GENETICS AND PLANT BREEDING

Breeding of Field Crops (Cereals)

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Introduction

The global human population grew by 90% during the two generation leading up to the turn of the century. Although food production expanded by 115% during this period, chronic hunger still afflicts more than 800 million people, who are under-nourished, 300 million children under the age of five die of hunger and malnutrition and one out of five babies is born under weight. Rice along with wheat and maize, underpin the world food supply, providing 44% of total edible dry matter and 40% of food energy consumed in the developing countries. The field crops science (including breeding, pathology, agronomy and economics) has contributed to a steady increase in crops productivity and improved livelihoods of producers during the last 40 years through, inter alia, the availability of better varieties and hybrids, more effective pest and disease control better production practices.

Rice is a staple food for above 60% world's population. It is called as the queen of cereals occupying 11% of world crop area. India is the foremost country of the world in area of rice cultivation and second to China in rice production. In India rice in cultivated in about 45 million ha area with production of 87 million tons (2001-04). It is cultivated from 8^0N to 35^0N latitudes and the crop grows under widely varying conditions of rainfall, altitude and climatic conditions. Presently, the area under irrigated ecosystem is about 20.6 million ha with productivity of 3.6 ton / ha and the rainfed area is 24.4 million ha with uncertainty of available water. Though rice production has increased about three folds from 30 million tons (1966) to 87 million tons (2005), but likely demand of rice of 143 million ton by 2025 has to be met by increased productivity as there is little scope to increase in rice area in future.

In mid eighties our share in the world rice trade was insignificant (5%), largely through export of small quantities of highly prized basmati rice. Since the nineties there has been a prolific rise in the quantum export from 5,34,988 tons earning Rs.456.7 crores (per year) to 4,796,670 tons earning Rs.6696.42 crores (2004-2005). This is a 9 times increase in quantum and 15 times increase in value. There is also a vast scope for increasing rice exports through value addition of indigenous aromatic rices; speciality rices for rice based products (Chokuwa rices of Assam) and those with medicinal / therapeutic use (navara rices from Kerala).

Wheat is the second most important cereal crop in India, after rice, both in terms of area and production. The country has witnessed spectacular progress in wheat production and is the second largest producer of wheat next to China. The trend setter for increase in production was the adoption and planting of semi-dwarf, high yielding, input responsive and photo-insensitive wheats in mid 1960's. The congruence of high productivity of introduced wheats, investment in inputs and strong political will heralded the Green Revolution in 1967, which transformed the country's food security and agricultural economy. National average of wheat yield increased from 1 ton / ha in early 1960's (pre-green revolution period) to nearly 2.8 tons per hectare in 2005. Development of wheat varieties possessing high productivity for various agro-ecological zones of the country has been the hallmark of country's wheat research. The wheat growing regions lie between 11^0N to 35^0N latitude and 72^0E and 92^0E longitude. They represent diverse agroclimatic conditions and a great diversity and range of soil and climatic conditions. The demand for wheat in expected to be 109 million tons by the year 2020. This target can only be achieved by increasing average yield from 2.8 ton / ha to 4.4 ton / ha by breaking the yield barrier for high yield potential, sustaining enhanced productivity through management of biotic and abiotic stresses and increasing the input use efficiency.

Maize is another important cereal crop of the world, occupying about 130 million ha area with the production of nearly 610 million tons. It has world wide significance due to its uses as human food, animal feed and in industries as a raw material for the manufacture of industrial products. The average yield of maize is more than 3000 kg / ha which is higher than rice, wheat and any other cereal crop. In India, maize is cultivated in an area of 7.7 million ha with the production of 15.10 million ton and productivity of 1953 kg / ha during the year 2004-05. The area under maize cultivation increased from 3.30 to 7.58 million ha since 1949-50. The productivity has risen from 0.6 ton / ha in 1949-50 to nearly 2 ton / ha (2005-06). It is grown from 58^0N to 48^0N in areas with 250 mm to more than 5000 mm of rainfall per year. In India more than 50% of maize is used as human food.

Rice

Origin

Oryza sativa (Asian rice) and *Oryza glaberrima* (African rice) are the only cultivated species in the genus Oryza, although there are about 22 wild species. Based on extensive historical, archeological genetic and cytogenetic evidences, researchers inferred that the large belt extending from North Eastern hills in India to the mountain ranges of the mainland South East Asia and South West China could be the primary center of origin of *O. glaberrima*. Ecogenetic differentiation due to migration, selection led to the various centers of diversity of cultivated rice in the foot hills of Himalayas, Chattisgarh area of Madhya Pradesh, Jeypore tract of Orissa in India, Myanmar, North parts of Thailand, Yunnan Province of China etc. for Asian rice and river Niger basin and areas around Guinean coast for African rice. It is believed that the Asian cultivated rice *O. sativa* has originated from perennial floating wild rices of Asia and African cultivated rice from natural wild rices in tropical West Africa.

Crop Systematics and Species Relationship

Rice belongs to the genus Oryza of the tribe Oryzae under the sub-family Oryzoidae in the grass family Graminae (Poaceae). Around 20-25 species are recognized and are broadly grouped into four complexes viz., Sativa, Officinalis, Ridley and Meyeriana (Table1). The Sativa complex comprises the cultivated species of *O. sativa* and *O. glaberrima* and their weedy/wild ancestors. Based on cytological investigations, the species relationship as understood revealed that the genus includes diploid (*O. sativa, O. glaberrima* and their wild relatives, *O. officianlis, O. australiensis* and *O. punctata*) with 2n=24 chromosomes and tetraploid (*O. minuta, O. latifolia, O. alta, O. Punctata, O. malamphuzhaensis, O. grandiglumis, O. longiglumis* and *O. ridelyi*) with 2n=48 chromosome species. Genome analysis done on the basis of chromosome pairing behaviour and fertility in the inter-specific hybrids, these species were grouped under six distinct genomes designated as A, B, C, D, E and F.

The grains of wild rices, *O. rufipogon* are essentially similar to those of cultivated rices, only that they are more slender, owned and are shed easily to facilitate easy dispersal. Cultivated rices are predominantly self fertilize while wild rices are largely cross fertilized, pollination taking place by wind.

Table1. Species complexes and classification of different species under genus Oryza

Species	Ploidy	Genome	Chr. No. (2n)	Distribution
I.*Sativa* Complex				
O. sativa	Diploid	AA	24	World wide
O. glaberrima	Diploid	A^gA^g	24	Africa
O. barthii	Diploid	A^gA^g	24	Africa
O. longistaminata	Diploid	A^gA^g	24	Africa
O. nivara	Diploid	AA	24	Tropical Asia (India)
O. rufipogon	Diploid	AA	24	Tropical Asia
O. mesidionalis	Diploid	AA	24	Tropical Australia
O. glumaepetula	Diploid	AA	24	South America
II. *Officinalis* Complex				
O. officinalis	Diploid	CC	24	Tropical Asia to New Guinea
O. eichingeri	Diploid	CC	24	East and West Africa
O. rhizomatis	Diploid	CC	24	Sri Lanka
O. minuta	Tetraploid	BBCC	48	Philippines, New Guinea
O. punctata	Diploid Tetraploid	BB BBCC	24 48	North East Tropical Africa North East Tropical Africa
O. latifolia	Tetraploid	CCDD	48	Latin America
O. grandiglumis	Tetraploid	CCDD	48	South America
O. australiensis	Diploid	EE	24	Australia
III. *Meyeriana* Complex				
O. granulata	Diploid	FF	24	South and South East Asia
O. meyeriana	Diploid	FF	24	South East Asia
O. brachyantha	Tetraploid	-	48	Africa
O. schlechteri	Tetraploid	-	48	New Guinea
IV. *Ridleyi* Complex				
O. longiglumis	Tetraploid	-	48	New Guinea
O. ridleyi	Tetraploid	-	48	South East Asia

Evolution and Domestication

Many authors suggested that evolution of *O. sativa* from the perennial *O. rufipogon* would have been mediated through an annual wild species. *O. perennis* was believed to be common ancestor for both the cultivated species that had diverted into *O. nivara* and *O. barthii* and got domesticated in South and South-east Asia and Tropical West Africa respectively. Cultivated rice is a secondary balanced polyploid derived from an ancestral graminaceous species with a basic chromosome number of 5. During the evolutionary process, two of the chromosomes were duplicated resulting in two types of plants viz., 2n-14, and 2n=10. The amphidiploid of the cross between two variants (2n=12) resulted in the cultivated rice and its wild ancestors with 2n=24 chromosomes. The Asian rice comprises of a perennial wild species *O. rufipogon* an annual wild species *O. nivara*, while *O. longistaminata* and *O. barthii* are the perennial and annual wild progenitors of *O. glaberrima* respectively.

The subspecies or varietal groups of *O. sativa* viz., *indica*, *japonica* and *javanica* evolved due to natural and human selection for desired quality and adaptation to new niches. They are believed to have evolved from three different populations of *O. nivara* then existed in different regions. The hill rices of South-East India, the *japoncia* 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 is believed to be evolved from upland rices of South-East India, while *aman* type from introgression of *rufipogon* genes into *aus* type in the lower Gangetic valley. Similarly, the s*ali* type of Assam had evolved from introgression of *O. rufipogon* genes into *japonica* like type in the Brahmaputra valley. Migration of hill rices of mainland South East Asia to Indonesia following introgression of genes from *O. rufipogon* had led to the evolution of *javanica* type. The ecotypes of *O. sativa* evolved with the following characteristics:

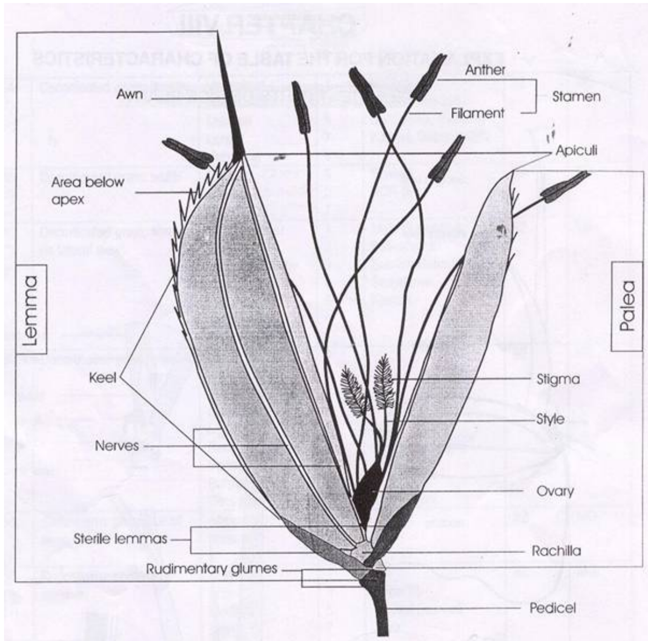
Indica: *Indica* rices are well adapted to, and occur in the tropical and sub-tropical Asia (India, Southern China, Vietnam, Thailand, Myanmar, the Philippines, Bangladesh, Sri Lanka etc.). These are tall plants with weak stems, long and droopy leaves, sensitive to low temperature and photoperiod.

***Japonica* (*Sinica*)**: adapted to sub-tropical and temperate regions of Korea, Japan, North China, etc. These are characterized by more leaves, few tillers and are relatively resistant to shattering. The grains are short, broad and lower in amylose content that makes the grain sticky when cooked.

Javanica: These are the intermediate types which were selected in Indonesia from tropical varieties. They are tall, thick stemmed, low tillering, resistant to shattering and have broad stiff leave, long awns and large bold grains.

Floral Biology

Rice is predominantly a self pollinated crop, although cross pollination occurs to an extent of 5 per cent. However, higher out crossing is observed in wild relatives of rice such as *O. longistaminata* and *O. sativa f spontanea*. The inflorescence of rice is a terminal panicle consisting of primary, secondary and tertiary branches. The panicle bears single flowered spikelets. Each individual spikelet consists of two short sterile lemmas (outer glumes) a normal fertile lemma and palea. The fertile lemma is either awnless or short or long owned. The fertile lemma and palea enclose the sexual organs which consist of six stamens and a pistil. The stamens are composed of bilobed anthers borne on the slender filaments, while the pistil consists of an ovary with a ovule and two feathery stigma lobes borne on feathery bifid stigma. At the base of lower two transparent lodicules which play a predominant role in the opening of the floret are present. In general there will be around 150-200 spikelets per panicle.



Rice Inflorescence

Anthesis and Pollination

Spikelet in a panicle bloom in nearly fixed order. Spikelets on the top branches open first and the spikelets on the lower branches open last. It takes 4 to 7 days for complete opening of all the spikelets in a panicle. The anthesis of rice inflorescence normally occurs between 10 a.m. and 2.0 p.m., although weather conditions influence floret opening to a great extent and also with the type of cultivars. Anther dehiscence may coincide with opening of lemmas to shed pollen on the stigma. The lemma and palea close after the pollen grains are shed from the anther sacs. From anthesis, the panicle takes around 30-35 days to grain maturity. The fruit is known as caryopsis enclosed by lemma and palea that forms the husk.

Objectives of Breeding

Increasing production is achievable by capturing the yield potential of the existing varieties, stabilizing and increasing yield through developing varieties with resistance to biotic and abiotic stresses are the main breeding objectives for rice.

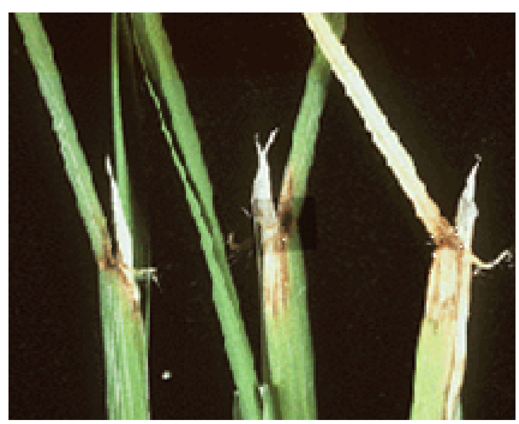
1. Enhancing Yield: Rice yields ranged from as little as 1 t/ha in many countries of Africa to more than 6 t/ha in China, Japan and South Korea. Genetic improvements in rice and the development of modern rice varieties, along with improved cultivation practices, account for the impressive growth in the production. To meet the increasing demand for rice, development of varieties with high yield potential by combining morphological characteristics like semi-dwarf high tillering, thick culms, compact panicles, erect leaves to reduce shading and utilize solar radiation efficiently and physiological characteristics like early maturity, photo-insensitivity and fertilizer responsiveness. The broadening the genetic base of the present day high yielding varieties necessitates the initiation to identify tall landraces with diverse and still unexploited yield genes and pool the harmonious ones by convergent recombination breeding for evolving varieties with higher yield potential.

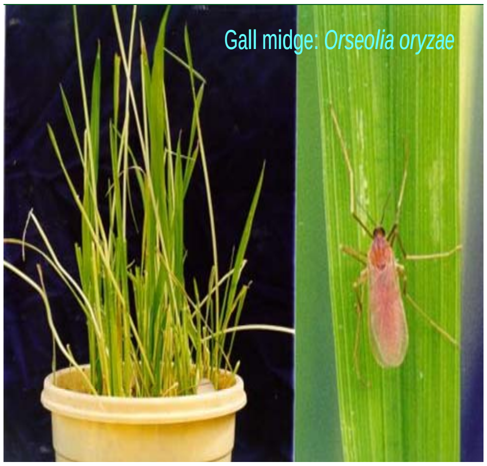
2. Stability and Adaptability: Stability particularly in yield refers to the ability of the plant genotype to express yield potential over a wide range of environments. The rice crop is grown over a wide range of climatic conditions and soil types including drought prone areas between 45^0N and 40^0S and over land from sea-level up to 3000 meters above the sea level. Hence we need to develop varieties for different agro-ecological situations. Constraints to productivity of rice crop due to seasonal fluctuations, such as low light intensity, floods, submergence, drought and others factors need to be taken into account to develop varieties that are suited to a specific location. Characterization and demarcation of areas on the basis of their relative vulnerability to weather aberration help in develop varieties to utilize still unexploited and under exploited seasonal variations to maximize the productivity potential.

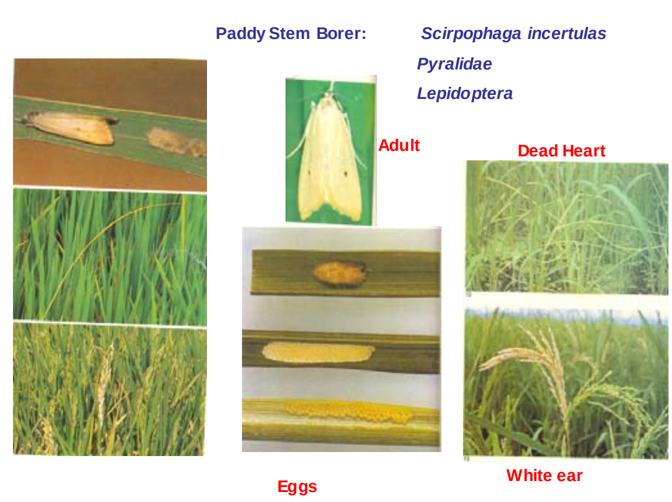
3. Disease and Pest Resistance: The rapid development of dwarf high yielding rice varieties and their spread together with high management and intensive cultivation resulted in the outbreak of pests and diseases. Yield losses due to pests and diseases were estimated to be around 10-51% (Kalode and Krishnaiah, 1991). Rice harbours about hundred pests of which atleast twenty are important. Besides age old problem of blast and brown spot, rice crop today suffers from viral, bacterial and other fungal diseases as well as from many insect-pest damage. Development of virulent strains of pathogen and rapid emergence of insect biotypes emphasizes the need to pyramid different resistant genes into an elite genetic background. Identification of suitable novel donor sources as well as understanding their genetic control of inheritance is necessary for the development of varieties with resistance/tolerance to the specific pests/diseases and deployment in target areas. Crop management following the Integrated Pest Management as well as Integrated Disease Management also plays an important role in resistance breeding strategies.

Sheath blight: *Rhizoctonia solanii*

Blast: *Pyricularia griesea*







4. Quality: Rice grain quality is a combination of many characteristics that affect its market value and utilization as food. Breeding objectives for quality in rice may be grouped into four classes: Market quality, Milling quality, Cooking and processing quality, and Nutritional quality.

1. Market quality: Market quality refers to the general appearance and physical properties of rice grain such as size, shape, uniformity of grain, hull pubescence, translucency, colour, freedom from chalkiness of kernel, etc. Depending on the geographical region, the preference of various quality traits also varies. Rice is classified in the market as long grain, medium grain or short grain as well as length/width ratio, thickness and grain weight. Each grain type possesses specific milling, cooking and eating qualities.

2. Milling quality: The unhusked rice grain is called rough rice or paddy. It is converted to brown rice by shelling the hulls and converted to milled rice by removing off the outer bran layers. The milling quality is determined by the yield and head rice (whole and broken grains of three quarter size or larger) to total rice, short and medium grain cultivars normally give larger mill yields than long grain cultivars. The milling output or recovery of head rice of advanced breeding lines need to be evaluated rigidly to ensure that newly released cultivars will produce high yields of head rice and total milled rice.

3. Cooking and processing quality: Cooking quality of rice is determined by physico-chemical properties of starch. Among them, amylose content determines the relative stickiness or dryness of cooked rice. Varieties with high amylose (> 25%) content cook dry and flaky, while those low amylose content cook sticky. Gelatinization temperature (GT), determines resistance to cooking. In India, moderate GT as well as intermediate amylose content is preferred.

Water uptake, amylose content and alkali reaction which measures gelatinization temperature are rated as predictors of cooking and processing characteristics. High amylose content, medium GT and low water absorption characterize long grain cultivars whereas low amylose, low GT and high water absorption characterize medium and short grain cultivars.

4. Nutritional quality: Breeding for improved nutritional quality would be beneficial if it could be accomplished without any yield loss. Protein averages about 8% in brown and 7% in milled rice. Although relatively low in protein compared to other cereals, the nutritional value rice protein is high due to its favourable balance of amino acids. Milled rice is relatively poor in fat, protein and a number of vitamins and micronutrients, particularly deficient in lysine, vitamin A, iron and zinc. Biofortification for enrichment of vitamin A as well as micronutrients into elite genetic background is also an important objective of breeding for quality. Gene sources for high iron (Nilagrosa, Jalmagna, Tong Lan, Mo Mi, Azucina) and zinc (Conjay Roozay, Zuchem, Xua Bue Nuo) are an important resources for the improvement of quality in rice.

Aromatic rices: Among the best quality rices which are grown in India, the aromatic rices, Basmati rice are important fetching highest premium in the International market for its unique quality. The Basmati rices are characterized by long slender superfine grains with pleasant aroma, extra elongation of kernel and soft texture, palatability, easy digestibility of cooked rice which is unmatched by any other rice variety. Besides Basmati, India also owns a large number of non-Basmati aromatic rice varieties grown and adapted to the specific agro-ecological conditions of the different rice growing regions of the country.

The traditional Basmati cultivars are tall, prone to lodging, photoperiod and temperature sensitive and very low yielding. Therefore, to combine the quality attributes of basmati rice in the high yielding background, a systematic programme on genetic improvement of Basmati rice was initiated at Indian Agricultural Research Institute, New Delhi and other state Agricultural Universities. This resulted in the development of varieties like Basmati-217, Type-3, Basmati-370, Taraori Basmati, Basmati-386 and Ranbir Basmati, Sabarmati, Impoved Sabarmati, Pusa 33 etc. which laid foundation for the Basmati breeding programme.

Pusa Basmati-1, the first semidwarf photoperiod insensitive and high yielding Basmati rice variety has revolutionized the Basmati rice production. This variety contributes nearly 50 percent of the total Basmati rice export in value terms approximately Rs.1000 crores per annum. Intensive breeding efforts and rigorous screening for grain and cooking quality characters resulted in the development varieties like Punjab Basmati-1, Kasturi, Mahi Sugandha were released. Recently several varieties namely, Pus Sugandh-2, 3, 4, (Pusa 1121) and 5, Yamini (CSR30), Vasumati and Pant Sugandh Dhan-15 have been released. Pusa RH-10, is the World's first superfine grain aromatic rice hybrid, with 40 percent higher yield was developed at Indian Agricultural Research Institute, New Delhi. Molecular analysis has revealed chromosome 8 (aroma), chromosome 1,2,3,6 and 11 (kernel elongation), chromosome 1, 2, and 7 (amylose content) chromosome 3, 4, 6 and 7 (grain length) and chromosome 10 (grain breadth) important for quality traits.

Methods of Breeding

Rice breeding in India was initiated at the beginning at 20th century. In 1952, FAO started a *japonica-indica* hybridization project aimed at transferring genes for fertilizer responsiveness from *japonicas* to *indicas* for increasing yields in South and South East Asian countries while retaining the quality and adaptability of *indicas* suited to these countries. A parallel scheme was taken up by the Indian Council of Agricultural Research (ICAR) for Indian states. The *japonica-indica* hybridization project could achieve limited success because the *japonica* parents selected from temperate regions were thermo-and photo-sensitive and also the hybrid combinations resulted in highly sterility due to restricted recombination. Only four varieties namely, Malinja and Mahsuri in Malaysia, ADT 27 in Tamil Nadu (India) and Circna in Australia could be released through this programme. To boost production and productivity in all the rice growing states and to have a coordinated approach to rice research at National level, an All India

Coordinated Rice Improvement Project (AICRIP) was established by ICAR, in 1965 with headquarters at Hyderabad. The various breeding approaches for increasing rice production representing diverse ecological zones can be grouped into conventional approaches and molecular approaches.

1. Conventional Approach

(i). Varietal improvement: The major break through in rice breeding as achieved with semi-dwarf, fertilizer responsive non-lodging plant type with greater capacity to trap solar energy for increased photosynthesis through efficient foliar architecture with the development of TN-1an *indica* rice from the cross between tall *indica* Tsai-Yuan-Chung and Dee-geo-wu-gen (DGWG) dwarf mutant.

Introductions played an important role in varietal improvement so as to enlarge and enrich genetic variability. The International Rice Research Institute (IRRI) located at Los Banos, Philippines through extensive breeding programmes has been distributing improved cultivars and breeding lines throughout the world. Mahsuri from Malaysia; Taichung (Native) 1, Taichung 65 and Tainan 3 from Taiwan; IR8, IR20, IR36, IR50, IR64 etc. from IRRI have become very popular and opened the gateway to green revolution. Similar Indian varieties like Jaya, Rasi, Sona, Swarna etc. being adopted in several countries. International Network for Genetic Enhancement of Rice (INGER) has proved an excellent vehicle to take advantage of exotic varieties / breeding lines.

a. Pure line breeding: This simple breeding / selection approach had its strength in the early years of breeding in the existing rich variability to isolate improved strains or varieties which have been widely cultivated. The process of purification starts either at farmer's field or farmer's strains raised at experimental station. Seed harvested from promising plants are raised in successive generations till they become uniform and stable. Following seed increase, the chosen best line(s) is intensively evaluated in replicated yield trial before it is released for commercial cultivation. Several hundred varieties have been developed by pure line selection. Some of the varieties develop through pure line selection that became very popular are with quality characteristics like GEB24, Mozhgolukulu, Basmati370, Taraori Basmati, etc., saline tolerant varieties like SR26B, Ptb33, Co44, Latisail etc. and deepwater rices FR13.

b. Pedigree method: Pedigree method of breeding is the most common method of rice breeding. Rice being a self pollinated, recombination breeding consisting of controlled crosses between parents of choice followed by selection for superior recombinants in the segregating generations for targeted traits is the widely employed approach in rice improvement. To combine a set of trait that make a variety unique, convergent improvement approach which involves stepwise addition of constituent traits is the best approach. Pedigree method is followed for improvement of both qualitative and quantitative traits where land / laboratory facilities and manpower are adequate while modified-pedigree or mass-pedigree method of selection is followed when selection environment is not appropriate to discriminate desirable genotypes from undesirable ones. In mass pedigree method, the segregating generations are bulked up to five generations from F_2 followed by pedigree selection. The selection methodology employed also varies depending on the genetic control of target trait as well as conducive environment for effective selection. Shuttle breeding which involves raising of breeding populations alternatively at two agro-climatically diverse environments by practicing selection at one center and advancing generation at the other to take advantage of its favourable weather or selection and generation advance at both the centers.

(ii).Breeding for Biotic Stresses: Resistance of host plant has been at greater importance in controlling spread of disease and pests. Several concerted efforts were made to evaluate rice germplasm against various pests and diseases and to identify sources of resistance. Utilizing these donors, resistance was incorporated into rice varieties developed for different rice ecosystems. However, of the sources available only a few donors were utilized for the development of various resistant varieties thereby leading to narrow genetic base of the present day. Hence, we need to utilize these sources to broaden the genetic base of the cultivars. Through conventional methods like selection, hybridization many varieties which are resistant to various biotic stresses have been developed. Wide hybridization between rice and related wild spreads has played an important role in the utilization of useful genes from wild species for resistance against brown plant hopper, white backed plant hopper, bacterial blight, blast and tungro. Various strategies to effectively manage the disease/pest either by sequential release of varieties with matching resistance gene or varietal mosaic consisting of planting varieties carrying different resistance gene is yet another approach in the endemic areas.

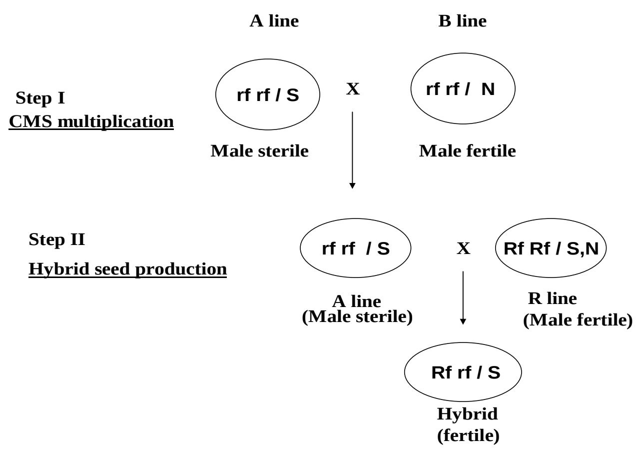
(iii). Breeding for resistance to abiotic stresses: Abiotic stresses are caused by several factors such as high temperature, stress, low temperature or cold stress, excess of water causing submergence stress, water-logging stress or flooding stress or water deficit stress like drought, increased salts chemicals etc. that the plant development at various stages. Varietal tolerance is the most reliable and cost effective strategy, although the nature of their genetics as well as stress environment is complex in nature. Of the various breeding strategies, pure line selection in the native well adapted varieties to a given stress environment as short term approach is given emphasis. In order to develop high yielding varieties combining tolerance to abiotic stresses there is need to identify donors possessing different mechanisms of tolerance to abiotic stresses.

(iv). Mutation breeding: Mutation breeding is very useful in situations where only one or two simple changes in well adapted local cultivars are needed so as to include gene complexes for tolerance to biotic and abiotic stresses, grain quality etc. A wide array of physical and chemical mutagens has been evaluated on rice and a wide array of economically useful point mutations affecting plant height, leaf, panicle, grain type has been recovered. Some of them have been either released directly as mutant varieties used as donor sources for improving specific characters. Among the notable mutants were early maturing Reimei of Japan, RD 15 of Thailand, dwarf statured fertilizer responsive Jagannath of India, Calrose 76 of the USA.

(v). Heterosis breeding: Heterosis in rice was reported first by Jones (1926) followed by many researchers to an exploitable level for grain yield. The first commercially usable CMS (Cytoplasmic Male Sterility) line Wild Abortive (WA) type as a spontaneous male sterile plant in a population of wild rice *O. sativa f spontanea* was developed by Chinese scientists. This effort led to the successful development of hybrid rice technology where China released the first hybrid for commercial cultivation in 1976. Hybrid rice has a yield advantage of 15-20% over the best inbred varieties. Following the success of hybrid rice in China, IRRI initiated research to evolve hybrids ideally suited to tropical environment. Similarly countries like India, the Philippines, Vietnam launched hybrid rice breeding programme.

Rice, with its wide variability, shows both nuclear and cytoplasmic male sterility system, many of these systems have been commercially utilized for hybrid seed production. There are three types of hybrid development system based on the number of parental lines involved: Three line hybrid system, Two line hybrid development system, One line hybrid development system.

a. Three line hybrid development system: It is based on cytoplasmic genetic male sterility stem, involving a CMS line, maintainer line and fertility restorer line designated as A, B and R lines respectively. This male sterility system is the result of interactions between male sterility inducing cytoplasm and nuclear fertility restorer genes. The genetic constitution A, B and R lines are rf rf / S, rf rf / N and Rf Rf / S/N, respectively. A CMS line is maintained by crossing it with its B line (maintainer line). The A and B lines are similar in all respects except the former is male sterile and the later is male fertile. The restorer gene possesses dominant fertility restoring gene. The hybrid seed is produced by crossing A and R lines and is fully fertile. The seed harvested from A-line after pollination with 'R' line is the hybrid seed. This three line system has been widely used in India particularly the WA source for the development of hybrids. Cytoplasmic genetic male sterility system in hybrid seed production is depicted as follows:



b. Two line hybrid development system: It can be obtained in two ways. One is the use of chemical hybridizing agents (CHA) or gametocides, which when sprayed on the panicle kills the pollen and makes the plant sterile. This male sterile plant can be crossed with other parental line to obtain hybrid seed. Another method of obtaining two line rice hybrid is the use of Environmental Sensitive Genic Male Sterility (EGMS) where male sterility is induced by environmental conditions like Temperature (TGMS) and photoperiod (PGMS) and has been reported to be under genetic control. In this system, only a male sterile line and pollinator are required. Hence seed production is easy and economical.

Temperature sensitive genetic male sterility (TGMS) system: The first TGMS line of rice, Annong-IS was isolated as a spontaneous mutant in China and the sterility is controlled by a recessive gene. In rice, temperate of more than 28^0C, the TGMS lines are male sterile, while at lower temperature (below 24^0C), these lines transform into fertile. Some other TGMS lines are Annong S, Hennong S, Novin PL 12, IR 68945, Pei Ai 64S etc. In tropics, where consistent temperature differences are found at different altitudes or during different seasons in the same location, TGMS system is ideal for developing two line hybrids.

Photoperiod sensitive Genetic male sterility (PGMS) system: Rice is a short day plant, as the onset of short days is accompanied by panicle initiation, heading and flowering. The PGMS system, which is under the control of recessive gene, induces male sterility in response to day length of more than 18 hours, while these male sterile plants transform into male fertile when grown in day length less than 10 hours. The first PGMS source was reported in the *japonica* cultivar Nongken 58S. Some other PGMS lines are Zennongs, X 88 and 700 IS. Using this system, the hybrid seed production can be undertaken in the longer day length seasons, while the seed of PGMS line can be multiplied in the shorter day length areas / seasons.

Advantages of two line system over three line system:

- There is no need for a maintainer line; hence development of hybrids is easy and simple.
- Any genotype can be utilized as pollinator parent thus ensuring greater flexibility in the choice of parents in hybrid combination.
- Negative side effects of male sterility inducing cytoplasm on the F_1 plants can be avoided.
- The seed production programme is simple and more efficient. The field area ratio between the female parent's seed multiplication, hybrid seed production, and commercial cultivation of an F_1 hybrid is 1:100:10000 as against 1:50:5000 in three line systems in rice.
- In case of CHA induced male sterility system the female line multiplication and hybrid seed production can be undertaken at a common location.

c. One line system of hybrid development: It is based on utilization of apomixis for hybrid seed production. In this system hybrid plant is produced by crossing two parental lines and it can be maintained indefinitely by apomixes without losing the genotypic constitution of the hybrid. This system is still in a preliminary state and has not generated any stable hybrid till now.

(vi). Molecular breeding approaches in rice: Advance in cellular and molecular biology techniques has given newer dimensions to rice breeding, genetics and genomics. Several new varieties have been developed and new traits introduced using cell and tissue culture techniques. Rice being the most important cereal crop is a major target for cellular and molecular genetic manipulations with focus on recovering fertile transgenic plants. Introduction of alien genes in rice through genetic transformation has now become routine. Transfer of DNA through protoplasts, biolistic method and *Agrobacterium* mediated methods are being used for rice transformation. Transgenic *Bt* rice with cry genes with excellent levels of resistance against stem borers have been developed. Similarly coat protein mediated protection against viral diseases is underway.

Improvement of nutritional quality through genetic transformation of rice plant with engineered provitamin-A biosynthetic pathway with three genes, phytoene synthase (psy), phytoene desaturase and lycopene cyclase is in progress. Efforts are on to transfer these genes to other varieties of commercial importance through backcrossing and marker assisted selection (MAS). In India, scientists at Directorate of Rice Research (DRR) and Indian Agricultural Research Institute (IARI) are carrying out backcrossing programme to introduce these genes into Indian varieties.

Using various marker techniques major genes conferring resistance to gall midge, brown plant hopper (BPH), white backed plant hopper (WBPH), green leaf hopper (GLH), bacterial leaf blight (BLB), blasts etc. have been tagged and mapped. Besides, closely linked and often flanking PCR based markers have been developed for marker aided selection (MAS) and marker aided backcrossing (MAB) protocols. Using these markers, the geneticists and breeders can now combine the most suitable major and minor gene in a controlled manner leading to breeding by design strategy. Another significant advantage of developing closely linked markers is the map based cloning of the gene. Development of varieties with durable resistance to BLB, blast etc. is the focus of a coordinated effort at IRRI and National Agricultural Research System using molecular marker technology. Huang and his group used DNA marker assisted selection to pyramid four bacterial blight resistance genes Xa4, xa5, xa13 and Xa21. Breeding lines with two, three and four resistance genes developed and tested for resistance to bacterial pathogen, which are being utilized in several countries for marker assisted pyramiding into their elite genetic background.

In India, utilizing these sources, many research groups have initiated pyramiding resistance to BLB into elite genetic background. At DRR, Hyderabad, marker assisted pyramiding (xa5, xa13 and Xa21) has been carried out to incorporated BLB resistance into an elite cultivar BPT 5204 (Samba Mahsuri). Similarly, a network project on gene pyramiding for multiple biotic stresses has been initiated. In Rice, gene pyramiding in already wide spread cultivars viz. BPT-5204, IR 64, Pusa Basmati-1, Lalat for BLB, blast and/or gall midge has been initiated at DRR, CRRI, IARI and SAU using conventional and molecular approaches.

Table 2: Genes to be pyramided in specific cultivars at different centre

Centre	**Cultivar**	**Genes for resistance to**		
		BLB	**Blast**	**Gall midge**
DRR, Hyderabad	BPT 5204, IR64	*xa*13 +*Xa*21	*Piz* + *Pik*^{h}	*Gm*1 + *Gm*4
CRRI, Cuttak	Swarna Lalat	*xa*13 + *Xa*21	*Piz* + *Pi*9	*Gm*1 + *Gm*4
IARI, New Delhi	Pusa Basmati-1, Pusa 6A/6B, PRR 78	*xa*13 + *Xa*21 (Pusa 1460 released) *xa*13 *xa*13 + *Xa*21	*Piz* + *Pik*^{h} *Piz* *Pi*9	-

Wheat

Origin

Wheat is the world's leading cereal grain and most important food crop. This is evolved from wild grasses. The genetic origin of wheat is a classic example how closely related species combine in nature to form a polyploid series. The place of origin was the area known in early historical times as the fertile crescent – a rich soil region in the upper reaches of the Tigris–Euphrates basin also known as Asia minor center of origin or Near East. As reported by Vavilov, 1926, the primary centre of origin for bread wheat was the Central Asia while *T. durum, T. turgidum* and *T. dicoccum* were originated in the Abyssinian centre of origin. Substantial genetic variability among the wild relatives of wheat is found in Iran, Israel, and bordering countries.

Crop Systematics and Species Relationship

Wheat belongs to the grass family Graminae and to the tribe Triticeae. The tribe forms a distinct natural group characterized by a compound spike, laterally compressed spikelets with two glumes, single starch grains and fairly large chromosomes in multiples of seven. The genera *Triticum, Aegilops, Secale, Agropyron* and *Haynaldia* are distinct and form a natural subtribe the Triticinae, within the tribe Triticeae. The genus *Triticum* has a large number of species including cultivated types (Table 1). All the species of wheats are grouped in three natural groups einkorn, emmer and dinkel wheat that form a polyploid series with chromosome numbers n=7, 14 and 21 respectively. The first domesticated forms of wheat are considered to have evolved through selectors of cultivable types from wild diploid species *T. boeticum* subsp. a*egilopoides* to produce *T. monococuum* (einkorn wheat) and the wild tetraploid *T. dicoccoides* to produce *T. dicoccum* (emmer wheat) simultaneously. The hexaploid wheats were the last to evolve and are the most modern.

Genetic Evolution

The genome analysis, the determination of evolutionary relationships on the basis of chromosome pairing in hybrids to understand the evolutionary and species relationship in *Triticum* has been extensively studied by Kihara and his colleagues. These studies indicated that allopolyploidy was involved and that wheat evolution followed a system of diploid divergence and polyploid convergence.

Evidences indicate that the tetraploid wheats (AABB genome) evolved from an allopolyploid combining *T. monococcum* (AA) and an unknown, which was supposed to be the progenitor of BB genome. Though it was believed to be *Ae .spelloides,* the 'B' genome donor, recent studies revealed that it could not be progenitors of hexaploid wheat. Further, natural hybridization of a tetraploid with wild grass (*Ae. squarrosa* L. DD genome renamed as *T. tauschii*) gave rise to hexaploid wheats like *T. aestivum, T. compactum* etc.

Origin of Hexaploid Wheat

Triticum monococcum 2n = 2x = 14 (AA)	x ↓	Unknown (*Ae. spelltoides*) 2n = 2x = 14 (BB)
	F_1 AB Chromosome doubled	
Ae. squarrosa (= *T. tauschii*) 2n = 2x = 14 (DD)	x ↓	Tetraploid wheat (*T. turgidum*) 2n = 4x = 28 (AABB)
	F_1 ABD	
	Chromosome doubling Hexaploid wheat 2n = 6x = 42 (AA BB DD)	

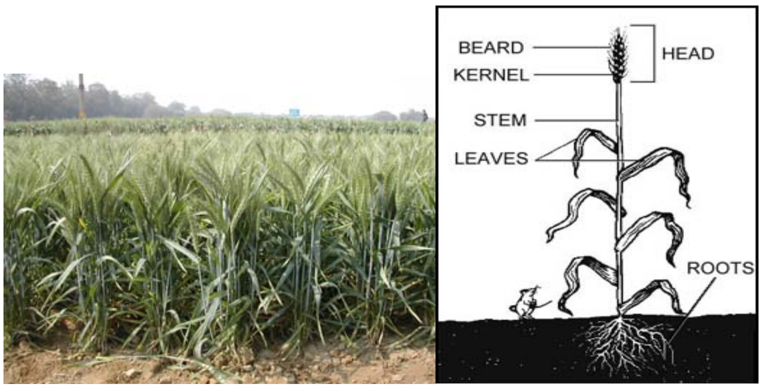
Table 3: Ploidy levels and Genomes of different species of the genus *Triticum*

Ploidy level	Scientific name	Common name	Genome
Diploid			
	T. urartu	Wild einkorn	AA
	T. boeticum Bioss *spp. aegilopoides* *ssp. thoudar*	Wild einkorn	 AA AA
	T. monococcum L.	Cultivated einkorn	AA
	T. sinskajae A. Filat and Kurk	Cultivated einkorn	AA
	T. speltoides (Tausch) Grene. x Richter	Cultivated einkorn	BB
Tetraploid			
	T. dicoccoides (Korn) Schweinf	Wild emmer	AABB
	T. dicoccum (Schrank.) Schulb	Cultivated einkorn	AABB
	T. palaecolchicum Men.	-	AABB
	T. carthlicum Nevski	Persian wheat	AABB
	T. turgidum L.	Rivet or cone wheat	AABB
	T. polonicum L.	Polish wheat	AABB
	T. durum Dest.	Durum or Macaroni wheat	AABB
	T. turanicum Jakabz	Khorasan wheat	AABB
	T. araraticum Jakabz	Wild emmer	AABB
	T. timopheevi Zhuk	-	AABB
Hexaploid			
	T. spelta L.	Spelt or dinkel	AABBDD
	T. vavilovi (Tum) Jakabz	-	AABBDD
	T. macha Dek *and* Men.	Spelt	AABBDD
	T. sphaerococcum Perc.	Indian dwarf	AABBD
	T. compactum Host.	Club wheat	AABBDD
	T. aestivum	Bread or common wheat	AABBDD
	T. zhukovskyi Men.		AABBGG

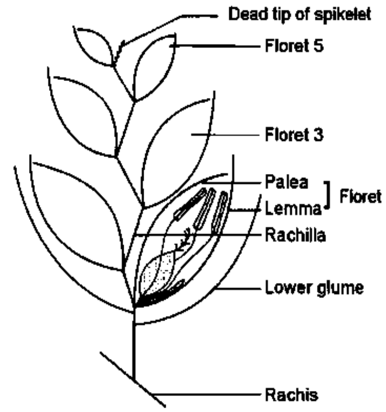
Miller, 1987

Floral Biology

The inflorescence of wheat is a spike bearing two opposite rows of lateral spikelets and a single terminal spikelet on the primary axis. The unit of spike is called spikelet. Two to five florets are born in each spikelet, subtended by a pair of glumes. Each floret contains three anthers and a pistil bearing two styles each with feathery stigma and two ovate lodicules which are modified perianth structure. Florets at anthesis are forced open by swelling of the lodicules. Flowering starts several days after the wheat spike emerges from the boot. Florets on the main culm flower first and those on the tillers flowering later. Flowering begins in the early morning and continues throughout the day. Two to three days are required for a spike to finish blooming. A wheat grain is caryopsis, a small dry, indehiscent, one seeded fruit with a thin pericarp consisting of a germ or embryo and an endosperm.



Wheat Plant



Wheat Spike

Objectives of Breeding

1. Grain yield: The main objective is to create new genotypes improved in features that contribute to greater yield potential and improved product quality. Yield potential in wheat refers to the ability of the plant to manufacture, translocate and store food materials in the wheat grain. Emphasis is now being given to the breeding of high yielding wheat cultivars. The strategy for turning the green revolution which started during 1960's with the introduction of Mexican dwarf wheat varieties such as Sonora 64 and Lerma Rojo into an ever-green revolution -includes

- Collection, evaluation and utilization of germplasm from diverse sources.
- Choice of appropriate parents using biometrical approaches.
- Exploitation of segregating generations from chosen crosses.
- Biparental mating for releasing locked up genetic variability.

2. Stability and adaptability: Breeding for stability implies that the variety developed is affected to minimal loss from vagaries of climate, stress or destructive pest. Breeding for adaptability implies that that variety is adaptable over a wide range of environments with consistency in performance.

For a given agro-climate, it is also necessary to develop varieties / hybrids that have high yield with specific adaptation.

3. Breeding for disease and pest resistance: The development of cultivars of wheat with resistance to destructive disease pathogens like rust, karnal bunt, leaf blotch, smuts, powdery mildews is also a major objective for increased yield in wheat breeding programme. Similarly breeding for resistance to insect pests such as hessian fly, particularly resistance to various biotypes is also important.

4. Breeding for quality: Wheat is cultivated primarily for its grain, which are mainly processed in to flour utilized for numerous end products. The quality of end product is of utmost consideration to the wheat consumers. Broadly the wheat grain quality criteria include features like physical appearance, processing qualities, nutritional values and biological properties each of these is composed of several components influenced by genetic make up of the variety.

(i) Breeding for physical quality: The objective is to develop a variety with well accepted physical characteristics like colour, vitreousness, texture / hardness, appearance, grain weight, test weight.

(ii) Breeding for chemical composition: Wheat grain is one of the important source of human nutrition and is a rich source of protein, starch and minerals. Some of the objectives that determine the chemical composition of wheat grain that has implications on higher quality include:

a. Starch composition – modification of functionality of starch and amylose and amylopectin content as per desirable end product such as noodles, pasta, thickness, binding agents, bread etc. If the objective is to produce starch with no amylase, then breeding for waxy type wheat would be necessary.

b. Protein content - Wheat grain has a special significance of breeding for high protein and low protein for bread and biscuit purposes respectively and also for different end products.

c. Protein quality: The ratio of gluten / gliadin fractions dictates the quality of end produce. The control of expression of these two under genetic control is targeted for specific end product quality.

(iii). Nutritional quality: Objective is to improve the amino acid balance for better nutritional quality. Wheat grains deficient in lysine and there is a negative correlation between protein and lysine content. Efforts to improve lysine as well as high protein content are needed to improve nutritional quality of wheat.

(iv). Breeding for market quality: Includes physical characteristics, flour recovery milling quality, dough quality as well as gluten content useful for specific product.

Methods of Breeding

1. Yield improvement: The wheat improvement programme in India is one of the biggest national programmes in the world. Being self pollinated crop, the basic methods of wheat improvement include pure line, pedigree, bulk and back cross method. The first phase for development of improved wheat genotypes was the adoption of pure line selection from indigenous landraces and then introduction of improved exotic types.

Later hybridization programme involving intercrossing of systematically selected genotypes in a system of single, double or complex multiple crossing schemes followed by various forms of pedigree selection.

Most systematic varietal improvement work was started by Sir Albert Howard and his wife Mrs. G.L.C. Howard at IARI in 1906. They made a comprehensive collection of local sorts / landraces grown in various parts of the country and selection among them led to the development of several varieties such as Pusa 4, Pusa 6 and Pusa 12. In durum wheat, the variety Ekdania 69 was developed through pure line selection.

(i). Hybridization: In the first stage, local selections and their derivatives were intercrossed to breed superior strains. Several improved varieties were developed such as NP 42, NP 80-5, NP 125, NP 165, NP 718, NP 842, NP 846, PbC 518, PbC 591, PbC 281 etc.

Development of semi-dwarf varieties : The semi-dwarf wheat varieties developed by Norman E. Borlaug and his colleagues using Norin 10 dwarfing genes Rht-B1 and Rht-D1 attracted the attention of Indian wheat breeders. Introduction of semi dwarf spring wheat, Sonora 63, Sonora 64 and Lerma Rojo 64A and Mayo 64 in 1963 became the base material for enhanced productivity. These varieties become popular with the farmers because of their higher yield and the source of quantum jumps in wheat production. In1964, these varieties significantly out yielded the Indian check varieties NP824 and C306 by 15-30% margin. Selection from 613 advance lines led to the development of Kalyan Sona, Sonalika, Chhoti Lerma and Safeda Lerma which triggered "wheat revolution in India. The next jump in yield improvement by the release of varieties like WL711 and Arjun (HD 2009) in 1975 and these varieties were dominated in north western plain zone comprised of plains of J & K and Himachal Pradesh, Punjab, Haryana, Rajasthan, Delhi, Western U.P. and Uttarakhand till they were replaced by HD 2329 because of its greater adaptability, short stature and other agronomic advantages.

During the period of yield plateuing (1975-85), IB/IR translocations have played a significant role in breaking the yield barriers resulting in spurt in wheat yields.The more recent genotypes like PBW 343, UP 2338 and WH 542 derived from crosses with Veery genotypes, but still carrying IB/IR translocation have higher yield potential.

(ii). Backcross breeding: It is important in improvement of one or more highly heritable characters in an otherwise promising variety. It is most rapid and inexpensive method for achieving short term goals in wheat breeding. Incorporation of genes for rust resistance in Indian wheat varieties through backcross method led to the development of several near isogenic lines like HW 2004 (backcross line of C 306 carrying *Lr24*), HW 2044 (backcross line of PBW 226) for commercial cultivation.

(iii). Mutation breeding: In mutation breeding, using mutagenic agents, several mutants were induced and the combination of traits from two or more mutants in the same genetic background to develop new varieties is carried out. Similarly mutant traits are recombined with those from other germplasm.

Using γ-rays, amber grained mutants of Sonora 64 and Lerma Rojo were produced and released as Sharbati Sonora and Pusa Lerma respectively.

2. Systematic breeding for rust resistance: Most organized work on breeding for rust resistance was carried out at IARI under the leadership of Dr. B.P. Pal. The research carried out during the period from 1935 to 1948 by Prof. K.C. Mehta, Dr. B.B. Mundkur and their associates had generated very comprehensive knowledge on the annual cycle of rust occurrence in India and also the physiological specialization of races.

Efforts to incorporate high degree of resistance to individual rusts led to the development of brown rust resistant varieties NP783, NP784, yellow rust resistant varieties NP785 and NP786 and black rust resistant varieties NP789 and NP790. Later on, attempts to combine resistance to more than one rusts resulted in the development of varieties like NP 792, NP 797, NP 798 and NP 799 combined high degree of resistance to black rust and fair degree of resistance to brown rust. Finally combining resistance to all the three rusts resulted in the development of wheat variety NP 809.

Similarly karnal bunt caused by *Nevossia indica* which was considered as minor disease became a major problem with severe epidemics. Using artificial inoculations methods, varieties resistant to karnal bunt have been identified. Durum variety PDW 215 and triticale TL210 showed immunity. Bread wheat varieties like HD29, HD30, HP1531, ISWRN191 and ISD227-5 were found promising for karnal bunt resistance.

3. Breeding for quality: In India, three types of wheat *T. aestivum* (Bread wheat). *T. durum* and *T. dicoccum* are being cultivated of which bread wheat accounts for a major share to prepare wide array of home foods and chapatti. Durum wheat is used for semolina preparation. Wheat is the only cereal which has gluten and this makes it unique in terms of processing possibilities into different products. Breeding programme for developing wheat cultivars targeted to specific food markets include understanding the genetic control of specific grain components as well as their relationship with processing qualities.

Grain hardness is an important criterion for starch quality and wheat end use and is the major determinant of the level of starch damage during milling. Starch from hard grains fracture more during milling and absorb more water by the flour. Hard grains are used for baking breads and noodle production while soft wheat are used for biscuit flour. The major factor controlling grains hardness is a single locus *Ha* on chromosome 5D of wheat encoding a 15 kDa protein called Friabilin. Friabilin is found to consist of three polypeptides namely puroindoline a, puroindoline b and GSP-1 which confer softness to the grains. Mutations at this locus transform grain from soft to hard type. Several mutants at this locus have been characterized.

Similarly grain protein content and quality are also most targeted traits in quality breeding and the highly influenced by the environmental conditions. The various components of wheat grain protein are Albumins, Globulins, Gliadins and Glutenins. Gliadins and glutenins together are known as gluten. Glutenins confer elasticity, while gliadins confer mainly viscous flow and extensibility to the gluten complex. The genes encoding glutenin and gliadins are characterized by group 1 and group 6 chromosomes of wheat. Several studies revealed that HMW (high molecular weight) glutenin subunits are important for various quality parameters for different end uses. The best breads are produced from dough that has a mix of strength, elasticity and plasticity properties largely determined by the balance between the gliadin and glutenin subunits.

Genetic control of quality traits has been well characterized. Introgression of a piece of 6B *dicoccoides* chromosome, a source of high protein into low protein lines of durum wheat as well as glutenin subunits from hexaploid wheat has been carried out to improve the quality characteristics for bread making in durum wheat which lacks ‘D’ genome.

The presence of translocations 1B/1R and 1 A/1R resulted in the poor quality due to the production of secalins from rye chromosome.

The complex and genetically additive nature of inheritance of most quality traits has led to the development of a range of indirect tests. By applying these tests in early generations, the population mean is favourably shifted and increased frequency of homozygous lines with desired quality characteristics can be expected at the end of the breeding process. Selection and testing for quality begins in early generations. Crop management x quality interactions is of critical importance. At least one parent with desired quality must be selected in designing crossing strategies as end use requirements determine the potential new cultivars. In general, pedigree or modified pedigree method has been widely used. Exploration of genetic variation for quality traits present in wild relatives and alien species may require pre-breeding before they are widely used in the breeding programme. Novel biotechnology techniques have opened the possibilities of investigating the basic and biochemical aspects of individual protein subunits and of other molecules contributing to the end use quality of wheat.

Biofortification is the process of breeding food crops that are rich in bioavailable micronutrients. CIMMYT (International Maize and Wheat Improvement Center) Mexico, is leading the Harvest Plus research effort in collaboration with national agricultural research and extension systems for biofortification of wheat for high iron and zinc content using conventional and molecular breeding approaches.

New Plant Type for Quantum Jump in Yield
To cope up the ever increasing demand of wheat which will be 109 million tons by the year 2020, the present level of productivity has to be increased to 4.4 tons / ha. The only approach for achieving quantum jump in productivity is to restructure the wheat plant architecture which can yield up to 8 tons / ha. the Indian Agricultural Research Institute, New Delhi developed new plant type (NPT) wheat's, utilizing a local germplasm SFW and released wheat's and genetic stocks, which have high 1000 grain weight; high grain number per spike; higher biomass; thick, broad, semi erect and dark green leaves; thick stem; plant height 85-100 cm and good root system. In these NPT genotypes the negative correlation between grain weight and grain number per spike has been broken. These genotypes are also having post-anthesis mobilization of stem reserve to sink.

New Plant Type Wheat

Biotechnology in Wheat Improvement

Biotechnology techniques and tools have immense potential in crop improvement programme, encompasses utilization of gametoclonal variation, somaclonal variation, genetic selection for biotic and abiotic stresses, gene transfer through embryo rescue, protoplast technology, somatic hybridization and recombinant DNA technology. The important aspects of wheat biotechnology are:

1. *In vitro* production of haploids: Haploids are of significance for studies on the induction of mutations and for the production of double haploids / homozygous plants. Most of the anther culture studies in wheat have been conducted with *T. aestivum* and callus, embryoids or haploid plants have been obtained with varied success.

2. Somaclonal variation: The variation observed in plants produced through tissue culture is known as somaclonal variation. Wheat has proved to be an excellent material for the induction of somaclonal variation. The variations have been observed for plant height, size and shape of leaves, length of awns, fertility of spikes and the size shape and colour of the seeds.

3. Molecular markers and wheat breeding: The development in molecular genetics in wheat have been relatively slow due to its ploidy level, the size and complexity of its genome, the very high percentage of repetitive sequences and the low level of polymorphism. However, due to the large number of disease and pest resistances controlled by major genes, the mapping of such genes has dominated the research activities in wheat molecular genetics. On the other hand, the hexaploid nature of wheat and its amenity to cytogenetic manipulation have offered unique tools for molecular genetics of wheat. The use of various aneuploid stocks, such as nullitetrasomic and ditelosomic lines to assign molecular markers to specific chromosome arms, chromosomal deletion stocks for physical mapping of markers and single chromosome substitution lines to map genes of known chromosomal location, are being taken up seriously. Despite the low level of variability available in wheat, extensive molecular maps have now been prepared and as many as 36 traits have been tagged using different molecular markers.

The availability of a large number of molecular markers in wheat suggests their use in intra-specific analysis, comparative analysis as well as gene introgression studies. However, the application of molecular markers to wheat breeding involving marker assisted selection is still in its infancy despite the availability of a large number of molecular markers. The availability of newer technologies such as DNA chips / micro-arrays and MALDT-TOF mass spectrometry will accelerate genome mapping and tagging of genes for efficient wheat breeding.

Maize

Maize (*Zea mays*) is an important cereal crop of the world. It ranks next to wheat with respect to production. Being a C_4 plant, it is physiologically more efficient and has higher grain yield and wider adaptation over a wide range of environmental conditions. The important maize growing countries are the USA, China, India, Brazil, Mexico, Philippines, South Africa and Indonesia. Maize has a wider range of uses than any other cereal as animal feed, human food and for hundreds of industrial purposes. Being a C_4 plant, maize is most productive in terms of food nutrients produced per unit land area, per unit of water transpired and per unit of time under the conditions for C_4 plants.

In India, the area under maize is around 7.7 million ha with a production of 15.1 million ton with a productivity of 1953 kg / ha (2005-06). Maize is grown mainly during *kharif* season although it is also cultivated during *rabi* as well as summer season. Major maize growing states in India are Andhra Pradesh, Karnataka, Bihar, Himachal Pradesh, accounting about 30 % of the maize acreage.

Origin

Maize is indigenous to the Americas, and was the principal food grain of Native Americans. Corn was domesticated about 8,000 years ago in wild form. The closest ancestor of maize was believed to be teosinte, from which the present day maize evolved. Evolutionary forces such as mutation, hybridization, genetic drift and selection aided by human beings resulted in differentiation of teosinte into maize and further differentiation of maize into over 300 races. These races got adapted to different agro-climatic regions away from the centre of origin. Modern corn cultivars differ from primitive corn in having more productive plants with increased number as well as weight of individual kernels on a cob of corn.

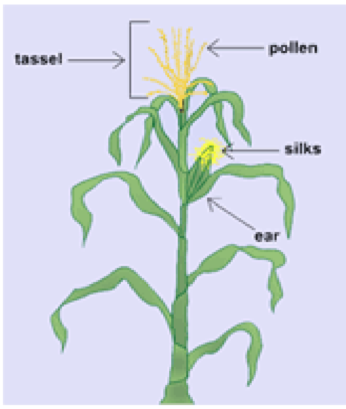
Various hypotheses have been proposed to explain the origin of maize. According to one hypothesis the corn originated by a single domestication from the basal branching teosinte sub sp. *Zea mays* L. spp. parviglumis or from the lateral branching subspecies *Zea mays* L. spp. mexicana by dual domestication from the two subspecies. Similarities between maize and teosinte is in being monoceous in flowering habit, with staminate and pistillate flowers born in separate inflorescence while the later differs from corn in that the pistillate spikes bears 60-12 kernels in hard, triangular, shell like structures and is prone to seed shattering. Recent molecular studies revealed that maize and teosinte maintain distinct genetic constitutions despite gene introgression between them.

Crop Systematics and Species Relationship

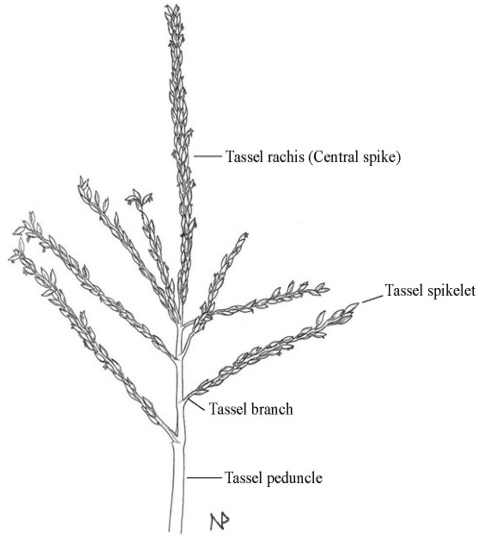
Maize belongs to tribe *Maydaea* of the family Graminae. The tribe *Maydaea* consists of seven genera viz. *Coix* (2n=10/20), *Chionachne* (2n=20), *Sclerachne* (2n=20), *Trilobachne* (2n=20) and *Polytocta* (2n=20) under old world group and *Zea* and *Tripsacum* under new world group. Varieties that had similar morphological physiological, genetic and cytological characteristics were grouped together into distinct races. These races are of important to breeders' search for germplasm containing particular characters of use in the breeding programme. These races are mainly classified into six kernel type viz. flint, dent flour, pop, pod and sweet corn. Of these races, the most important races being Corn Belt dent, the southern dents and the northern flints and the most productive race is the US Corn Belt Dent which is a hybrid of northern flints and southern dents. In India greater diversity among maize germplasm exists in the North Eastern Himalayan region, where land races with untapped alleles do exist. These land races have been described as Sikkim primitives by Dhawan (1964). Besides these races, there are several local varieties from Jaunpur, Jullundhar, Anantnag, Hyderabad, Coimbatore, Rudrapur Malan and Sikkim.

Floral Biology

Maize is a monoecious cross pollinated plant with staminate flowers borne in the tassel and pistillate flowers on a cob. Self pollination is about 5 %. The main stem of the corn plant terminates into a tassel (male inflorescence).



Maize Plant with male and female inflorescence



Zea mays Tassel (Male Inflorescence)


Flowering (Tasseling) in Maize- Male Inflorescence


Maize cob with silks


Flowering (Silking) in Maize (Female inflorescence)

The main axis and branches of the tassel bear spikelets usually in pairs, one sessile and the other pedicellate. Each spikelet bears two florets each with a lemma, a palea, three stamens two lodicules and a rudimentary pistil. The pollen grains are very small, light in weight and easily carried by wind.

Shoot buds are formed in the leaf axils. About midway up the stalk, one or two shoot buds develop into lateral shoots bearing the female inflorescence known as the ear. The ear shoot is composed of a shank which bears modified leaf sheaths as husks and the internodes of the shank are highly condensed. On the ear shoot, pistillate spikelets are borne in pairs in longitudinal rows from base to tip. Each spikelet has two flowers of which one is fertile and other being sterile. The ovary is surrounded by a long slender, bifid style known as the silks. Silks function both as style and stigma throughout their length.

Maize is protandrous in nature wherein pollen shedding begins before the emergence of silks thus facilitating cross pollination via wind borne pollen grains. Pollen shedding begins about 2 or 3 days after the tassel is fully emerged and it continues for few days. Fertilization of ovules begin one-third up from the base of the ear. Kernels borne on an ear remain intact covered by husks without any seed dispersal mechanism. The maize kernel is a one seeded fruit (caryopsis).

Objectives of Breeding

Since maize has wide range of food and industrial uses, the breeding objective depend on various factors like targeted end product of the market, farmer's perspective, specific agroclimatic situation as well constraints and production levels. Maize being of C_4 plant, the breeding objective should exploit the inherent productive potential of crop.

1. Yield improvement: The most important objective is to increase grain yield which is a quantitatively inherited complex trait and its expression is influenced by several yield component. The various yield components contributing to yield in maize include number of ears, number of kernel rows, number of kernels per row, test weight and shelling percentage. Grain yield is also dependent on several physiological characteristics such as nutrient uptake, photosynthesis, translocation, sink size and transpiration. Maize is a C_4 plant, has a higher rate of photosynthesis. Grain yield is also affected by genes associated with characters that contribute to the stability of production, such as optimum maturity, stalk quality, resistance to biotic and abiotic stresses.

2. Adaptability and stability: Development of varieties or hybrids with wide adaptability and stability is to ensure higher and stable returns to the farmers. Adaptability is also a complex objective that is affected by various factors like agro-climatic conditions of the region, soil fertility level, tillage practices as well as tolerance to cold, heat and drought.

Maize is a short day plant and the time of flowering is influenced by photoperiod and temperature. Development of photoinsensitive varieties / hybrids is the priority so as to facilitate its cultivation throughout the year. In tropical and sub-tropical climates, it can be grown throughout the year as soil moisture and other factors are not limiting, while in temperate regions the growing season is restricted to frost-free period. Hence hybrids with cold tolerance and early maturity have advantage of enabling different cropping systems. Similarly early maturing hybrids are adapted to the shorter growing seasons in higher latitudes and lower latitudes with longer growing season. Adaptation of hybrids / varieties depends on the productivity of the soil as well as they respond more to the fertility levels.

In addition to higher yield performance, the cultivars should possess inherent potential to perform well over a wide range of environments particularly in areas where it is cultivated during seasons characterized by erratic rainfall as well as in environments for which resistance / tolerance to stresses is very important i.e. when grown in less favourable environments. Prolificacy is considered to be an important mechanism contributing to stability. Breeding for appropriate maturity as determined by the agroclimatic factors is an important objective.

3. Breeding for disease and pest resistance: The most serious diseases of maize in India are turcium leaf blight (*Drschlera turcica*), *maydis* leaf blight (*D. maydis*), post-flowering stalk rot complex (*Macrophomina phaseolina, Fusarium spp.*, *Cephalsporium spp.*), downy mildew (*Perenosclerophthora soghi*) and common rust (*Puccinia sorghi*). Similarly insect pests like stem borers, army worms, aphids, cutworm, jassids, thrips, root worm, leaf miner etc. are important that are causing severe losses at various stages of crop growth. Understanding the genetic control of these diseases and insect pests as well as the identification of resistance sources against them is important so as to plan an appropriate breeding strategy. Methods of creating artificial epiphytotic conditions, to facilitate the selection of resistant genotypes and incorporation of resistance genes into the inbred lines and hybrids, are being developed.

4. Breeding for quality: The maize kernel is composed of approximately 7% starch, 10% protein, 5% oil, 2% sugar and 1% ash. The maize protein is called Zein and is low in biological value due to low concentration of the essential amino acids lysine and tryptophan. Maize breeders have made significant progress in altering the composition of various quality traits. Several mutants have been discovered and developed to alter the starch fractions of the maize endosperm. Genes that modify either the structure or quality of the kernel endosperm have been effectively used to develop specialty corn. A break through was made with the discovery of opaque-2 gene which doubled the lysine and tryptophan content in the endosperm and breeding efforts led to the development of opaque-2 based hybrids, synthetics and composites although they have poor agronomic characters which are being improved.

Thus the breeding objectives for quality not only emphasize their improvement but also the agronomic characteristics as well. Physical quality of grain is usually measured by kernel hardness, kernel breakage susceptibility (brittleness) and stress cracking. To improve physical quality of maize grain, breeding for grain resisting mechanical damage and drying grain at low temperature is being carried out. Nutritional quality includes protein concentration as well as amino acid balance. In general, the increase in grain yield increases the starch concentration of the grain while reducing the grain protein concentration. The correlation need to be broken to develop varieties with high yield and protein concentration. It was also found that the greater nitrogen supply increased grain protein concentration linearly while grain yield response to added nitrogen had a diminishing return relationship. We need to identify genotypes that can accumulate more protein even at low nitrogen concentration by changing physiological architecture of the plant itself. Market quality includes kernel size, kernel weight and extractable starch depending on the specific end use. Environmental and genetic factors appear to be more important than agronomic practices for physical quality and extractable starch parameters. In general dry millers prefer uniform large, unbroken, kernels as well with low phytate concentration. Hence objective of quality breeding in maize include the development of cultivars with high protein and balanced amino acid profile and also high oil, waxy, amylase and low phytate to the quality parameters specifically associated with intended end use.

Methods of Breeding

Maize is a cross pollinated crop. The breeding methods should focus on exploitation of the heterozygosity in a desirable direction as well as large scale exploitation of hybrid vigor. The cultivar may be open pollinated population or hybrid. Major breeding methods in maize are population improvement and hybrid breeding. All these methods involve selection which acts on existing indigenous and exotic variability or variability created through hybridization, gene segregation and recombination.

1. Introduction: Many of the introductions have been used directly as commercial cultivars in many countries including India such as composite Laxmi and Suwan released in Bihar state and these introductions also used as a source material to develop cultivars or inbred lines.

2. Population improvement: Population improvement aims at increasing the frequency of favourable alleles in the population and at the same time maintaining considerable genetic variability. It involves various recurrent selections procedures that are broadly classified into intra-population improvement and inter-population improvement schemes.

Intra-population improvement:

(i). Mass selection: It involves selection of ears on the basis of plant and ear characteristics and harvested seeds are bulked to grow the next generation and the process is repeated for several cycles. Mass selection was the only method adopted earlier to improve local maize types grown by the farmers. Later, varietal hybridization involving indigenous germplasm, accompanied by mass selection resulted in the development of many open pollinated varieties. Because of its limitations to identify superior genotypes based on phenotype alone as well no control over pollination and severe inbreeding depression led to the various modifications of the mass selection procedures, although varieties like KT 41 and Basi were developed by mass selection method in India

Various modified mass selection methods are:

(a). Modified mass selection without pollen control which was also known as Grid method developed by Gardner in 1964. In this method, experimental area is divided into sub-plots or grids and selection for superior traits is carried out within the grid, which are bulked for growing the next generation.

(b). Ear to row selection or Half-sib progeny selection. It was developed by Hopkins. In this method, the superior ears are selected from the source population and are kept separate without bulking. In the next year, progeny rows of each individual ear are raised from half the seed and based on superior progeny rows, the remaining seed of the selected progeny rows is bulked to constitute an improved population.

(c). Modified ear to row selection proposed by Lonnquist (1964) in which the progenies are evaluated over locations in replicated traits.

(ii). Half-sib family selection: Individuals having one parent in common are called half-sibs. The half-sib families are developed by random mating in an isolated plot or by pollinating plant with bulk pollen of a large number of plants. Small amount of seed of half-sib families are evaluated and the remnant seed of the selected families is used to reconstitute the population. Ear to row method is a type of half-sib selection and has been widely used in maize improvement programme.

(iii). Full-sib selection: Individuals having both parents common are known as full sibs. Full sibs are produced by crossing selected plants in pairs in the source population and the crossed seeds are used for progeny test as well as for reconstituting the improved new base population.

(iv). Selfed progeny selection: The selfed progeny is produced by selfing the selected plants from the source population. They may be S_1 for one or S_2 for two selfings. The progenies are evaluated and selected ones are recombined to constitute a new improved population in which the 2^{nd} cycle of progeny selection may be carried out.

Inter population improvement:

Inter-population improvement involves one / two population and aims at simultaneous improvement of one / two heterozygous and heterogeneous populations. Yield has been the primary trait of selection for the inter-population selection methods. These methods include:

- Simple recurrent selection.
- Recurrent selection for gca.
- Recurrent selection for sca.
- Reciprocal recurrent selection.
  - (a). Half-sib reciprocal recurrent selection
  - (b). Full-sib reciprocal recurrent selection

(i). Simple recurrent selection: In this method a number of plants with desirable phenotype are selected and selfed. In the next year, progeny rows from the selfed seeds of the selected plants and the progenies are intercrossed in all possible combinations and equal amount of seed from each cross is composited to produce the next generation. From composited population, a round of recurrent selection is carried out. Recurrent selection is effective in increasing the frequency of desirable genes in the selected population. It is most suited for characters with high heritability.

(ii). Recurrent selection for general combining ability (RSGCA): In case of recurrent selection for gca, the progeny for progeny testing are obtained by crossing the selected plants to a broad base tester (an open-pollinated variety, a synthetic variety or the segregating generations of double or multiple cross). In the first year, a number of phentoypically outstanding plants are selected from source population. Each selected plant is selfed as well as crossed to a number of randomly selected plants from a tester with broad genetic base. In the second year, the test cross progeny are evaluated in a replicated trial. The selfed seed from those plants that produced superior test cross progenies (as identified in the second years) are planted in the progeny rows and are intercrossed in all possible combinations. Equal amount of seeds from all the intercrosses are composited to obtain the next generation. This completes original cycle of selection and further recurrent selections are carried out in the same manner. RSGCA is effective in increasing the yielding ability of the population obtained at the end of selection cycle. It also accumulates genes for superior GCA.

(iii). Recurrent selection for specific combining ability (RSSCA): It was proposed by Hull (1945). The procedure is identical with that for GCA, except that in this an inbred is used as tester than an open pollinated variety. RSSCA helps to isolate from a population, such lines that will combine well with a given inbred and is useful in exploiting heterosis due to non-additive gene action.

(iv). Reciprocal recurrent selection (RRS): It was proposed by Comstock, Robinson and Harvey in 1949 for the improvement of two different populations in their ability to combine well with each other. Two genetically broad based populations (A and B) such that 'A' serves as tester for B and 'B' serves as tester for A. This method is as effective as RSGCA when additive gene action predominates and is as effective as RSSCA when non-additive effects are of major importance. The modification of these methods is full-sib reciprocal recurrent selection as well as half-sib reciprocal recurrent selection.

3. Development of synthetic varieties: A synthetic variety is a variety produced by crossing in all combinations a number of inbred lines (with high gca that combine well with each other) and a synthetic variety is maintained by open pollination in isolation. In maize, development of synthetics includes:

- Evaluation of lines on the basis of general combining ability.
- These selected lines are intercrossed in all possible combinations.
- Equal amount of seed from these crosses is composited to constitute a synthetic.

4. Development of composite varieties: Composite varieties in maize are derived by mixing the seeds of several phenotypically outstanding lines and allowing open pollination among the mixed lines. The lines used to produce a composite variety are rarely tested for combining ability.

5. Hybrid breeding: Exploitation of heterosis through hybrids can be mainly attributed to the pioneering work done by G.H. Shull and D.F. Jones. Various types of hybrids in maize based on inbred lines are:

- Single crosses hybrid - A single cross hybrid is produced by crossing two unrelated inbreds which produce best performing F_1 hybrids.
- Three way crosses hybrid - A three way cross hybrid is produced by crossing a single cross with an inbred line. Hence it involves three inbred lines. = (A x B) x C.
- Double cross hybrid - Produced by a cross between two single crosses. Four unrelated inbred lines are involved = (A x B) x (C x D).
- Top-cross hybrid - Crossing an inbred with an open pollinated variety also known as inbred-variety hybrid.
- Double top-cross hybrid - A double top cross is the progeny of a single cross and a variety [(Ax B) x variety].

Various operations in the production of hybrids are:

- Development of inbred lines.
- Evaluation of inbred lines.
- Production of hybrid seed.

(i). Development of inbred line: Inbred is a nearly homozygous line developed by continued inbreeding usually selfing accompanied by selection. Five to six selfing are required to produce inbreds. The plants selected for developing inbred lines may be derived from open pollinated varieties, synthetics and composite or from a F_2 population of crosses of desirable of desirable parental lines.

(ii). Evaluation of inbred: Evaluation of inbred is done either by phenotypic evaluation or top cross test or by single cross evaluation to identify the superior inbred lines. Hence inbred lines with high GCA are selected for hybrid development.

(iii). Hybrid seed production: Growing two rows of inbred lines used as male parent and six rows of female lines in isolation is the common method of producing hybrid corn in India. The female lines are detasseled before they produce the pollen. In hybrid seed production, the female and male parental lines are grown in the ratio of 6:2 rows. The female rows are detasseled before the male inflorescene shed pollen and these detasseled female lines are pollinated by male and the seed produced on these detasseled plants is the hybrid seed. In case male sterility is utilized, the female line need not be detasseled as it does not produce functional pollen grains. In USA, detasseling and CMS system are used. The requirement of hybrid seed production are (1) easy detasseling of the female parent, (2) effective pollen dispersal from male parent to ensure a satisfactory seed set in the female parent.

Hybrids for Special Uses

Hybrids in maize are also being developed for special purposes, such as sweet corn, popcorn and waxy corn in addition to the larger use for feeding livestock and corn-milling industry. Sweet corn hybrids are called as Super sweet due the presence of shrunken-2 (sh2) gene which increases sugar content along with extended peak quality in these hybrids. Waxy corn is used in the manufacture of adhesives, gums, paper sizing and puddings due to the presence of amylopectin a special type of endosperm starch.

Biotechnology in Maize Improvement

Use of molecular techniques has many applications in crop improvement. Identification of tightly linked molecular markers to the genes of interest can be indirectly used to select for the desirable allele in marker assisted selection. They can be used to accelerate the backcrossing of such an allele or gene or in pyramiding several desirable alleles. Markers can also be used to dissect polygenic traits into their Mendelian components or quantitative trait loci. Maize was one of the first major crop species for which a complete molecular marker map was developed. One of the most studied traits at CIMMYT, Mexico is abiotic stress tolerance.

In maize extensive genome mapping based on molecular markers has been accomplished. DNA based markers along with conventional breeding procedures are being utilized to develop QPM (quality protein maize) genotypes with improved nutritional quality. Similarly, development of markers for genes related to quality such as Sugary-1, Shrunken-2 in sweet corn breeding programmes has been carried out, so as to incorporate those genes into elite genetic and agronomically superior genotypes through marker assisted selection. Various genetic transformation techniques provide an important tool for quality improvement as well as introduction of genes for insect and disease resistance.

Future Research to Enhance Production and Productivity of Cereal Crops

Rice

- Genetic resource management of farmer's varieties, land races, commercial cultivars, parental lines of released hybrids and wild relatives. Evaluation of germplasm in *in situ* conditions. *In situ* conservation of land races and documentation are the priority areas.
- Enhancement of yield potential and stability for irrigated, rainfed lowland and upland situations, and also for different farming practices such as aerobic rice and boro rice.
- Enhancement of yield through development of hybrid rice by utilizing *indica* / *japonica* derived parental lines.
- Improvement of grain quality, which include pleasant aroma, linear kernel elongation on cooking and soft texture, keeping in view regional preference and export demand.
- Developing rice varieties suitable for cultivation under aerobic situations.
- Marker aided selection for enhancement of yield and incorporation of resistance to biotic and abiotic stresses.

Wheat

- Improvement wheat for favourable environments and sub-optimal environments including temperature and moisture stress suppressive environments prevailing in central and peninsular India.
- Developing better genotypes specifically suited to saline and sodic soils and for cold region in the upper reaches of Himalayas.
- To design and develop new plant types (NPT) with changed plant architecture, physiological efficiency and grain size and weight for economic yield advantage and tailoring it into variety.
- Breeding wheats with increased level of resistance to leaf blight, Karnal bunt and rusts especially stem rust race Ug99.
- Generation of genetic variability for various yield components through wide hybridization.
- Development of hybrid wheat technology for enhancement of productivity.
- Winter x spring wheat hybridization in order to harness the advantage of genetic variability present in these gene pools.
- Development of wheat varieties with improved grain quality especially with desirable combinations of HMW glutenin, LMW glutenin and gliadin for diversified end uses.
- Breeding durum wheat with superior yield, disease resistance, heat tolerance, freedom from yellow berry, better semolina recovery, high protein and B-carotene content.

Maize

- Enhancement of yield potential through breeding for single cross hybrids. The yield components should include number of ears, kernel rows and kernels per row, kernel test weight and shelling percentage which need to be given due importance in the endeavour of enhancing the grain yield. Selection for prolificacy (plants with more than one ear) is another potential trait for enhancing productivity.
- Development of vigorous inbred lines for tolerance to inbreedin stress and better yield required for seed production.
- Stability of performance of hybrids under varied agro-ecological conditions and a biotic stresses especially under water stress conditions. The useful traits for drought resistance include small male tassel, small leaf area, profligacy, leaf elongation, heat tolerance, high abscisic acid content.
- Development of hybrids and composites with higher level of resistance / tolerance to biotic stresses, which is possible by identification of inbreds possessing multiple disease and pests resistance.
- Development of quality protein maize with higher contents of essential amino acids, lysine and tryptophan. High oil content is also an important goal for some maize breeding programme as the maize oil is of higher industrial value.
- Due to increased demand for specialized products, there is need to breed varieties / hybrids for human and live stock health, nutrition and taste.
- Transgenic corn has to be made reality in the country with increased content of starch, oil and protein.

Table4: List of varieties/ hybrids of Rice, Wheat and Maize released by Central Variety Release Committee

S. No.	Name of Variety/Hybrids	Year of Release	States Recommended for Cultivation
Rice			
1.	Vivekdhan 82	2001	Himachal Pradesh, Meghalaya and Uttrakhand
2.	Pantdhan 16	2001	Bihar, West Bengal, Haryana
3.	Yamini	2001	For sodic and normal basmatii growing areas of Haryana, Punjab and Uttar Pradesh
4.	Krishna Hamsa	2001	Tripura, West Bengal, Bihar
5.	Vasumati	2001	Basmati growing areas in northwestern states of Punjab, Haryana, Uttrakhand and western Uttar Pradesh
6.	Pusa Sugandh 2	2001	Basmati growing areas in northwestern states of Punjab, Haryana, Delhi, Uttrakhand and western Uttar Pradesh
7.	Pusa Sugandh 3	2001	Basmati growing areas in northwestern states of Punjab, Haryana, Delhi, Uttrakhand and western Uttar Pradesh
8.	HRI 120	2001	Southern, eastern, western regions
9.	Pusa RH 10	2001	Haryana, Delhi and Uttrakhand
10.	IET 15358	2003	Andhra Pradesh, Maharashtra, Karnataka and Tamil Nadu
11.	IET 16442 EXPH	2003	Andhra Pradesh, Karnataka, Tamil Nadu, Haryana and Rajasthan

	204		
12.	CSR 23	2004	Coastal saline and alkaline areas of the country
13.	Sukardhan 1	2004	Upland hills of Himachal Pradesh, Meghalaya and Uttrakhand
14.	Sumati	2004	Coastal saline areas of West Bengal, Orissa, Kerala and Andhra Pradesh
15.	JKRH 401	2006	West Bengal, Bihar and Orissa under irrigated and transplanted conditions
16.	Abhishek	2006	Uttar Pradesh, Bihar, Jharkhand and Assam under irrigated conditions
17.	Shusk Samrat	2006	Uttar Pradesh, Orissa and Bihar under direct seeded upland conditions
18.	Virender	2006	Orissa and Gujarat under rainfed, direct seeded (upland conditions)
19.	VL Dhan 86	2006	Uttarakhand and Himachal Pardesh in irrigated transplanted conditions
20.	Bhuthnath	2006	West Bengal, Orissa and Maharashtra
Wheat			
1	HD 2733 (VSM)	2001	Eastern Uttar Pradesh, (except hilly regions), Bihar, Orissa, West Bengal, Assam, Sikkim, Arunachal Pradesh and other Far Eastern States
2	HUW 510	2001	Maharashtra, Karnataka and plains of Andhra Pradesh and Tamil Nadu
3	GW 322	2002	Madhya Pradesh, Chhattisgarh, Gujarat, southern & western Rajasthan, and Bundelkhand region of Uttar Pradesh, Maharashtra and Karnataka
4	HD 2781 (Aditya)	2002	Maharashtra, Karnataka, parts of Andhra Pradesh, Goa and plains of Tamil Nadu
5	HW 2045 (Kaushambi)	2002	Central and eastern Uttar Pradesh, Bihar, West Bengal and parts of Assam
6	VL 804	2002	Hilly area of Himachal Pradesh, Uttarakhand, and Jammu & Kashmir
7	VL 829	2002	Western Himalayan regions of Jammu & Kashmir (except Jammu and Kathua distt.); Himachal Pradesh (except Una and Paonta Valley); Uttarakhand (except Tarai area); Sikkim and hills of West Bengal and N.E. States
8	DBW 14	2002	Eastern Uttar Pradesh, Bihar, West Bengal, Jharkhand, Orissa and Assam
9	HS 420 (Shivalik)	2002	Western Himalayan regions of Jammu & Kashmir (except Jammu and Kathua distt.); Himachal Pradesh (except Una and Paonta Valley); Uttarakhand (except Tarai area); Sikkim and hills of West Bengal and N.E. States
11	HI 1500 (Amrita)	2003	Madhya Pradesh, Chhatisgarh, Gujarat, South Rajasthan and Bundelkhand region of Uttar Pradesh.
12	HS 375 (Himgiri)	2003	High altitudes of northern Hills zone comprising, Himachal Pradesh, Uttarakhand, Jammu & Kashmir regions.
13	HS 420 (Shivalik)	2003	Himachal Pradesh, Uttarakhand, Jammu and Kashmir
14	MP 4010	2003	Madhya Pradesh, Chhattisgarh, Gujarat, Kota and Udaipur divisions of Rajasthan and Jhansi division of Uttar Pradesh
15	NW 2036	2003	Uttar Pradesh, Bihar, Jharkhand, and West Bengal
16	VL 829	2003	Western Himalayan regions of Jammu & Kashmir (except Jammu and Kathua distt.); Himachal Pradesh (except Una and Paonta Valley); Uttarakhand (except Tarai area); Sikkim and hills of West Bengal and N.E. States
17	SKW 196 (Shalimar Wheat 1)	2004	Western Himalayan regions of Jammu & Kashmir (except Jammu and Kathua distt.); Himachal Pradesh (except Una and Paonta Valley); Uttarakhand (except Tarai area); Sikkim and hills of West Bengal and N.E. States
18	HD 2824 (Poorva)	2004	Eastern Uttar Pradesh, Bihar, West Bengal, Jharkhand, Orissa and Assam
19	PBW 502	2004	Punjab, Haryana, Western Uttar Pradesh, and parts of Rajasthan state, Delhi
20	Raj 4037	2004	Maharashtra, Karnataka, Andhra Pradesh, Goa, plains of Tamil Nadu
21	VL 832	2004	High altitude conditions of Jammu & Kashmir, Himachal Pradesh and Hill district of Uttarakhand
22	HD 2864 (URJA)	2004	Madhya Pradesh, Chhattisgarh, Gujarat, Kota and Udaipur divisions of Rajasthan and Jhansi division of Uttar Pradesh

23	PBW 291	2005	Punjab, Haryana, Western Uttar Pradesh, and parts of Rajasthan state, Delhi
24	HI 1531(Harshita)	2006	Madhya Pradesh, Chhattisgarh, Gujarat, Kota and Udaipur divisions of Rajasthan and Jhansi division of Uttar Pradesh
25	HD 2888 (Pusa Wheat 107)^	2006	Eastern Uttar Pradesh, Bihar, West Bengal, Jharkhand, Orissa and Assam
26	DBW 16	2006	Punjab, Haryana, Western Uttar Pradesh, and parts of Rajasthan state, Delhi
27	PBW 533	2006	Maharashtra, Karnataka, parts of Andhra Pradesh, Goa and plains of Tamil Nadu
28	HD 2333 (Pusa Wheat 105)	2006	Maharashtra, Karnataka, parts of Andhra Pradesh, Goa and plains of Tamil Nadu
Maize			
1	Buland	2002	Delhi, Haryana, Pujanb and Uttar Pradesh
2	PEHM-5	2003	Delhi, Haryana, Punjab and Uttar Pradesh
3	Deccan 115	2003	Punjab, Uttar Pradesh, Bihar, Assam, Orissa, West Bengal and Jharkhand
4	Pratap Composite-4	2003	Delhi, Haryana, Punjab, Uttar Pradesh, Bihar, Assam, Orissa and Jharkhand
5	FH3210	2003	Eastern Uttar Pradesh, Bihar, Assam, Orissa, Jharkhand and Chattisgarh
6	Vivek-15	2004	Jammu & Kashmir, Himachal Pradesh, Uttrakhand hills and West Bengal
7	Vivek 17	2004	Delhi, Haryana, Punjab, Andhra Pradesh, Maharashtra, Karnataka and Tamil Nadu
8	Buland Rabi	2004	Andhra Pradesh, Maharashtra, Karnataka and Tamil Nadu
9	Amber Shakti-1(QPM)	2004	Himachal Pradesh, Uttrakhand, Bihar, Haryana, Karnataka, Rajasthan and Andhra Pradesh
10	Pratap Makka-3	2004	Rajasthan,Gujarat and Madhya Pradesh
11	Win Yellow (Sweet corn)	2004	Himachal Pradesh, Jammu and Kashmir and Uttranchal
12	VL78 (Baby corn)	2004	All India under Kharif and Rabi season
13	JH3851	2005	Andhra Pradesh, Maharastra, Karnataka, Tamil Nadu, Rajasthan, Madhya Pradesh, Gujarat, Jharkhand and Orissa.
14	PMH-1	2006	Punjab, Haryana and Eastern Uttar Pradesh
15	Vivek-21	2006	Uttrakhand and Himachal Pradesh
16	HQPM-1	2006	All India
17	JKMH1701	2006	Uttrakhand, north eastern Himalaya, Himachal Pradesh, West Bengal, Maharastra, Andhra Pradesh, Karnataka and Tamil Nadu
18	Y1280M	2006	Maharastra, Andhra Pradesh, Karnataka and Tamil Nadu for rabi season

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