Plant Molecular Biology **35:** 25–34, 1997.

Origin, dispersal, cultivation and variation of rice

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Key words: wild species, domestication, indica rice, japonica rice, rice ecosystems, isozymes

Abstract

There are two cultivated and twenty-one wild species of genus *Oryza*. *O. sativa*, the Asian cultivated rice is grown all over the world. The African cultivated rice, *O. glaberrima* is grown on a small scale in West Africa. The genus *Oryza* probably originated about 130 million years ago in Gondwanaland and different species got distributed into different continents with the breakup of Gondwanaland. The cultivated species originated from a common ancestor with AA genome. Perennial and annual ancestors of *O. sativa* are *O. rufipogon and O. nivara* and those of *O. glaberrima* are *O. longistaminata*, *O. breviligulata* and *O. glaberrima* probably domesticated in Niger river delta. Varieties of *O. sativa* are classified into six groups on the basis of genetic affinity. Widely known indica rices correspond to group I and japonicas to group VI. The so called javanica rices also belong to group VI and are designated as tropical japonicas in contrast to temperate japonicas grown in temperate climate. Indica and japonica rices had a polyphyletic origin. Indicas were probably domesticated in the foothills of Himalayas in Eastern India and japonicas somewhere in South China. The indica rices dispersed throughout the tropics and subtropics from India. The japonica rices moved northward from South China and became the temperate ecotype. They also moved southward to Southeast Asia and from there to West Africa and Brazil and became tropical ecotype. Rice is now grown between 55°N and 36°S latitudes. It is grown under diverse growing conditions such as irrigated, rainfed lowland, rainfed upland and floodprone ecosystems. Human selection and adaptation to diverse environments has resulted in numerous cultivars. It is estimated that about 120 000 varieties of rice exist in the world. After the establishment of International Rice Research Institute in 1960, rice varietal improvement was intensified and high yielding varieties were developed. These varieties are now planted to 70% of world's riceland. Rice production doubled between 1966 and 1990 due to large scale adoption of these improved varieties. Rice production must increase by 60% by 2025 to feed the additional rice consumers. New tools of molecular and cellular biology such as anther culture, molecular marker aided selection and genetic engineering will play increasing role in rice improvement.

Abbreviations: IRRI, International Rice Research Institute.

Introduction

Rice is the world's single most important food crop and a primary food source for more than a third of the world's population. More than 90% of the world's rice is grown and consumed in Asia where 60% of the earth's people live. Rice accounts for 35 to 60% of the calories consumed by 3 billion Asians. Rice is planted on about 148 million hectares annually, or on 11% of the world's cultivated land. Wheat covers a slightly larger land area, but a considerable amount of wheat is used as animal feed. Rice is the only major cereal crop that is consumed almost exclusively by humans. World's rice production was 553 million tons in 1996. China, the largest producer, produced 187 million tons followed by India (122 million tons), Indonesia (50 million tons), Bangladesh (27 million tons), Vietnam

Table 1. Rice production, area, and productivity of rice, 1995.

Major rice consuming and producing countries	Paddy production (000 t)	Paddy area (000 ha)	Area under irrigated rice (%)	Paddy yield (t/ha)
Asia	505 332	132 821	56	3.7
Bangladesh	27 128	9 950	25	2.8
Cambodia	3 433	1 924	16	1.1
China	187 334	31 107	92	5.9
India	121 562	42 300	46	2.8
Indonesia	49 744	11 439	54	4.3
Japan	13 435	2 118	99	6.8
Korea, DPR	2 580	650	67	3.5
Korea, Republic	6 343	1 050	70	6.1
Lao PDR	1,418	522	7	2.6
Malaysia	2 126	681	66	3.1
Myanmar	19 568	6 144	33	2.9
Nepal	2 906	1 368	49	2.4
Pakistan	5 920	2 162	100	2.5
Philippines	10 541	3 759	61	3.0
Sri Lanka	1 900	890	72	3.1
Thailand	21 130	9 020	10	2.2
Vietnam	24 464	6 766	51	3.5
Latin America	20 774	6 690	33	2.9
Africa	15 092	6 957	17	2.2
Australia	1 016	118	100	8.3
USA	7 888	1 252	100	6.7
Rest of the world	3 312	897	88	4.0
World	553 414	148 735	54	3.7

Source: World Rice Statistics Database. IRRI.

(24 million tons), Thailand (21 million tons) and Myanmar (20 million tons) (Table 1).

Only about 4% of the world's rice production is traded internationally. Thailand is world's leading rice exporter, selling about 4–6 million tons annually. The United States is the second largest exporter, even though it ranks 11th in production. It produces 6 million tons annually and exports about 40% of it. Vietnam, Pakistan and Myanmar each export about a million tons annually. India exported about 4 million tons in 1995 but exports were only about 2 million tons in 1996.

Iran, Iraq and Saudi Arabia are the major importers, taking about 0.9, 0.7, and 0.5 million tons per year, respectively. African countries, where demand for rice is increasing at a rate of about 2% annually, buy around 3 million tons or about 25% of the total world imports each year.

The importance of rice in the diet varies among countries. It accounts for over 70% of the daily calorie intake in countries such as Bangladesh, Cambodia, Laos, and Myanmar but drops to about 40% in countries such as China and India whose northern areas consume more wheat. Rice is also an important staple in Latin America, Africa and Middle East. Health food advocates in Western countries pay a premium price for brown or unpolished rice but rice is polished wherever it is staple food. Why? Because its bran layers contain oils (free fatty acids) that turn rancid if the surface is scarred. Thus, brown rice cannot be stored for more than a week. In fact, brown rice may be less nutritious than white rice, because the body's digestion and absorption of it is lower. However, brown rice does have more B vitamins and 1% more protein. The difference in fiber and minerals is insignificant. Rice is 8–9% protein (wheat is 11–12%).

Origin of cultivated rice

There are two cultivated species of rice. *O. sativa*, the Asian rice, is grown worldwide. *O. glaberrima*, the African rice, is grown on a limited scale in West Africa.

Like wheat, corn, rye, oats and barley, rice belongs to Gramineae or grass family. The genus *Oryza* to which cultivated rice belongs, probably originated at least 130 million years ago and spread as a wild grass in Gondwanaland the super continent that eventually broke up and drifted apart to become Asia, Africa, the Americas, Australia and Antarctica [4]. Today's species of genus *Oryza* are distributed in all of these continents except Antarctica (Table 2).

There are twenty-one wild species in genus *Oryza*. Nine of the wild species are tetraploid. Remaining wild species as well as the cultivated species are diploid. Harlan and De Wet [7] proposed classifying the wild relatives of a crop species into three categories on the basis of isolation barriers and the ease of gene transfer to the cultivated species. This is a useful concept for breeders. In *Oryza*, however, F_1 sterility and other dysfunctions of hybrids occur irrespective of the genetic distance, and the distinction between the three categories is not always clear. However, the pattern of variation among species examined through methods of numerical taxonomy is helpful. A variation study of 16 species based on 42 morphological traits, reported by Morishima and Oka [13], suggested that *Oryza* species can be divided into three main groups; (1) *O. sativa* and its relatives, (2) *O. officinalis* and its relatives, and (3) other more distantly related species.

In recent years efforts have been made to introgress useful genes from wild species to cultivated rice through interspecific hybridization [3, 8, 14]. On the basis of ease of gene transfer, wild species *O. rufipogon, O. nivara, O. glumaepatula, O. meridionalis, O. breviligulata, O. longistaminata* and the cultivated *O. sativa* and *O. glaberrima* constitute the primary gene pool. They share the AA genome and gene transfer can be accomplished through conventional hybridization and selection procedures. Species belonging to the *O. officinalis* complex constitute the secondary gene pool. Crosses between *O. sativa* and the species of this complex can be accomplished through embryo rescue technique. Since there is limited homology between the A genome of *O. sativa* and BB, CC, CCDD, EE, and FF genomes of wild species, only limited gene transfer is possible. Species belonging to *O. meyeriana, O. ridleyi,* and *O. schlechteri* complexes constitute the tertiary gene pool. Crosses between *O. sativa* and the species belonging to these complexes are extremely difficult to accomplish and gene transfer is rare if at all.

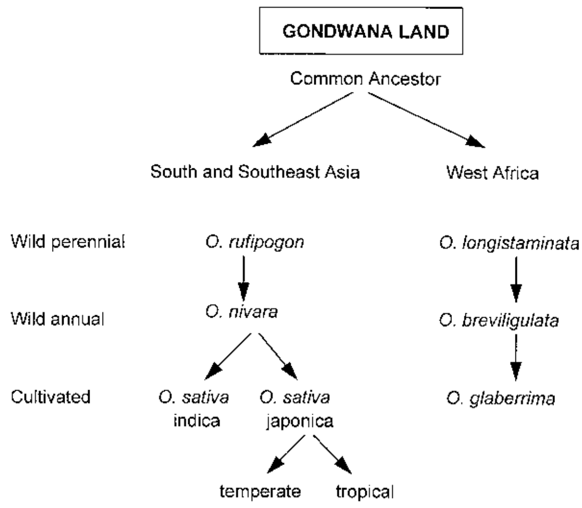

Figure 1. Evolutionary pathway of two cultivated species of rice.

Wild progenitors of cultivated rice

The common rice, *O. sativa* and the African rice *O. glaberrima* are thought to be an example of parallel evolution in crop plants. The wild progenitor of *O. sativa* is the Asian common wild rice, *O. rufipogon*, which shows a range of variation from perennial to annual types. Annual types, also given a specific name of *O. nivara*, were domesticated to become *O. sativa*. In a parallel evolutionary path, *O. glaberrima* was domesticated for annual *O. breviligulata* which in turn evolved from perennial *O. longistaminata* (Figure 1).

O. rufipogon is distributed from Pakistan to China and Indonesia and its populations vary between perennial and annual types which differ markedly in life-history traits [16]. In short, the perennial types have higher outcrossing rates and lower seed productivity than annual types. In monsoonal Asia, the perennial types grow in deep swamps, which retain moisture throughout the year while the annual types occur in temporary marshes, which are parched in dry season. All these wild rices cross with cultivated rice under natural conditions producing hybrid swarms in the field.

Domestication of wild rices probably started about 9000 years ago. Development of annuals at different elevations in East India, Northern Southeast Asia and West China was enhanced by alternating peri-

Table 2. Chromosome number, genomic composition and potential useful traits of *Oryza* species.

Species	2n	Genome	Distribution	Useful or potentially useful traits[a]
***O. sativa* complex**				
O. sativa L.	24	AA	Worldwide	Cultigen
O. nivara Sharma et Shastry	24	AA	Tropical and sub-tropical Asia	Resistance to grassy stunt virus, blast, drought avoidance
O. rufipogon Griff.	24	AA	Tropical and sub-tropical Asia, tropical Australia	Elongation ability, resistance to BB, source of CMS
O. breviligulata A. Chev. et Roehr.	24	A^gA^g	Africa	Resistance to GLH, BB, drought avoidance
O. glaberrima Steud.	24	A^gA^g	West Africa	Cultigen
O. longistaminata A. Chev. et Roehr.	24	A^gA^g	Africa	Resistance to BB, drought avoidance
O. meridionalis Ng	24	A^mA^m	Tropical Australia	Elongation ability, drought avoidance
O. glumaepatula Steud.	24	$A^{gp}A^{gp}$	South and Central America	Elongation ability, source of CMS
***O. officinalis* complex**				
O. punctata Kotschy ex Steud.	24, 48	BB, BBCC	Africa	Resistance to BPH, zigzag leafhopper
O. minuta J. S. Pesl. ex C.B. Presl.	48	BBCC	Philippine and Papua New Guinea	Resistance to sheath blight, BB, BPH, GLH
O. officinalis Wall ex Watt	24	CC	Tropical and sub-tropical Asia, tropical Australia	Resistance to thrips, BPH, GLH, WBPH
O. rhizomatis Vaughan	24	CC	Sri Lanka	Drought avoidance, rhizomatous
O. eichingeri A. Peter	24,	CC	South Asia and East Africa	Resistance to yellow mottle virus, BPH, WBPH, GLH
O. latifolia Desv.	48	CCDD	South and Central America	Resistance to BPH, high biomass production
O. alta Swallen	48	CCDD	South and Central America	Resistance to striped stemborer, high biomass production
O. grandiglumis (Doell) Prod.	48	CCDD	South and Central America	High biomass production
O. australiensis Domin.	24	EE	Tropical Australia	Drought avoidance, resistance to BPH
O. brachyantha A. Chev. et Roehr.	24	FF	Africa	Resistance to yellow stem-borer, leaf-folder, whorl maggot, tolerance to laterite soil
***O. meyeriana* complex**				
O. granulata Nees et Arn. ex Watt	24	GG	South and Southeast Asia	Shade tolerance, adaptation to aerobic soil
O. meyeriana (Zoll. et Mor. ex Steud.) Baill.	24	GG	Southeast Asia	Shade tolerance, adaptation to aerobic soil

Table 2. continued

Species	2n	Genome	Distribution	Useful or potentially useful traits[a]
O. ridleyi complex				
O. longiglumis Jansen	48	HHJJ	Irian Jaya, Indonesia and Papua New Guinea	Resistance to blast, BB
O. ridleyi Hook. f.	48	HHJJ	South Asia	Resistance to stemborer, whorl maggot, blast, BB
Unknown genome				
O. schlechteri Pilger	48	unknown	Papua New Guinea	Stoloniferous

[a]BPH = brown planthopper; GLH = green leafhopper; WBPH = white-backed planthopper; BB = bacterial blight; CMS = cytoplasmic male sterility.

ods of drought and variations in temperature during Neothermal age about 10 000–15 000 years ago [24]. Domestication in Asia could have occurred independently and concurrently at several sites within or bordering a broad belt that extends from the plains below the eastern foothills of the Himalayas in India through upper Myanmar, Northern Thailand, Laos and Vietnam, to Southwest or South China [4, 19, 20]. In this Asian arc, rice was grown in forest clearings under a system of shifting cultivation. The crop was probably grown by direct seeding and without standing water. It was in China that the process of soil puddling and transplanting seedlings was likely refined. With the development of puddling and transplanting, rice became truly domesticated. In Southeast Asia, by contrast, rice was originally produced under dryland conditions in the uplands and only recently did it come to occupy vast river deltas. Linguistic evidence also points to the early origin of cultivated rice in this Asian arc. In several regional languages, the general terms for rice and food or for rice and agriculture are synonymous.

The earliest and most convincing archeological evidence for domestication of rice in Southeast Asia was discovered by Welhelm G. Solheim II in 1966 [22]. Pottery sherds bearing the imprints of grain and husks of *O. sativa* were discovered at Non Nok Tha in the Korat area of Thailand. These remains have been confirmed by ^{14}C and thermoluminescence testing as dating to at least 4000 B.C.

Ancient India is undoubtedly one of the oldest regions where cultivation of *O. sativa* began. The oldest grain samples excavated at Mohenjodaro now in Pakistan date back to about 2500 B.C. [1]. The oldest carbonized grains found in India date back to about 6750 B.C. [21]. The antiquity of rice cultivation in China has long been a subject of debate [4]. The oldest remains of cultivated rice date back to five centuries before Christ. Carbonized rice grains from Tongxieng County of Zhejiang province were identified as 7040 years old. The second oldest, 6960 years old is from Hemdu relic in Yuyao county of Zhejiang province.

The African cultivar, *O. glaberrima*, originated in Niger river delta. The primary center of diversity for *O. glaberrima* is the swampy basin of the upper Niger river and two secondary centers to the southwest near the Guinean Coast. The primary center was probably formed around 1500 BC, while the secondary centers were formed 500 years later [18].

Polyphyletic origin of O. sativa

O. sativa is tremendously variable species and has worldwide distribution. The Chinese have recognized two rice varietal groups, Hsien and Keng, since the Han dynasty. They correspond to indica and japonica classification introduced by Kato *et al.* [9]. Indica and japonica cultivars differ in many characters when typical varieties are compared but show overlapping variations. The indica and japonica types are each characterized by an association of certain diagnostic characters, such as $KCl0_3$ resistance, cold tolerance, apiculus hair length and phenol reaction [15]. Classification based on the scores given by a discriminant function combining measurements of these characters have a low probability of misplacement into varietal groups. Even then a few varieties remain unclassified as atypical [16].

Morinaga [12] proposed a third group to include bulu and gundil varieties of Indonesia under the name javanica but he gave no description and did not use this name in his later publications. Several authors have ranked javanicas at the same taxonomic level as indicas and japonicas. However, they cannot be considered to have the same level of differentiation as indicas and japonicas [5]. As shown by Glaszmann [6] on the basis of genetic affinity using isozyme analysis, javanica varieties fall within the japonica group and are now referred to as tropical japonicas and the so called typical japonicas are referred to as temperate japonicas (Figure 1).

Glaszmann [6] examined 1688 rice cultivars from different Asian countries for allelic frequencies at 15 isozyme loci and analyzed the data by a multivariate analysis. The results showed that 95% of the cultivars fell into six groups, the remaining 5% being scattered over intermediate positions. This classification involves no morphological criteria. When the six groups were compared with the varietal groups classified by morphological characters, Group I corresponded to the indica and group VI to the japonica. Group VI also included the bulu and gundil varieties formerly classified into so called javanicas. Groups II, III, IV and V were atypical but also classified as indicas in the conventional classification. Group II corresponds to very early maturing and drought tolerant upland rices called Aus varieties grown in Bangladesh and West Bengal state of India during the so called Aus season (March–June). Floating rices of Bangladesh and India called Ashinas and Rayadas belong to groups III and IV, respectively. Group V includes aromatic rices of Indian subcontinent. Various levels of sterility are observed in the F_1 hybrids of intergroup crosses but not in the intragroup crosses. For example, crosses between varieties of temperate and tropical japonicas show no sterility.

Various opinions have been forwarded about the origin of indica and japonica rices. Kato *et al* [9] expressed the opinion that indica and japonica rices originated independently from a wild ancestor. Ting [23] on the other hand proposed that japonicas were derived from the indicas. Earlier studies primarily focused on indica-japonica differentiation. However, so called indicas are such a diverse group that several morphological types can be recognized which correspond to Glaszmann's classification based on isozymes. Thus, the information from isolation barriers (F_1 sterility), genetic affinity (isozyme analysis) and morphological grouping suggests that the six groups may have been domesticated from different populations of *O. nivara* at different locations and on different time scales. Rayada rices (Group IV) of Bangladesh adapted to deepwater conditions, for example may have been domesticated in only recent times as more deep water areas were brought under cultivation. These rices still share several traits with wild rices.

Dispersal of cultivated rices

From the Himalayan foot hills rice spread to Western and Northern India, to Afghanistan and Iran and South to Sri Lanka. The data of 2500 BC has already been mentioned for Mohenjodarao, while in Sri Lanka rice was a major crop as early as 1000 BC. The rice crop may well have been introduced to Greece and neighboring countries of Mediterranean by returning members of Alexander the Great's expedition to India in 324 BC. However, in all probability rice did not become an established crop in Europe much later perhaps in 15th or 16th century. Rices grown in the Mediterranean region are japonicas while the rices grown in the Indian subcontinent are indicas. Rice also travelled from India to Madagascar and East Africa and then to countries of West Africa. Indica rices also spread eastward to Southeast Asia and north to China.

The japonica rice was most likely domesticated somewhere in northern parts of Southeast Asia or South China. It moved north to become a temperate japonica. From China, temperate japonicas were introduced in Korea and from Korea to Japan around the beginning of 1st century. In the hilly areas of Southeast Asia japonica rices were grown under upland culture as a component of shifting cultivation before the upland tribes moved into the lowlands and introduced the japonicas into lowland culture. From mainland Southeast Asia, both indica and japonica rices were introduced into Malaysia, Philippines, and Indonesia and from Philippines to Taiwan. Migrating Malays from Indonesia, introduced tropical japonicas into Madagascar in 5th or 6th century. Portuguese priests introduced the tropical japonicas from Indonesia into Guinea Bissau from where they spread to other West African countries. Thus, most of upland rice varieties grown in West Africa are tropical japonicas. The Portuguese also introduced tropical japonicas and lowland indicas to Brazil and Spanish people brought them to other Latin American countries. Thus, in Brazil today, most of the upland varieties are tropical japonicas and lowland varieties that belong to indica group. The first record of rice for U.S.A. dates from 1685, and it was probably introduced from Madagascar with slave trade.

Table 3. Distribution of rice area in different ecologies in different region of world.

Region	Rice area in 1000 ha			
	Irrigated	Rainfed Lowland	Upland	Floodprone
South Asia	24 120	10 488	7 309	5 589
Southeast Asia	14 924	16 073	2 381	4 361
East Asia	34 372	1 888	778	0
Latin America	2 046	427	3 685	108
Africa	1 107	280	2 800	1 327
Other countries	2 144	0	127	0
Total	79 210	40 553	17 152	11 451

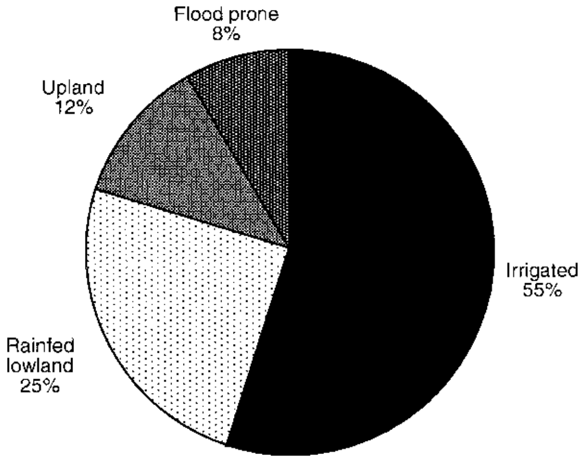

Figure 2. Distribution of world rice area in different ecologies.

Rice cultivation

Rice is grown under diverse growing conditions. Four major ecosystems are generally recognized [10] as follows: (1) Irrigated, (2) Rainfed lowland, (3) Upland, and (4) Floodprone. The distribution of rice area in different ecologies in different regions of the world is shown in Table 3.

Irrigated rice

Approximately, 55% of the world rice area planted to rice, is irrigated (Figure 2) and is the most productive rice growing system. Perhaps 75% of the world rice production comes from irrigated areas and Asian mega cities are fed from irrigated rice. Irrigation water is provided by human intervention through a variety of works including river diversions, reservoirs and wells. The area of irrigated rice has expanded markedly in the last 3 decades. Modern rice varieties and improved cultivation techniques have had their greatest impact on increasing the productivity of irrigated lands. Most of the irrigated areas are planted to improved varieties and more fertilizer and other inputs are used than in other ecologies. Rice yields in irrigated areas have more than doubled to five tons per ha in the past 30 years and there is considerable scope for further yield improvement. Irrigated areas are further divided into irrigated wet season when rainfall is supplemental with irrigation water and irrigated dry season when rainfall is very low and irrigation is the primary source of water supply. Yields during the dry season are higher than during the wet season due to higher incoming solar radiation.

Rainfed lowland rice

About one-fourth of the world rice area is rainfed lowland. Yields average about two tons per hectare. Rainfed lowlands have a great diversity of growing conditions that vary by amount of rainfall and duration of rainfall, depth of standing water, duration of standing water, flooding frequency, time of flooding, soil type and topography. Rainfed lowland fields are bunded and water is impounded, when available, just like irrigated fields. Rainfed lowlands are further subdivided into five categories.

Rainfed shallow favorable, where rainfall is adequate. Short periods of moisture stress may occur. Improved varieties developed for irrigated conditions are grown in such area and yields average around three tons.

Rainfed shallow drought prone, where rainy period is short (90–110 days) and periods of mild to severe drought stress occur during the growing season. Photoperiod insensitive varieties with short duration and degree of drought tolerance are most suitable.

Rainfed shallow submergence prone, where rice crop is submerged during periods of heavy rainfall for up to 10 days. Rainy period is generally long and crop is harvested after the rainy season is over. Photoperiod sensitive varieties are generally grown.

Rainfed medium deep, where water accumulates in the fields in low lying areas and stagnates for 2–5 months because of impeded drainage. Photoperiod sensitive varieties with tolerance to stagnant water are grown.

Upland rice

Upland or dryland rice is grown under rainfed, naturally well drained soils in bunded or unbunded fields without surface water accumulation. Some of the upland rice areas are on sloping mountain sides. Rice is planted under dry conditions just as wheat or maize. Rice varieties are photoperiod insensitive, have deep roots and some level of drought tolerance. Many of the upland soils have low pH and are deficient in nutrients. Yields average about 1.2 tons per hectare. About 16 million hectares of world rice land is classified as upland.

Floodprone rice

Floodprone rice is grown in low lying lands in river deltas of South and Southeast Asia. Standing water depth may vary from 50 cm to more than 3 m. However, flooding occurs only during part of the growing season. Fields are unbunded. Rice is broadcast sown. Tall varieties with photoperiod sensitivity are grown. Varieties grown in deeper areas ($>$ 100 cm) have elongation ability. About 9 million hectares are planted to floodprone rice of which 3 million fall in the category of deepwater rice. Average yields are around 1.6 tons per hectare.

Varietal diversity of rice

From its subtropical origins rice is now cultivated between 55°N in China and 36°S in Chile. Cultivation and farmer selection for centuries under varied growing conditions has resulted in a myriad of rice varieties. It is estimated that after removing duplicates, about 120 000 distinct rice varieties exist in the world. Approximately, 80 000 are preserved in Genetic Resources Center of International Rice Research Institute (IRRI). China has about 40 000 and India about 25 000 in the gene banks. Other countries have smaller collections.

Rice varieties differ from each other in growth duration. Some mature in less than 80 days from seed to seed. Other like Rayada have a growth cycle of about 280 days. The latter are photoperiod sensitive while the former are insensitive to photoperiod. Rice varieties also differ in endosperm traits. While vast majority of rice varieties are non-glutinous, glutinous varieties form everyday diet of the people of Laos and Northeast Thailand. Most of the major rice growing countries have a few aromatic varieties which are prized in the market. Varieties differ in level of cold tolerance and other abiotic stresses such as tolerance to drought, salinity and submergence. There are also differences in resistance to diseases and insects. In some countries, varieties are classified according to the season in which they are grown. For example, in Bangladesh where rice is grown throughout the year, varieties exist for the following seasons:

1. Boro: Winter rice, broadcast, cold tolerant, grown during December–May.
2. Aus: Summer rice, broadcast, drought tolerant, grown during April–July.
3. Transplanted Aman: Autumn rice, transplanted, photoperiod sensitive, grown during July to December.
4. Broadcast Aman: deepwater rice, broadcast, photoperiod sensitive, grown during April to November.
5. Rayada: Deepwater, photoperiod sensitive, very long duration, grown during March to December.
6. Ashina: deepwater Aus, broadcast sown, grown during April to August.
7. Hill rice: grown on upland fields, usually on sloping hillsides, direct seeded, grown during June to September.

Similar varietal differentiations exist in South India and Sri Lanka where rice is grown during several distinct season.

Rice today

During the 1950 and 1960, the rapidly increasing world population caused great concern about the availability of sufficient food to forestall massive starvation. Forecasts of doom carried the day and books such as *Famine* 1975 [17] and *Too Many* [2] found ready believers around the world. Fortunately, a group of forward-looking leaders of the Rockfeller Foundation and the Ford Foundation decided to establish an institution which objective would be to improve the production efficiency of rice and to do this for the benefit of rice farmers and consumers. Thus, IRRI was established in 1960 with the cooperation of Government of Philippines, to apply science to solve the age old problems of rice production. A major breakthrough came six years later in 1966 with the development of IR8, the first variety with improved plant type and with double the yield potential of tropical rice. Since then a series of improved rice varieties have been developed at IRRI and by the National Agricultural Research Systems (NARS). These varieties have been improved in many other traits such as grain quality, growth duration, disease and insect resistance and tolerance to abiotic stresses. More than 300 improved varieties have been selected from the breeding materials developed at IRRI. These and others developed by NARS are now planted to about 70% of the world's rice land. Due to widescale adoption of these varieties and associated technology, world rice production doubled in a 25-year period from 257 million tons in 1966 to 520 million tons in 1990. Most of the major rice growing countries achieved self-sufficiency in rice and the famines forecast by doomsday sayers did not occur.

During this intensive breeding effort, varieties have been developed which have genes from various ecotypes of rice. Even the genes from wild species have been introduced into modern varieties. Thus, the ecotypic differentiation present in the landraces of rice no longer exists in the improved varieties. Environmentalists have expressed concern about the reduction in biodiversity due to replacement of numerous old varieties by a selected number of improved varieties. However, genes of numerous landraces have been incorporated into the new varieties. For example, IR64 has 20 landraces in its ancestry [11]. Moreover, most of the traditional varieties grown before the green revolution have been preserved in the gene banks and are available for future rice improvement.

Challenges for the future

The population of rice consumers is increasing at the rate of 1.8% annually. The present annual rice production of 560 million tons must be increased to 850 million tons by 2025. There are no additional lands available for rice cultivation. In fact, the area planted to rice is going down in several countries due to pressures of urbanization. Thus, we need the rice varieties with higher yield potential and yield stability for meeting the challenges of increased rice production. Recent breakthroughs in molecular and cellular biology discussed in this volume have provided tools which will be increasingly used as aids to conventional plant breeding for developing rice varieties for 21st century. Transformation techniques allow us to introduce novel genes from unrelated sources into rice. Molecular marker aided selection is helping us to move the genes from one varietal background to another with greater efficiency. Anther culture has helped reduce the time in developing new varieties. Embryo rescue technique is being used to produce distant hybrids and thus introduce alien genes from wild species into cultivated rice. Molecular analysis of pathogen populations is helping us in determining pathogen variability pattern and establish gene deployment strategies.

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