1984. Seed germination and seedling growth. Chapter 3. In: S Tsunoda, N. Takashi, eds. Biology of rice, Volume 7. Elsevier, Amsterdam. pp 77-88.

Tamtwar, K. 2003. Gene flow studies in genus *Oryza* and its consequences in deployment of transgenics. Thesis no 1380 Nehru Library IGKV Raipur.

Tateoka, T. 1962a. Taxonomic studies of *Oryza*. I. *O. latifolia* complex. *Bot Mag* 75 : 418-427.

Tunwar, N.S. and Singh, S.V. 1988. Indian Minimum Seed Certification Standards. The Central Seed Certification Board, Department of Agriculture and Cooperation, Ministry of Agriculture, Government of India.

Vaughan, D.A. 1994. The wild relatives of rice. International Rice Research Institute, Manila.

Vaughan, D.A. and Morishima, H. 2003. Biosystematics of genus *Oryza.* Chapter 1.2. In: CW Smith, C.W. and Dilday, R.H. eds. Rice. *Origin, History, Technology, and Production.* pp 27-65. John Wiley and Sons Inc., Hoboken, New Jersey.

Vaughan, D.A., Lu, B.R. and Tomooka, N. 2008. The evolving story of rice evolution. *Plant Science* 174 (4): 394–408.

Wagenaar, C.A.W, Schouenburg, J.Ch, Siregar, H. 1952. Semisterility of rice hybrids in Indonesia in relation to the *indica-japonica* problem. Pemberitan Balai Besar Penjelidikan Pertanian (Contrib Gen Agric Research Sta) Bogor, Indonesia. 127: 1-28.

Yu, J., Hu, S., Wang, J., Wong, G., Li, S., Liu, B., Deng, Y., Dai, L., Zhou, Y., Zhang, X., Cao, M., Liu, J., Sun, J., Tang, J., Chen, Y., Huang, X., Lin, W., Ye, C., Tong, W., Cong, L., Geng, J., Han, Y., Li, L., Li, W., Hu, G., Huang, X., Li, W., Li, J., Liu, Z., Li, L., Liu, J., Qi, Q., Liu, J., Li, L., Li, T., Wang, X., Lu, H., Wu, T., Zhu, M., Ni, P., Han, H., Dong, W., Ren, X., Feng, X., Cui, P., Li, X., Wang, H., Xu, X., Zhai, W., Xu, Z., Zhang, J., He, S., Zhang, J., Xu, J., Zhang, K., Zheng, X., Dong, J., Zeng, W., Tao, L., Ye, J., Tan, J., Ren, X., Chen, X., He, J., Liu, D., Tian, W., Tian, C., Xia, H., Bao, Q., Li, G., Gao, H., Cao, T., Wang, J., Zhao, W., Li, P., Chen, W., Wang, X., Zhang, Y., Hu, J., Wang, J., Liu, S., Yang, J., Zhang, G., Xiong, Y., Li, Z., Mao, L., Zhou, C., Zhu, Z., Chen, R., Hao, B., Zheng, W., Chen, S., Guo, W., Li, G., Liu, S., Tao, M., Wang, J., Zhu, L., Yuan, L. and Yang, H., 2002, A draft sequence of the rice genome (*Oryza sativa* L. ssp. *indica*). *Science.* 296 (5565): 79-92.

Yuan, L.P. 1977. The execution and theory of developing hybrid rice. *Chinese Agricultural Science*. 1B: 27-31 (In Chinese).

Zhang, N., Linscombe, S. and Oard, J. 2004. Out-crossing frequency and genetic analysis of hybrids between transgenic glufosinate herbicide-resistant rice and the weed, red rice. *Euphytica* 130:35-45.

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