LECTURE – 1 CENTRES OF ORIGIN – CENTRES OF DIVERSITY

Centre of Origin

It is generally accepted that cultivated plants were not distributed uniformly throughout the world. Even today, certain areas show far greater diversity than others for certain cultivated crops and their wild relatives. In 1926, N.I.Vavilov proposed that crop plants evolved from wild species in the areas which showing greater diversity. The concept of centres of origin was given by Vavilov based on his studies of a vast collection at the Institute of Plant Industry, Leningrad. He also postulated the *law of homologous series in variation*. Eight main centres of origin were originally proposed by Vavilov in 1926 (Table 1).

The concept that centres of diversity represent centres of origin has been seriously questioned. Plants of a species growing in different environments are likely to be different. Thus, a plant species is likely to show greater variation in a region with varied climatic and other ecological conditions. Areas with mountains and valleys show considerable variation in the prevalent environment; therefore, plant species shows a greater variation in such areas. Interestingly, the centres of origin are situated in such mountain-valley areas.

Centre of Origin is the region of the world where a crop is believed to have originated. It has two types (1) primary centre of origin and (2) secondary centres of origin.

Crop plants evolved from wild species in the areas showing great diversity are known as primary centre of origin.

In some areas, certain crops species show considerable diversity of forms although they did not originate there; such areas are known as secondary centres of origin.

Table 1 : Vavilov (1926, 1935) proposed eight main centres of origin

Sr.No.	Centre of origin	Sr.No.	Centre of origin
1.	China Centre	**2.**	Hindustan Centre Divided in to: (1) Indo-Burma (2) Siam-Malaya-Java Centres
3.	Central Asia Centre	**4.**	Asia Minor Centre
5.	Mediterranean Centre	**6.**	Abyssinia Centre

7.	Central America Centre	**8.**	South America Centre Divided into: (1) Peru (2) Chile (3) Brazil-Paraguay centres

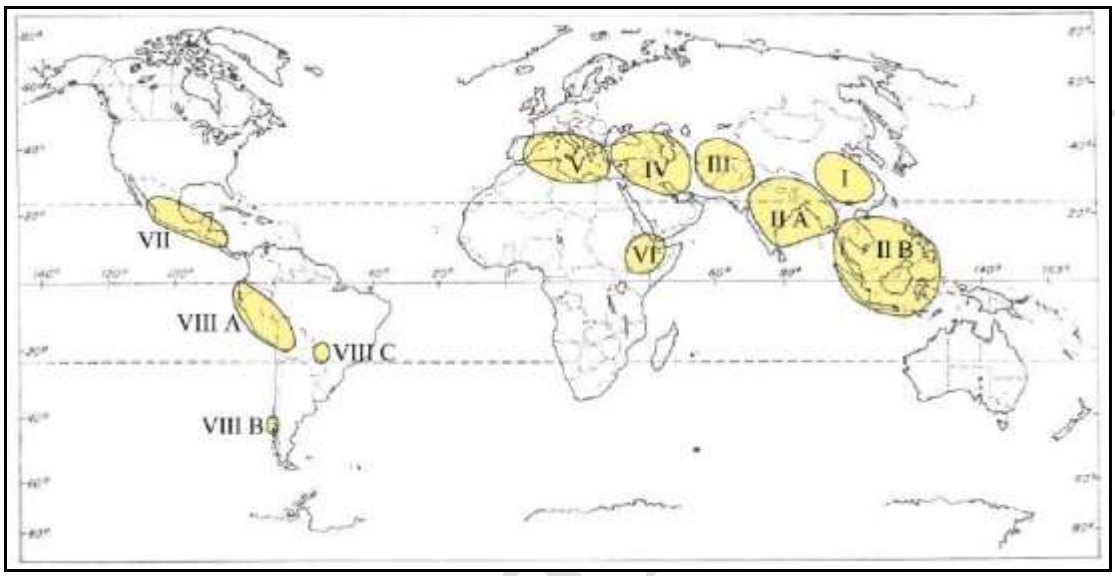


Figure 1 : Main centres of origin

Law of Parallel Variation

The concept of parallel variation also known as *law of homologous series of variation* was developed by Vavilov (1951) based on his study of crop diversity and centres of origin. *Law of homologous series states that a particular variation observed in a crop species is also expected to be available in its related species.* For instance, if we get dwarf collections in one species of a crop, the same may be observed in another related species also. Vavilov used principle of homologous series of variation as a clue for discovering similar characters in related species.

Centers of Diversity

Centre of diversity refers to the geographical region in which greatest variability of a crop occurs.

A plant species is likely to show a greater variation in region with varied climatic and other ecological conditions. Areas with mountains and valley show considerable variation in the prevalent environment. Therefore, plant species would show a great variation in such areas.

Interestingly, the center of origin is situated in such mountain-valley areas. Further the center of diversity of many species has shifted with time. This shift in diversity was brought by a shift in the area with a greatest cultivation and due to the introduction of concerned species into an area with greater ecological diversity than where they existed before. These processes have given rise to the secondary center of diversity (Table 2). Consequently, several species have two or more centers of diversity and it is often difficult to determine, which one of them is the real center of origin. *Thus the centers of origin may be more appropriately called centers of diversity.* Zhukovsky, in 1965, recognized 12 mega-gene centers of crop plant diversity (Table 3).

Types of Centres of Diversity Three types:

(1) Primary centres of diversity

(2) Secondary centres of diversity

(3) Micro centres

(1.) Primary Centres of Diversity

Primary centres are regions of vast genetic diversity of crop plants. These are original homes of the crop plants which are generally uncultivated areas like, mountains, hills, river valleys, forests, etc.

Main features:

1. They have wide genetic diversity
2. They have large number of dominant genes
3. Mostly they have wild characters
4. They exhibit less crossing over
5. Natural selection operates in primary centre of diversity

(2) Secondary Centres of Diversity

These are the areas where certain crop species show considerable diversity although they did not originate there. These are generally the cultivated areas.

Main features:

1. They have lesser genetic diversity than primary centres
2. They have large number of recessive genes
3. They exhibit more crossing over

4. Both natural and artificial selections operate in secondary centre of diversity

(3) Micro centres

In some cases, small areas within the centres of diversity exhibited tremendous genetic diversity of some crop plants; are referred to as micro-centres.

Main features:

1. They represent small areas within the centre of diversity
2. They exhibit tremendous genetic diversity
3. The rate of natural evolution is faster than larger areas
4. They are important sites for the study of crop evolution

Table : 2 Difference between primary centre of diversity and secondary centre of diversity

Sr.No.	Feature	Primary centres of diversity	Secondary centres of diversity
1.	Definition	Regions of vast genetic diversity of crop plants	Valuable forms of crop plants are found far away from their primary areas of origin
2.	Genetic diversity	Wide	Lesser than primary
3.	Regions includes	Original homes of the crop plants which are generally uncultivated areas like mountain, hills, river valleys	Generally cultivated areas
4.	Genetic activity	Dominant genes	Recessive genes
5.	Characters contains	Wild characters	Desirable characters
6.	Crossing over	Exhibits lesser	Exhibits more
7.	Selection operates	Only natural	Both natural and artificial

Main difference between centre of origin and centre of diversity

Centre of origin are geographical areas where crop plants have originated. A centre of diversity refers to a location where vast genetic variability for a crop and its wild species is found. ***Thus, the centre of origin and centre of diversity for a crop may the same or may be different.***

The primary centres of origin and domestication and secondary centres of diversity of some of the important vegetable crops (Zeven and Zhukovsky, 1975) from important place for collection of genetic diversity given in the following Table 3.

Table : 3 Centres of diversity of the major vegetable crop species (Zeven and Zhukovsky, 1975)

Mega gene centre	Primary centres of origin and domestication	Secondary centres
Chinese - Japanese	Egg plant, Wax gourd, Chinese cabbage, Kangkong, Welsh onion	Water melon, Amaranth
Indo- Chinese	Wax gourd, Sponge gourd, Ridge gourd, Bitter gourd, Sword bean, Winged bean, Taro, Cucumber, Bottle gourd, Chayote, Yam	Cucumber, Bottle gourd, Chayote, Shallot, Yam bean, Yard long bean, Chinese cabbage, Amaranth, Kangkong
Australian	-	-
Hindustani	Eggplant, Wax gourd, Cucumber, Ridge gourd, Sponge gourd, Bitter gourd, Hyacinth bean, Kangkong, Okra, Drumstick	Watermelon, Melon, Bottle gourd, Amaranth, Roselle
Central Asia	Onion, Garlic, Mustard, Spinach, Carrot	Eggplant, Watermelon, Melon, Cauliflower
Near East	Onion, Garlic, Leek, Mustard Beet	Okra
Mediterranean	White cabbage, Cauliflower, Broccoli, Bean, Radish	Sweet pepper, Garlic, Okra
African	Eggplant, Watermelon, Melon, Bottle gourd, Locust bean, Cowpea, Okra, Roselle	Onion, Shallot, Lima bean, Mustard, Amaranth, Corchorus
European - Siberian	Lettuce	Onion, Common bean, White cabbage, Cauliflower, Spinach, Carrot
South American	Tomato, Hot pepper, Pumpkins and Squashes, Lima bean, Common bean, Cassava, Xanthosoma, Chayote	Common bean

Central American and Mexican Region	Tomato, Hot pepper, Pumpkins and Squashes, Yam bean, Common bean, Amaranth, Sweet potato	-
North America	-	Tomato, Eggplant, Pepper, Melon, Watermelon, Pumpkin and Squashes, Onion, Lettuce, Common bean, Lima bean, Okra

Need for improvement of vegetable crops:

- Higher yield and better quality
- Extended harvest period and areas of adaptability
- Photo insensitivity, salt tolerance and moisture stress
- Synchronous maturity and non-shattering characteristics
- Better nutritional, processing quality and seed production
- Resistance against biotic and abiotic stresses
- Long shelf-life and export quality produce **History of Vegetable Breeding:**
- **1940 :** Successful attempt of seed production of temperate vegetables at Quetta (now in Pakistan)
- **1949 :** Establishment of a vegetable breeding station at Katrain in Kullu Valley
- **1955 :** Vegetable breeding station, Katrain came under IARI, New Delhi
- **1956 :** Creation of Division of Horticulture at the IARI, New Delhi
- **1960 :** Establishment of first Agricultural University at Pantnagar, UP (now in Uttarakhand)
- **1968 :** Establishment of IIHR at Bangalore
- **1970 :** Initiation of All-India Co-ordinated Vegetable Improvement Project
- **1987 :** Start of Project Directorate of Vegetable Research (PDVR) at IARI
- **1992 :** Shifting of the headquarters of PDVR from New Delhi to Varanasi

LECTURE – 2 PLANT BIODIVERSITY AND GERMPLASM CONSERVATION

Introduction

Biodiversity or **biological diversity** is a neologism and a portmanteau word, from *bio* and diversity. It is the diversity of living nature. Diversity, at its heart, implies the number of different kinds of objects, such as species.

The term biological diversity, was coined by Thomas Lovejoy in 1980, while the word biodiversity itself, was coined by the entomologist E.O. Wilson in 1986, in a report for the first American Forum on biological diversity organized by the National Research Council (NRC). The word biodiversity was suggested to him by the staff of NRC, to replace 'biological diversity' a word which was considered to be less effective in terms of communications. **Biodiversity definitions**

Biological diversity has no single standard definition. One definition holds that biological diversity is a measure of the relative diversity among organisms present in different ecosystems. "Diversity" in this definition includes diversity among species, within species and comparative diversity among the types in different ecosystems.

Another definition, simpler and clearer, but more challenging, is the totality of genes, species, and ecosystems of a region. An advantage of this definition is that it seems to describe most instances of its use, and one possibly unified view of the traditional three levels at which biodiversity has been identified. **Types of Biodiversity**

- ***Genetic Diversity*** - diversity of genes within a species. There is a genetic variability among the populations and the individuals of the same species
- ***Species Diversity*** - diversity among species
- ***Ecosystem Diversity*** - diversity at a higher level of organization, the ecosystem (richness in the different processes to which the genes ultimately contribute)

The latter definition, which conforms to the traditional five organization layers in biology, provides additional justification for multilevel approaches.

Benefits of biodiversity

The importance of biodiversity is as follows:

- Biodiversity in relation to ecosystems provides us various *supports of production* (soil fertility, pollinators of plants, predators, decomposition of wastes) *and services* such as purification of the air and water, stabilization and moderation of the climate, decrease of flooding, drought and other environmental disasters.
- It is reservoir of resources to be drawn upon for the manufacture of food, pharmaceutical and cosmetic products.
- It is source of fibres for clothing and wood for shelter and warmth. Other industrial products such as oils, lubricants, perfumes, fragrances, dyes, paper, waxes, rubber, latex, resins, poisons and cork can all be derived from various plant species.
- It is a source of economical wealth for many areas, such as many parks and forests, where wild plants and animals are a source of beauty and joy.
- Biodiversity can also act as a mirror of our relationships with the other living species, an ethical view with rights, duties, and education. It is also a part of many cultures of spiritual heritage.
- Biodiversity is important because each species can give scientists some clue as to how life evolved and will continue to evolve on Earth. In addition, biodiversity helps scientists understand how life functions and the role of each species in sustaining ecosystems.

GERMPLASM

It refers to sum total of all genes/alleles present in a crop species and its wild relatives.

Germplasm is also termed as genetic resource. Genetic resources can be broadly grouped into two types: (1) cultivated germplasm and (2) wild germplasm.

Germplasm includes

(i). Land races or primitive varieties

These are primitive varieties, which have evolved over centuries through both natural and artificial selection, but without a systematic and sustained plant breeding efforts. They are store house of genetic variability. They are adapted to survive under unfavourable conditions and have low but stable yields.

(ii). Obsolete cultivar

These varieties were developed by systematic breeding efforts, were once commercially cultivated, but are no more grown. These varieties do have some desirable and useful features.

(iii). Varieties in cultivation

They are the easiest to use in breeding programme. They are good source of genes for yield, quality etc. They are evolved through planned plant breeding.

(iv). Breeding lines

These are lines/populations developed in breeding programme. They have narrow genetic base and often contain valuable gene combinations. They are ordinarily maintained as working collections by breeders.

(v). Special genetic stocks

This category includes lines carrying gene mutations, chromosomal aberrations, marker genes, etc. These lines may have been obtained spontaneously or often induced artificially. They are useful in genetic analysis and may find use in breeding programme as well.

(vi). Wild forms and wild relatives

Wild forms are the wild species from which crop species were directly derived. They are easy to cross with the concerned crop species. The wild relatives include all other species, which are related to the crop species by descent during their evolution. Both these groups are sources of valuable genes for insects and disease resistance, tolerance to abiotic stresses and even for quality traits and yields.

Germplasm Conservation

Conservation refers to protection of genetic diversity of crop plants from genetic erosion. There are two important methods of germplasm conservation or preservation *viz*., *in situ* conservation and *ex situ* conservation. These are described below.

(1). *In situ* conservation

Conservation of germplasm under natural conditions is referred to as *in situ* conservation. This is achieved by protecting the area from human interference, such an area is

often called natural park, biosphere reserve or gene sanctuary. The NBPGR, New Delhi, established gene sanctuaries in Meghalaya for *Citrus*, North Eastern regions for *Musa*, *Citrus*, *Oryza* and *Saccharum*.

Merits

In this method of conservation, the wild species and the complete natural or seminatural ecosystems are preserved together. **Demerits**

- Each protected area will cover only very small portion of total diversity of a crop species, hence several areas will have to be conserved for a single species.
- The management of such areas also poses several problems.
- This is a costly method of germplasm conservation.

(2). *Ex situ* conservation

Conservation of germplasm away from its natural habitat is called ***ex situ* germplasm conservation**. This is the most practical method of germplasm conservation.

This method has following advantages.

- It is possible to preserve entire genetic diversity of a crop species at one place.
- Handling of germplasm is also easy.
- This is a cheap method of germplasm conservation.

It can be achieved in the following five ways:

1. Seed gene banks
2. Plant or field gene banks
3. Shoot-tip gene banks
4. Cell and organ gene banks and
5. DNA gene banks.

(1). Seed gene banks

Germplasm is stored as seeds of various accessions in seed gene banks. Virtually all gene banks are essentially seed gene banks. Seed conservation is quite easy, relatively safe and ordinarily needs minimum space. Under suitable conditions, seeds of many species can be stored for up to 50-100 years. Containers of glass, tin, plastic or a combination of these may

be used for seed storage. Seeds are classified, mainly on the basis of their storability, into two major groups; (a). Orthodox seeds and (b) Recalcitrant seeds. This grouping of seeds was proposed by Roberts in 1973.

(a). Orthodox Seeds

Seeds of this type can be dried to moisture content of 5% or lower without lowering their viability. Most crop seeds belong to this category. Such seeds can be easily stored for long periods; their longevity increase in response to lower humidity and storage temperature.

(b). Recalcitrant Seeds

The viability of this group of seed drops drastically if their moisture content is reduced below 12-30%. Seeds of many forest and fruit trees and of several tropical crops like citrus, cocoa, coffee, rubber, oil palm, mango, jackfruit, etc. belong to this group. Such seeds present considerable difficulties in storage. Therefore, germplasm of such plants are conserved by alternative approaches.

The conditions for seed storage depend mainly on the duration of storage. Generally, seed bank collections are classified into three groups: (i) base collections, (ii) active collections and (iii) working collections. This grouping increases the efficiency of use and the level of management of the collections.

(i). Base collections

These consist of all the accessions present in the germplasm of a crop, which are stored at about - 20°C with 5% moisture content; they are disturbed only for regeneration. Germination tests are done every 5-10 years. When the germination of an accession falls below, usually, 95% of its germination at the start of storage, the accession is regenerated. For reasons of safety, duplicates of base collections should be conserved in other Germplasm banks as well. High quality orthodox seeds can maintain good viability upto 100 years.

(ii). Active collections

The accessions in an active collection are stored at temperatures below 15°C (often near 0°C) and the seed moisture is kept at 5%. The storage is for medium duration, *i.e.,* 10-15 years. These collections are used for evaluation, multiplication and distribution of the accessions. Active collections are usually maintained by multiplying the seeds of their own

accessions. But from time to time, base collection material should be used for regeneration of these collections. This is essential to prevent any appreciable shift in the genetic make up of the collections.

(iii). Working collections

The accessions being actively used in crop improvement programmes constitute working collections. Their seeds are stored for 3-5 years at less than 15°C and they usually contain about 10% moisture. These collections are maintained by the breeders using them.

(2). Plant or Field Gene Banks

Essentially, a field or plant gene bank is an orchard or a field, in which accessions of fruit trees or vegetatively propagated crops are grown and maintained.

Field banks suffer from the following serious limitations:

1. They require large areas
2. They are expensive to establish and maintain, and are prone to damage from disease and insect attacks
3. They are man-made
4. There are natural disasters and human errors in handling
5. Few good plant banks exist in India

(3). Shoot Tip Gene Banks

In such gene banks, germplasm is conserved as slow growth cultures of shoot-tips and nodal segments. Their regeneration consists of sub culturing the cultures, which may be done every 6 months to 3 years. This approach offers the following advantages for the conservation of germplasm of vegetatively propagated crops and tree species.

1. Genotypes of the accessions can be conserved indefinitely, free from diseases and pests.
2. They can be used for such crops, which either do not produce seeds or produce recalcitrant seeds.
3. Sub-culture becomes necessary only after relatively long periods (every 6-36 months).
4. Regeneration, *i.e.,* sub-culturing requires comparatively very short time.

In addition, cuttings, bulbs and tubers can be maintained under controlled humidity and temperature conditions; however, this approach is practical for the short and medium term storage, and it should be used in conjunction with a field gene bank.

(4). Cell and organ gene banks

A germplasm conservation based on cryo-preserved (at – 196^{O}C in liquid nitrogen) embryogenic cell cultures, shoot tips or somatic/ zygotic embryos they be called cell and organ bank. **Cryo-preservation:**

It is a process where cells, whole tissues or any other substances susceptible to damage caused by chemical reactivity or time are preserved by cooling to sub-zero temperature.

(5). DNA gene banks

In this bank, DNA segment of the germplasm accessions are maintained as cosmid clones or phage lysates. This DNA Segment can be evaluated and desired one may be used to produce transgenic plants.

Plant Quarantine

Quarantine means to keep material in isolation to prevent spread of disease, etc. present in them to other materials. In case of plant introduction, all propagules are thoroughly inspected for contamination by weeds, diseases and insect pests. Materials that are suspected to be contaminated are fumigated or are given treatments to free them from contamination. If necessary, the materials are grown in isolation for observation of diseases, insect-pests and weeds. This entire process is known as quarantine and the rules prescribing them are termed as quarantine rules.

According to the destructive Insects and Pests Act 1914, all plant produce imported in India must be free from diseases, insect pests and weeds. At present, the Plant Quarantine Order 2004, is operative, which has been revised in the light of 'New Policy on Seed Development (1988) and the World Trade Organization (WTO) agreements.

The process of quarantine at the NBPGR, New Delhi takes at least three weeks. The quarantine of short-lived propagules is done at top priority. Each imported sample must be accompanied by a '*phytosanitary certificate*' from the sender certifying that the seeds/propagules are free from weeds, diseases and pests.

LECTURE – 3 SELF INCOMPATIBILITY

Introduction

There are several natural mechanisms that affect the mode of pollination in crop plants. Out of these all mechanisms; two mechanisms, namely, self incompatibility and male sterility, are of special significance because of their use in hybrid seed production.

The term self incompatibility was originally coined by Stout in 1917. Self incompatibility (SI) was first reported by Koelreuter in *Verbascum phoeniceum* plant in 18th century. Self incompatibility (SI) *refers to the failure of pollen from a flower to fertilize the same flower or other flowers on the same plant*. In case of SI, pollen grains fail to germinate on the stigma of the flower that produced them. If, a plant does not set seed when pollinated with its own functional pollen, but exhibits normal seed setting when cross pollinated, it indicates presence of self incompatibility. **Main features**

- Self-incompatibility is an important out-breeding mechanism which prevents autogamy and promotes allogamy.
- Self incompatibility species do not produce seed on self pollination but lead to normal seed set on cross pollination.
- It maintains high degree of heterozygosity in a species due to out-breeding and reduces homozygosity due to elimination of inbreeding or selfing.
- It can operate at any stage between pollination and fertilization.

Physiological hindrance of self-incompatibility

- Failure of the pollen to germinate on the stigma.
- If some pollen grains do germinate, pollen tube fails to enter the stigma *e.g.* Rye, Radish, Cabbage etc.
- If the pollen tube enters the style but they grow too slowly to effect fertilization before the flower drops.
- Sometimes fertilization is effected but the embryo degenerate at very early stage *e.g.* Sugarbeet.

Self-incompatibility appears to be a biochemical reaction but the precise nature of this reaction is not clearly understood. The genetic control of incompatibility reaction is relatively simple and governed by multiple alleles of single gene.

Classification of Self Incompatibility

(1) Based on flower morphology

(i) Heteromorphic system: It this system, flowers of different incompatibility groups is different in morphology. This system is of two types *viz., distyly* and *trisyly* depending upon the differences in the length of style and stamens.

(ii) Homomorphic system: The homomorphic system, is found in the majority of self incompatible species, and incompatibility is not associated with morphological differences among flowers.

(2) Based on genes involved

(a) Monoallelic: Self incompatibility is controlled by single gene

(b) Diallelic: Self incompatibility is govern by two genes

(c) Polyallelic: Self incompatibility is govern by several genes

(3) Based on sites of expression

(a) Stigmatic: Self incompatibility genes express on the stigma

(b) Stylar: Self incompatibility genes express in the style

(c) Ovarium: Self incompatibility genes express in the ovary

(4) Based on pollen cytology

(a) Binucleate : The pollen grains have two nuclei

(b) Trinucleate : The pollen grains have three nuclei

Types of self Incompatibility

(i) Heteromorphic system

In this system, flowers of different incompatibility groups are different in morphology. *E.g.* In Primula, there are two types of flowers namely, *pin* and *thrum*. Pin flowers have long style and short stamens, while thrum flowers have short styles and long stamens. This situation is referred as *distyly*. In this, the crosses are compatible between *Pin* x *Thrum* or *Thrum* x *Pin* but not between *Pin* x *Pin* and *Thrum* x *Thrum* flower. This characteristic is governed by a single gene '*S'* which behaves in Mendelian fashion. It is considered that *thrum* is heterozygous *i.e., 'Ss'* whereas '*ss'* produces *pin* flowers which is homozygous. The incompatibility reaction of pollen is determined by the genotype of the plant producing them. Allele '*S'* is dominant over allele '*s'*. The incompatibility systems, therefore, is *heteromorphic sporophytic*.

Tristyly is known in some plant species *e.g. Lythrum.* In such case, the style of a flower may be either short, long or of medium length. The '*S'* gene gives rise to short style, '*sM* 'to medium style and '*sm'* to long style. Short style may have *Ssmm*, *SsMm* or *SsMM* genotypes, medium style has *ssMm* or *ssMM* genotypes and long style has *ssmm* genotypes.

(ii) Homomorphic system

In the homomorphic system, incompatibility is not associated with morphological differences among flowers. Self incompatibility results due to physiological causes rather than differences in flower morphology. The plants do not have differences in the length of style and stamens or other floral parts. This system is very much important and more common than heteromorphic system in crop plants. The incompatibility reaction of pollen may be controlled by the genotype of the plant on which it is produced (*Sporophytic control*) or by its own genotype (*Gametophytic control*).

It can operate in various ways

- The pollen grains do not germinate on the stigma of same flower. If they germinate, the pollen tube fails to penetrate the stigma as in Rye, Cabbage and Radish.
- The pollen grains may germinate but there is retardation of pollen tube growth.
- In some cases, there is slow rate of pollen tube growth and it rarely reaches the ovary in time to effect self fertilization.
- In some cases, pollen tube growth may be normal, but it does not release the male gamete.

Types of homomorphic system

(a) **Gametophytic system:** When the self incompatibility is controlled by the genetic constitution of gametes, it is known as gametophytic self incompatibility system.

(b) **Sporophytic system:** When the self incompatibility is governed by the genotype of pollen producing plant (*Sporophyte*), it is called sporophytic self incompatibility system.

(a) Gametophytic self-incompatibility

This type of self incompatibility was first described by East and Mangelsdorf in *Nicotiana sanderae* in 1925. This form of self-incompatibility is more common than SSI but not so well understood. In this system, the incompatibility reaction of pollen is determined by its

own genotypes, and not by the genotype of the plant on which it is produced. It occurs in nearly one-half of all the families of angiosperms, including the solanaceous crops (Rye, sugarbeet, alfalfa, potatoes, tomatoes, ranunculus, lilies, roses, and many grasses).

(b) Sporophytic self-incompatibility

This type of self incompatibility was first reported by Hughes and Babcock (1950) in *Crepis foetida* and by Gerstel in *Parthenium argentatum.* It is observed in mustard family (*Brassica*), including turnips, rape, cabbage, broccoli, and cauliflower. In this system, self incompatibility is governed by a single gene, S, with multiple alleles. The incompatibility reaction of pollen is governed by the genotype of plant on which the pollen is produced, and not by the genotype of pollen. In this system, rejection of self pollen is controlled by the diploid genotype of the sporophyte generation.

Mechanism of self incompatibility

There are two different types of events which are considered to constitute the basis of self incompatibility systems: (i) the stimulation of unlike genotypes and (ii) the inhibition of like genotypes. Thus, the two hypotheses have been proposed to explain the mechanism of self incompatibility in plants. There are: (1) Complementary hypothesis and (2) Oppositional hypothesis.

(1) Complementary hypothesis

The hypothesis was proposed by Bateman in 1952. According to this hypothesis, self incompatibility results due to absence of stimulation by the pistil on pollen growth in the like genotypes (S_1S_2 x S_1S_2). In other words, self incompatibility results due to absence of substances in the pistil or pollen which is essential for pollen tube preparation. On selfing, the pollen and/or the pistil fail to produce the substance which is essential for the pollen to germinate or for pollen tube growth in the style and the ovary. Thus, there is lack of substance required for stimulation of pollen germination or pollen tube growth in the like genotypes.

However, unlike genotypes (S_1S_2 x S_3S_4) lead to normal pollen germination and pollen tube growth due to presence of stimulation. Unlike genes in pollen and style lead to production of stimulant (a chemical substance) which is essential for normal tube growth and like alleles in pollen and style lead to inhibition of pollen tube growth.

(2) Oppositional hypothesis

This hypothesis stated that interaction between like alleles (S_1S_2 x S_1S_2) leads to production of inhibitor which inhibits the growth of pollen tube in pistil. The inhibitor can act in three ways: (1) it may inhibit an enzyme or auxin necessary for pollen tube growth, (2) may block pollen tube membrane and (3) may inhibit a necessary enzyme for the penetration of style.

Site of gene expression

The genes which govern self incompatibility may express only at three different locations in the flower, *viz.,* (1) on the stigma, (2) in the style, and (3) in the ovary.

1. Stigmatic inhibition

The inhibition of pollen germination or pollen tube growth on the stigma occurs in majority of self incompatible plant species with ***tri-nucleate pollens***. Thus, stigmatic incompatibility reaction is confined to the *sporophytic* system with some exceptions. The stigmatic inhibition is found in Radish, Cabbage and Cauliflower etc.

2. Stylar inhibition

The inhibition of pollen tube growth in the stylar region is a common feature of the majority of self incompatible plants with ***bi-nucleate pollen***. The pollen tubes usually swell and burst at the apex in the upper region of the incompatible style. The inhibition of pollen tubes in the style takes place from few to many hours after pollen germination.

3. Ovarian inhibition

In some species, the self incompatibility reaction occurs only when the pollen tubes reach the ovary. Most species in which inhibition occurs in ovary, have hollow styles.

Measures to overcome self incompatibility

There are several ways and means to overcome self incompatibility in crop plants like;

1. Surgical techniques

Removal of the stigmatic surface, the whole of stigma or a part or whole of the style may permit an otherwise incompatible mating. Removal of the stigma is very useful in the sporophytic system, e.g., *Brassica oleracea* but it did not work on *Brassica campestris.*

2. End-of-season pollination

In some species, the degree of incompatibility is reduced towards the end of flowering season or in mature plants. But there are controversial reports on the usefulness of this technique.

3. High temperature

In some lines, temperatures of 30 ^{0}C or more induce seed set on self pollination. But in many cases, it is a genotype dependent response. In some species, like *Trifolium, hybridum* a single dominant gene produces self-incompatibility at 32°C.

4. Increased CO_2 concentration

Increased CO_2 concentration is reported to overcome self-incompatibility in the sporophytic system. This approach has promise for use on a large scale for multiplication of inbred lines.

5. Bud pollination

Mature pollen is applied to non receptive stigmas 1-2 days before anthesis. It is the most successful technique in both the SI system.

6. Salt (NaCl) sprays

Chinese workers have developed a salt spray technique to overcome selfincompatibility in *B. napus*. In this technique, the flowers are sprayed with a 5-10% sodium chloride solution for 3 to 5 days. The method is easy, economical and as effective as bud pollination.

7. Double pollination

In some species, self-incompatible mating become possible when incompatible pollen in applied as a mixture with a compatible pollen, or it is applied after pollination with a compatible pollen.

8. Irradiation

Irradiation of style with X-rays immediately before selfing resulted in breakdown of self incompatibility in Petunia. Gamma irradiation significantly increased seed setting upon selfing in *Lycopersicon*.

9. *In vitro* Fertilization:

Placing of pollen grains in direct contact with ovule resulted in breakdown of self incompatibility in many crop species. (Maheshwari and Kanta, 1964).

Utilization in Plant Breeding

1. Production of hybrids

Self incompatibility provides a way for hybrid seed production without emasculation and without resorting to genetic or cytoplasmic male sterility. *e.g.* in

Cabbage, sun flower

2. Combining desirable genes

Self incompatibility system permits combining of desirable genes in a single genotype from two or more different sources through natural cross pollination which is not possible in self compatible species. **Limitations**

- It is very difficult to produce **homozygous inbred lines** in a self incompatible species. Bud pollination has to be made to maintain the parental lines.
- Self incompatibility is affected by environmental factors such as temperature and humidity. Incompatibility is reduced or **broken down at high temperature** and humidity.
- Hybrid seed produced under unfavourable conditions using self incompatibility may contain high proportion of sib crossed seeds which is not desirable. High temperature and humidity are favourable for maintenance of parental lines.
- Sometimes, bees visit only one parental line in seed production plot resulting in sib mating. This poses problems in the use of self incompatibility in hybrid seed production programmes.

Table:1 Comparison of gametophytic and sporophytic system of self incompatibility

Sr.No.	Gametophytic SI	Sporophytic SI
1.	SI is controlled by genetic constitution of pollen	SI is controlled by the genotype of the pollen producing plant (Sporophyte)
2.	It is governed by single gene S with multiple alleles	SI is also governed by a single gene S with multiple alleles
3.	Alleles have individual action in style without interaction	Alleles may show dominance, individual action or interaction in either pollens or style
4.	Pollen tube growth is usually inhibited in the style or ovary	Pollen germination or pollen tube growth is inhibited on stigma
5.	Plants belonging to this system have binucleate pollen grains	Plant species belonging to this system have trinucleate pollen grains
6.	Reciprocal differences are not observed	Reciprocal differences are observed
7.	Recovery of only male parent is possible from crosses	Recovery of both male and female parents is possible from crosses
8.	Does not permit the production of homozygotes	Permits production of some homozygotes
9.	Crosses may be sterile, partially fertile or fully fertile	Crosses would be either fully sterile or fully fertile

10.	Biochemical substances associated with incompatibility is formed during pollen formation	Biochemical substances associated with incompatibility is formed before pollen formation
11.	Such incompatibility can be overcome by polyploidy	This cannot be overcome by polyploidy
12.	***Examples:*** White clover, Rye, Potato, Tomato, etc.	***Examples:*** Radish, Cabbage, Cauliflower etc.,

Table: 2 Homomorphic self incompatibility in some crop plants

Family	**Crop**	**Botanical Name**	**Types**
Leguminosae	Red Clove	*Trifolium pratense*	G
	White Clove	*Trifolium repens*	G
	Lucern	*Medicago sativa*	G
Solanaceae	Tobacco	*Nicotiana sanderae*	G
	Tomato	*Lycopersicon peruvianum*	G
	Potato	*Solanum tuberosum*	G
Cruciferae	Radish	*Raphanus sativus*	S
	Cabbage	*Brassica oleracea* var. *capitata*	S
	Cauliflower	*Brassica oleracea* var. *botrytis*	S
Chenopodiaceae	Sugarbeet	*Beta vulgaris*	G

LECTURE – 4 MALE STERILITY

Introduction:

Male sterility *refers to the absence of functional pollen grains in hermaphrodite flowers*. Or *Male sterility refers to a condition in which pollen is either absent or nonfunctional in flowering plants, while female gametes function normally.* It is characterized by the production of non-functional or sterile pollen grain while female gamete functions normally. Male Sterility occurs in nature due to natural mutation. It can also be induced through interspecific crosses or by the use of gametocides, which will suppress the production of pollen grain. The male sterility attains diverse forms such as :

- Absence, malformation of male organ in bisexual plants.
- Fail to develop normal microsporogenous tissue.
- Anomalies in microsporogenesis yielding in viable, deformed or aborted pollen.
- Viable pollen development but anthers indehiscent.

Steps in utilization of male sterility:

Male sterility is manifested in several vegetable crops. It may be genic (GMS), cytoplasmic (CMS) or interaction of nuclear gene and cytoplasm (CGMS). Utilization of male sterility involves following steps:

1. Identification of male sterility and transfer of male sterile character into the desirable variety by repeated back crossing which will be used as female parent in hybrid seed production,
2. Perpetuation of male sterile lines by developing maintainer lines and
3. Development of hybrid seeds in open or by hand pollination.

The male sterile (female) lines are grown with male fertile (pollinator or male) lines in proportions of 4-6 : 1 in isolation for production of hybrid seeds.

History of Male Sterility:

- In flowering plants, the first report of male sterility by Koelreuter in 1763.
- First report of male sterility in Onion is given by Jones and Clarke in 1943.
- Male sterility in carrot was first reported by Welch and Grimball in 1951.
- Male sterility in pepper was first documented by Martin and Grawford in 1951.
- Genic male sterility has been reported in cabbage and cauliflower by Nieuwhof in 1961.

Table : 1 Classification of male sterility in plants:

(i) Inherited (genic) male sterility		
Phenotypic basis	**(i)**	**Sporogenous male sterility:** Pollen formation is completely disrupted.
	(ii)	**Structural sterility or positional sterility:** Floral organs are modified in such a way that selfing does not occur.
	(iii)	**Functional sterility:** Pollens are produced but they are unable to self fertilize due to non-dehisence nature of anthers.
Genetic basis	**(i)**	**Genetic Male Sterility (GMS):** Male sterility is caused by the gene(s) from nuclear compartment (nuclear gene)
	(ii)	**Cytoplasmic Male Sterility (CMS):** Male sterility is caused by the gene(s) from cytoplasm (mitochondrial genes)
	(iii)	**Cytoplasmic Genetic Male Sterility (CGMS):** Male sterility is caused by mitochondrial genes and restored by the nuclear genes.
(ii) Non-inherited (nongenetic) Male Sterility		This kind of male sterility is temporally induced by certain environmental stresses *e.g.* temperature *etc.*

Male Sterility is classified into following groups:

1. Cytoplasmic Male Sterility (CMS)

This type of sterility is determined by the cytoplasm. The zygote gets cytoplasm from mother or egg cell. Hence the progeny will also be male sterile. This type of male sterility is known in many crop plants such as onion. Genes conditioning male sterility is located in mitochondria or plasmid.

It is utilized in ornamental species a few vegetables where vegetative part is of economic use. In seed crops it is not useful because F_1 will be male sterile.

The CMS can be transferred from strain 'A' to strain 'B' by repeated back crossing. By this cytoplasmic background of process the nuclear genes from strain 'B' will be reconstituted in strain 'A'. Back crossing is repeated for 7-8 generations and the end product will be strain 'B' with male sterility.

The male sterility is governed by cytoplasmic factor (sterile cytoplasm) and is found in carrot, sweet pepper, radish, turnip, cauliflower, cabbage, broccoli, Chinese cabbage and cucumber.

2. Genic Male Sterility (GMS)

GMS is normally governed by nuclear recessive genes '*msms*'. The 'A' line is sterile because it has '*msms*' gene. The 'B' line is similar to 'A' line but for the heterozygous condition (*Msms*). The 'R' line is completely fertile (*MsMs*). This type of male sterility is used in tomato for the production of hybrids.

Male sterile line will be having white translucent anthers, while fertile line will be having yellow, plumpy anthers. At the time of flowering, each and every plant is to be examined for identification of sterile and fertile lines. They are to be tied with different colour threads. At the time of harvest, sterile line and fertile line are to be harvested separately.

The difficulties in the use of GMS are:

1) Maintenance of GMS requires skilled labour to identify fertile and sterile lines. Labeling is time consuming.
2) In hybrid seed production, spot identification of fertile line and removing them is expensive.
3) Use of double the seed rate of GMS line is also expensive.
4) High temperature leads to break down of male sterility in some crops.

This male sterility is generally controlled by a single recessive gene (ms) and has been reported in tomato, brinjal, chilli, sweet pepper, pea, lima bean, pumpkin, squash, water melon, musk melon, ridge gourd, cucumber, cauliflower, cabbage, broccoli and brussels sprout.

GMS commercially utilized in chilli and cucurbits crops, while CMS utilized in cole crops and root crops.

Environment sensitive Genic Male Sterility (EGMS)

EGMS is more popularly termed as "Two line Hybrid Breeding" as against "Three Line Hybrid Breeding" in case of CGMS system. Certain genetic male sterile lines are conditional mutants i.e., male sterility is expressed only in certain set or range of environmental conditions, in absence of which the male sterile plants turn into male fertile.

After determination of critical environment sterility and fertility expression, such GMS mutants are classified as Temperature sensitive Genic Male Sterility (TGMS) line or Photoperiod sensitive Genic Male Sterility (PGMS) lines. EGMS lines (mostly temperature sensitive) have been reported in several vegetable crops like cabbge, Brussels sprout, Broccoli, peppers (Chilli and Sweet pepper), tomato and Carrot.

Seeds of EGMS line can be multiplied in an environment where it expresses male fertility trait, while hybrid seed can be produced in other environment, where it expresses

male sterility trait. Initially EGMS lines were thought to be very less practical value, as they were unstable. But now they are considered to represent most efficient system for hybrid seed production.

3. Cytoplasmic – Genic Male Sterility (CGMS)

This is a case of cytoplasmic male sterility where dominant nuclear gene restores fertility. This system is utilized for the production of hybrids in onion, maize and many other crops. The A line which is male sterile is maintained by crossing it with isogenic B line (Maintainer line). The B line is similar to that of a line in all characters (isogenic) except fertile cytoplasm. The male sterile a line when crossed with R line (restorer) restores fertility in F_1.

The limitations of CGMS lines are:

a. Undesirable effects of the cytoplasm

Male sterile cytoplasm's generally have undesirable side effects. For example, the Texas cytoplasm (CMS-T) in maize is used commercially but it slightly retards growth, yield, plant height and leaf numbers. It also makes the plants highly susceptible to a new race, race T of *Helminthosporium* leaf blight. **b. Unsatisfactory fertility restoration**

In many cases, restoration of fertility in not satisfactory, *e.g.,* CMS-tour in *Juncea*. As a result, these sources cannot be used for hybrid seed production. **c.**

Unsatisfactory pollination

Poor pollination would always be a major problem in self pollinated crop. This reduces the production of hybrid seed, and thereby increases its cost. In Capsicum, this problem has prevented the use of male sterility in hybrid seed production. In rice, this problem is overcome by regular tripping of the ears in the morning, generally using a rope.

d. Spontaneous reversion

Many commercially useful male sterility cytoplasms, e.g., Tifton (A1) cytoplasm of pearl millet, may show a low frequency of spontaneous reversion so that in each generation of the CMS line some pollen shedding plants are present. This is a nuisance in hybrid seed production.

e. Modifying genes

Modifying genes may reduce the effectiveness of cytoplasmic male sterility. During backcrosses, while transferring male sterile cytoplasms, the nuclear genetic background

may disturb to some pollen production by the new male sterile lines. **f. Environmental effects**

Many sterility mechanisms may breakdown partially under certain environmental conditions resulting in some pollen production by the male sterile lines. **g. Non availability of a suitable restorer line**

In crops like wheat, polyploidy nature of the crop and undesirable linkages with the restorer genes make it very difficult to develop a suitable restorer line.

4. Chemical Induced Male Sterility (CIMS)

Chemical hybridizing agent (CHA) are the chemicals that induce male sterility in plants. Potential of certain chemicals (malic hydrazide) to induce selective male sterility was demonstrated during 1950 in Maize.

The chemical which induces male sterility artificially is called as male gametocide. It is rapid method but the sterility is non-heritable. In this system A, B and R lines are not maintained.

Table : 2 A list of chemicals used to produce male sterility in vegetables.

Chemicals	**Crops**
Ethrel	Beet
FW 450	Beet, Tomato
Gibberellic acid (GA_3)	Lettuce, Onion
Maleic hydrazide (MH)	Cucurbits, Onion, Tomato
Naphthalene acetic acid (NAA)	Cucurbits

Application of Cytoplasmic Male Sterility in Plant Breeding

It is applicable in production of hybrids in ornamental crops and vegetatively propagated crops. But in those of crop plants where seed is the economic part, it is of no use because the hybrid progeny would be male sterile.

Example – Onion

Application of Genic Male Sterility in Plant Breeding

It is applicable in production of hybrids in both, vegetative propagated crops and crops important for fruit or seed yield.

Crops	Gene number/condition	Gene	Variety developed
Tomato	Single recessive gene	ps-2	Shalimar Tomato Hybrid-1 Shalimar Tomato Hybrid-2
Chilli	Single recessive gene	ms-12 & ms-3	CH-1, CH-3
Muskmelon	Single recessive gene	ms-1	Punjab Hybrid-1

Application of Cytoplasmic-Genic Male Sterility in Plant Breeding

It is used in commercial production of hybrid seeds in vegetable crops like chilli, onion etc.

Crops	Gene	Commercially utilized	Variety
Chilli	Single recessive gene	ms-2	Arka Meghna Arka Sweta Arka Harita Kashi Surkh
Onion	Single recessive gene	-	Arka Kirtiman Arka Lalima
Carrot	Single recessive gene	-	Pusa Nayanjyoti Pusa Vasuda

Pistillate condition:

In case of monoecious crops like castor, cucurbits, etc., some mutants produce only pistillate flowers in the place of both male and female flowers; this is called as pistillate condition and such a line is known as pistillate line. This line is used for hybrid seed production, *e.g.* castor.

LECTURE – 5 BREEDING METHODS

Introduction:

Various approaches (viz., selection, hybridization, mutation etc.) that are used for genetic improvement of crop plants are referred to as plant breeding methods or plant breeding procedures or plant breeding techniques. The choice of breeding methods mainly depends on the mode of pollination, mode of reproduction, gene action and breeding objective of crop species. Plant breeding methods are generally classified on the basis of application in crop improvement (general methods, special methods and population improvement approaches) and hybridization (methods involving hybridization and methods not involving hybridization).

Various breeding procedures that are more commonly used for genetic improvement of different crop plants are known as general breeding methods. Such breeding methods include introduction, selection (pure line selection, mass selection, progeny selection), hybridization (pedigree, bulk and back cross methods), heterosis breeding, synthetic and composite breeding. On the other hand, *those breeding procedures that are rarely used for improvement of crop plants are referred to as special breeding methods.* Such methods include: mutation breeding, polyploidy breeding, wide crossing or distant hybridization and biotechnology. Four breeding approaches *viz.,* recurrent selection, disruptive mating and selection, diallel selective mating system and biparental mating are used mainly for population improvement. There are some differences in the breeding methods used for self pollinated and cross pollinated species. Self pollinated species are homozygous, hence we can start hybridization directly. Cross pollinated species, on the other hand, are highly heterozygous hence, we can not start hybridization directly. First we have to develop inbred lines by selfing or inbreeding and then only hybridization can be taken up. We have to exploit homozygosity in self pollinated crops and heterozygosity in cross pollinated crops.

Table 1 : Classification of Breeding Methods

Types of methods	Breeding methods included

A.	**Application in crop improvement**	
1.	General Methods	Plant Introduction, Pure line selection, mass selection, progeny selection, pedigree method, bulk method, back cross method, Single Seed Decent method, clonal selection, heterosis breeding, synthetic and composites
2.	Special Methods	Mutation breeding, Polyploidy breeding, Transgenic breeding, Molecular breeding
3.	Population Improvement Approaches	Recurrent selection, Disruptive selection, Diallel Selective Mating system, Bi-parental Mating
B.	**Hybridization**	
1.	Methods involving hybridization	Pedigree methods, Backcross methods and Single Seed Decent Methods, Heterosis breeding and Population Improvement Approaches and Molecular Breeding (Marker Aided Selection)
2.	Methods not involving hybridization	Plant Introduction, Pureline selection, Mass selection, Progeny selection, Clonal selection, mutation breeding and Transgenic breeding

Table 2 : Brief account of Breeding Methods

Sr.No.	Breeding Methods	Self Pollinated Crops	Cross Pollinated Crops	Asexually Propagated Crops
1	Plant Introduction	Yes	Yes	Yes
2	Pureline Selection	Yes	Sometimes	No
3	Mass Selection	Rare	Yes	Rare
4	Progeny Selection	No	Yes	No
5	Pedigree Method	Yes	Yes	No
6	Backcross Method	Yes	Yes	Yes
7	Multiline Variety	Yes	No	No
8	Clonal Selection	No	No	Yes
9	Heterosis Breeding	Yes	Yes	Yes
10	Synthetic Variety	No	Yes	No
11	Composite Variety	No	Yes	No
12	Mutation Breeding	Yes	No	Yes
13	Polyploidy Breeding	No	No	Yes
14	Distant Hybridization	Yes	Yes	Yes
15	Transgenic Breeding	Yes	Yes	Yes
16	Recurrent Selection	No	Yes	No

Some important breeding techniques which are used frequently in crop improvements are discussed below.

Pureline selection:

A pureline is the progeny of a single, homozygous, self pollinated plant. In pure line selection, large numbers of plants are selected from a self-pollinated crop and are harvested individually, individual plant progenies from them are evaluated separately and the best one is released as pure line variety. Therefore it is also known as individual plant selection.

Pedigree method:

The method used for genetic improvement of self - pollinated species in which superior genotype are selected from segregating generations. Method is often used to correct some specific weakness of a released or established variety, it is also known as *combination breeding.* Useful in the selection of new superior recombinant types as transgressive segregants. Commonly used for improving polygenic traits than oligogenic traits. The general procedure with suitable illustration is depicted in Fig.1.

Bulk Method:

Bulk population method of breeding in self–pollinated crop is also known as mass method or population method of breeding. It was first used by Nilsson Ehle in 1908. It refers to a species is grown in bulk plot (from F_1 to F_5) with or without selection, a part of the bulk seed is used to grow the next generation and individual plant selection is practiced in F_6 or later generation. In this method duration of bulking may vary from 6-7 to 30 generation.

Single seed decent (SSD) method:

It is a modification of bulk method. Under this method there is raising of F_2 and later generations from a bulk of one seed from each F_2 and subsequent generation, one random seed is selected from every plant present in the population. Method used in self pollinated crop species for improvement of quantitative traits with low heritability ***i****.e.* yield. The general procedure with suitable illustration is depicted in Fig.2.

Back cross method:

A cross between a hybrid (F_1 or a segregating generation) and one of its parents is known as back cross. In this method the hybrid and the progenies in the subsequent generation are repeatedly backcross to one of the parent. Using back cross method there is possibility to transfer dominant as well as recessive genes from donor to the recurrent parent.

The general procedure with suitable illustrations is depicted in Fig 3 & Fig. 4.

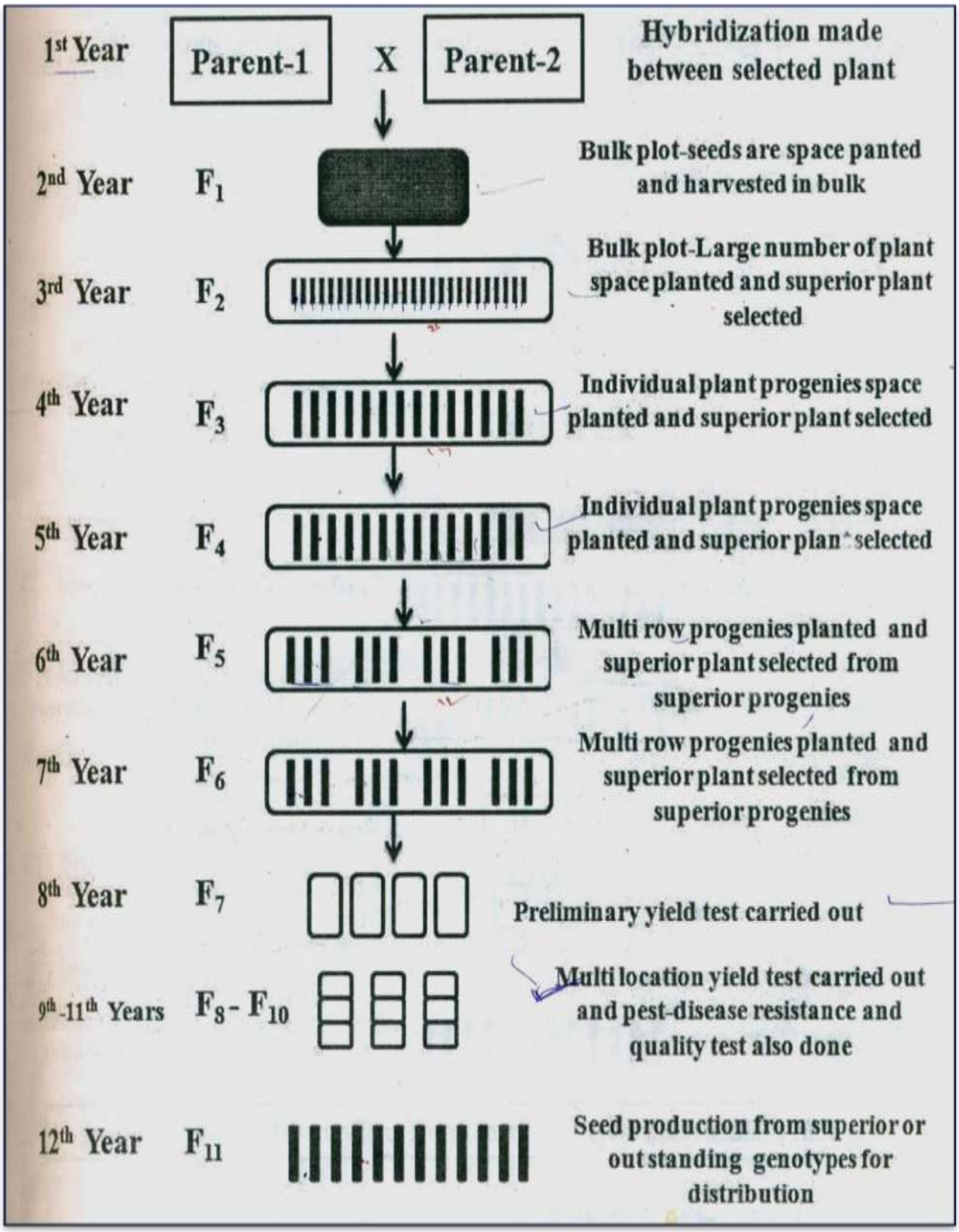

1st Year
Parent-1
X
Parent-2
Hybridization made between selected plant
2nd Year
F1
Bulk plot-seeds are space panted and harvested in bulk
3rd Year
F2
Bulk plot-Large number of plant space planted and superior plant selected
4th Year
F3
Individual plant progenies space planted and superior plant selected
5th Year
F4
Individual plant progenies space planted and superior plan selected
6th Year
F5
Multi row progenies planted and superior plant selected from superior progenies
7th Year
F6
Multi row progenies planted and superior plant selected from superior progenies
8th Year
F7
Preliminary yield test carried out
9th-11th Years
F8 - F10
Multi location yield test carried out and pest-disease resistance and quality test also done
12th Year
F11
Seed production from superior or out standing genotypes for distribution

Fig. 1 Schematic representation of pedigree method of breeding

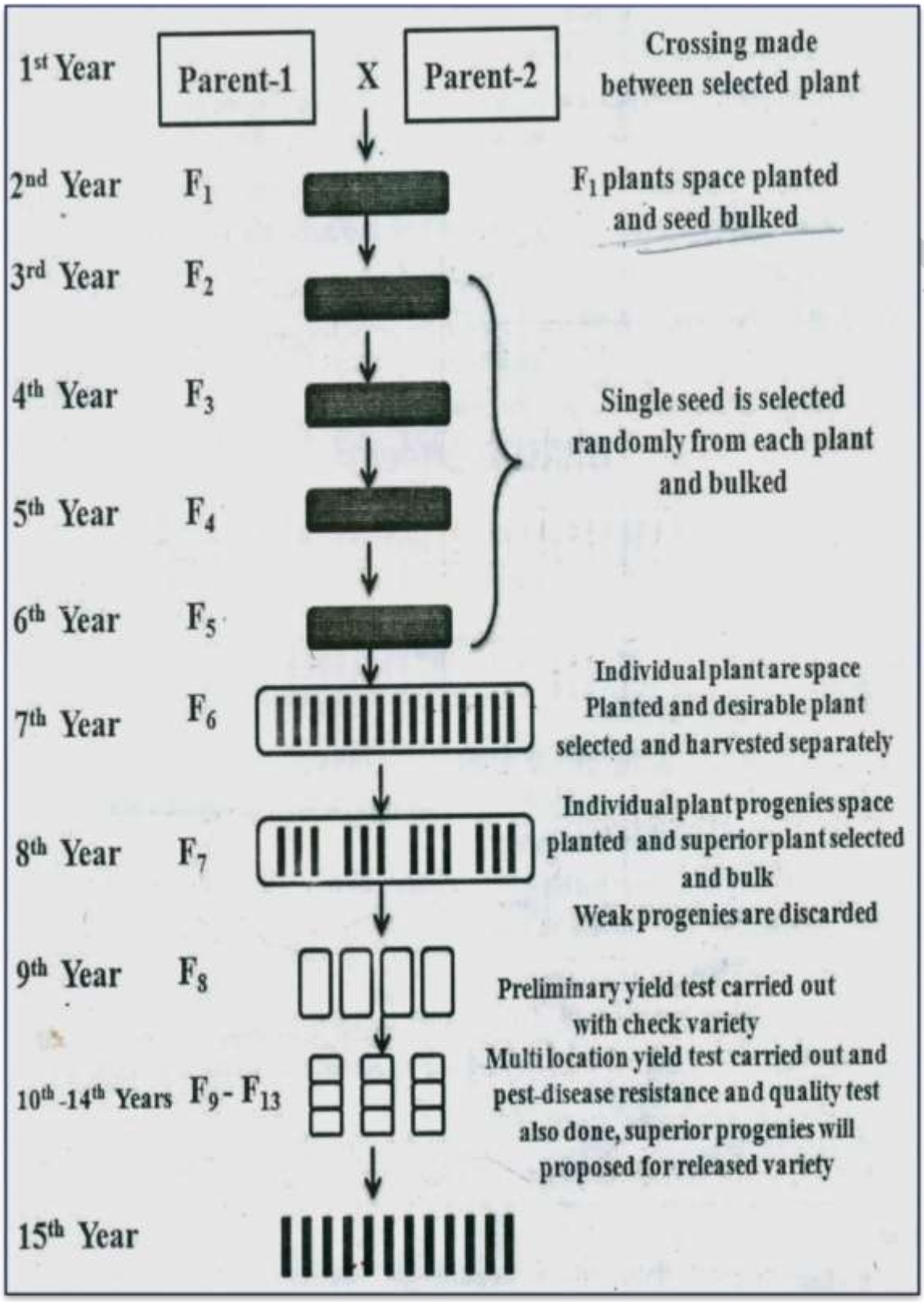


Fig. 2 Schematic representation of SSD method of breeding

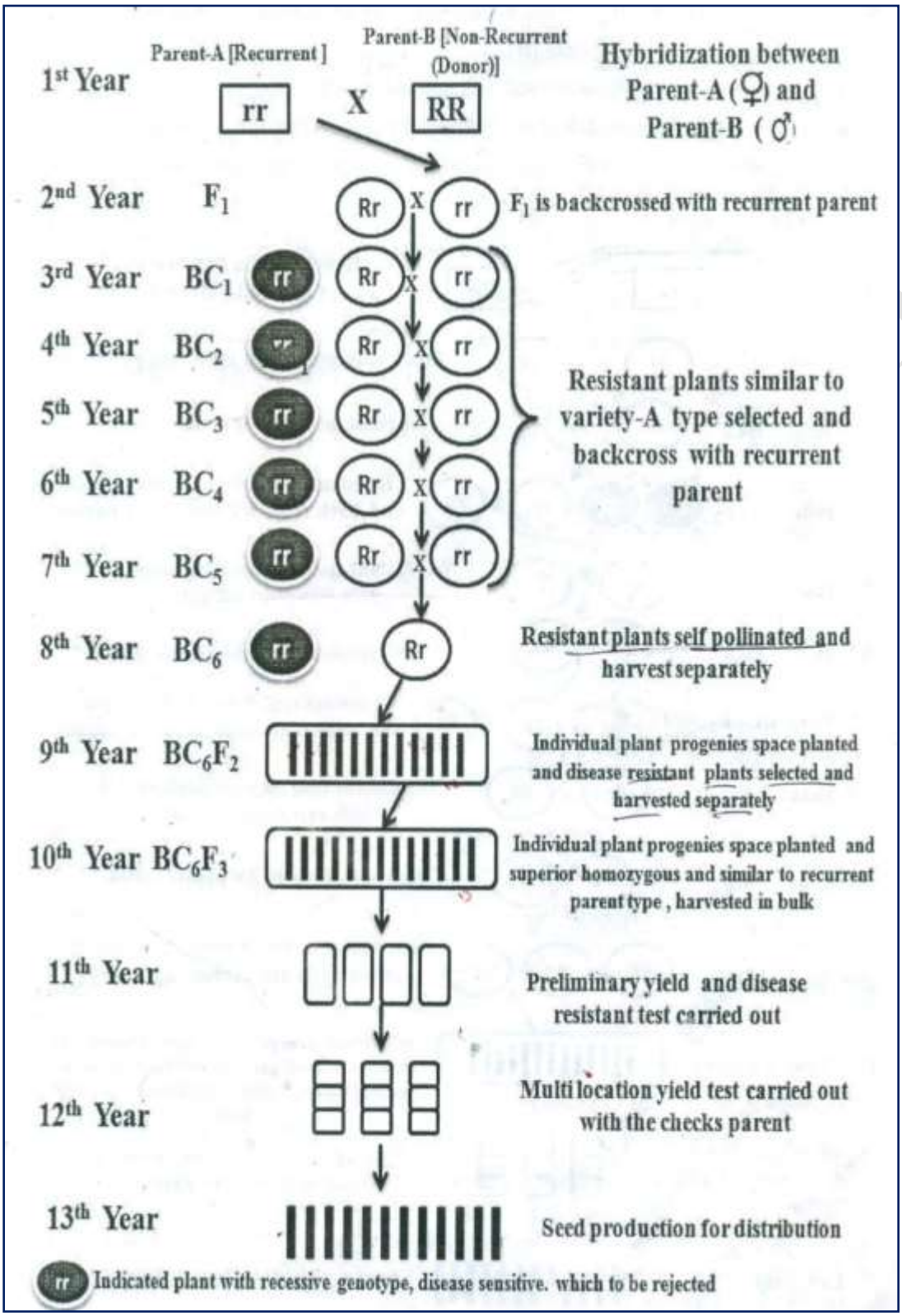


Fig. 3 Schematic representation of Backcross method for dominant gene

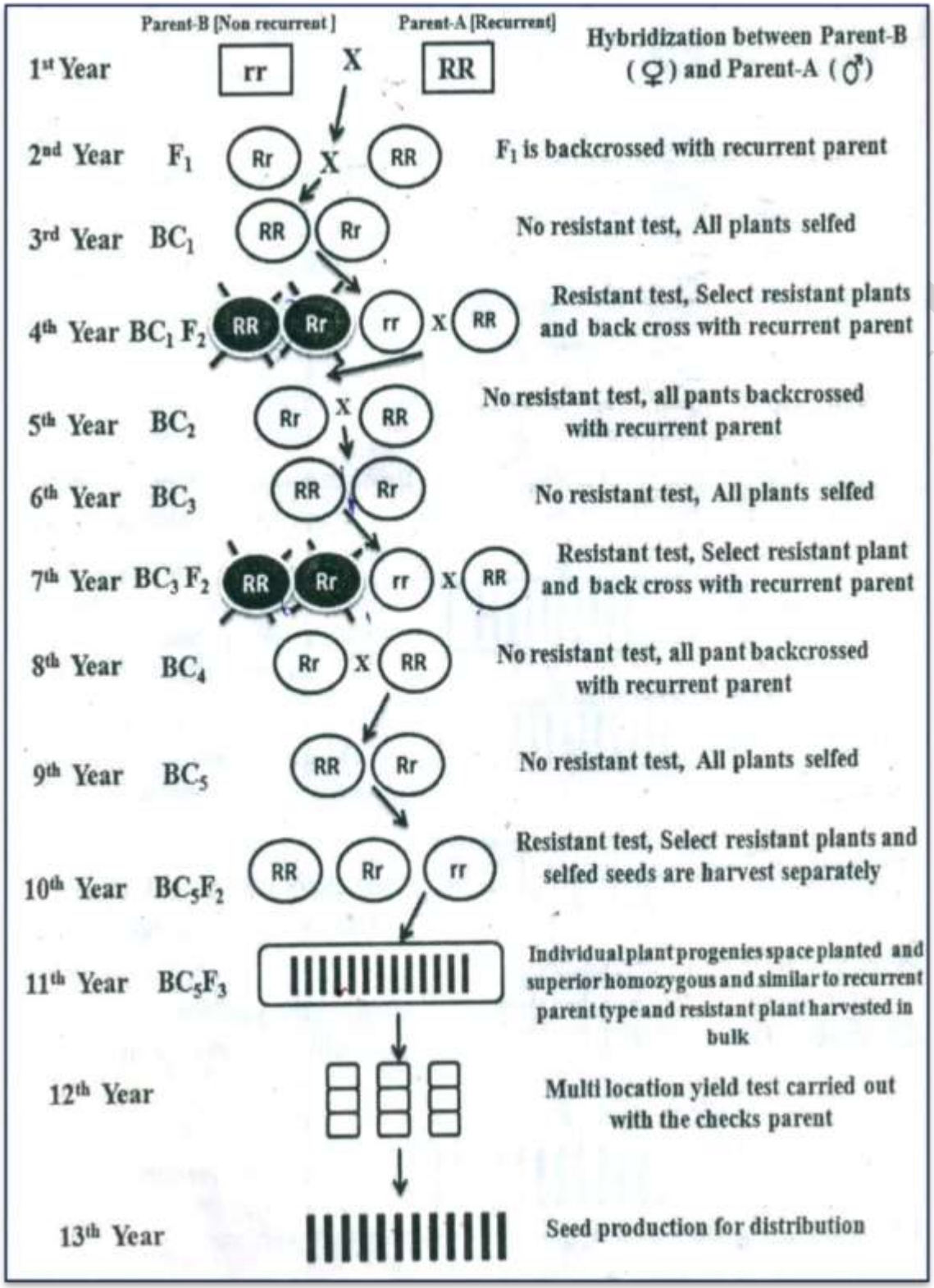


Fig. 4 Schematic representation of Backcross method for recessive gene

CHAPTER – 6 BRINJAL BREEDING

Introduction:

Brinjal (*Solanum melongena* L., 2n=24) belongs to family solanaceae; is one of the most important warm season fruit vegetable which is grown in different parts of the world namely, India, Japan, Indonesia, China, Bulgaria, France, Italy, USA and different countries in Africa. India ranks second in the production of brinjal, next to china. Usually brinjal is a self pollinated crop but due to the presence of heterostyly, a greater extent of cross pollination is observed (48 %) hence brinjal is classified as often cross pollinated crop. A high anthocyanin (for purple colour) content and a low glycoalkaloid (produce bitter taste) is desirable. Discoloration of brinjal due to polyphenol oxidase activity so less polyphenol activity is desirable in processing industry. The first record of eggplant in Europe was in the fifteenth century; the name was probably derived from the white egglike fruits.

Origin and Distribution:

It is probably a native of India. According to De Candolle, eggplant was known in India in ancient times. It is believed that eggplant may have originated in Indo-Burma. China may be the secondary centre of origin. It is distributed in India, Japan, Indonesia, China, Bulgaria, France, Italy, USA and different countries in Africa.

Taxonomy:

It is diploid (2n=2x=24) but polyploids with 2n=36 and 2n=48 were also produced, but they had no significant economic relevance. Genus *Solanum* contains around 2000 species which includes both, tuber bearing and non-tuber bearing species. The non tuber bearing edible species are *viz., S.melongena, S.torvum, S.nigrum, S.macrocarpon, S.ferox and S.Aethiopicum.* The species *S.sisimbrifolium* Lam. is considered the ancestral species of *S.melongena.*

There are four botanical varieties of *S.melongena* characterized by the shape and size and growth habit of plant.

1. *S. melongena* var. *melongena :* Cultivar with round and egg shaped fruit
2. *S. melongena* var. *serpentinum* Desf.*:* Long and slender fruits; called as "Snake Brinjal"
3. *S. melongena* var. *depressum:* Early and dwarf cultivar
4. *S. meongena* var. *insanum:* Wild and prickly plants with small fruits

Botany and Floral biology:

Plant is erect, semi erect or prostrate, herbaceous and branched with around 1.0 m height. Stem may be spiny, Non-spiny with or without purple pigmentation which is due to anthocyanin. Flowers are bisexual, complete, actinomorphus, solitary or 2-7 flowered cymes. Calyx is five lobbed, gamopetalous, persistent and may be spiny or non-spiny. Corolla is five lobbed, gamopetalous with margin of lobes incurved. It has different shapes and colors ranging from purple to light pink and white. Stamens are five which are free and inserted at the throat of corolla. Anthers are cone shaped, free and with apical dehiscence. Ovary is hypogynous, bicarpellary and syncarpous with basal placentation. Fruit is a berry with wide variation is size, shape and colour. Fruit shape may be long, round, oviod, cylindrical or elongated. Colour of fruit may be green, white, different shades of purple, nearly black and variegated.

Flower emerges 40-45 days after transplanting. Anthesis and dehiscence in brinjal are mainly influenced by daylight, temp and humidity. Usually anthesis starts from 6 to 7:30 am and continues up to 11 am. Peak time for anthesis 8:30 to 10:30 am. Anther dehiscence starts from 9:30 to 10:00 am. Stigma receptivity is highest during anthesis. Anther usually dehisces 15 to 20 minutes after flowers have opened. Stigma receptivity could be observed from the plump and sticky appearance which gradually turns brown with loss of receptivity. Pollen remains viable for a day in summer and for 2-3 days in winter under field condition and stigma remains receptive for 6-8 days.

Brinjal is having heteromorphic flower structure called as heterostyly. Four types of flowers are observed in brinjal depending on length of style in relation to position of anthers.

1. ***Long styled :*** stigma above the anthers
2. ***Medium styled:*** stigma and style at same level
3. ***Short styled:*** style is short
4. ***Pseudo short styled:*** style is rudimentary

Fruit setting takes place only in long styles and medium styled flowers. Fruit setting in long styled flowers ranges from 70-85% and in medium styled flowers it ranges from 12-55%. The short and pseudo styled flowers will not set fruits. Androecium is fertile in them, but stigma is smaller with underdeveloped papillae. Hence, they may act as male flowers.

Genetic resources:

Solanum is very large genus. Among the 22 Indian species, there is a group of 5 related ones. All are prickly and diploid with 2n = 24, which are:

1. *Solanum melongena*
2. *Solanum coagulans*
3. *Solanum xanthocarpum*
4. *Solanum maccanii*
5. *Solanum indicum*

Some species are giving resistance against biotic stresses also. The species are as under:

- *Solanum melongena* var. *insanum*- Bacterial wilt resistant
- *S. xanthocarpum*- Fruit rot resistant
- *S. nigrum*- Spotted beetle, Epilanchna resistance
- *S. indicum*- wilt resistance
- *S. sisymbrifolium* – Root knot nematode resistance **Male sterility:**

Male sterility can be used for the production of hybrid seeds. Functional male sterility is controlled by a single recessive gene. Popova and Daskalov attempted to utilize functional male sterile lines originating from Canada. Male sterility was induced by spraying the flower buds with 10 p.p.m. 2,4-dichlorophenoxyacetic acid (2,4-D) without causing female sterility, and hybrid seed was obtained by hand pollination. Hybrid seed can be produced without prior emasculation of the flower. Pollination at bud coloration stage gave up to 97% hybrid seed even without emasculation. Some excreted lines such as 202-9, 120b, BR 112 and PBR 91-2 are available in eggplant and can be used for the production of hybrids.

Functional male sterile lines have been identified in some cultivars, but not yet been done in commercial hybrid seed production. Only 2-4% chance self's are expected which can be avoided by using markers especially purple plant colour in pollen parent. For commercial hybrid seed production, the ratio of seed parent to pollen parent should be 5:1 in the field. **Breeding objectives:**

- High yield
- Earliness
- Erect and self staked plant habit
- Less branching nature
- Uniform fruit size, shape and colour as per consumers' preference
- Thick and soft flesh

- Low proportion of seed
- Resistance to major disease and pest like bacterial wilt, fusarium wilt, shoot and fruit borer, jassid and root knot nematodes **Breeding methods:**

1. Introduction:

There is no introduced cultivar in Brinjal except some breeding materials.

2. Pureline selection:

The varieties developed under this methods are *e.g.,* Pusa purple long, Pusa purple round, Pusa purple cluster, Arka Kusumkar, Arka Sheel etc.

3. Pedigree method:

Many varieties have been developed through hybridization and subsequent pedigree selection. *e.g.* Pusa Kranti, Pusa Anupam, Punjab barsati, Pusa sadabahar, Pusa uttam, Pusa Upkar etc.

4. Heterosis breeding:

Bailey and Munson (1891) first reported artificial hybridization in Brinjal. First positive report on heterosis was given by **Halsted (1901).** Hybrid vigour in Japanese varieties was observed by **Nagai and Kida (1926).** First attempt was made to hybridize eggplant in India by **Rao (1934). Popova *et al* (1976)** reported use of male sterility for hybrid seed production in brinjal. **Salehuzzaman and Joardes (1978)** noticed that high yielding hybrids can be obtained by crossing high yielding parents in brinjal.

Many F_1 hybrids have been developed and released for commercial cultivation. *e.g.* Arka Navneet, Kashi Ganesh, Pus Hybrid – 5, Pant Brinjal Hybrid, Pusa Hybrid – 6, Anand Brinjal – 1, BH-1, BH-2, Narendra Hybrid Brinjal – 1, Swarna Ajay, Narendra Hybrid Brinjal – 3, Kashi Sandesh *etc.* The other methods like backcrossing, mutation breeding and biotechnology are used for improvement of brinjal crop but it has some limited applications.

Breeding for Quality, Processing and Physiological Traits

The quality of eggplant fruit mainly depends upon its physical appearance. Generally colour and shape are important. Anthocyanin controls the colour of fruits. Flavour quality is linked with the presence of glycoalkaloids with the solasonine structure which are concentrated in the placental pulp, and saponin which occurs mainly in the seeds and pulp. Saponin content was higher with lengthened harvesting period. Frequent

harvesting produced better-quality fruits. Screening should be done at biological ripeness or before, and the seed or seed vessel should be tested in order to develop varieties with low solanin content.

***Bt* Brinjal:**

Bt means *Bacillus thuringiensis* is a soil borne bacteria and it contains cry protein. In the insect gut, the protein breaks down to release a protein, known as Ddeltaednotoxin. It creates pore in intestinal lining, resulting in ion imbalance, paralysis of the digestive system and after few days insect death. Different versions of the Cry genes, also known as Bt genes have been identified. In *Bt* Brinjal – Cry 1A(c) gene is inserted through *Agrobacterium mediated vector and it gives resistance against* Lepidoptera insects like fruit and shoot borer. Transformation work was started in year 2000 and backcrossing programme was in 2002. In India, *Bt* Brinjal hybrid developed by MAHYCO, TNAU, Coimbatore and UAS, Dharwad.

Important Varieties released in India:

Sr.No.	Developing Institute	Name of Variety
1	**IIHR, Banglore**	Arka Kusumkar, Arka Sheel, Arka Nidhi, Arka Shirish, Arka NeelKanth, Arka Keshav
2	**IARI, New Delhi**	Pusa Kranti, Pusa purple cluster, Pusa Purple Long, Pusa Anupam, Pusa Purple Round, Pusa Bairav, Pusa Uttam, Pusa Upkar, Pusa Bindu, Pusa Ankur, Pusa Shyamla
3	**KAU, Thrissur**	Surya, Swetha, Haritha
4	**TNAU, Coimbatore**	CO 1, CO 2, PKM 1, PLR 1, MDU 1, KKM 1
5	**Annamalai Uni, Tamil Nadu**	Annamalai
6	**GBPUA&T Pantnagar**	Pant Rituraj, Pant Samrat

Important Varieties and Hybrids from Gujarat:

	JAU, Junagadh		
1.	Junagadh Brinjal Green Round 1 (JBGR 1)	**2.**	Gujarat Junagadh Brinjal 2 (GJB 2)
3.	Gujarat Junagadh Brinjal 3 (GJB 3)	**4.**	Gujarat Junagadh Long Brinjal 4 (GJLB 4)

5.	Gujarat Round Brinjal 5 (GRB 5)	**6.**	Gujarat JunagadhBrinjal Hybrid 4 (GJBH 4)
	AAU, Anand		
1.	ABH-1	**2.**	GOB-1
3.	GABH-3		
	NAU, Navsari		
1.	GNRB – 1		

Varieties with its specific characters:

- **Long purple: -** Pusa Purple Long, Pusa Purple, Cluster, Pusa Kranti, KT-4, DBSR-31, Arka Sheel, Azad Kranti, ARV-1, S-16, Punjab barsati, Punjab Sadabahar, Pant Samrat, NDB-25, BB-26, JB-15, Pant Hybrid-1, MHB-1, Pusa Bhairav
- **Long green: -** Arka kusumakar, Arka shirish, Krishnanagar green long
- **Round purple: -** PB-91-2, T-3, K-202-9, H-8, KS- 224, DBR-8, AB-1, Pusa Hybrid-6, Vijay Hybrid, NDBH-1, JVH-1, Round 14, Azad Hybrid, Pusa purple round, Black beauty, Jamuni gola, Krishnanagar purple round, Pant Rituraj, Surti gota, T-3
- **Round green: -** Banaras giant, Ramnagar giant
- **Small round: -** Aruna, DBSR-44, PLR-1, DBSR-91, Phule Hybrid-2
- **Oval or Oblong purple: -** Arka Navneet, H-4, Pusa Anmol, Suphal (F_1 Hybrid)
- **Round with strips (purple white) : -** Manjari, Manjari Gota
- **Round white : -** Swarna shree

CHAPTER – 7 TOMATO BREEDING

Introduction

Tomato, *Solanum lycopersicum* L. (*2n = 2x* = 24), is one of the most important vegetable crops of Solanaceae grown all over the world. The tomato is a native of South America and Mexico, and the domestication of tomato took place in Mexico. It is rich source of vitamin C and adds a variety of colours and flavours to the food. Tomato is one of the most popular protective foods because of its high lycopene content. Name tomato was derived from word "Tomatl" (the swelling fruit). Commonly it is known by different names *viz.,* Amorous apple or love apple in Europe, Golden apple, Poor's man orange. It is

day neutral plant and self pollinated and cultivated mostly in tropical and subtropical climate, so it is also called as warm season crop. Tomato was thought to be poison but a farmer in USA named Robert Gibbon Johanson tasted it first time and then it spread throughout the world. **Origin and Distribution**

Tomato is a native of Peru in South America. The crop spread to North America primarily by migrating birds. The largest collections of wild tomatoes are seen in Mexico.

Taxonomy

Taxonomic classification of tomato is still debated. In 1753, the Swedish Botanist Linnaeus named it as *Solanum lycopersicon.* After fifteen years in 1768, Philip Miller named it as *Lycopersicon esculentum*. Today, based on evidence from phylogenetic studies using DNA sequences and in-depth studies of plant morphology and distribution tomato is included in the genus *Solanum* by both taxonomists and breeders.

Botany and Floral biology

The tomato plant, though perennial by nature, is most universally cultivated as annual and it produce taproot. Stem is soft, brittle and hairy the initial stage but turn hard and woody at maturity stage. The number of flowers per cluster varies from three to several. The flowers are actinomorphic, yellow and bisexual in nature.

Anther dehiscence occurs 1-2 days after opening of flower. Dehiscence occurs from base to top and is longitudinal. It is mainly self pollinated due to chasmogamy but certain percentage of cross pollination also occurs when the stigma protrudes outside the level of anther. If the pollen is shed as the style grows up through the anther tube, self pollination is the rule. Self pollination takes place when the style is short and the stigma is not extroverted beyond connivent anther.

Flower anthesis time is 6:30 to 11:00 AM while anther dehiscence time upto two days after anthesis. Hand emasculation and pollination are used for development of hybrids. Emasculation should be done in the evening 4 to 6 pm (*i.e.,* one day before the anther should dehisce). One flower can pollinate 5 to 7 emasculated flower at the time of hybridization. An ideal night temperature for fruit setting is 15-20 °C and optimum day temperature for fruit setting 21 to 24 °C. If the temperature is below 10°C, there is no colour formation in the fruit. An ideal temp for red and yellow colour is 18- 25°C for tomato fruit.

Tomato can be classified into three groups *viz.,* determinate, semi-determinate and indeterminate based on growth habit.

Table 1 : Difference between determinate and indeterminate tomatoes

Sr.No.	Determinate tomatoes	Sr.No.	Indeterminate tomatoes
1	Limited height	**1**	Continuous growth habit
2	No requirement of stacking	**2**	Requirement of stacking
3	Crop duration 4-5 months	**3**	Crop duration is around 10 months
4	Less yield than indeterminate type	**4**	More yield than determinate type

Important related species:

1. *Solanum pimpinellifolium*

The plant is annual, week, slender, profusely branched and flowers in cluster. Fruits are too small. It is a source of resistance to *fusarium wilt, bacterial wilt,* and *early blight*. Some accessions are tolerant to *TMV*. It is suited to low temperature conditions. It is also a good source of high ascorbic acid and carotenoid.

2. *Solanum peruvianum*

The plant is perennial bearing bright yellow flowers in cluster with excreted stigma. Fruits are small, greenish-white and purplish at ripening. It is a source of resistance to *Verticillum wilt* and leaf curl virus.

3. *Solanum glandulosum*

The fruits are small and greenish and the seeds are hairy.

4. *Solanum hirsutum*

The plants are perennial with light green colour foliage. Fruits are greenish, small with irregular streaks and sweetish to bitter in taste. It is immune to leaf-mould and it is resistant to fruit borer, *Fusarium wilt*, and mosaic. Some accessions are self-incompatible. It is good source of carotenoid content.

5. *Solanum cheesmanii*

The plants are perennial and fruits are globose. The β-carotene synthesizing gene is present in this species. It is used as a source for developing salt resistant variety.

6. *Solanum pissisi*

The plants are perennial with less foliage and purple to dark green stem. Its fruit are greenish, non-bitter and globular.

7. *Solanum pennelli*

Some accessions are self incompatible. It is drought tolerant.

8. *Solanum minutum*

The plants have long epidermal hair, inflorescence is bracteate and fruits are green.

9. *Solanum parviflorum*

The plant is branched, perennial with slender stem. The leaves are broad. The fruit is globose and whitish green.

10. *Solanum chimelewskii*

Fruits are yellowish green.

Table : 1 The species of the genus *Lycopersicon*

Species	Common Name	Chromosome Number	Reproductive features
L. esculentum	Common tomato	24	SP
L. pimpinellifolium	Currant tomato	24	SP + CP
L. cheesmanii	Wild	24	SP
L. parviflorum	Wild	24	SP
L. chemielewskii	Wild	24	CP
L. Pennellii	Wild	24	SI
L. hirsutum	Wild	24	SF, SI
L. chilense	Wild	24	SI
L. peruvianum	Wild	24	SI

Forms of tomato

1) Pear tomato

It is the common name for any one in a group of indeterminate heirloom tomatoes. It originated in Europe in the 18th century. There are yellow, orange, and red varieties of this tomato; the yellow variety being most common. They are generally sweet, and are in the shape of a pear, but smaller. They are heirlooms and have 3 common other names, such as the “Red/ Orange/ Yellow” Pear Tomato Plants.

2) Cherry tomato

It is a rounded, small fruited tomato believed to be an intermediate genetic admixture between wild currant-type tomatoes and domesticated garden tomatoes. Cherry tomatoes range in size from a thumb tip up to the size of a golf ball, and can range from being spherical to slightly oblong in shape. Usually red, other varieties such as yellow, green, and black also exist.

3) Upright Tomato

Any of various stout erect compact tomatoes with the leaves crowded and curled that probably have developed in cultivation and are usually considered a distinct variety (*Lycopersicon esculentum validum*).

The major types of tomatoes which serve as common breeding targets are

1. Fresh market tomatoes

These are meant for fresh consumption and have unique characteristics which greatly depend upon the traditional consumer experience in the locality.

2. Processing tomatoes

These are mainly grown for turning into several major products, such as, tomato paste, ketchup, juice, sauce, puree, canning etc., each requiring special desirable features.

3. Green house tomatoes

This is a special category because tomato cultivars are bred suiting to the conditions inside the greenhouse. Generally, indeterminate cultivars suit for greenhouse production which is productive for several months, medium to large-fruited, relatively uniform in size within the individual clusters**.**

4. Home-garden tomatoes

This is another special type in which the cultivars are developed to suit the fancy of consumers who prefer to grow their own tomatoes in their backyards. **Breeding objectives**

- Earliness
- Increased fruit yield
- Fruit quality (Table purpose- Colour, texture, firmness, flavour; processing quality- Colour, pH, titrable acidity, TSS, viscosity)
- Indeterminate cultivars for green house cultivation
- Resistant to disease (wilt, tospo virus, TLCV, blight, anthracnose, mosaic, root knot nematode)
- Resistant to insect (Fruit borer, white fly, leaf minor)
- Abiotic stress resistant(cold, hot, drought, salt, chilling injury, herbicide tolerance)

Male Sterility

Male sterility was identified by Rick (1944) in tomato. Various types of male sterility are observed in tomato *viz.,* GMS, CGMS, TGMS and PGMS etc.

GMS in Tomato

More than 55 male sterile alleles were reported in tomato. The ms gene *ms-10* is linked with recessive marker gene (a) responsible for absence of anthocyanin. Hence, *ms10*

sterile plant can be identified at seedling stage and fertile plant can be rouged out in the nursery itself.

CGMS in Tomato

Recently, sterile cytoplasm from *S. peruvianum* has been transferred into *S. pennelli* in tomato. *S. pennelli* crossed with *S. esculentum* successfully in tomato. This hybrid provides the basis for the development of CGMS system.

TGMS in tomato

The effect of temperature on male sterility has been examined in the variable male sterile (*vms*) mutant of tomato, *vms* plants exposed to temperature of 30°C and above are male sterile but these are normal when grown in greenhouse.

PGMS in tomato

A change in photoperiod can have a strong influence on expression of male sterility. In tomato, a photoperiod sensitive male sterile mutant 7B-1 is completely male sterile in summer field condition in Saskatoon. However, at a day length 8-10 hours, 7B-1 plants produce many flowers with normal anthers that contain normal and viable pollen.

Breeding methods

1. **Introduction:** Sioux, Marglobe, Best of all, Roma, Keckruth Agethi, La Bonita (all from America), Marvel, Money Maker
2. **Pureline Selection:** Pusa 120 (from Anahu lines), Arka Vikas (from Tip-Top American Variety, Arka Saurabh (U65- Canadian Variety)
3. **Single Seed Descent Method:** Shakti from North Carolina line
4. **Mass selection :** Used for purification
5. **Pedigree Method:** Pusa Ruby (Improved Meeruti x Sioux), Pusa Early dwarf (Improved Meeruti x Red cloud), Hisar Arun (Pusa early dwarf x K2), Punjan Chhuhara (Punjab Tropic x EC 55055), Pusa Sheetal (Balkan x Jemnorrosniej), Pusa Gaurav (Glamour x Watch)
6. **Mutation Breeding :** S – 12 (From sioux), Pusa lal meeruti (from Improved Meeruti), Marutham (from Co-1), PKM -1 (from Anjali)
7. **Heterosis Breeding**

   Heterosis in vegetables was first noticed in tomato in USA during 1908. However, it took nearly twenty seven years to release the first commercial F_1 hybrid in vegetables, which was in cucumber in Japan. First hybrid was developed in India namely “Karnataka” in 1973 by Indo-American Hybrid Seeds Co., Bangalore.

Breeding for diseases resistance

Tomato is one of the important vegetable crops grown in India. Among biotic factors, diseases like Tomato Leaf Curl Virus (ToLCV), Bacterial wilt (BW) and early blight (EB) cause yield loss up to 70-100 per cent if uncontrolled. The Indian Institute of Horticultural Research, Bangalore under the leadership of Dr A. T. Sadashiva, Tomato breeder developed first time in India the triple disease resistance tomato hybrid Arka Rakshak, resistant to Tomato Leaf Curl Virus (ToLCV) + Bacterial wilt (BW) + early blight (EB) during 2010. Another tomato hybrid, Arka Abhed giving resistance against Tomato Leaf Curl Disease (*Ty2+Ty3*), Bacterial wilt, Early blight and Late blight (*Ph2+ Ph3*). Arka Apeksha is a high yielding hybrid developed by IIHR has triple disease resistance to Tomato Leaf Curl Disease (Ty1+Ty2), Bacterial wilt and Early blight.

Advances in Biotechnology

Tomato was the first food crop for which transgenic fruits were commercially available. The first transgenic '***Flavr Savr***' was released in 1994. Its advantages were delayed softening, and has got resistance against virus and pest. It was later withdrawn from market in 1997 due to controversies.

Quality improvement

IIHR Bangalore scientists have developed a purple coloured genetically engineered tomato which contains two genes from the flowers of snapdragon plant. The fruits are rich in anti-oxidents and may protect people from a host of diseases including cancer and heart ailments. The level of anthocyanin as well as purple colour has gone up by 70-100% in transformed fruits. IIHR, Bangalore developed two hybrids viz., Arka Vishesh and Arka Apeksha for processing industries which contain higher total soluble solids (TSS) & lycopene content.

Important Varieties

Sr.No.	Institute	Variety
1	IARI, New Delhi	Pusa Ruby, Pusa Early Dwarf, Pusa Gaurav, Pusa Sadabahar, Pusa Sheethal, Pusa Uphar, Pusa 120
2	HAU, Hisar	HS 101, HS 102, HS 110, Hisar Anmol, Hisar Arun, Hisar Gaurav, Hisar Lalima, Hisar Lalit
3	PAU, Ludhiana	Punjab Chhuhara, Punjab Kesari, Punjab Tropic, Sel 1-6-1-4

4	GBPUA&T, Pantnagar	Pant Bahar, Pant T1, Pant T3
5	NDAU, Faizabad	Narendra Tomato 1, Narendra Tomato 2
6	IIHR, Hessarghatta	Arka Vikas, Arka Ashish,Arka Saurabh, Arka Ahuti, Arka Abha, Arka Alok, Arka Meghali, Arka Vardhan
7	TNAU, Coimbatore	CO 1, CO2, CO 3 (Maruthum), PKM 1, Paiyur 1
8	KAU	Sakthi, Mukthi, Anagha, Vellayani Vijay
9	HARP, Ranchi	Swarna Naveen, Swarna Lalima
10	IIVR, Varanasi	Kashi Amrit
11	OUAT, Bhubaneshwar	Utkal Kumari
12	JNKV, Jabalpur	Jawahar Tamatar 99

Important Hybrids

Sr.No.	Institute	Variety
1	IARI, New Delhi	Pusa Divya, Pusa Hybrid – 1, Pusa Hybrid – 2, Pusa Hybrid – 4, Pusa Hybrid - 8
2	IIHR, Hessarghatta	Arka Vishal, Arka Abhijit, Arka Shreshtha, Arka Ananya
3	HARP, Ranchi	Swarna Baibhav
4	TNAU, Coimbatore	COTH – 1, COLCRH – 3
5	IIVR, Varanasi	Kashi Hybrid – 1, Kashi Hybrid - 2

Varieties/Hybrids developed by SAU's of Gujarat:

	JAU, Junagadh		
1.	Junagadh Tomato – 3	**2.**	Gujarat Tomato – 6
	AAU, Anand		
1.	GAT-1	**2.**	GAT-5

3.	Anand Tomato - 3	**4.**	GT-2
	NAU, Navsari		
1.	GT - 7		

CHAPTER – 8 CHILLI BREEDING

Introduction

Chilli (*Capsicum* spp., 2n = 24) belongs to solanaceae family, is an important commercial spice and vegetable crop for small and marginal farmers in Asia, Africa and South America. Being a warm season crop it is cultivated throughout the world in tropical and sub tropical climates. Among the five cultivated species of genus Capsicum, *C. annum* is the most widely cultivated in India for its pungent (chilli *syn.* Hot pepper) and non-pungent (sweet pepper syn. Capsicum, bell pepper) fruits. The cultivation of *C. frutescens, C. chinense,* and *C. baccatum* is limited and usually restricted to homestead gardening in different regions. In Australia, New Zealand and India, mild pungent species is called as Capsicums and hot pungent species is called as Chilli/Chillies. In united kingdom and Ireland, heatless varieties are called as peppers (Green or red peppers) while hot one are called as chilli/chillies or chilli peppers. In India, the term *Capsicum* is often used for the fruits of bell pepper. Capsicin is responsible for pungency and Capsanthin is responsible for red colour pigment in chilli.

Pepper (chilli and sweet) market types prevalent in India can broadly be grouped into four categories : (i) fresh market (green, red, multi-colour whole fruits), (ii) fresh processing (sauce, paste, canning, pickling), (iii) dried spice (whole fruits and powder) and (iv) industrial extracts (paprika, oleoresin, capsaicinoids and carotenoids). Chillies are also called as pungent pepper grown all over the world except in colder climates.

Bell peppers are constituents of many foods, add flavor, colour, vitamin C and pungency. Fresh green capsicum contains more vitamin C than citrus fruits and fresh red chilli has more vitamin A than carrot (Than *et al.* 2008). Chillies are low in sodium and cholesterol free. Chillies have some medicinal properties are *viz.,* stimulate blood circulation, improves the digestion process, rich source of anti-oxidants and source of natural bactericidal agents. Apart from some medicinal uses it is used in cosmetic, liquor and industries and as a weapon for self defense (chilli spray) also.

Green chilli, Chilli pepper, cayenne pepper, tabasco, paprika, sweet/bell pepper, pimentos, serrano pepper, are all derived from the fruit of different species of *capsium*. It contains Oleoresin content which is important for processed food as well as for export purpose. Hot chilli commercially grown in countries like India, China, Korea, Indonesia, Pakistan, Sri-

Lanka, Turkey, Japan, Mexico, Ethiopia, Nigeria, Uganda, Yugoslavia, Hungry, Italy, Spain and Bulgaria. India is the leading country in the world with respect to growing area and production.

China is the world's largest producer with more than 33% of the total production area and nearly 50% of total world production. In India, it is grown in states namely, Andhra Pradesh, Maharashtra, Karnataka, Tamil Nadu, Gujarat, and Punjab in which Andhra Pradesh and Punjab ranks top in average yield. The average productivity of chilli in India is around 1 ton/ha while USA, Korea, and Japan produced 3-4 ton/ha. Main reason for low yield in India is (i) Low coverage of high yielding varieties/hybrids (ii) heavy incidence of pests and diseases and (iii) lack of adoption of scientific package of practices in cultivation.

Origin and distribution

The native of chilli is Tropical America (South America). In India it is introduced by Portuguese in 17th century through Goa. Mainly it is distributed and cultivated in Brazil, Mexico, Spain, South and Central America, China and India.

Taxonomy

Capsicum species are diploids, with most having 24 chromosomes ($n = x = 12$), but with several wild species having 26 chromosomes ($n = x = 13$). Polyploidy with 2n = 36, 48 and aneuploids with 2n = 25 have been reported in chilli. Five major cultivated species in the genus *Capsicum* are *viz., Capsicum annum, C. frutescens, C. chinense, C. baccatum* and *C. pubescens*.

Table 1 : Cultivated species of genus *Capsicum*.

Sr.No.	Species	Synonymous	Place of origin	Characteristics
1	*C. annum* (Annual)	*C.purpureum, C. grossum, C. cerasiformae*	Mexico/Central America	• Milky and white large corolla • Single flower at each node • Presence of calyx teeth • Yellow and smooth seed • Medium to large size fruits • Medium pungent
2	*C. chinense*	*C. luteum, C. umbilicatum, C. sinense*	Amazonia	• Dull white corolla • Two or more flowers at each node

				• Devoid calyx teeth • Constriction between the base of calyx and pedicel • Yellow and smooth seeds
3	*C. frutescens* (Perennial)	*C. minimum*	Amazonia	• Greenish white corolla • Two or more flowers at each node • Devoid calyx teeth • No constriction between the base of calyx and pedicel • Yellow and smooth seeds • Small fruit size • Highly pungent
4	*C. baccatum*	*C. pendulum, C. microcarpum, C.angulosum*	Peru and Bolivia	• Cream to white colour corolla with yellow to green spot on each corolla lobe • One or more flowers at each node • Presence of calyx teeth • Yellow and smooth seeds
5	*C. pubescens*	*C. eximum, C. tovari, C. cardenasii*	Peru and Bolivia	• Deep purple to faintly violate corolla with white centre • One and more flowers in each node • Presence of calyx with small teeth • Black to brown and rough seeds

Chilli type based on fruit characters are as under:

(i) *C. annum* var. *acuminatum* (Nepal pepper) : Fruits are long, thin, pendulous and pungent

(ii) *C. annum* var. *longum* (Long chilli) : the fruits are long and stout with a very broad base

(iii) *C. annum* var. *grossum* (Big chilli, sweet pepper, bell pepper) : Fruits are large and bell shaped, turn bright red on ripening, little pungent, used as vegetables

(iv) *C. annum* var. *ceraciferma* : Very small chilli fruits, round and slightly pungent

(v) *C. frutescens* var. *minima* : bird pepper with white and long pedicel, fruits are small and it is highly pungent

Botany and floral biology

Flowers are borne in ones, twos or rarely in clusters at the apex of the main shoot as well as on the axils of the lateral branches. The flowers are bisexual which contains five to six stamens. Anthers are short, elliptic in shape and yellow or violet blue in colour. Up to 100 flowers develop in the plant during the growing season. Morphologically the fruit type is berry.

Both self and cross pollination occur in chilli. The extend of cross pollination is 7.00 to 36.00 % by bees, ants and thrips. Pollination is also aided by gravitational force. Cross pollination mainly due to heterostyly and protogyny. Flowers open by 4 am and continue up to 1 pm with a peak at 6-8 am. Anthesis in chilli occurs between 6.00 to 9.00 hrs. Flower remains open for 2 to 3 days. Receptivity of stigma is the highest at the day of flower anthesis. The percentage of fruit set is 5-35%.

Male sterility

Male sterility in *C. annuum* L. was first reported by Martin and Grawford (1951) and later on by Petersosn (1958). Around 20 genes are reported for male sterility. Shifriss and Frankel (1969) reported first male sterile gene – *ms1* – spontaneous stable male sterile mutant from *C. annuum* cv. All Big. Second male sterile gene – *ms2* - spontaneous stable male sterile mutant from cv. California wonder (Shifriss and Rylski, 1972). Daskalov (1973b) identified five male sterile genes – *ms-3, ms-4, ms-6, ms-7 and ms-8.* These seven genes are monogenic in nature. Pochard identified another three genes – *ms-9, ms-10 and ms-11* and Shifriss (1973) identified *ms-12 from C. annuum* cv. Gambo. Meshram and Narkhede (1982) identified *ms - 13* from *C. annuum* cv. Ca452. Pathak *et al*. (1983) isolated *ms* gene from cv. Kalyanpur selection and prove that it was governed by single recessive gene *ms-14.* Deshpande *et al* (1983) presented more than 20 *ms* mutants in India. A dominant GMS is also reported in *capsicum* by Daskalov and Poulos (1994).

Cytoplasmic Male Sterility (CMS)

The inheritance of CMS in *C. annuum* was first studied by Peterson (1958) which is controlled by major gene – *ms* – interacting with a specific S plasma type to generate (S) *msms* CMS plants. CMS has also been reported in inter-specific hybrids between *C. baccatum x C.*

annuum. No adequate restorer has been found for this system. *C. chacoense x C. annuum* has been reported to give male sterility but no restorer or maintainers have been found for this.

Application of male sterility in F_1 hybrid seed production

PAU Ludhiana has developed MS-12 which carries GMS controlled by recessive gene (*msms*). The plant having recessive gene in homozygous state (*msms*) are male sterile while heterozygous (*Msms*) and homozygous dominant (*MsMs*) state are male fertile. The male sterile line (*MS-12*) is developed by transferring sterility gene from France (*ms-509*) into the cultivar "Punjabi Lal" through back crossing. Patel *et al* (1998) at AAU, Anand also reported GMS line ACMS2 having monogenic recessive gene.

CGMS is first reported by Peterson (1958) in an introduction of *C. annuum* from India (PI 164853). The main advantages of the CGMS system over the genic male sterility is that one can get 100% male sterile plant for direct use as females. *The known cytoplasm source in C. annuum (Peterson, 1958) is not exploited commercially because*; (i) unstable under fluctuating conditions, particularly temperatures and (ii) a low rate or natural cross pollination in cultivated peppers.

Hybrid seed production

Flower is very small that is why hand emasculation is very difficult. Hence male sterile lines can be used for hybrid seed production. In chili emasculation and pollination can be attempted simultaneously. The flower opening in chilli takes place between 5am - 6 am and anther dehiscence take place at 8 am - 11 am. The maximum fruit set takes place, when pollination is done at the time of opening of flower. Anthesis is completed by 8 am. Bees (*Exomopsis pulchella*) and thrips are the pollinating agents in chillies. Both self and cross pollination occur the later being about 16% by bees, ants and thrips. **Breeding Objectives**

- High yield
- Earliness
- Unripe fruit colour
- Ripe fruit colour
- Shape of fruit (long fruits in chillies), segment wise fruit shape, wrinkleness, fruit colour, seed content and pungency in Indian context.
- Size of fruit

- Pungency
- High oleoresin in chillies
- Retention of colour on storage (in dry chillies on drying)
- Pericarp thickness and seed content
- Disease resistant (Virus complex, Anthracnose, fruit rot, powdery mildew, cercospora leaf spot, fusarium wilt)
- Resistant to insect (thrips, aphids, mites, borer and gall midge)
- Abiotic stress- drought, moisture stress and salinity

Breeding Methods

1. Pureline selection

Varieties K1, Bhagyalakshmi, CO 1, CO 3 and Arka Abir has been developed through pureline selection.

2. Pedigree method

It is used when character under improvement is governed by both additive and nonadditive gene action. K2, Jawahar Mirch 218, X 235, G5, NP46 A, Pusa Jwala, Punjabi Lal, Pant C1 and Pusa Sadabahar have been evolved through this method.

3. Backcross Method

It is commonly used for disease resistance and for transferring male sterility genes in chilli. It is preferred for incorporating simple inherited qualitative characters like colour of fruit, skin or flesh, shape of fruit and moderately to highly heritable quantitative characters like maturity.

4. Heterosis Breeding

The first report on heterosis came from Deshpande (1933) who observed it for earliness, plant height, fruit girth, fruits per plant and yield per plant. F_1 hybrids are popular in the USA and Europe and gaining popularity in India.

First public sector hybrid CH-1 was developed by PAU using male sterile ms-12 (based on GMS system).

Inter-specific hybridization

The Capsicum genus consists of 27 species, of which 5 domesticated and 22 wild types. Wild and related species are useful not only for breeding disease resistance but also for

increasing the nutritional quality, yield and adaptation to stresses. TMV resistant genes were transferred from *C. chinense or C. chacoense* into *C. annuum. Due to several types of cross incompatibility, use of interspecific hybridization is limited.*

5. Mutation Breeding

MDU 1 is an induced mutant from K1 chillies by using 30 kr of gamma rays.

Breeding for fruit quality

In chilli, pungency is produced by the capsaicinoids, alkaloid compounds that are found only in the plant genus, *Capsicum*. Capsaicin is a powerful and stable alkaloid that can be detected by human taste buds solutions of ten parts per million. Capsaicin's composition ($C_{18}H_{27}NO_3$) is similar to peperin ($C_{17}H_{19}NO_3$) that gives black pepper. The chilli pungency level has genetic and environmental components. The capsaicinoid content is affected by genetic makeup of the cultivar, weather condition and fruit age. Pungency is increased with increased environmental stress. A few hot days can increase the capsaicinoid content significantly. A peculiar chilli category is paprika. It is a product in the United States, while in Europe, there are chile pod-types that are paprikas and in the Hungarian language "Paprika" means *Capsicum*. Paprika is defined in the United States as a sweet, dried, red powder. This mild powder can be made from any type of *C. annuum* that is non-pungent and has brilliant red colour. Paprika may be pungent in Hungary, but paprika is always nonpungent in international trade. Colour is very important in paprika and chilli powder.

Transgenic in Pepper

Transgenic research in pepper is carried out with the following objectives: (i) To improve efficiency of the plants in terms of yield, nutritional quality or agronomic characteristics by specific metabolic pathway modification and (ii) To improve resistance to insect-pests and diseases and to correct some limiting factors such as toxins in plant products, intolerance to herbicide and abiotic stresses. To exploit metabolic engineering this changes the nature of harvested products. China successfully transformed transgene of *C. frutescens* (Wang *et al,* 1991) and *C. annuum* (Zhu *et al* 1996). A similar work was reported by Korean group, which described the transformation of hot pepper (*C. annuum*) with a CMV satellite construct (Kim *et al,* 1997).

Scoville scale

The Scoville scale is the measurement of the pungency (spicy heat) of chili peppers. The number of Scoville heat units (SHU) indicates the amount of capsaicin present. The scale is named after its creator, American pharmacist Wilbur Scoville. His method, devised in 1912, is known as the Scoville Organoleptic test.

Bell peppers rank at 0 (SHU). Naga Jolokia is a chilli pepper that grows in North Eastern India and Bangladesh is the hottest chilli in the world, measuring over 1,000,000 SHU. Pure capsaicin, measures 16,000,000 SHU.

Bhut Jolokia: The Hottest Pepper in the World

In 2005, researchers at New Mexico State University tested the capsaicinoid levels of the Bhut Jolokia pepper found in Bangladesh and northeastern (Nagaland & Assam) India. The tests revealed that the pepper had enough capsaicinoid to equal 1,001,304 Scoville Heat Units, making it the hottest pepper in the world. So Bhut Jolokia (*Capsicum chinensis* × *C. frutescence*) is also called as Ghost pepper/chilli having Guinness world record. **Table 2 : Important varieties/hybrids developed by different institutes in India**

Sr.No.	Developing institute	Varieties
1	IIHR, Banglore	Arka Lohit (sel.1), Arka Abhir, Arka Haritha(MSH-96), Arka Swetha (MSH 149), Arka Meghna (MSH 172)
2	IARI, New Delhi	NP-46-A, Pusa Jwala, Pusa Sadabahar
3	Kerala Agril. Uni., Trichur	Jwalamukhi, Jwalasakhi, Ujwala, Anugraha
4	TNAU, Coimbatore	K-1, K-2, Co-1, Co-2, Co-3, Co-4, PKM-1, PMK-1, PLR-1, MDU-1
5	RARS, APAU, LAM, Guntur	G-3, Bhagyalakxmi (G-4), Aparna, Bhaskar, Prakash, LCA-305, X 197, LCA-304, Kiran
6	MPKV, Rahuri	Musalwadi, Phule Jyoti, Phule Suryamukhi, Shankheshwer-32, Phule Sai
7	GBPUA&T, Pantnagar	Pant C-1, Pant C-2
8	HAU, Hisar	Hisar Vijay, Hisar Shakthi
9	PAU, Ludhiana	Punjab Lal, Punjab Surkh, CH 1 (F1), CH3-3 (F1)
10	PDKV, Akola	Surakta
11	UAS, Dharwad	KDC-1, HCH-9646 (F1)

12	JNKV, Jabalpur	Jawahar-218, Jawahar-283, JCA-154, Bharini, Japani Laungi, Surya Rekha, Resham Patty
13	RAU, Sabur, Bihar	Sabur Arun
14	OUAT, Bhubneshwar	Utkal Ava, Utkal Rashmi, Utkal Ragini
15	SDAU, Sardarkrushinagar	Gujarat Chilli 2, Gujarat Chilli 3
16	AAU, Anand	Gujarat Anand Vegetable Chilli hybrid 1 (CMS based first in Gujarat), Gujarat Anand Vegetable Chilli 112, Gujarat Vegetable Chilli 111, 121,101, Vegetable Non Pungent Chilli 131

CAPSICUM BREEDING

Introduction

Capsicum, bell pepper or "sweet pepper" or "Shimla mirch" (In India, it was first introduced by the Britishers in Nineteenth century in Shimla hills therefore, known as 'Shimla Mirch') is one of the important vegetable crops grown all over the world. The pepper fruits can be consumed fresh, cooked as vegetable or widely used in stuffings and are of great importance for their high nutritional value and the fact that the vitamins are wholly used by the human body.

Bell pepper fruits are bulky shape having 3-4 lobes and rich in vitamin A and C content. The crop is originated in New World Tropics and sub-tropics and was introduced in India by Britishers in Himachal Pradesh and Tamil Nadu (Nilgiri hills). Bell pepper is a solanaceous vegetable having diploid chromosome with 2n = 24. Genetic resources for improvement of peppers in tropical regions are far from exhausted by capsicum breeders. Germplasm collection and conservation is the major step in the improvement of bell pepper.

This material can be used in hybridization programme.

Botany

Bell pepper is an annual or short lived perennial herb up to 1.5 m in height. It has well developed tap root system with many laterals. Stems are branched, erect and often woody, growth determinate or indeterminate. The fruits have many seeded berries with 2 or more locules.

Breeding objectives

- Earliness
- Higher yield
- Good average fruit weight
- More number of fruits per plant
- Fruit shape (oblate or round)
- Flesh thickness
- Pleasing flavor
- Superior fruit qualities like high vitamin C and pigment content
- Wider adaptability
- Resistant to diseases like leaf blight and fruit rot, anthracnose, cercospora leaf spot, viruses, powdery mildew and bacterial wilt etc.
- Resistance to insects like thrips, mites, aphids, fruit borer
- Resistance to abiotic stresses like heat, water stress, salinity

Breeding methods

1. Introduction

In bell pepper, International Board of Plant Genetic Resources (IBPGR), Rome, and Asian Vegetable Research and Development Centre (AVRDC), Taiwan, are important international sources for enriching the germplasm base.

Some promising direct introductions in bell pepper are Yolo Wonder, California Wonder, Sweet Banana, Chinese Giant, World Beater, Ruby king and King of North.

2. Pureline selection

Arka mohini from Titan (USA), Arka Gaurav from Golden Dal Wonder (USA) and Arka Basant from Soroksari (Hungary) were selected through pureline selection. (These are developed by mass selection)

3. Pedigree method

The varieties developed through this method are viz., Spartan Garnet (California Wonder x Dwarf Pisniento), Spartan Enerold (Morgold x California Wonder) and Sannette (Morgold x California Wonder) x Keystone Resistant Giant.

4. Heterosis breeding

The goal of increasing productivity in the quickest possible time can be achieved by utilizing heterosis breeding. An F1 hybrid variety is the result of a cross between two

homozygous (but genetically distinct) pure lines. The prerequisite is that all the F1 plants should resemble each other phenotypically.

The first hybrid in India was "Bharat" developed by Indo-American Hybrid Seed Company, Banglore (1973).

Hybrid development Public sector hybrid

- Pusa Deepti (Kt-1):- hybrid between Yolo Wonder and Runion Yellow, released by IARI Regional Station, Katrain (HP). High yielding, tolerant to bacterial leaf spot and anthracnose.
- Solan Hybrid-2:- Released by YSPUHF, Solan. Resistant to fruit rot and virus.
- Solan Hybrid-1: Released by YSPUHF, Solan.
- Solan Bharpur: Released by YSPUHF, Solan.
- KTCPH- 3: Yolo Wonder x HL-201, released by IARI Regional Station, Katrain (HP).
- KTCPH- 5: Yolo Wonder x EC- 143570, released by IARI Regional Station, Katrain (HP).

Use of male sterility

Both genic and cytoplasmic male sterility have been reported in sweet pepper. Functional male sterility can successfully be utilized in hybrid seed production. Male sterility is one of the most important traits used in hybrid pepper breeding. Application of male sterility reduces hybrid production costs by excluding the need for manual emasculation of maternal line and elimination of impurities of the seed material originated from selfpollination.

Table 3 : Varieties of bell pepper

Sr.No.	Varieties	Institution
1	California Wonder, Yolo Wonder	IARI, New Delhi
2	Arka Mohini, Arka Gaurav, Arka Basant	IIHR, Banglore
3	Solan Bharpur	UHF, Solan
4	Punjab-27	PAU, Ludhiana

Breeding for quality attributes

C. annum L. is a diverse group of vegetables while bell pepper from a small group of peppers. The main breeding objective in bell pepper group is fruit shape and non-pungency. Beside this, breeding for fruit colour is another important objective. However, fruit colour trait entirely dependent upon consumer preference. In some regions, people prefer dark green coloured fruits while in other cream or yellow and red coloured fruits may be preferred.

CHAPTER – 9 OKRA BREEDING

Introduction

Okra [*Abelmoschus esculentus* (L.) Moench, 2n=2x=130], a member of Malvaceae (Linnaeus, 1753) family, is one of the important fruit vegetable crop grown in tropical, subtropical and warmer parts of the temperate regions in the world. It is known by many local names in different parts of the world *viz.,* lady's finger in England, gumbo in the United States of America, guino-gombo in Spanish, guibeiro in Portuguese and bhindi in India. Even within India, different names have been given in different regional languages (Chauhan, 1972). It is one of the most common vegetable in India and is available almost throughout year. It is a highly adaptable crop mainly grown for its green non-fibrous tender fruits, which are cooked and consumed in various forms and also used for canning. It is grown commercially in country like India, Turkey, Iran, Western Africa, Yugoslavia, Bangladesh, Afghanistan, Pakistan, Burma, Japan, Malayasia, Brazil, Ghana, Ethiopia, Cyprus and the Southern United States. With respect to okra production, India ranks first in world. In India, it has been grown commercially for many years in the states of Gujarat, Maharashtra, Andhra Pradesh, Karnataka and Tamil Nadu.

Okra is commonly known as bhindi or lady's finger *[Abelmoschus esculentus* (L.) Moench] has a prominent position among vegetable due to its wide adaptability, year round cultivation, export potential and high nutritive value. It has been reported that okra has an average nutritive value of 3.21, which is higher than tomato, eggplant and most of the cucurbits except bitter gourd (Grubben, 1977). Due to its easy cultivation, dependable yield and adaptability to varying moisture conditions it is quite popular as well as potential export earner in India. Okra roots and stems are used for clarification of sugarcane juice from which "gur" is prepared (Chauhan, 1972). Its ripe seeds are used as a substitute for coffee in some countries. Its mature fruits and stems containing crude fibre are used in the paper industry. Its extracts from the seeds is an alternative source for edible oil. The edible oil has a pleasant taste and odour which is high in unsaturated fats such as oleic acid and linoleic acid. It is a rich source of calcium, iron, vitamin A and fibre content and also posses medicinal qualities like diuretic properties. It is very useful against genito-urinary disorders, spermatorrhoea and chronic

dysentery (Nadkarni, 1927) and has also been reported in curing ulcers and relief from hemorrhoids (Adams, 1975).

Origin and distribution

It is originated at Tropical Africa or Hindustan center /India center of origin. Very contradicting evidence exists on the geographical origin of *Abelmoschus esculentus*. One putative ancestor *Abelmoschus tuberculatus* is native to Uttar Pradesh in North India, suggesting that *Abelmoschus esculentus* originated in India (Rao, 1985). The other evidence is based on the plants cultivation in ancient times, and the presence of another putative ancestor *Abelmoschus ficulneus* in East Africa, suggesting northern Egypt or Ethiopia as the geographical origin of *A. esculentus*. The other species *Abelmoschus caillei* (2*n* = 196 to 200) has been located only in West Africa, so this region can be recognized as its origin and is believed to be amphipolyploids between *Abelmoschus esculentus* (2*n* = 130 to 140) and *Abelmoschus manihot* (2n = 60 to 68).

Taxonomy and Cytology

Abelmoschus esculentus is one of the most heat and drought tolerant vegetable species in the world. Previously, Okra was included in the genus *Hibiscus* but later, it was designated to *Abelmoschus*, which is distinguished from the genus *Hibiscus* by the characteristics of the calyx and corolla (Kundu and Biswas, 1973; Terrell and Winters 1974).

About 50 species have been described in genus *Abelmoschus*, in which eight are most widely accepted (Borssum, 1966; IBPGR, 1990). Significant variation in the chromosome numbers and ploidy levels was observed in *Abelmoschus.* The lowest chromosome number is 2*n* = 56 found in *A. angulosus* (Ford, 1938) and the highest are close to 200 for *A. caillei* (Siemonsma, 1982). Within *A. esculentus*, chromosome numbers 2*n* = 72, 108, 120, 132 and 144 are found in regular series of polyploids with *n* = 12 (Dutta and Naug, 1968).

There are four known domesticated species of *Abelmoschus,* among these; *A. esculentus* (common okra) is most widely cultivated in South-East Asia, Africa, and the southern USA. *A. caillei* (West African okra), is also cultivated with a longer production cycle cultivated in humid zone of West Africa (Siemonsma, 1982). *A. manihot* is extensively cultivated for leaves in Papua New Guinea (Hamon and Sloten, 1995), Solomon Islands and other South Pacific Islands (Keatinge, 2009). The fourth domesticated species is *A. moschatus,*

cultivated for its seed, which is used for ambretee in India and several animism practices in South Togo and Benin (Hamon and Sloten, 1995).

A. esculentus (common okra) is cultivated in 95 % area of the world. It is an amphidiploid (2n=130-140); cross between *A. tuberculatus* or *A. ficulneus* (2n=58-60) and unknown species. It is poorly adapted in humid zone, more susceptible to biotic stresses, less vigorous, short life cycle, usually day neutral and cultivated in both rainy and dry seasons. While, *A. caillei* (West African okra) is cultivated in remaining 5% area; is amphipolyploidy (2n=196-200); cross between *A. esculentus* (2n=130-140) and *A. manihot* (2n=60-68). It has better adaptation in humid zone, tolerance/resistant to biotic stresses, more vigorous, longer life cycle, mostly photoperiod sensitive and cultivated mainly in dry season.

The most chromosome number of cultivated okra *i.e., A.* esculentus varies from 72 to 144 (ICAR Book KV Peter & T.Pradeepkumar page no- 261, 2008 edition) but most common chromosome number in cultivated is considered as 2n=2x=130 (Singh & Bhatnagar, 1975).

Table 1 : The species of *Abelmoschus* (IBPGR1, 1991)

Sr.No.	Species	Chromosome Number	Genepool	Distribution in India
1	*A. moschatus spp. moschatus*	72	GP3	Uttaranchal, Orissa, Kerala, Karnataka, Andaman & Nicobar Islands
	A. moschatus spp. tuberosus			Kerala and parts of Western Ghats in Tamil Nadu
2	*A. manihot* (L.) *spp. tetraphyllus var.tetraphyllus*	60 to 138	GP3	Uttar Pradesh, Rajasthan, Madhya Pradesh, Maharashtra, Orissa, Chhattisgarh
	A. manihot (L.) *spp. tetraphyllus var.pungens*			Uttaranchal, Himachal Pradesh, Jammu & Kashmir, Assam, Andaman & Nicobar Islands
3	*A.esculentus* (L.) Moench	66 to 144	GP1	-
4	*A. tuberculatus* Pal & Singh	58	GP2	Uttar Pradesh, Rajasthan, Madhya Pradesh, Maharashtra
5	*A. ficulneus* (L.) W & A. ex. Wight	72	GP2	Jammu & Kashmir, Rajasthan, Madhya Pradesh, Chhattisgarh, Maharashtra,

				Tamil Nadu, Andhra Pradesh, Uttar Pradesh
6	*A. crinitus* Wall	-	-	Uttaranchal, Madhya Pradesh, Orissa
7	*A. angulosus* Wall. ex. W & A	56	GP3	Tamil Nadu, Kerala
8	*A. caillei* (A. Chev.) Stevels	194	GP3	-

Botany

Okra plant is an upright annual herbaceous plant with 0.5 to 4.0 meter tall with deep tap-root system. Okra stem is semi-woody green in colour or pigmented with green or reddish tinge colour. The plant is erect and having 3-5 branches while leaves are alternate with dark green in colour.

Generally, the okra flower borne vertically and is axillary and solitary with the flower peduncle is 2-2.5 cm long. The flowers are hermaphrodite, actinomorphic as well as self compatible and withers within one day. Flowering in okra is continuous but highly dependent upon biotic and abiotic stress. The plant usually bears its first flower one to two months after sowing. The okra flowers are about 2 inches in diameter, with five white to yellow petals, with a red or purple spot at the base of each petal. Flower bud appears in the axil of each leaf, and it takes about 22-26 days from initiation to full bloom. The style is surrounded by a staminal column which may bear more than 100 anthers. The anther bears thousands of mature pollen grains which may come in contact with the stigmas through a lengthening of the staminal column or through insect foraging (Thakur and Arora, 1986). So, the flowers of okra are self fertile. The pollen grain of okra is large with many pores, and every pore is a potential tube source; therefore, many tubes can develop from one pollen grain (Purewal and Randhawa, 1947).

In Okra, flower bud initiation, flowering, anthesis as well as stigma receptivity all are influenced by genotype and climatic factors *viz.,* temperature and humidity (Venkatramini, 1952). Anthesis was observed between 6 a.m and 10 a.m. while anthers dehisce before flower opening and hence self pollination may occur during anthesis time. The dehiscence of anthers is transverse and complete dehiscence occurs in 5-10 minutes (Purewal and Randhawa, 1947). Pollen fertility is maximum in the period between an hour before and an hour after opening of the flower (Srivastava, 1964). The stigma receptivity was high on the day of flowering (90-

100%) but it was low day before flowering (50-70%) and the day after (115%). Flowers open only once in the morning and close after pollination on the same day.

The perfect flowers (male and female reproductive parts in the same flower) found in okra so it is called as a self-pollinated crop (Purewal and Randhawa, 1947). The inbreeding depression was common and very high in cross-pollinated crops but it is not reported in this crop (Duranti, 1964). It is self pollinated crop so insects are unnecessary for pollination and fertilization but okra flowers are very attractive to bees hence some amount of crosspollination occurred in this crop. So this crop is truly called as often cross pollinated crop. The cross pollination was observed between 4-19% (Purewal and Randhawa, 1947; Choudhury *et al.,* 1970; Shalaby, 1972) while maximum of 42.2% (Mitidieri and Vencovsky, 1974). The extent of cross-pollination will depend upon the cultivar, competitive flora, insect population and season, etc in a particular place. However, it is not so highly cross pollinated as other crops of this group and self pollination can be assured in the breeding nursery by bagging the flowers (Swarup, 1977).

Male Sterility

In India, commercial production of F_1 hybrid in okra is done by hand emasculation and hand pollination which is a tedious process which takes 70% of the time and labour in cultivation process. In okra, Genetic Male Sterile (GMS) line MS-1 identified by the Division of Vegetable Crops, Indian Institute of Horticultural Research (IIHR), is being used for development of a commercial F_1 hybrid. Male sterility in okra is controlled by a pair of single, recessive genes and can be utilized by hybrid seed production. The gene was stable, not being influenced by environmental factors (Pitchaimuthu *et al.,* 2012). In okra, male sterility has not been observed in nature, but, has been induced by gamma radiation (Dutta,
1971). Male gametocides also called as CHA's are known to induce male sterility in okra (Dubey & Singh, 1967; Deepak *et al.,* 2007) and male gametocides will selectively kills only male gametes, spores or organs and render the treated plants to male sterile. Artificial induction of pollen sterility with the application of MH may cause abnormalities like shrivelling of microspores or premature disintegration of tapetum starved microspore which leads to death of the pollen in okra (Deepak *et al.,* 2007). Malic hydrazide also induced maximum pollen sterility in okra (Dubey & Singh, 1967; Verma & Singh 1978).

Breeding Objectives

- Higher yield
- Early and prolonged harvest
- Fruits are tender, dark green in colour with 6-9 cm long at marketable stage
- Medium tall plant with short internodes
- Fruits are good for processing purpose
- Breeding for disease resistant like yellow vein mosaic virus, enation leaf curl virus, *fusarium* wilt, cercospora leaf spot etc.
- Breeding for resistant/tolerance to insect pests like fruit and shoot borer, jassids and whitefly
- Breeding for abiotic stresses like low temperature, excessive rains, saline and alkaline soils

Breeding Methods

Basically okra is considered as self pollinated crop, but due to protogyny situation some amount of cross pollination observed in this crop. So this crop is called as often crosspollinated crop. Considering these aspects following breeding methods can be adopted for improvement in okra.

1. Introduction

"*A.manihot* ssp. *manihot*" is introduced from Africa (Ghana) in India which has been successfully used as a source of YVMV resistance. The genotype "Perkins Long Green" was also introduced from USA; it is suitable for cultivation in hilly areas. This introduced variety was released as Harbhajan bhendi from Dr YSPUH & F, Solan.

2. Pureline selection

"Pusa Makhamali" was bred from a material collected from West Bengal while "Gujarat Bhindi-1" was from an unknown bulk seed sample received from IARI, New Delhi. "Kashi Mangli" was bred by IIVR through pureline selection.

3. Mass Selection

None of the variety was developed through mass selection in okra.

4. Pedigree method

Through this method *viz.,* "Pusa Sawani", "Varsha Uphar", "Hisar Unnat", "Azad

Krant", "Arka Anamika", "Arka Abhay", "Kashi Vibhuti", "Kashi Pragati", "Kashi Satdhari", "Kashi Lila", "Punjab Padmini" as well as many more varieties were developed in okra.

5. Backcross method

A variety "Punjab 7" was developed by PAU, Ludhiana through this method.

6. Heterosis Breeding

It is an already established fact that the amount of yield heterosis obtains by hybrids depends largely on the genetic divergence of the populations from which the parental lines have been extracted (Moll *et al.,* 1962). Heterosis for increased fruit size, fruit weight and fruits per plant in okra was first reported by Vijayaraghvan and Warriar (1946). Many researchers have advocated heterosis breeding as a tool for genetic improvement of yield and yield components in okra. In okra, commercial exploitation owing to the phenomenon of protogyny and its floral biology, this enables easy emasculation and pollination besides being able to produce large number of seeds in single pollination (Reddy, 2010). Important hybrids viz., "Arka Nikhita", "Shital Uphar", "Shital Jyoti", "Kashi bhairav", "Kashi Mahima", "HBH-142", "COBhH – 1" and many more developed through this method.

7. Mutation Breeding

Okra variety "MDU-1" and "Punjab – 8 (EMS-8)"were developed through mutation breeding; developed by TNAU, Coimbatore and PAU, Ludhiana, respectively.

Hybrid Seed Production

Hybrid vigour in okra has been first reported by Vijayaraghavan and Warier (1946). Hybrid seed of okra on commercial scale is mostly produced in Ranebennur area of Karnataka and Buldha district of Maharashtra. The system is totally manual, where large scale emasculations followed by pollinations are practiced by trained family members of the contract growers. The production season is rainy season. The size of production plots is 1000 m^2/unit plot. Each production plot needs 200 g seed of female parent and 50 g seed of male parent. These seeds give rise to about 2000-2500 female plants and 500 male plants. During this process, all open flowers and already set pods are also removed. Next morning, fully developed flower buds, not open are collected from the male parent and are left as such in the sun for some time. Calyx and corolla of those flowers are removed and the dehiscing, staminal column is used to brush against stigma of already emasculated flowers of the female parent. One male flower can be used to pollinate 3-4 female flowers. In some cases, mature but unopened flower

buds of male parent are collected in the evening, calyx is removed and the buds are taken home and kept under bulb. In this process, they open in the night and anthers start dehiscing. These are used for pollination next morning. Under normal circumstances about 50 kg hybrid seed/unit plot of 1000 m^2 is produced. **Salient breeding achievements**

- Variety Pusa Sawani (Released in 1962), a selection from Pusa Makhamali × IC 1542 was first YVMV resistant variety released in India and also it was tolerant to high pH & salinity but now resistance is broken down.
- After that from Pusa Sawani, new variety was released that was Pusa A-4 IN 1994 which was resistant to YVMV, Jassida, shoot and fruit borer.
- High yielding variety Lam selection, Sel 2,Vaishati Vadhu, Lam Hybrid, R 7, EMS 8, Co 1 and Beltes five have been evolved (Suresh Babu and Peter, 1984).
- Related species *A. manihot var. pungens*, *A. crinitus,A. vitifolius* and varieties Sel. 4 and Arka Anamika and Arka Abhay were observed resistant to yellow vein mosaic disease.
- Kiran and Salkeerthi are light green types and Aruna is a red fruited type from the KAU.
- Variety Long Green Smooth has showed high resistance to nematode (*Meloidogyne javanica*).
- Co 3 is a high yielding F_1 hybrid (Prabhani Kranti × MDU 1) from the TNAU with an yield potential of 16-18 tonnes/ha.
- Azad Bhindi 1, a new okra cultivar ,developed from Pusa Sawani × Prabhani Kranti, exhibits higher yield (10-12.5 tonnes/ha), earlier fruiting (40-42 days) and more resistance to bhindi yellow vein mosaic virus than Pusa Sawani and Prabhani Kranti.
- The F_1 hybrids *viz.,* Vijay, Varsha, Panchali, AROH 221, SOH 77, Karishma, Mahabeej, Anokhi, Ever Green, Biokeerti and NOH 24 developed by private seed companies are also popular among farmers.
- Variety Perkins long green of okra was released in 1983-84 as Harbhajan Bhendi (in the honour of Dr. Harbhajan Singh, Indian Vavilov) from College of Agriculture, Solan which was resistant to YVMV.

Table 2 : Improved Varieties/Hybrids

Sr.No.	Developing Institute	Name of Variety

1	IIHR, Banglore	Arka Abhay (sel.4), Arka Anamika
2	IARI, New Delhi	Pusa Makhmali, Pusa Sawani, Pusa A4, Perkins Long Green, Selection 2-2
3	IIVR, Varanasi	VRO 3, VRO 4, VRO 6, Kashi Vibhuti, Kashi Pragati, Kashi Satdhari, Kashi Bhairav, Kashi Mahima
4	Kerala Agricultural University	Kiran, Salkeerthi, Aruna, Susthira, Anjitha, Manjima
5	TNAU	MDU 1 (Mutation Breeding), Co-1
6	HAU, Hissar	Varsha Uphar, Hissar Unnat (HRB 55)
7	PAU, Ludhiana	Punjab 7 (P 7), Punjab Padmini, Punjab 8 (EMS 8)
8	MAU, Parbhani	Parbhani Kranti
9	CSAUA & T, Kanpur	Azad Kranthi
10	Dr YSPUH & F, Solan	Harbhajan Bhindi / Perkins long green
11.	AAU, Anand	Gujarat Anand Okra 5
12.	JAU, Junagadh	GO 3, GOH 2, GJO 3, GJOH 3, GJOH 4, GO 6

Breeding for Biotic Resistance

Although okra is considered a robust crop under large scale commercial production, yield losses are very high due to the incidence of a number of biotic and abiotic stresses. The most relevant biotic stresses with respect to diseases are *viz.,* yellow vein mosaic virus (YVMC), okra leaf curl virus (OLCV), okra enation leaf curl virus (OELCV), powdery mildew, cercospora blight and fusarium wilt while with respect to insects and pest are *viz.,* fruit and shoot borer, mites, jassids, microphomina, spotted ball worm and root knot nematodes.

CHAPTER – 10 POTATO BREEDING

Introduction:

Potato [*Solanum tuberosum* L., 2n=48] is one of the fourth major food crops of the world, other than rice, wheat and maize. Potato has water, sugar and starch, fat, minerals, vitamins and protein. The crop is unique where the food materials are stored in underground stem parts called tubers. Potato is originated in the environs of Lake Titicaca in the high Andean region of South America probably 10,000 years ago. Till 16th century it was unknown to the people of Europe, Asia, Africa and North America. Potatoes are being grown in wide variety of soils and climate in nearly 150 countries. Among the major potato growing countries of the world, China ranks first in area, followed by the Russian Federation, Ukraine and Poland. India ranks fourth in the world. Potato was introduced in India by Portuguese and except Kerala, it is grown in all states of India. UP is first in area and production while Gujarat is first in productivity. Year 2008 was celebrated as International year of Potato by United Nation.

Weather is a limiting factor in cultivation of potato. Tuberization is not favoured by high temperature. It is basically a cool season crop although sensitive to frost. 20 °C is optimum for tuberization, more than 23°C at night decreases tuberization. Potato is raised when maximum day temperature is below 35°C and night temperature below 20°C.

The commendable growth of potato crop in India due to:

- Potato produces highest dry matter and protein per unit area and time
- Potato is nutritious food
- Being a short duration crop, it fits well in the intensive cropping system
- It can be grown round year in one part or other in India

European varieties were not successful in India because;

- The introduced European varieties were long-day adapted
- The multiplication of these varieties in Indian conditions was accompanied by progressive accumulation of degenerative viral diseases
- Physiological limitations on tuber storage and utilization in hot/humid Indian summers

Potato breeding development in India:

In India, potato breeding programme was initiated in 1935 at the Potato Breeding Station, Shimla. Regular breeding programme was started in 1949 with the establishment of

the Central Potato Research Institute (CPRI) at Patna, Bihar. Headquarter of the CPRI was later on shifted to Shimla (1956) in order to facilitate hybridization and maintenance of seed health. The major breakthrough in potato improvement programme came in 1963 with the development of "Seed Plot Technique", which made it possible to raise, evaluate, select and multiply breeding material under disease free conditions in plains. This led to the development of a system, wherein crossing was attempted in the hills and raising of seedling, evaluation and maintenance of segregating population was done in the plains. This approach yielded rich dividends both for potato improvement and potato seed production in the country. All varieties released by the CPRI carry the prefix 'KUFRI' as a memento to the place of hybridization.

Origin, Evolution and Domestication:

It is originated in South America. Tuber bearing species distributed from south western United States (38°N) to Central Argentina and adjacent Chile (41°S). The basic chromosome number of the genus *Solanum* is x = 12. Ploidy level of potato species varies from 2n=2x=24 to 2n=6x=72. In Potato, nearly all diploids are self incompatible while all tetraploids and hexaploids are mostly self compatible. Most primitive diploid species like ***S. stenotomum*** might have been the first to be domesticated.

Cytology:

Potato has basic chromosome number as 12 and right from diploid to hexaploid species are available. Majority (about 75%) of the species are diploid followed by tetraploids which are about 15%. In potato, ploidy level of potato species varies from 2x to 6x, among which 73 % diploids, 4 % triploids, 15 % tetraploids , 2 % pentaploids and 6 % hexaploids. Main tuber-bearing species are *viz., S. tuberosum* ssp. *tuberosum* and *S. tuberosum* ssp. *andigena* (Both are tetraploid). Triploid potato species are derived from spontaneous crosses between diploid and tetraploid species. Pentaploids are obtained from crosses of hexaploids with tetraploids. Triploids and pentaploids are highly sterile and are maintained by vegetative propagation.

There are 3 cultivated diploids *viz., S. stenotomum, S. phureja* and *S. ajanhuiri*; of which former two are sexually fertile and the latter one is less fertile and does not breed true. The two cultivated triploid species *viz., S. chaucha* and *S. juzepczukii* are more or less sterile. The cultivated tetraploid species *viz., S. tuberosum* ssp *tuberosum* and *S. tuberosum* ssp *andigena* are usually fertile except in a number of highly bred clones outside South America. In

pentaploid category, there is only one species *i.e. S. curtilobum* which is reasonably fertile in a cross with *S. tuberosum.*

Potato species:

This contains 68 wild species and 8 cultivated species of which most common are tetraploids and are known as *S. tuberosum* L. There are 2 sub-species under this species are given below:

Sub-species *tuberosum*:

It has originated from the coastal regions of South Central Chile. Tubers are formed under long days or under short days in the tropics at lower altitudes only (500-2000 m). Initially it was cultivated on the southern coast and islands of southern Chile but is now spread worldwide.

Sub-species *andigena* (Juz. et Buk) Hawkes:

Tubers are formed at high altitudes only (over 2000 m) under short day conditions. This is the ancestral spp. of *S. tuberosum* formed probably from crosses of *S. stenotomum* x *S. sparsipilium* in the Andes of Peru and Bolivia.

Table 1: Distinct characters of *S. tuberosum* and *S. andigenum* :

Distinct character	***S. tuberosum***	***S. andigenum***
Origin	Andean region	Chile region
Day length response	Long day plants	Short day plants
Polyploidy	Many types of polyploids	Tetraploids
Yield potential	high	Low
Maturity	Early	Late
Distinct varieties	Up-to-date, Magnum Bonum etc	All desi varieties like Darjeeling Red Round, Phulwa and Gola

Description regarding species:

***Solanum ajanhuiri* (2n = 2× = 24):**

This diploid species was formed by natural hybridization between diploid cultivars of *S. tuberosum* L. *andigenum* group and the tetraploid wild species *S. bolivense* (*S. megistacrolobum*). This landrace possesses frost resistance and is distributed in the high

Andean Altiplano between southern Peru and central to North Bolivia, at elevations between 3700 and 4100 m.

***S. juzepczukii* (triploid) (2n = 3× = 36):**

It is formed by hybridization between a diploid cultivar of *S. tuberosum* L. *andigenum* group, and the tetraploid wild species *S. acaule* Bitter. It can be found from central Peru to southern Bolivia and can grow at an altitude of 4000 m. This species contains high levels of glycoalkaloids, and local people prepare detoxified processed potato "chuño" by freeze drying.

***S. curtilobum* (2n = 5× = 60):**

It is formed by hybridization between tetraploid forms of *S. tuberosum* L. *andigenum* group (synonym for *S. tuberosum* subsp. *andigenum*) and *S. juzepczukii* is cultivated in the Andean Altiplano at an altitude range of approximately 4000 m. Because the tubers are bitter, owing to high glycoalkaloid content, the species is also used to prepare "chuño". ***S. tuberosum:***

The most popular cultivated potato is *S. tuberosum*, which is also known as "common potato" in most parts of the world. It has originated from the coastal regions of South Central Chile.

***S. chaucha*:**

S. chaucha is a cultivated triploid species that supposedly originated from natural hybridization between *S. tuberosum* subsp. *andigena* and *S. stenotomum* distributed from 2100 to 4100 msl throughout Peru, with lower frequency in Bolivia, and rarely found in Ecuador and Colombia. ***S. phureja*:**

This species was cultivated from central Peru to Ecuador, Colombia, and Venezuela since the pre-Spanish era and is believed to have originated from *S. stenotomum.*

***S. stenotomum*:**

The species is diploid and cultivated from Central Peru to Central Bolivia. This is most primitive form of cultivated potato. *S. stenotomum* shows the diversity within species, suggesting it to be the first domesticated potato derived from diploid wild species.

Botany:

The aerial stem behaves as an annual but the plant is a perennial because of its underground stem, which is specifically called stolon. Stolon has nodes and internodes and under favorable

conditions develops into branches which grow more or less horizontally outwards. These branches differ in frequency, length and colour. Since they develop into structures with reduced leaves occurring at the nodes, these are called as stolons. At the end of stolons, tuberization takes place.

Floral Biology:

Potato is a long day plant. A cool weather, moderate degree of humidity and long-day environmental conditions favour flowering. These conditions are available in hill tracts and flowering and fruit set occur only in those tracts. The ***Kufri region*** in the HP is ideal for flowering and fruit set. Potatoes flower are set true seed in berries following natural pollination by insects, particularly bumble bees. Out-crossing is enforced in cultivated diploid species by a gemetophytic self incompatibility system.

The flowering of *tuberosum* depends on variety and region of cultivation. Under short day conditions in the plains, most of the potato varieties do not flower but they flower in cooler climate in the hills when planted in summer. The flowers are born on a stalk known as floral axis. Potato flower is a complete flower, as it possesses all the four essential parts of flower such as calyx, corolla, androecium and gynoecium. The flower colour may be white, blue, red-purple, blue-purple and their shades according to variety. The flowers of potato are perfect and self pollinated, however, cross pollination up to 2-4 % may occur with the help of insect pollinators. Most of the varieties of potato bear sterile pollen; therefore formation of fruits or berries does not take place. The seeds are formed in small green berries, which turn yellow on maturity. **Flowering in potato:**

Availability of ample flowers at proper time with functional male and female parts is an indispensable requirement for hybridization. Genotype, day-length and temperature are main factors, which determine the flowering and fruiting in potatoes. Though flower primordia of potato can arise in total darkness, a photoperiod of 14-18 hours and night temperature of 15 to 20°C favour flower production and berry setting. In tropics and subtropics, conditions conducive to flowering and fruiting are available only at high altitudes (>1500m above sea level) where crop is grown during summer season.

Flower Induction by extended photoperiod:

Under short day conditions, flowering in potato is achieved through extended photoperiod (LD) of 6 hours by 250w high pressure sodium vapour lamps. About 30% genotypes reached up to flowering stage through this treatment.

Flower Induction by hormonal treatment:

Three repeated sprays of GA 50 ppm + IBA 10 ppm + Kinetin 2 ppm at week interval starting from bud initiation stage enhances the flowering intensity, flowering duration and advances the flowering as well. About 70% genotypes reached up to flowering stage through this treatment. However hormonal induced flowering (LD+H) reduces flower vigour and size and in some genotypes abnormal flowers are obtained leading to pollen sterility. Pollen fertility is tested by squashing anthers in 2% aqueous solution of Aceto-carmine.

Chromosome number:

Potato has 2n=24, 36, 48 and a basic chromosome number of 12. *S. andigena* Juzet Buk. is an autotetraploid with 2n=48. Presence of male sterility with no pollen or a few sterile pollen gives evidence for the autoploidy nature of *S. andigena.*

Breeding uniqueness of potato:

- Propagated asexually
- Transmission of diseases via tubers
- Easy maintenance and multiplication of elite material in original genetic state through vegetative propagation
- Complex tetrasomic inheritance due to autotetraploidy
- Diverse source of germplasm including wild relatives for resistance to abiotic and biotic stresses

Breeding objectives:

- High tuber yield
- Earliness
- Photoperiod insensitivity
- Responsiveness to fertilizers
- Better keeping quality
- Resistance to biotic and abiotic stresses **Breeding Methods:**

Potato is a self pollinated crop but is vegetatively propagated. The cultivated tetraploid varieties are highly heterozygous. Most of them are pollen sterile. Selfing or inbreeding in

potato leads to loss of vigour of the progeny and non-flowering. Hence, the conventional method or pureline method of breeding is generally not practiced.

1. Introduction:

Many high yielding varieties with desirable characters have been introduced to India. *e.g.,* Magnum Bonum, Craigs Defiance and Up to Date. A few of the introductions have been used to develop hybrids and varieties. Hybrid D.N. 45 is developed through crossing of Katahdin with President. Kufri Kisan is multicross involving Ekishrazu from Japan, Katahdin from the USA, Up to date from Scotland and Phulwa, a desi variety.

2. Clonal Selection:

Kufri Red is selected from Darjeeling Red Round while K 1241 is selected from Phulwa.

3. Hybridization:

Potato naturally flowers under cool climate and long day condition of more than 14 hours light. Such conditions are available during long summer days when potatoes are grown in the hills. Hills are therefore ideal for hybridization work. Potato flowers are hermaphrodite and therefore emasculation is done in selected female parents mostly in evening.

Emasculation will be carried out in previous day of pollination. In rainy season for emasculation, thick butter paper bag covering with insertion of 1-2 leaves in to the bag in retaining the humid climate. Crossing in plains is not done because potato requires long day which is not available in plains. The parental variety may not flower at same time even in the staggered sowing of male parent in different dates. Interspecific hybrids risk of frost injury to the breeding materials should be avoided.

Interspecific hybridization:

In India, many varieties have been evolved through interspecific hybridization.

- Kufri Kuber – selection from *S. curtilobum* x *S. tuberosum*
- Late blight resistant lines – *S. demissum* x *S. Tuberosum*

The following methods are suggested to remove difficulties encountered during interspecific hybridization:

(a) Chromosome doubling:

When one parent in the cross is a diploid and the other a tetraploid, the chromosome number of diploid species is doubled through colchicine treatment and the crosses are made at tetraploid level. When both the parents are diploids and there is sterility of F_1 hybrids, amphidiploids are synthesized by treating the F_1 seeds with colchicine.

(b) Use of Bridging Species:

A number of species like *S. demissum, S. acaule* etc carry desirable genes for disease and insect resistance. But they will not cross readily with *S. tuberosum*. The F_1 developed through crossing between *S. demissum X S. tuberosum* is sterile because of univalents during meiosis. By making use of *S. rybini* as a bridging species, meiosis could be made regular in the progenies and the commercial qualities of *S. tuberosum* maintained. The species *S. rybini* and *S. simplicifolim* are called bridging species.

(c) Mixed Pollination:

In potato, cross incompatibility is break through:

1. Using pollen from both the parents,
2. Spray of IAA on the stigma and then pollination,
3. Grafting the female parent of male parent and then pollinating the scion with pollen from male parent
4. **Backcross Method:**

Cultivated potatoes do not possess resistance to most of the disease and pests. Resistant genes are mostly found in wild and semi cultivated species available in the centre of origin and diversity in South America. In this, transfer of the resistant genes from wild species into cultivated potato is difficult.

5. **Heterosis Breeding:**

No male sterility systems are required for potato.

Heterosis has been observed for:

- Earliness
- Tuber yield,
- Tuber size and
- Tuber weight.
- F_1 is produced through hand emasculation and pollination
- Selection is made in F_1 clones.

6. Polyploidy Breeding:

It is basically a polyploid. Homozygous parental lines are produced through development through haploids and through their polyploidization. Haploids are produced through crossing of tetraploid varieties with pollen from diploid varieties. The homozygous lines have utility in disease resistance breeding where disease resistance is governed by recessive genes.

True Potato Seed (TPS) Technology:

To increase potato yield per unit area, new technologies will always be sought after. One of the constraints for potato production in India and other developing countries is the inadequate supply of healthy seed tubers at an affordable cost. The problem could be overcome to some extent by using true potato seed (TPS). It is possible to propagate potato through true seed collected from ripe barries. This saves considerably large quantity of seed tubers required for and their storage, space and transport.

This concept was first realized to raise commercial crop in India by Dr. S. Ramanujam, the first Director of the Central Potato Research Institute in early fifties at Patna. *The advantages conceived by him were:*

1. Requirement of TPS in small quantity
2. Freedom of TSP crop from viral diseases common in seed tuber crops
3. Elimination of storage losses in seed tubers

Hybrid TPS has shown superiority over open-pollinated TPS. TPS can be stored safely at ordinary room temperature and under low humidity for 2-3 years. Freshly extracted TPS have dormancy of 5-6 months. Dormancy can be broken by dipping the TPS in GA_3 for 48 hrs (1500-2000ppm). To be appealing to farmers; TPS technology must; 1). Increase yield potential 2). Improve the size distribution in the produce of both seedling transplants and seedling tubers.

Central Potato Research Institute (CPRI) – Shimla:

Formally, it begun in April 1, 1935 at Shimla. It has two seed production farms at Bhowali (UP) and Kufri (Shimla). Dr S. Ramanujam was first Director of this station. There are seven regional research stations viz., CPRS Patna, Ooty, Kufri, Gwaliar, Jalandhar, Shillong and Modipuram.

Advances in Biotechnology:

(a) Micropropagation:

It helps in developing countries to produce low cost, disease free tuber "Seed" and increase potato yields. It protects collections of potato varieties and wild and cultivated relatives from possible diseases and pest outbreaks. Potato samples are stored under *in vitro* sterile conditions.

(b) Anther culture:

This technique may prove better than induced pollinations for dihaploid and monohaploid production of any genotypes.

(c) Protoplast fusion:

It applied as a way to overcome barriers to sexual hybridization with wild species and it is used for limited chromosome transfer.

(d) Molecular Markers:

It is widely used for marker assisted selection, tracking introgression, identifying sexual and somatic hybrids, fingerprinting new cultivars for identification and it is a prerequisite of map based cloning.

(e) Genetic engineering:

The first commercial cultivar was Monsanto's "NewLeaf" Russet Burbank with Bt resistance to Colorado beetle which was granted registration in the USA in 1995. NewLeaf Plus with the addition of replicase mediated resistance to PLRV is another transgenic potato in USA.

EBN (Endosperm balance Number):

EBN may act as a powerful isolating mechanism in sexual reproduction, maintaining the genome integrity of the species and playing an important role in the speciation of polyploids from diploids. Endosperm failure is considered the primary reason for the lack of success in intra-and interspecific crosses. The Endosperm Balance Number (EBN) hypothesis is a unifying concept for predicting endosperm function in intraspecific, interploidy, and interspecific crosses. In the EBN system, every species has an 'effective ploidy' (EBN), which must be in a 2:1 maternal to paternal ratio in the endosperm for crosses to succeed. The knowledge of EBN is very useful in the transfer of genes from exotic germplasm, and in the development of new breeding schemes in potato. 2x(1EBN), 2x(2EBN), 4x(2EBN) and 6x(4EBN) germplasm has been introduced into the cultivated 4x(4EBN) potato gene pool. A new methodology for producing 4x(4EBN) and 2x(2EBN) chromosome addition lines is also

discussed. EBN has evolutionary importance in the origin of tuber-bearing Solanums. The role of the EBN in the origin of diploid and polyploid potato species, and as a barrier for hybridization and speciation of sympatric species within the same ploidy level is demonstrated. The origin of 3x and 5x cultivated tuber-bearing Solanums may also be explained using the EBN concept. EBN has been reported to exist in other plant species: alfalfa, beans, blueberries, rice, soybeans, squashes, tomato, forage legumes, grasses, ornamentals and *Datura stramonium*. This indicates that EBN may have broad application and could be useful for germplasm transfer and breeding.

Breeding Achievements:

Sr.No.	Developing Institute	Varieties
1	CPRI, Shimla	Kufri Kisan, Kufri Kuber, Kufri Kumar, Kufri Kundan, Kufri Red, Kufri Safed, Kufri Neela, Kufri Sindhuri, Kufri Alankar, Kufri Chamtakar, Kufri Chandramukhi, Kufri Jeevan, Kufri Jyoti, Kufri Khasigaro, Kufri Naveen, Kufri Neelamani, Kufri Sheetman, Kufri Muthu, Kufri Laukar, Kufri Dewa, Kufri Badshah, Kufri Bahar, Kufri Lalima, Kufri Sherpa, Kufri Swarna, Kufri Megha, Kufri Jawahar, Kufri Saltej, Kufri Ashoka, Kufri Pukharaj, Kufri Giriraj, Kufri Chipsona-1, Kufri Chipsona-2, Kufri Anand, Kufri Kanchan, Kufri Arun, Kufri Pushkar, Kufri Shailaja, Kufri Surya, Kufri Chipsona-3, Kufri Himalini, Kufri Himsona

CHAPTER – 11 COWPEA BREEDING

Introduction

Cowpea (*Vigna unguiculata* L.) syn. Southern pea, Black eyed pea, yard long bean, lobia, karmani, Baragudi, Avadai, Barbati, chola, Mambayar, chavli, is diploid with 2n= 22, belong to the family Fabaceae, and Genus *vigna*. It is well adapted to the tropics. The major cowpea growing countries are Nigeria, Niger, Burkina Faso, Ghana, Kenya, Uganda, Malawi, Tanzania (all in Africa) and India, Sri Lanka, Burma, Bangladesh, Philippines, Indonesia, Thailand etc. Cowpea is primarily used in the form of dry seeds, fodder, green pod, green manure, and cover crop. Three cultivated sub-species have been identified under the species *Vigna unguiculata*.

Origin and Distribution of Cowpea

All the evidences indicate that cowpea originated in Africa. The exact place of domestication is uncertain. Ethiopia, Central Africa, Central and South Africa and West Africa, all have been considered as probable centers of domestication as reviewed by Ng and Marechal (1985). According to Simmonds (1976) West Africa and India both are modern centers of diversity for this crop. However, it is generally agreed that the cowpea is of African origin as conspecific (means belong to the same family) wild forms are found in Africa but are absent in Asia. Of the 170 species of genus *Vigna*, 120 are in Africa, 22 in India and Southern Asia and the rest in America and Australia. The crop has spread from Africa to Asia and Europe through Egypt. Now cowpea is widely distributed throughout the tropics and subtropics.

Taxonomy of Cowpea

Vigna unguiculata (L.) Walp. Verdcourt (1970) recognized 5 subspecies. These are *viz.,*

1. *V. unguiculata* (L.) Walp. subsp. *unguiculata* (syn. *V. unguiculata* var. *radiata*) (used as pulse crop)
2. *V. unguiculata* (L.) Walp. subsp. *cylindrica* (dual purpose-both as pulse crop as well as vegetable)
3. *V. unguiculata* (L.) Walp. subsp. *sequipedalis* (vegetable type)
4. *V. unguiculata* (L.) Walp. subsp. *dekindtiana*
5. *V. unguiculata* (L.) Walp. subsp. *mensesis*

First three are cultivated and the others are wild. And the other related species are *V. luteola, V. nilotica* and *V. marina*. The three cultivated species could be easily crossed among themselves. The hybrid among them was fertile like inter-varietal hybrids.

Floral biology

It is highly self pollinated because of Cleistogamy, close proximity of the anther and sigma and simultaneous maturity of anther and stigma. Cowpea flowers are large and showy. Flowers open only once between 7 and 9 am. On cloudy days the flowers may open even in the afternoon. Though the flowers open late in the morning, the dehiscence of the anthers is much earlier. It may vary from 10 pm to 10.45 am. Cowpea is being a self pollinated crop it does not required any artificial selfing methods but for the betterment we generally go for bagging of the mature flower bud. Emasculation carried out in mature flower bud in preceding evening. Pollination is done simultaneously or in next morning from freshly opened flowers. **Breeding objectives**

- High green pod yield (vegetable type varieties)
- High seed yield (dry-seed type varieties)
- High fodder yield (fodder type varieties)
- Dual purpose (seed and vegetable type and seed and fodder)
- Earliness
- Appropriate plant type (erect, determinate for vegetable and seed type cultivars and spreading type for fodder type cultivars)
- Wider adaptability
- Photo-insensitive
- Short tender pods for whole pod processing
- Long, tender and string-less pods for fresh consumption
- Varieties suitable for inter-cropping
- **Resistance to disease:** Anthracnose, Cercospora leaf spot, Powdery mildew, Fusarium wilt, Ascochyta blight, Bacterial blight, Bacterial pustules, Cowpea yellow mosaic virus
- **Resistance to insects:** Hairy caterpillar, Leaf hoppers, Aphids, Thrips, Bruchids, Pod borer, Pod sucking insects
- **Better seed quality (acceptable to consumers):** Medium to large seed size, uniformly white/creamy/light red without black/brown scar around hilum

Breeding methods

Cowpea is a self pollinated crop, and hence the methods employed for the improvement of other self pollinated crops could well be adopted. The basic methods by which new cultivars can be developed are (a) introduction (b) selection and (c) hybridization.

These methods tend to follow a systematic sequence of steps for best results.

1. Introduction

Several countries have released cowpea varieties derived primarily from mass selection of introduced germplasm and occasionally from local varieties that are not purelines. In India, the cultivar 'Pusa Phalguni' was selected from the Canadian cultivar

'Dolique du Tonkin' and 'Pusa Barsati' from a collection from the Philippines.

2. Selection

Generally two methods of selection are practiced – mass selection and pure line selection for development of variety.

a) **Pureline selection:** It is done to improve a local variety or to select from an introduced variety or to improve an old pure line or for selection of a new character in a pure line. Malika and Sharika are single plant selection. Vyjayanthi, Lola, Kanakamony, Kairali and Pusa Phalguni are also developed through this method.

b) **Mass Selection:** It is used to improve local variety or purify existing pureline variety. In cowpea, variety developed through mass selection will be a mixture of pure lines and it will show better adaptability when compared to a single pureline.

3. Pedigree Method

Pusa Dofasli, Pusa Komal, Pusa Rituraj, CO2, Arka Garima and Arka Samridhi have been developed by this method.

4. Mutation Breeding

Protruded stigma types and male sterile lines have been developed through mutation breeding. VITA 25 is an erect breeding line carrying male sterility genes.

Breeding achievements

Sr.No.	Developing Institute	Variety
1.	IARI, New Delhi	Pusa Phalguni, Pusa Barsati, Pusa Do Fasali, Pusa Komal, Pusa Rituraj, Lola
2.	KAU, Kerala	Bhagya Lakshmi
3.	IIHR, Bangalore	IIHR 16, Arka Samrudhi, Arka Garima, Arka Suman
4.	NDUAT, Faizabad	Narendra Lobia 1
5.	TNAU, Coimbatore	Co 2, Vamban
6.	AAU,Anand	Anand Vegetable Cowpea 1
7.	SDAU, S K Nagar	GDVC 2(Gujarat Dantiwada Vegetable Cowpea 2), GC 6 (Gujarat Cowpea 6)

CHAPTER – 12 GARDEN PEA BREEDING

Introduction:

Pea [*Pisum sativum* L., 2n=14] belongs to fabaceae or leguminosae; is a commonly grown vegetable in the world. It can be grown also in mid climate of the tropics. It is commonly known as *Matar* (Hindi, Nepali) pea, split pea, garden pea, seed pea, shelling pea, combing pea, field pea, dry pea, vining pea (English), *Vatana* (Gujarati). In India pea is an extensively cultivated in Uttar Pradesh, Bihar and Madhya Pradesh. The important producers of pea in the world are USA, China, France, UK, Holland, Russia, Egypt and Australia. Pea is used as a fresh or processed vegetable. Pea is ~~a~~ also used for dehydration (Sun dried) canning and freezing.

Origin and Distribution:

The origin and progenitors of *Pisum sativum* are not well known. According to Vavilov (1949), it is originated in Ethiopia. The Mediterranean region, western and central Asia and Ethiopia have been indicated as centers of origin. Recently the Food and Agriculture Organization (FAO) designated Ethiopia and Western Asia as centers of diversity, with secondary centers in southern Asia and the Mediterranean region. The first cultivation of peas appears to have been in Western Asia, from where it spread to Europe, China and India. In classical times, Greek and Roman authors mentioned its cultivation as a pulse and fodder crop.

In India, the earliest reference to pea are found in the dictionary of Amarsimha, where it was named “Khandika” or “Harenu” in Sanskrit. De Candolle (1886) believed that the progenitor of *Pisum* existed in northern India. Purseglove (1968) opined that wild forms found in Georgia and Russia are very similar to the cultivated variety, therefore *P. elatius* may be progenitor.

Botany:

Peas (*Pisum sativum* L.) are diploid with a chromosome number of n =7 (2n=14). There are two sub species, namely *Pisum arvense* known as field pea having coloured flowers (purple, lavender or others) whose seeds are typically round with either yellow or green cotyledons and seed coat may be clear or pigmented and *Pisum sativum*, the white flowered horticultural or garden pea also known as sweet pea possesses round, dimpled or wrinkled seed whose colours varying from green, cream, or yellow.

It is an annual herbaceous legume adapted to cool and humid climates. At maturity, plant is a prostrate vine. Flowers are borne in the axil of leaf always in pairs. Lowest node at which flower initiation occurs is almost fixed for genotypes in a given environment. Most early cultivars produce first flower from nodes 5 to 11 while most late cultivars start flowering at nodes 13-15. Most early cultivars are single flowered or bear some single or some double flowers. Late cultivars are mostly double or triple flowered and number may vary from node to node.

Taxonomy:

The chromosome number of pea is 2n=14. *Pisum sativum* includes the following sub species based on the crossability and cytogentics evidence, (Simmonds, 1970).

1. *Pisum sativum* Linn. var. *hortense*: Garden pea
2. *Pisum sativum* Linn. var. *arvense*: Field pea
3. *Pisum sativum* Linn. var. *macrocarpum*: Edible podded pea
4. *Pisum sativum* Linn. var. *elatius*: wild form
5. *Pisum sativum* Linn. var. *sysiacum* : wild form **Flower biology:**

Flowers are zygomorphic (floral parts unequal in size or form**)**. Flowers are borne in the axial of leaf always in pairs. It contains five sepals in gamosepalous condition. Androecium consists of 10 stamens in 9+1 arrangement. Pollination occurs about 24 hours before flower opening. Pollen on the stigma germinates in about 8-12 hr and fertilization occurs about 24-28 hr after pollination.

It is predominantly a self pollinated crop because of chasmogamous nature. Only 0.5% to 3% cross pollination can occur due to insects.

Breeding objectives:

- High green pod yield
- Long attractive pods with more seeds/pod (9-12 seed)
- Sweetness
- High shelling percentage
- Specific maturity (Early, medium, late)
- Suitable for freezing and canning
- Resistant/tolerant to frost
- Resistant of diseases, like Downy mildew, Powdery mildew, Rust and wilt

- Resistance to insects, like Leaf minor, Aphids, Pea borer and pea stem fly **Breeding Methods:**

Introduction:

Introduction was the main method of improvement followed in earlier days. Some of the important introduced varieties is viz., Bonneville, Early Giant, Greater Progress, Early Superb, Early Badger, Little Marvel, Khapadkheda, Perfection New Line and Wisconsin.

Pedigree Method:

This is a system of breeding in which individual plants are selected in segregating generations from a cross on the basis of a pedigree record. Jawahar Mattar series 1, 2, 3, 4, 54 and 83 have been developed through this method.

Breeding for Nutritional Quality:

The wrinkled seed peas contain 26-33% protein content and in smooth seeds it is 2331%. The inheritance of protein content is governed by polygenic recessive genes which is mostly genotype dependent. The varieties GC 195 and the local cultivar Kinnauri have high soluble protein content due to the presence of a very high number of dominant genes.

Breeding for processing qualities:

Dehydration, canning and freezing are the most common processing methods of peas. Large sized wrinkled and dark green peas like Arkel are suitable for dehydration. For canning, both round and wrinkled seeded varieties like T 19 and Bonneville can be used and for freezing purpose wrinkled seeds varieties are used.

Breeding Achievements:

Sr.No.	Developed Institution	Variety/Hybrids
1	IIHR, Bangalore	Arka Ajit, UN 53-6
2	IARI, New Delhi	Arkel, Bonneville, Sylvia
3	IARI, Regional Station, Katrain	Lincoln
4	IIVR, Varanasi	VRP 2, VRP 3, Kashi Nandini, Kashi Shakti
5	TNAU, Coimbatore	Ooty 1
6	NDAU&T, Faizabad UP	NDVP 8, NDVP 10
7	PAU, Ludhiana	Punjab 88, Matar Ageta 6
8	CSAUA&T, Kanpur	Azad P-2, Azad P-3

9	JNKV, Jabalpur	Jawahar Matar 1, Jawahar Matar 2, Jawahar Matar 3, Jawahar Matar 4, Jawahar Matar 15, Jawahar Matar 54, Jawahar Peas 83, Harbhajan
10	GBPUA&T, Pantnagar	PM 2, Pant Uphar, Pant Sabji Matar 3
11	HAU, Hisar	Hisar Harit
12	VPKAS, Almora	VL Matar 3, VL Agethi Matar 7, VL 8, Vivek

CHAPTER – 13 BITTER GOURD BREEDING

Introduction:

Bitter gourd [*Momordica charantia* (L.), 2n = 22] is one of the important cucurbitaceous vegetables grown in India. It is also known as bitter melon, balsam pear or bitter cucumber. The green fruits have high nutritive value and can very well be compared with any other vegetables. The bitter principle in bitter gourd is "momordicine" an alkaloid. It is a good source of Fe, Vit- A,B,C , protein and minerals. It is good for curing blood diseases, diabetes and asthma & easily digestible. It is also known to have herbicidal effect.

Origin and Distribution:

Bitter gourd has originated in India (Indo-Burma center of origin). The regions of eastern India and southern China are suggested as possible centres of domestication. Bitter gourd is widely distributed in China, Malaysia, India, Tropical Africa and North and South America. Wild *Momordica charantia* var. *abbreviate*, a native of Asia, may be the progenitor to domesticate.

Botany:

It has six valid species in India. They are grouped under two headings:

Monoecious group:

- *M. charantia* L. (Bitter gourd)
- *M. balsamina* L. (Balsam pear) **Dioecious group:**
- *M. dioica* Roxb. (Spine gourd)
- *M. sahyadrica* Joseph and Antony
- *M. cochinchinensis* (Lour) Spreng (Sweet bitter gourd of Assam)
- *M. subangulata* Blume ***M. dioica :***

Momordica dioica, commonly known as kakrol or spiny gourd or spine gourd and also known as bristly balsam pear, prickly carolaho, teasle gourd, kantola, is a species of flowering plant in the Cucurbitaceae/gourd family. It is used as a vegetable in all regions of India and some parts in South Asia. It is perennial dioecious climber with tuberous root and spiny fruits. The species occurs throughout India and in Asia, mostly in wild state. It is grown for its non-bitter fruits. The chromosome number is 2n=28. *M. dioica* will not cross with *M. charantia*.

M. cochinchinensis :

It is also called as sweet gourd of Assam or *kheksa*. It is cultivated in Asia for its immature fruits. Oil extracted from large black seeds used for cooking purpose.

Plants are monoecious annuals with medium size vines. Satminate flowers are small, yellow and borne on long slender pedicles. The pistillate flowers are solitary, have small pedicel and are easily distinguishable by oblong to long distinct green colour ovary.

Floral Biology:

The crop is highly cross pollinated due to monoecy. Male and female flowers are being borne on the same plant. Flowers are unisexual, large, showy and yellow. There are five calyx and five corolla. Staminate flowers are produced mostly in long pedicels and borne singly. Ovary is inferior and style is short and thick.

Flowers opening by 4.00 AM and gets completed by 9.00 AM. Anther dehiscence starts by 5.00 AM and completed by 7.30 AM. There is a varietal difference for time of anthesis and anther dehiscence. Male flower are drop in the evening. Stigma is receptive 24 hr before to 24 hr after anthesis. Pollination takes place by bees. Pollen fertility is maximum at the time of anther dehiscence.

Chromosome number:

M. charantia and *M. balsamina* have 2n=22 while *M. dioica* has 2n = 28 chromosome. *M. charantia* probably originated from *M. tuberose.* In *M. charantia* natural triploids are reported in India which contain 2n=33 chromosome.

The polyploids are found inferior then diploid in economic characters to diploids with fewer female flowers, large flowers and petals and flowering later than diploid. The fruit set has been poor, and seed viability and germination also decreased.

Breeding Objectives:

- To develop early bearing cultivars
- To increase high female to male sex ratio
- To breed varieties for fruit shape, size, and colour as per consumers' preference
- To develop varieties which should have immature seeds for longer period during green edible stage
- To increase yield
- To develop resistance against powdery mildew, downy mildew and mosaic
- To develop resistance to abiotic stress.

Hybridization techniques:

The monoecious nature of the plant, with male flowers appearing first, makes hybridization simple. Male flower buds from the chosen parent can be nipped off as and when they appear, and pollination resorted using pollen collected from male parents. This method can be used for large-scale F_1 seed production. Low temperature increases the production of female flower under short day condition.

Breeding Methods:

1. Selection methods:

In India, single plant selection and mass selection have been followed to develop high yielding varieties in bitter gourd in India. Pusa Do Mousmi, Preethi, Priyanka, Konkan Tara, Arka Harit, CO 1 and Pusa Vishesh have been developed through single plant selection.

2. Heterosis Breeding:

Bitter gourd is monoecious. Male flower bud from female parent is nipped off as and when they appear and pollination is resorted using pollen collected from male parent. This method can be used for large scale F_1 seed production.

Gynoecious line was also reported in bitter gourd (Gy263B) and this line can be exploited for heterosis breeding.

3. Mutation Breeding:

Rajasekharan and Shanmugvelu (1984) irradiated local cultivar MC 103 with gamma rays and a promising line was isolated in M_2. It was subsequently stabilized for its characters for 6 generation and released as MOD 1.

4. Polyploidy Breeding:

Wanjari and Phadnis (1971) induced tetraploidy in bitter gourd by colchicine treatment.

Breeding for quality traits:

BG 12, BG 13, BG 14, C 96 and Sel. 1 were suitable for processing (Kalra *et al* 1983). BG 14 was the best for canning and dehydration. Awasthi and Jaiswal (1988) identified Coimbatore Long, Ripe Gang Gorakhpur and Karela jhalardar suitable for processing.

Breeding Achievements:

Sr.No.	Developing Institute	Variety
1	IIHR, Banglore	Arka Harit

2	IARI, New Delhi	Pusa Vishesh, Pusa Do Mausami, Pusa Hybrid 1, Pusa Hybrid 2
3	KAU	Priya (VK1), Preethi (MC 84), Priyanka
4	TNAU, Coimbatore	Co 1, Coimbatore Long Green, MDU 1, Coimbatore Long White, CoBg H1
5	CSAUA&T, Kanpur	Kalyanpur Barmasi, Kalpyanpur Sona
6	Konkan Krishi Vidyapith, Dapoli	Konkan Tara
7	PAU, Ludhiana	Punjab 14
8	MPKV, Rahuri	Hirkani, Phule Green Gold, Phule Priyanka
9	GBPUAT, Pantnagar	Pant Karela 2, 3
10	YSPU of H&F, Solan	Solan Green, Solan safed

CHAPTER - 14
ASH GOURD BREEDING

Introduction:

Ash gourd [*Benincasa hispita* (Thunb.) Cogn., 2n=24](*syn.,* wax gourd, hairy melon, winter melon, ash pumpkin, white pumpkin, fussy melon, Chinese preserving melon, white gourd) is an important warm season cucurbit vegetable. It is grown throughout old world tropics. In India, it is grown in U.P. and Delhi for preparation of petha and in southern states for vegetables. The famous petha is made of mature ash gourd fruits. It is also grown for its immature fruits which are used as vegetables. It has curative property against peptic ulcers. Seeds are used as a vermifuge. Young shoots, leaves and flowers are used as food. It is also used a rootstock for melon.

Origin and Distribution:

Ash gourd is probably a native of Malaysia. It is grown throughout the plains of India, Burma and Ceylon up to an altitude of 1500 m. The cultivated forms may have originated in Southeast Asia. It is not found in wild form. No related species is known in the genus *Benincasa.* It is grown throughout tropical Asia, Caribbean and United states. It is also grown in east and southern Africa.

Taxonomy and Botany and floral biology:

It is the only species with a chromosome number 2n=24. It is monoecious annual herb growing to about 5-6 m length. Fruits are called as pepo. Because of wax coating, mature fruits can be stored for longer period. It is cross pollinated due to monoecious condition. Climates play an important role in determining the ratio of pistillate to staminate flowers. Bees are the pollinators.

Two botanical forms are seen in the ash gourd viz., the *typical and emarginated.* The *emarginated forms* are lacks the velvet testa and marginal band around the seeds which are characterize the *typical form*. Randhawa *et al.,* (1982) observed both monoecious and andromonoecious forms in ash gourd. The ratio of staminate to pistillate flower was 34.1. Anthesis takes place between 4.30 to 7.30 hrs with anther dehiscence between 3.00 to 5.00 hrs. Pollen fertility is maximum at anthesis.

Walters and Walters (1989) proposed 4 major categories as cultivar group:

- Unridged winter melon group
- Ridged winter melon group

- Fuzzy gourd group
- Wax gourd group

Mortan (1971) described 3 cultivar types in wax group on the basis of fruit characters:

- Fruits nearly round and essentially hairless
- Fruits nearly round and hairy and
- Fruits oblong and hairy **Breeding methods:**

Ash gourd is an under exploited and underutilized cucurbit vegetable. Being a cross pollinated crop, breeding methods like Mass selection, Pedigree method, Bulk method and Back cross method can be used.

Breeding Achievements:

Sr.No.	Developing Institute	Variety
1	TNAU, Coimbatore	Co 1, Co 2
2	KAU, Vellanikkara	KAU Local, Indu
3	IARI, New Delhi	Pusa Ujjawal
4	IIVR, Varanasi	Kashi Ujjawal, Kashi Dhawal
5	APAU, Rajendranagar	APAU Sakthi

CHAPTER – 15 BOTTLE GOURD BREEDING

Introduction:

Bottle gourd [*Langenaria siceraria* (Mol.), Standl., 2n=22] also known as *Calabash,* is one of the major cucurbits grown throughout the tropics and subtropics of the world especially Asia, Africa and South America. The word bottle gourd may have derived from mature harvested fruits used as bottle, utensil or pipe. It is grown throughout India and its fruits are available in the market all through the year. It is also known as white flowered gourd. It is one of the most important vegetables of ancient China. There is a wide range of plant variability in India and Africa. The mature dried fruits are used for making storage jars, utensils and musical instruments (Decker-Walters *et al.*, 2001). It is commonly cultivated in India, Sri Lanka, Indonesia, Malaysia, Philippines, China, Hong Kong, Tropical Africa, Colombia and Brazil.

It is a herb widely grown in tropical countries like India. The unripe fruit is commonly eaten as a vegetable (Ghule *et al.*, 2009). Traditional medicine is widely practiced in India. It is generally grown for its tender fruits, which contains 96.1 g water, 2.5 g carbohydrates, 0.6 g fibers, 0.5 g minerals, 0.2 g proteins and 0.1 g fats in 100 g edible parts of the fruit (Gopalan *et al.*, 1982). Bottle gourd prevents excess loss of sodium and reduces fatigue especially during summer. It is low calories diet, good for peoples suffering from diabetes and jaundice. The fruits have medicinal values and used as cardio-tonic, aphrodisiac, hepatoprotective, analgesic, anti-inflammatory, expectorant, diuretic and antioxidant agents (Ghule *et al*., 2009 and Mohan *et al*., 2012). Bottle gourd fruit juice is advocated by traditional healers for flatulence, diabetes mellitus, hypertension, liver diseases and as a diuretic (Ghule *et al.*, 2007).

The crop thrives well in hot humid weather conditions, but it also grows well and continues to produce good harvest under frost free low temperature conditions if the plants have attained sufficient vegetative growth before the onset of cool weather, as is common in northern Indian plains where August- September sown crops of Bottle gourd produce remunerative off season produce during cool months of November, December and January.

Bottle gourd, generally known as poor man's vegetable in India, is attaining fast popularity among the health conscious urban elite, which has encouraged round the year cultivation of this potentially important vegetable in almost all part of the country, except in very cool regions during winter.

Origin and Distribution:

According to De Candolle (1882), bottle gourd has been found wild in India, east Africa and Madagascar. The centre of origin has been located as the coastal area of Malabar (North Kerala) and humid forest of Dehradun (North India). It has spread to western countries from India to Africa. It is known to be the first plant to be domesticated in America and also the oldest cultivated plant.

Sex Expression:

In bottle gourd, flowering starts 40–50 days of sowing, but influenced by cultivar and environmental conditions also. In general, staminate flowers appeared first than the pistillate in the axis of nodes on main and secondary branches. The node of first female flower is considered as an indicator of earliness. The monoecious sex expression predominates in bottle gourd. Male flowers have larger petals than female flowers.

Botany and Floral Biology:

Bottle gourd is monoecious, annual vine with soft pubescence. The flowers are white, solitary, showy and open at night. Since flowers open at night, selfing or crossing must be done earliest in the morning. The flowers have five petals. The staminate flowers are on long pedicels. The pistillate flowers are single with short peduncle and hairy ovary. The fruits are variable in size and shape.

Being a monoecious crop, it is strictly cross pollinated crop. Bees are pollinators. Time of anthesis is between 5 PM and 8 PM under Punjab conditions. Stigma is receptive 36 hr before anthesis and 60 hr after anthesis. The studies at IIHR, Banglore have indicated that anthesis starts from 9 AM and gets completed by 7 PM the same day. Anther dehiscence begins at 11 AM and completes at 2 PM the same day. Both male and female flowers open at the same time.

Fruit Shape and Size

Although fruit is essentially a berry, it is called a pepo because of its hard and tough rind at maturity. The term 'gourd' refers to the hard tough rind. The fruits are indehiscent. A great variability is encountered in fruit shapes. They may be long, cylindrical, curved, necked, oblong, round, flat-round, conical, pear-shaped, club-shaped etc. But Bottle gourds are broadly classified as long and round types.

Crossability:

It has been found that cultivated bottle gourd is not crossable with other five relatives of genus *Lagenaria i.e. L. breviflora*, *L. abyssinica*, *L. rufa*, *L.sphaerica* and *L. guineensis.*

Genetics:

Information on inheritance of characters is limited in bottle gourd. In bottle gourd fruit colour is monogenic and green colour is dominant over white. Fruit shape is monogenic.

Long fruit is dominant over round fruit. Maturity time and seed size is polygenic in nature.

Breeding objectives:

- To have higher yield
- To increased more fruit number per vine
- To have suitable fruit weight as per market demand
- To develop early variety
- To develop non-bitter fruit
- To develop variety having non-fibrous flesh at edible stage
- To develop variety having sparse hairs present on skin
- To develop varieties having various shapes like, round, long, cylindrical
- To increase high female : male flower ratio
- To have attractive green fruit with long colour retention

- To develop varieties resistant to powdery mildew, downy mildew and cucumber mosaic virus and red pumpkin beetle **Breeding methods:**

The breeding methods in bottle gourd are same as of other cucurbits and form a distinct group from other cross-pollinated crops. The cultivated bottle gourd is monoecious and entomophilous. Self-pollination also occurs, because insects do not distinguish flowers from the same plant or different plants at the time of involuntary pollination. This is one of the reasons for absence or even, if present, negligible degree of inbreeding depression than other cross-pollinated vegetable crops like onion, cabbage, cauliflower, carrot, radish etc. Though, cucurbits are cross-pollinated and monoecious, but the population structure is similar to the inbreeder than that of out-breeders (Allard, 1960). Therefore, inbred lines can be developed without loss of vigour in the bottle gourd. This does not mean that mass selection is not suitable, but does have value for breeding superior populations rather than individual plants (Alvarez, 1998). Thus, taking advantage of both methods, suitable modifications can be made for improvement as per objectives and inheritance of the traits.

Plant introduction, mass selection, recurrent selection, pedigree method, bulk population method, back cross method, hybridization and heterosis breeding are the common approaches followed for genetic improvement in bottle gourd.

Varieties developed in India by selection from local material are Pusa Summer Prolific Long, Pusa Summer Prolific Round, Pusa Naveen, Pusa Sandesh, Pusa Samridhi, Punjab Long, Kalyanpur Long Green, Narendra Jyoti, Narendra Rashmi, Narendra Sankar Lauki-4, Kashi Bahar, Kashi Komal, Pant Lauki-3, CO-1, Samrat, Rajinder Chamtkar, Arka Bahar, Azad Nutan and BBOG-3-2 and those through hybridization and selection are Punjab Round (LC-11 × LC-5), Punjab Komal (LC- 11 × LC-5), Narendra Dharidar (NDBG-108 × NDBG-1), Kashi Ganga-1 (IC 92465 × DVBG 151) and Thar Samridhi (Banswara Local-1 × Gujarat Local-1).

Heterosis Breeding:

Heterosis breeding offers an opportunity in bottle gourd due to monoecious nature of flowers, high number of seeds per fruit or per pollination and requirement of less number of plants per unit area. This can be exploited not only for high yield, but for early maturity, uniform size, shape, colour, tenderness, longer harvesting span and resistance to biotic and abiotic stresses.

The first public sector hybrids *viz.,* Pusa Meghdoot (Pusa summer long × Sel 2) was developed by IARI, Pusa, New Delhi in 1971 which was suitable for both spring and summer season. In

same year *i.e.,* 1971 another hybrid, Pusa Manjari (Pusa Summer Prolific Round × Sel 11) was developed by IARI, Pusa. Other released hybrids include Pant Sankar Lauki – 1, Pant Sankar Lauki – 2 and Pusa hybrid.

Male Sterility:

In bottle gourd, genic male sterility controlled by *ms* allele was reported by Dutta (1983), but so far has not been utilized for development of hybrids. Heterosis breeding has been commercially exploited and a number of popular hybrids have been developed in both public and private sector (Singh and Nath, 2011).

Hybrid seed production:

Bottle gourd is endowed with following unique combination of desirable attributes that make it suitable for heterosis breeding programme.

- It is generally monoecious in nature, which makes hand emasculation easier in female parents by merely pinching off the male flower buds prior to dehiscence and anthesis.
- Both male and female flowers are large due to which controlled hand pollination becomes an easier task.
- The fruit set success in the hand pollinated female flowers is very high, provided chosen flowers are at the proper position in the plant.
- It is a cross pollinated crop where high degree of economic heterosis is reported for desirable traits such as yield, earliness, number of fruits etc.
- The crop suffers only negligible inbreeding depression in the process of development of uniform inbred lines.
- Good parents produce several hundred seeds per fruit which weigh nearly 100g, and due to wider spacing requirements 2.5 kg to 3.0 kg seeds are enough for planting one hectare land area which can be produced only by 25 to 30 good fruits.

Thus hybrid seed production in Bottlegourd is economically feasible. However, very little information is available regarding the standardised method of hybrid seed production in this crop. Choudhury and Singh (1971b) proposed a method of hybrid seed production in which male buds are pinched off when male and female parents are grown in adjacent rows. Thus all the fruit set in female parent would be through cross pollination by insects. The precaution should be made that no single male bud is left in the female parent; otherwise it could promote selfing or sibbing within the female parent. Hybrid seed production can also be done by direct

and reciprocal controlled hand pollination on both the parents. This procedure doubles the amount of hybrid seed produced within a given area, as compared to the method suggested by Choudhury and Singh (1971b). The use of genic male sterile line as proposed by Dutta (1983) in hybrid seed production needs further investigation. Similarly search of dominant genetic markers to facilitate the identity of true to the type F1 hybrid plants before the onset of flowering is also an important aspect to be worked out to strengthen the hybrid seed production in this crop.

Maintenance of Inbreds:

Since there is no much vigour loss due to inbreeding, uniform inbreds of bottle gourd could be developed with comparable vigour of open pollinated varieties. They can be maintained through open pollination by growing them at proper isolation distance. 1000-m isolation distance is quite appropriate. Alternatively, the inbreds can also be maintained by hand pollination along with other genetic stocks. Seed production principles such as land requirement, field inspection etc. should be carefully observed. Care must be taken for rouging out the undesirable off types at right stages of plant growth *viz.* (i) before flowering, (ii) at the time of flowering and (iii) at the time of fruit set and maturity to maintain true-to type plant characteristics. To bring about improvement in heterosis level in the F_1 hybrids, progeny breeding, recurrent, and reciprocal recurrent selections may also be practiced to improve the inbreds, as suggested by Sharma *et al.* (1983). The seed production of open pollinated varieties is similar to that of maintenance of inbreds.

Breeding achievements:

Sr.No.	Developing institute	Variety/Hybrid name
1	*Variety* Pusa summer prolific long, Pusa summer prolific round, Pusa Naveen, Pusa Sneha, Pusa Supriya	IARI, New Delhi
	Hybrid Pusa Meghdut, Pusa Manjari, Pusa Hybrid 3	
2	Punjab Komal, Punjab Round, Punjab Long	PAU, Ludhiana
3	Arka Bahar	IIHR, Banglore
4	Kalyanpur Long Green	CSAUAT, Kanpur
5.	Pant Sankar Lauki 1, Pant Sankar Lauki 2 (Hybrids)	GBPUAT, Pantnagar
6.	Gujarat Anand Bottle Gourd Hybrid 1, Anand Bottle Gourd 1	AAU, Anand
7.	Samrat	MPKV, Rahuri
8.	Rajendra Chamatkar	RPCAU, Smastipur, Pusa

CHAPTER – 16 RIDGE GOURD BREEDING

Introduction:

Ridge gourd [*Luffa acutangula* (Roxb.) L., 2n=26] also known as four angled gourd/angled loofah/ribbed gourd is an underexploited vegetable crop. Tender fruits which are green in colour with shallow ridges are used in soups and curries or as a cooked vegetable. The fiber obtained from this dry fruit is used in industries for filters or various sorts, good pot holders, table mats, bath room mats, slippers and shoe soles. In ridge gourd, the medicinal properties due to secondary metabolite "cucurbitacin".

Origin, Distribution and taxonomy:

Ridge gourd belongs to family Cucurbitaceae and it is domesticated in India. Wild forms of ridge gourd are found in the north-west of India. They are grown in Malaysia, Ceylon, Japan and Brazil. The genus *Luffa* is comprises nine species, of these, seven are native to India *viz., L. acutangula, L. cylindrical, L. echinate, L. graveolens, L. hermaprodiya, L. tuberosa* and *L. umbellate.* Morphological evidence suggests that var. *acutangula* was derived from var. *amara*. Trimonoecious form of *L. acutangula* is common in Nepal. Trimonoecious cultivar – Satputia is cultivated in Bihar and Bengal. It is easily crossed with *L. acutangula.* Other related species are *L. operculate* (L.) Cogn. [grown in tropical America], *L. graveolens, L. umbellate, L. achinata, L. pentalldra, L. gigante, L. scabra* and *L. narylandica.*

Botany:

Ridge gourd is a large climber with long tap root system and Palmate leaves with 5-7 lobes. The fruits are about 15-30 cm long, cylindrical or club shaped with 10 prominent wing like ridges. The seeds are much compressed, 10-12 mm long, slightly corrugated on the edge and black when ripe.

Floral Biology:

Ridge gourd is monoecious in nature but different sex forms are available *viz.,* androecious, gynoecious, gynomonoecious, andromonoecious and hermaphrodite. Male flowers with 5 stamens are born on 10-20 flowered racemes and female flowers are solitary on the same axis as that of male flower.

Flowers are open in the evening. Seeds are black and pitted while in smooth gourd, seeds are flattened. Anthesis occur between 17-20 hrs and anther dehiscence is between 17 and 20 hrs. Pollen fertility is maximum on the day of anthesis and lasts till 2-3 days in winter and

one to one and half days in the rainy season. Stigma is receptive 6 he before to 84 after synthesis. Expression of female flower is more prone to micro environmental stress factors.

Breeding Objectives:

- Earliness
- High female : male sex ratio
- Uniform, thick, cylindrical fruits free from bitterness, green to light green
- Tender, non-fibrous fruits for longer periods
- High fruit yield
- Resistance to powdery mildew and downy mildew **Breeding Methods:**

1. Mass selection:

Variety "Haritham" has been evolved through this method by KAU.

2. Heterosis Breeding:

Application of male sterility in heterosis breeding:

It is an important component and widely used in hybrid seed productions of vegetables. Emasculation can be avoided and labour saved if MS line used as female parent. Male sterile line in ridge gourd was first reported by **Deshpande *et al* (1979).** They reported that there are no observable differences in germination and vegetative growth between male sterile plant and normal plants except in inflorescence and male flower. They also reported that no viable pollen was developed by the mutant. Novel source of male sterility in ridge gourd was reported from Kerala (Pradeepkumar *et al.,* 2008). They developed tissue culture protocol for maintenance of MS line.

3. Polyploidy Breeding:

Colchicine induced tetraploids of Taiwan variety "Tokado" exhibited thicker and shorter fruits, stouter fibres and lower fertility than corresponding diploids.

Advances in Biotechnology:

Protocol for the clonal propagation of male sterile mutant was standardized by Pradeepkumar *et al.,* 2008. MS + BA 0.5 mg/l and MS + IAA 105 mg/l + BA 2.0 mg/l were used for inoculating nodal cuttings of male sterile line from field. MS + BA 1.0 mg/l was the promising establishment media. The in vitro shoots were successfully rooted in MS medium (Half strength) fortified with IBA 1 mg/l and charcoal 200 mg/l.

Breeding achievements:

Sr.No.	Developing institute	Variety

1	IIHR, Banglore	Arka Sumeet, Arka Sujat
2	IARI, Dew Delhi	Pusa Nasdar
3	GBPUA&T, Pantnagar	Pant Torai-1
4	TNAU, Coimbatore	Co 1, PKM 1, Co 2
5	HARP, Ranchi	Swarna Manjari, Swarna Uphar
6	PAU, Ludhiana	Punjab Sadababar
7	KKV, Dapoli	Konkan Karita
8	OUAT	Ukal Trupti
9	KAU, trichur	Deepthi, Haritham

CHAPTER – 17 SMOOTH GOURD BREEDING

Introduction:

Smooth gourd [*Luffa cylindrica* L. Roem.] has 2n=26, is one of the most important cucurbits which is grown widely in India. Smooth gourd belongs to family Cucurbitaceae and it is domesticated in India. It has known as dish rag gourd, smooth luffa, gourd luffa, loofah, vegetable sponge, bath sponge and dish cloth sponge. Wild forms of wild gourd are found in the north-west of India. Its unripe tender fruits popular and well known culinary vegetables in India with good nutritive value and high yield potentials. *Luffa cylindrica* has been reported to possess both medicinal and nutritional properties. *Luffa* sponges are used for personal hygiene and household cleaning in many countries. Some other uses of *luffa* sponges are bathroom sponge, component of shock absorbers, sound proof linings, utensils cleaning sponge, packaging materials, making crafts, filters in factories, bio-diesel and chemical extractions etc. In the developed world, the demand of *luffa* sponges products for skin care. Smooth gourd is very much similar to ridge gourd with respect to the morphology, physiology and breeding aspects. But there are certain differences between both of them which are represented in the below table:

Sr.No.	Ridge Gourd	Smooth gourd
1	It is generally having six sex forms	It is having only one sex form *i.e.,* monoecious
2	Leaves are shallow lobed and larger	Leaves are deeply lobbed and smaller
3	Generally no white patches are seen on the leaves	White patches are observed on the leaves
4	Ovary is disc shape and not tomentose	Ovary is cylindrical and tomentose
5	Fruits are angled	Fruits are smooth
6	Seeds are black and pitted	Seeds are black & white flat which are not pitted
7	Male flowers are smaller	Male flowers are relatively larger than ridge gourds

Origin and Distribution:

Smooth gourd belongs to the family Cucurbitaceae and *Luffa* an old world genus comprises of nine species. Out of them, seven species including *Luffa acutangula, L. cylindrica, L. echinata, L. graveolens, L. hermaphrodita, L. tuberose* and *L. umbellate* are native to India. Sanskrit name "Koshataki" indicates its early cultivation in India. Among the available species *L. acutangula, L. cylindrica* and *L. hermaprodita* are economically important for their tender fruits consumed as vegetable. Both monoecious cultivated species *Luffa aculangula* and *Luffa cylindrica* have evolved from the monoecious wild species *L. graveolens.* They have a long history of cultivation in the tropical countries of Asia and Africa. Indo-Burma is reported to be

the centre of diversity for sponge gourd. The main commercial production countries are China, Korea, India, Japan and central America. In

India, sponge gourd is cultivated in Andhra Pradesh, Tamil Nadu, Karnataka, Gujarat, Maharashtra, Assam, West Bengal, Uttar Pradesh and Punjab.

Botany:

Luffa requires warmer season temperatures and a long frost-free growing season when grown in temperate regions. *Luffa cylindrica* is a large climbing vine, with a thin but very tough light green, succulent stem, attaining a length of 10 to 30 feet. The flowers are monoecious, five petals, united below into a bell shaped corolla. Both male and female flowers are on same plant and are pollinated by bees. The fruits are smooth and cylindrical shaped and it produces at least 30 flat blackish seeds.

Floral Biology:

It is monoecious but male and female flowers are borne at the same node. Female flowers are borne singly whereas male flowers appear in clusters. One male flower from the cluster opens at one time. Flowers are unisexual-monoecious in nature. Female flowers solitary between male inflorescences. Pistilate and staminate flowers may occur in the same leaf axil also. Flowers are yellow and showy, open in the early morning hours and are suitable for selfing/crossing almost throughout the day. Pollen fertility is maximum on the day of anthesis.

Genetics:

Four sex forms are available in *L. acutangula. L. cylinricda* is strictly monoecious and the Interspecific hybrids between two species is also monoecious. Bitterness is governed by single dominant gene 'Bi' (Thakur and Choudhary, 1966). They are also reported that: Corolla colour (Orange yellow with green veins), fruit surface (smooth), seed surface (non pitted) and type of androecium (five free stamens) were monogenically inherited (Ram, 2006).

Breeding Objectives:

- Earliness
- High female : Male ratio
- Uniform thick cylindrical fruits free from bitterness
- Tender non-fibrous fruits for longer time
- High fruit yield
- Resistance to powdery mildew, downy mildew, fusarium wilt, tomato leaf curl New Delhi virus, leaf minor, fruit fly and red pumpkin beetle **Breeding Methods:**
- Single plant selection:

- Mass selection:
- Pedigree method:
- Bulk population method:
- Heterosis breeding:
- Polyploidy breeding:

Breeding achievements:

Sr.No.	Developing Institute	Variety
1	IARI, New Delhi	Pusa Chikni (1975, Selection from indigenous material), Pusa Supriya (1997, Selection from indigenous material) Pusa Sneha (2004, Selection from indigenous material)
2	CSAUA&T, Kanpur	Kalyanpur Hari Chikni (1983, selection) Azad Toria Chikni 1 (2006, selection)
3	HARP, Ranchi	Swarna Prabha (2006, selection)
4	MPKV, Rahuri	Phule Prajakta (2001, selection)
5	GAU, Anand	Gujarat Sponge Gourd 1 (2005)
6	PAU, Ludhiana	PSG-9 (Selection)

CHAPTER – 18 POINTED GOURD BREEDING

Introduction:

The pointed gourd (*Trichosanthus dioica* Roxb., 2n = 22) also called 'parwal' or 'patal', is an important cucurbitaceous vegetable extensively cultivated in India particularly in the state of Bihar, eastern Uttar Pradesh, West Bengal, Assam and to some extent in Orissa, Madhya Pradesh, Maharashtra and Gujarat. This is perennial and dioecious vegetable crop. The green, tender fruits of pointed gourd are consumed as a vegetable; however, new, tender shoots and leaves are also used as vegetables. It is easily digestible, diuretic and laxative. The fruits show some prospects in the control of certain cancer like conditions.

Pointed gourd is a perennial herbaceous vine. In pointed gourd, fruits are rich in vitamin - A and protein levels at 10 times higher than that of bottle gourd and 4 times higher that of snake gourd, ridge gourd and any other cucurbits. That is why it is recommended during convalescence. Because of its nutritive content also known as**,**

'King of gourds' and **'Green potato'.** It is mostly propagated through vine cuttings and root suckers.

Trichosanthes is the largest genus of family cucurbitaceae. Important species of *Trichosanthes* are as under:-

1. *Trichosanthes cucumerina var. anguina* (snake gourd)
2. *Trichosanthes pilosa* (Japanese snake gourd)
3. *Trichosanthes kirilowii* (Chinese snake gourd / Chinese cucumber *)*
4. *Trichosanthes rosthornii*
5. *Trichosanthes lobata* **Origin and Distribution:**

Trichosanthus is a large genus, principally of Indo-Malayan distribution, with about 44 species of which 22 are found in India. The centre of origin of *Trichosanthus* is not precisely known but most authors agree on India or the Indo-Malayan region as its original home.

Botany and Floral Biology:

The pointed gourd, a vegetatively propagated perennial cucurbit, is viny in nature. Bitter principles (cucurbitacin) are found in root, shoot and even in leaf, but generally not in fruit. The plant is dioecious, with male and female flowers produced in separate plants.

Flowers are white in colour, solitary, and sessile. Inflorescence is racemose type. A staminate flower contains three stamens with short filament. Anthers are free and have no staminodes. Pistillate flowers have gynoecium with 5 carpels. Ovary is oblong, fusiform, globose. Anthesis time is between 7:00 am to 7:00 pm and till the 9:00 pm.

Pollen remains viable for 46 -49 hrs. Stigma becomes receptive for 7 hrs. **Breeding objectives:-**

1. Development of high yielding and early maturing variety
2. Fruit have immature seed, with desired tenderness for marketing
3. Clonal selection is promising approach for genetic improvement in this species
4. There is as wide scope for varietal improvement through hybridization and selection
5. Need to introduce parthenocarpy in pointed gourd to develop fruit without pollination and fertilization
6. Increase the storage life
7. Introduced polyploidy **Breeding methods:**

Pointed gourd is an asexually propagated, perennial vegetable crop. This crop is highly cross pollinated due to dioecy and is thereby heterozygous in relation to the seedlings. The clones are heterozygous and this situation is maintained indefinitely by vegetative propagation. Breeding methods in this crop are as outlined below:

1. Clonal selection:

Asexual propagation provides unique advantages and opportunity in the breeding of this crop. A single outstanding plant selected from a population may form the basis of new variety.

Singh assigned the pointed gourd plants to four groups based on morphological variation (shape, size and striation) of the fruit as follows:

1. Plants bearing 10-13 cm long, dark-green fruits with white strips
2. Plants bearing 10-16 cm long, thick, dark-green fruits with very faint pale-green strips
3. Plants with small (5-8 cm long) roundish, dark-green stripped fruits
4. Plants with small fruits tapering towards the ends, green and striped

NDUAT, Faizabad developed three varieties *viz.,* FP-1 (round, green), FP-3 (spindle-shapped, green stripped) and FP-4 (spindle-shapped, light green) for commercial cultivation through this method.

Swarna alaukik, Swarna rekha and Swarna Suruchi also developed through this method. Rajendra parwal 1 & 2 were developed by Rajendra Agriculture University, Samstipur, Bihar.

2. Hybridization:

Pointed gourd is a dioecious crop so it is impracticable to render to homozygosity in the male and female parents. In this case, a male parent selected from an established pointed gourd field may be used as a tester parent. In India, some hybrids were released by different institute are *viz.*, Chess hybrid 1 (First hybrid of country), Chess hybrid 2, Kashi alankar and Arka Neelachal kirti.

3. Selection:

A large number of selection known by localities are Bihar sharif, Faizabad parval 1, 2 & 4, Chhota hilli, hilli, and Dandali. NAU also developed a variety GNPG 1.

Parthenocarpy:

Parthenocarpy has been introduced by spraying of 2000-3000mg/L of NAA prior to anthesis. Mixed pollen from *L. leucanta* and *M. Charantia* increase the parthenocarpy.

CHAPTER – 19 IVY GOURD BREEDING

Introduction:

Ivy gourd (*Coccinia grandis* (L.) Voigt, 2n=24); is also known as little gourd, kundru, kundri, tindora, gilodi, baby watermelon, gentleman's toe, coccinia *etc.* which is a popular vegetable in many parts of West Bengal and Karnataka. It is a semi-perennial dioecious plant with small fruits, It's tender immature fruits make excellent curries.

Apart from its culinary uses it has many medicinal and therapeutic uses. It is a good source of Vitamin A, Vitamin C, Beta-carotene, B_1, B_2. The fruit is aphrodisiac, allays thirst useful in biliousness and diseases of the blood. Juice which is prepared from thick tap root is useful in diabetes and its leaf extract is useful for fever. The green fruit chewed to cure sores on the tongue. Powder which is prepared from bark acts as a good cathartic. Leaves applied externally in eruptions of the skin.

Origin and distribution:

This originated in India, is distributed in Burma, Pakistan and whole of the south-East Asia. It is also seen in tropical Africa.

Botany:

It belongs to family Cucurbitaceae, genus *Coccinia*. *C. indica* & *C. cordifolia* are used as synonyms of *C. grandis.* The genus has 35 species distributed in tropical Africa and Asia. The genus is included in the subtribe Benincasicae *(Sr.)* C. Jdffr. tribe Benincaseae Ser., and subfamily Cucurbitaideae. The plant is semi-perennial, dioecious, creeper, consisting distinct male and female plants. It has long tuberous root. Fruits are ovoid or elliptic, about 4-5 cm long and 1-2 cm in diameter. They are smooth and bright green with white stripes when immature and scarlet red when ripe.

Floral Biology:

Ivy gourd is highly cross pollinated due to dioecious nature. Gynodioecious forms consisting of female and hermaphrodite flowers have also been observed. The flower colour of ivy gourd is white. The male flower is 2 -3.8 cm long subfilliform, whereas female flower is 1.3 – 2.5 cm long, having fusiform, glabrous and slightly ribbed ovary. Corolla is 2.5 cm

long, veined and pubescent from inside and glabrous outside. Methods of propagation are essentially through stem-cuttings and seeds.

Chromosome Number:

The somatic chromosome number is 2n=24. Triploids with 2n= 36 have also been observed.

Breeding Objectives:

(1) To develop high yielding variety

(2) To develop early maturing variety

(3) To develop bold and tender fruits

(4) To increase the storage life

(5) To develop varieties resistant to biotic and abiotic stresses **Breeding Methods:**

Breeding work done on ivy gourd is very meager. Selection of a few desirable strains was made in some regions. At the IIHR, Bangalore, preliminary evaluation of a few local collections led to isolation of line IHRS, which has good fruit quality and bearing capacity. Being strictly a cross-pollinated crop with possibility for vegetative propagation, methods of breeding which can be successfully are individual plant selection, mass selection to improve varieties, heterosis breeding and vegetative propagation of heterotic combinations, intergeneric crosses, polyploidy breeding, micro-propagation and clonal selection.

Breeding Achievements:

Sr.No.	Institute	Varieties/Hybrids
1	IGKV, Raipur, Chattisgarh	Indira Kundru-05, 35
2	KAU	Sulabha
3	NAU, Navsari	GNLG 1

CHAPTER – 20 SPINE GOURD BREEDING

Introduction:

Spine gourd [*Momordica dioca* Roxb., 2n=28] is a perennial and distinctly dioecious climber belongs to family cucurbitacae. It is locally known as Kakrol, Kankoda, Kantola, Kartoli, Kantoli, Metha Karela, Khekhsa, Padora, Bhat Karela, Kankro and Bhat korola. It is medicinally and economically important vegetable crop. It is found in the forest and semi forest areas of Southern India, West Bengal, Maharashtra, Madhya Pradesh and Orissa. This vegetable did not gain much popularity until it was discovered to have high nutritional and medicinal value. It is consumed by tribal groups living around the natural forest areas. Its immature tender green fruits are cooked as vegetable. Young leaves, flowers and seeds are also edible. No systematic attempt has been made for its domestication and thus yield is poor. The fruit is a delicacy for its typical taste. It is rich in protein, calcium, iron and carotene. It is minor crop and a number of types are available in India.

Spine gourd is a minor crop and a number of types are available in India. Two to three types of this vegetable are commercially grown in some districts of Kerala. Now this vegetable becomes popular in the state like Delhi also. The fruits do not remain fresh too more than 2 days and gets shriveled within 2-3 days. Moreover, the farmers harvest the produce either at immature stage or at a stage which is not acceptable to the consumers. In India, spine gourd is naturally occurring and widely distributed in forest area of different state *viz.,* Chhattisgarh, Maharashtra, Madhya Pradesh, Utter Pradesh, Orissa, Assam, West Bengal, Jharkhand, Bihar and Andhra Pradesh.

Origin and Distribution:

Spine gourd is believed to be originated in the tropics of the old world. In India, West Bengal and Karnataka are two major states that grow Kantola commercially. Kantola is largely cultivated in Malda and Nadia district of West Bengal. Spine gourd is indigenous to India or South East Asia and grows widely on hedges throughout the country. It grows in thickets and secondary forests, at low and medium altitudes. It is distributed in India, Malaysia, China, Bangladesh, Nepal, Myanmar, Sri Lanka and Pakistan.

Taxonomy:

Somatic chromosome number and detained karyotype analysis were carried out in six Indian *Momordica* species *viz., M. balsamina, M. charantia, M. cochinchinensis, M. dioica, M. sahyadrica* and *M. cymbalaria.* Among the different species; *M. balsamina and M. charantia are* monoecious species while *M. cochinchinensis, M. dioica, M. sahyadrica and M. cymbalaria are* dioecious species. *M. cymbalaria* is reported new chromosome number, 2n=18; while earlier it was 2n = 16, 22.

Nutritional Content and Active ingredients in spine gourd:

All parts of the plant, seeds, leaves, fruits, and the roots have high concentrations of bioactive compounds and antioxidants. It has the highest amount of carotene – vitamin A in cucurbitaceous vegetables. It is a rich source of Minerals like Zinc, Potassium, Phosphorus, and Sodium. It is a good source of Calcium, Magnesium, Chromium, and Iron.

Medical properties:

- Spine Gourd is considered to have cooling, analgesic, sedative, and diuretic properties.
- It is also used against snake bites and a scorpion sting for its anti-venom properties.
- It supports functions of the heart and vital cleansing organs such as liver, kidneys, and skin.

Distinct characters:

- In spine gourd, Anthesis at evening time between 6 - 7 PM.
- It starts flowering 30-40 days after planting depending upon prevailing weather condition and lasts up to 4-5 months.
- In spine gourd, individual fruit weight is around 5-20 gm.
- It is tolerant to pumpkin caterpillar, gall fly and root knot nematode.

Botany:

Spine gourd is dioecious in nature and it is regenerated through tubers. Tuber size was also related with the age and sex of the plant. An 8 year old plant exhibited tuber weight of 2 to 2.5 kg. The female plants had bigger tubers compared to the male plants. Old plants also possessed higher number of fruits per plant than the younger ones.

Floral Biology:

Spine gourd is a rainy season crop and bear flowers during July and August. The single flower bud appears in every axial on both male and female vines. The male flower buds take 18-20 days from visible initiation of full blooming. The female flower buds take about 15 days to full bloom. The male flowers begin to appear from second week of August and differentiation continues till the first week of October.

The female flower opens from the third week of August and continues till the end of September. The maximum anthesis was noted at 8.30 pm at the temperature range from 26 to 27 °C. The dehiscence start four and a half hours before anthesis and individual flower take about 45 minutes to complete the process. Maximum release of pollen grains was observed during 2.45 to 4.15 pm. Stigma is receptive up to 12 h before and after anthesis.

Propagation:

It is propagated through seeds, tuber and cuttings. It has high seed dormancy (5-6 months); dormancy should be broken to dip the seeds in H_2O solution for 24 hrs. 30 º C temperatures is better for germination. Plants from seeds cannot be determined (1:1 male and female). Dormancy period of tuber is around 4-5 months. Planting time is good during SepOct or Feb- Mar.

Use of PGRs for sex alteration:

- Application of ethephon to male plants of Karol did not affected the plants at any level of concentration tested while application of $AgNO_3$ (400 ppm) produced the highest number of bisexual flowers per vine (Ali *et al.* 1991).
- Foliar Sprays $AgNO_3$ (400 ppm) at pre-flowering Stage could induce 70-90% hermaphrodite flowers in *M. dioica*. (Rajput *et al.* 1994).

Parthenocarpy :

- A high parthenocarpic fruit set (70%) was observed in an interspecific hybrid between *M. dioica* and *M. cochinchinensis* when the F_1 was pollinated with pollen from *M. cochinchinensis.* [Bharathi *et al.* (2012)]
- Induction of parthenocarpy in *M. Dioica* with pollen of related taxa (*M. Chatrantia* and *Lagenaria leucantha*) and mixture of the pollens from these two species. [Singh (1978)].
- The parthenocarpic fruit setting was higher with the stimulus of extraneous pollen (66% against 36%), compared to natural pollination.

Other species :

M. subangulata* subsp. *renigera:

- Wild vegetable native to Assam Myanmar region.
- Distinct dark dots at the base of pale yellow to nearly white corolla.
- The fruit of *M. subangulata* are narrowed distinctly towards tip.
- In *M. subangulata*, there are two subspecies, *subangulat*a with longitudinal ridges, no spines, surface totally smooth.
- And subsp. *renigera* with tubercles present and in longitudinal rows, surface more or less spine scent if ridges are present.

Momordica sahyadrica:

- Native to Assam-Myanmar region
- Tendrillar, dioecious, perennial climbers.
- Flowers are bright yellow with a narrow greenish yellow bas.
- Fruits broadly ellipsoid, or ovoid to fusiform, or with round bas and prostrate apex.
- Turning bright orange on ripening, densely, soft short spines 2-4 mm long; pulp sweet when ripe, carmine red.

Momordica muricata:

- Annual climber with unbranched glabrous tendrils, monoecious
- Stem pubescent to glabrescent
- Flower yellow
- Male flowers solitary, (1.5) cm long peduncle, bearing near the apex
- Female flowers are 5-15 mm long **Homozygous Balance In Cucurbits:**

The cross- fertilized species that are generally grown in very small populations. For example- Cucurbits would show some degree of homozygosity due to inbreeding. This would leads to the development of homozygous balance in such cross fertilized species. These species therefore develop a genetic organization, which is adapted to homozygosity *i.e* which does not produce undesirable effects in the homozygous state.

Breeding Achievements:

Sr.No.	Developing Institution	Variety

1	IIHR, Banglore	Arka Neelachal Shree, Arka Neelachal Gaurav
2	IGAU, Raipur	Indira Kankoda-1

CHAPTER – 21 CUCUMBER BREEDING

Introduction:

The Cucurbitaceae or vine crop family is a distinct family without any close relatives. It includes important vegetables such as cucumber, melon, watermelon, squash and pumpkin. In which, cucumber [*Cucumis sativus* L., 2n=14] is an important vegetable crop in the cucurbitaceae family that has been cultivated in Northern India and is widely distributed throughout the world. It is one of the most important warm season fruit vegetables extensively grown in tropics, subtropics and milder temperate zones of India. It is also known as gherkins and khira. With respect to economic importance, it ranks fourth after tomatoes, cabbage and onion in Asia and second after tomatoes in Western Europe. In spite of being native of India sub-continent and endowed with enormous variability and genetic divergence, cucumber remains under-utilized given its economic potential and unexploited from breeding point of view.

Cucumber (*Cucumis sativus* var. *sativus*), grown for fresh and processing markets, is one of the most important cultivated cucurbits. Cultivated cucumber and its wild relatives, including *Cucumis sativus* var. *hardwickii*, exhibit large variation in traits such as fruit skin (ridges, colors, speckling), spines (size, density and color), growth habit (vine length and branching), fruit size, sex expression, and flesh bitterness.

In developed countries it is grown as a glasshouse vegetable and in developing countries as an open field vegetable. Cucumber forms an essential item of dietary in the west. Cucumber is regarded as the fourth most important vegetable crop after tomato, cabbage and onion. Cucumbers are produced around the world in China, India, Russia and U.S. These are grown throughout the world to be consumed as fresh fruits, as slicing cucumber, and as pickles in immature stage. Apart from its culinary uses its fruits help in curing constipation, jaundice and indigestion. In India the cultivated forms of cucumber are broadly divided into two groups: the hot weather forms and the rainy season forms. Generally cucumbers have three distinct types: seedless, seeded, and mini.

Origin and Distribution:

According to De Candolle (1886) cucumber is an indigenous vegetable to India. The possible progenitor of Cucumber, *Cucumis hardwickii* L., is seen in the foothills of Himalayas. This

species is similar to cucumber except for smooth fruit surface and extremely bitter flesh and falls within the range of variability of cucumber. Burma could be regarded as the secondary center of origin of this crop. Cucumber was probably domesticated in Asia, and then introduced into Europe. Cucumbers were brought to the Americas by Christopher Columbus, and Native Americans were growing cucumbers from Florida to Canada by the early 16th century. It is now grown throughout the world in tropical and subtropical climates. **Botany:**

It belongs to family Cucurbitaceae, genus *Cucumis*. It is an annual, monoecious creeping vine that grows up trellises or other supports, wrapping around them with thin, spiral tendrils. The key characters of the genus are fleshy fruits, many seeded pepo, solitary flowers, lemon-yellow to deep orange, deeply or shallowly lobed leaves, not pinnatifid, and corolla is rotate, deeply 5 parted and small. The genus *Cucumis* has over 40 species, of which 8 are India (Chakravarthy, 1959); either in wild or in cultivated forms. *C. sativus* houses several botanical varieties including var. *sativus*, the cultivated cucumber and the wild, free living var. *hardwickii* (R) whereas *C. trigonus* is closest species to cucumber.

Chromosome number:

C. sativus has 2n= 14. *C. trigonus* Roxb., its closest species also has 2n=14. Cytological studies were carried out on *C. callosus, C. hardwickii, C. melo, C. prophaterum and C. dispaceus* (Singh and Roy, 1974). This reveals genus as dibasic with both 7 and 12 as the basic chromosome number.

Botanical classification:

Boss (1959) classified *C. sativus* into subspecies based on the origin and fruit shape.

- *C. sativus* ssp. *rigidus* (The English long –fruited cucumber of East Asiatic type)
- *C. sativus* ssp*. agrestis* (The Soviet Far East type)
- *C. sativus* ssp. *gracillis*
- *C. sativus* ssp. *sphaerocarpus* (syn. *C. sphaerocarpus*)

1. Cucumber varieties are either monoecious or gynoecious in their flowering patterns.
2. Gynoecious varieties produce only female flowers and have a more concentrated period of fruit production.
3. There are also parthenocarpic varieties that do not need to be pollinated to produce fruit.

Monoecious cucumber:

1. Most older varieties of cucumber are monoecious, often producing more male than female flowers.
2. The male flowers typically develop on the main stem earlier and in larger numbers than female flower.
3. This may be concerning to some, as the plants appear to be only producing male flowers, but the female flowers will start to develop a little later, so that when they are ready to be pollinated, viable pollen will already be present.

Gynoecious cucumber:

1. Many mordan cucumber hybrids are gynoecious.
2. Gynoecious varieties produced large number of female flowers and have a fairly concentrated flowering period. Thus they produce a lot of fruit over a relatively short amount of time.
3. The female flowers of gynoecious varieties still need to be fertilized with pollen from male flowers, so a certain percentage of monoecious plants need to be planted along with the gynoecious plans to serve as pollinizers.
4. Most seed companies provide cucumber seed blends that contain 85% to 90% gynoecious seed and 10% to 15% monoecious.

Parthenocarpic cucumber:

1. In addition to gynoecious and monoecious varieties, there is also a third type of cucumber variety, parthenocarpic varieties. Unlike the gynoecious and monoecious varieties, which required pollination to produce fruits but parthenocarpic varieties produce fruits without the need for pollination.
2. Parthenocarpic varieties are seedless or nearly so and the fruit develop in the absence of fertilized seed. These varieties can produce seed if pollinated. Therefore, parthenocarpic varieties should be spatially isolated from other types of cucumbers to keep the fruit seedless.
3. Because parthenocarpic varieties do not produce large number of seed, even when pollinated, the cost of seed production is high, and the seed of these varieties is typically more expensive than the seed of other varieties.

Floral Biology:

Unisexual flower of monoecious plants are having diameter of 3-4 cm. Male flowers are yellow which are born axillary in clusters on slender pedicels whereas yellow female flowers are solitary, axillary, on stout peduncles. Male flowers consist of 3 stamens and there filament are free which ending in thickened connective with anthers on outer surface. Female flowers contain 3 united carpels having simple style and 3 thick stigmas. Choudhary and Pathak (1959) studied floral biology in cucumber. The whole developmental process from the initial bud stage to stage when flower detaches from pedicle has been divided into 8 stages (1 to 9). Opening and closing of male flowers are mainly influenced by sun-rise and sun set, that is, by light and time of day. Anthers in all varieties dehisce between temperature
20.5 and 21.5 ˚C. Pollen fertility is considerable up to noon and by afternoon (2.00 PM). Fertility is greatly reduced, and is negligible by the evening.

Sex expression in cucurbits

The type (*e.g.,* gynoecious or monoecious) and intensity of sex expression is important to commercial cucumber production since difference in sex type and flowering can affect harvest date and relative yield.

1. Genes that are hormonally controlled and influenced by growing environment affect both the type and intensity of sex expression.
2. The main stem of monoecious cucumber is usually characterized by three phase of sex expression.
3. Only staminate flowers are produced in the first phase followed by a phase of irregularly alternating female, male or mixed nodes and finally a phase of only pistillate flowers.
4. Lateral shoots of monoecious cultivars usually have stronger female tendencies.
5. Fruit from perigynous flowers are more rounded as opposed to elongated ones from epigynous ones. The rounded fruit are horticulturally poor due to larger seed cavity.
6. Under long day and high light intensities staminate flowers predominate, whereas, under short day and low light intensities female flowers predominate.

Following main sex types are reported in cucumber:

1. Monoecious: staminate and pistillate flowers
2. Androecious : only staminate flower
3. Gynoecious : only pistillate flowers
4. Hermophrodite plants: only bisexual flower **Genetics of sex in cucumber:**

The sex expression in cucumber is determined by three major genes, namely, *F* (also known as *Acr*), *M* and *A.* The *F* locus determined degree of femaleness (*FF>Ff>ff*). *M* locus determines whether flowers are unisexual (*M_*) or bisexual (*mm*). The *A* locus conditions increased male tendency if the plant is homozygous recessive for *aa* and *ff*. Interaction between these three loci is responsible for producing basic sex types in cucumber. Along with three major genes, there are several modifying genes and environmental factors influencing sex types in cucumber. The existence of sex modifying genes is supported by the observations that gynoecious plants differ in the level of gynoecy and their ability to confer femaleness in F_1 hybrids. The combination of genotypes at these loci gives the basic sex types. The phenotypes and genotypes of basic sex types in cucumber are as follows:

	m	**F**	**A**	**Phenotype**
Hermaphrodite	m/m	F/F	-/-	Both sex in same flower
Androecium	-/-	F+/F+	a/a	Only male sex
Monoecious	m+/m+	F+/F+	-/-	Separate sex inflorescence
Gynoecious	m+/m+	F/F	-/-	Only female sex

Male Sterility:

- Male sterility has been reported but it is little practical importance because the genetic control of dicliny *vs* monocliny and staminate flower *vs* pistillate flowers.
- GMS is controlled by ms-1 and ms-2 condition of staminate flower, CMS has not reported in cucumber.
- Several genes for male sterility have been reported for cucumber, but because of the ease of changing sex expression with growth regulators, little commercial use has been made of them.
- Five genes, *ms-1*, *ms-2*, *ap*, *cl* and *gi* have been identified. The genes *ms-1* and *ms-2* cause sterility by pollen abortion before anthesis; *ms-1* plants are also partially female sterile (Robinson and Mishanec, 1965; Shanmugasundarum and Williams, 1971; Whelan, 1972).
- Apetalous mutants (*ap*) on the other hand have infertile anthers which appear to have been transformed into sepal-like structures (Grimbly, 1980).
- Ginko (*gi*), mentioned earlier as a leaf mutant, also causes male sterility (John and Wilson, 1952).

Like other cucurbits, chemical regulation of sex expression is also reported in cucumber. Use of Auxin, Ethylene, Acetylene and 2- chloroethyl phosphonic acid are advisable for increasing female tendency whereas for increasing male flower promotion: GA_3, GA_4, GA_7, Silver nitrate, Silver thiosulfate, Aminoethoxy-vinylglycine *etc.,* are advisable to be used. **Breeding objectives:**

1. To obtain higher fruit yield
2. To induce early fruiting
3. To increase higher female to male sex ratio
4. To increase more number of lateral branches
5. To breed for desire fruit size, shape and color as per need of consumer/ processing industry
6. To breed for attractive green or dark green with smooth surface and without prominent spines or prickles
7. To develop cultivar of uniform long cylindrical shape without crook neck
8. To decrease the cucurbitacin content in fruit
9. To obtain cultivar with less seeds at edible maturity
10. To develop variety that should be resistance to powdery mildew, downy mildew, anthracnose, cucumber mosaic virus, insect pest and abiotic stresses.

Breeding Methods:

1. Introduction:

A number of varieties have been have been introduced which are high yielding, and have quality fruits and also resistance to diseases. Japanese Long Green, Straight Eight and Poinnsette are popular varieties introduced to India.

2. Mass Selection:

Cucumber lines with desirable recessive characters like bush habit, spinelessness, spindlelessness and lack of bitterness have been obtained by selection.

3. Backcross method:

Scab resistant lines have been developed through backcrossing. Lines which combine high yield with quality fruits have been developed through repeated backcrossing. Chinese Long, Tokyo Long Green, Ohayo Lines, Wisconsin, SMR 9, Wisconsin, SMR 12, Stono, Wantee have been through back cross.

4. Heterosis breeding:

Heterosis has been exploited for earliness, high yield and quality fruits. Cucumber is a cross pollinated crop. Bees are the main pollinating agents. The female flowers develop later than the more number of male flowers and have a ring of nectiferous tissue surrounding the style. The main sex forms are gynoecious, hermaphrodite and monoecious, which have been greatly used in developing single and triple F_1 hybrids. Different techniques are being used to produce hybrid in cucumber *viz.,* a) Removal of male buds and use of inset pollinators b) Use of Gynomonoecious lines & c) Use of Gynoecious lines. But at commercial level use of gynoecious line is more preferred.

Use of *Gynoecious* line:

In cucumber, hybrids are produced commercially using a gynoecious inbred as female parent crossed with monoecious inbred as male and honeybees as pollen vectors. Gynoecious inbreds can be maintained by inducing male flowers for self pollination through treatment with silver nitrate or other ethylene inhibitors (Tolla and Peterson, 1979). Dominant nature of gynoecious sex expression ensures development of pistillate flowers in every node of F_1 hybrids. A monoecious pollinizer must be mixed with the hybrid, if it is not parthenocarpic for ensuring pollination and full productivity (Wehner and Miller, 1985). Specific combinations involving gynoecious line and male parental lines are planted in 10:1 ratio and hybrid seeds are collected from gynoecious lines. Gynoecious lines are maintained through spraying with gibberellic acid, which induces male flower production in the lines. Spartan Dawn was the first hybrid developed through using gynoecious line. In 1971, India developed first hybrid named Pusa Sanyog which was based on gynoecious line. DCH 1, DCH 2, Phule Chmapa, Phule Prachi, Ragini, Shivneri, NCH 38, Hybrid No-2, PCUCH1 etc are important hybrids of cucumber.

5. Interspecific hybridization:

There are nearly 40 species under *Cucumis*; with all non-cultivated forms that have originated in Africa. *Cucumis sativus* (2n=14) is crossable with other species with 2n=14, producing fertile F_1.

6. Polyploidy breeding:

Two species of *Cucumis* viz., *C. heptadactylus* and *C. ficifoli* are natural hexaploids (2n=42). Tetraploids can be obtained by colchicine treatment. They are not of any economic value due to poor productive capacity. Triploids can be produced by crossing tetraploids with diploids. Increased chromosome number did not affect taste or quality of yielded parthenocarpic fruits.

7. Mutation Breeding:

Swarna Ageti variety of cucumber has been developed through mutation.

Breeding Achievement:

Varieties of Cucumber	**Institute/Organization**
Pusa Barkha, Pusa seedless cucumber-6, Pusa Khira-1, Pusa Uday	IARI, New Delhi
Pant Parthenocarpic Cucumber-2, 3	GBPUA&T, Pantnagar
Kalyanpur Green	CSAUA&T, Kanpur
Swarna Poorna, Swarna Ageti, Swarna Sheetal	ICAR Research Complex for Eastern Region

CHAPTER – 22 WATERMELON BREEDING

Introduction:

Watermelon [*Citrullus lanatus* (Thunb.), 2n=2x=22] is of ancient cultivation in Mediterranean region, and was grown in Egypt in ancient times. It reached India in prehistoric times. It was introduced into New World in post- Columbian times, and is now widely cultivated in tropics. Watermelon is most commonly grown in the Middle East, the United Sate of America, Africa, India, Japan and Europe.

Plant growth favored high temperature and adequate sunlight. Watermelon fruits are produced in different sizes (ice box, small, medium, large, giant), different shapes (round, oval blocky, elongate), different rind patterns (gray, narrow, stripes, medium strips, wide strips, light solid, dark solid) different flesh color (white, yellow, orange, red) and different types (seeded or seedless). Commercially most popular seeded cultivars are red flesh, blocky shaped, 8-11 kg. For seedless watermelon, the popular cultivars are red flesh, oval shape, 5-8 kg.

Watermelon hybrids from private seed companies have become very popular in India and 70 tons of hybrid seed is traded annually.

Center of origin:

The primary center of diversity lies in Southern Africa where wild forms are still found. Domestication is likely to have occurred in Egypt and India. Primary center of diversity for watermelon is Southern Africa. The secondary center is China and related species can be found in India.

Genetic Resources:

The USDA watermelon collection is stored at the Regional plant Introduction Station, Griffin, Georgia with the backup collection at the National Seed Storage Laboratory, Fort Collins, Colorado. There are 1644 accessions in the collection, with most currently available to researchers. The collection includes representatives of all *Citrullus* species and botanical varieties. In addition, approximately 300 heirloom cultivars are kept at the National Seed Storage Laboratory. In India, watermelon germplasm are conserved at IIVR, Varanasi, NBPGR, New Delhi and a few SAUs and IIHR, Bangalore. Durgapur and Faizabad centres made responses for collection and evaluation of germplasm of watermelon.

Classification :

Shimotsuma (1965) classified watermelon as *Citrullus lanatus* (Thunb.) Mans, *C. ecirrohsus*, and *C. colocynthis* (L.) Schrad. Possible ancestors of watermelon are *C. naudinus*, *C. fistulosus* (round melon) and *C. vulgaris* var. *citroides* (citron melon).

Citrullus colocynthis:

It is perennial type, indigenous to North Africa and differs from *Citullus lanatus* in plant organs. Leaves are small with narrow lobes and hairy greyish colour. Flowers are monoecious and small profuse flowering in autumn season. Fruit are small, less than 3" diameter with rind and spongy flesh but bitter always.

Citrullus ecirrohsus:

It is closely resembles to *Citrullus colocynthis* in vegetative characteristics, with leaves are more divided and covered with dense fine hairs, tendrils are lacking, fruits are subglobose with white flesh.

Citrullus vulgaris:

It is an annual crop. The leaves are broad with 3-5 lobed triangular to ovate shape. The fruits are medium to large size, thick rind solid flesh with high water content, flesh color is red or yellow or white.

***Citrullus naudinians* and *Citrullus ecirrhosus*:**

These both are perennials and indigenous to south and west Africa. Flowering is dioecious and flowers are not formed until second year of growth. Fruit are ellipsoid in shape, medium to large size, thin rind and soft juicy flesh, seed white colour and will not germinate in natural condition.

Flower biology:

Citrullus lanatus is a slender, hairy, monoecious or andromonoecious annual (predominant Monoecious), often sprawling over ground. Its flowers are unisexual and hermaphrodite, solitary, axillary; usually there are more male flowers than female ones. Ovary is ovoid with woolly hairs.

First female and hermaphrodite flowers are formed on the main vine. The male flowers open first in the axil of 4^{th} to 12^{th} leaf and a few days later; female and hermaphrodite flowers open, those of early cultivars in the axil of 5^{th} to 7^{th} leaf and of late cultivars in the axil of 25^{th} to 30^{th} leaf. Male : female ratio ranges from 6 to 10 : 1 in early and 20 to 25 : 1 in late cultivars. More female flowers are formed in spring than in autumn. Most flowers open between 6:30 and 8.00 hr. in autumn, and 5.30 and 7.00 hr in spring. Pollen from hermaphrodite flowers germinates rather slowly than those from female flowers but is equally effective for fertilization.

Pollination :

Watermelon flowers are insect pollinated, mainly by honeybees. The plants are selfcompatible, but because flowers are unisexual a high percentage of cross-pollination occurs. Usually the anthers have dehisced when the corolla expands, and the pollen is visually evident in sticky masses adhering to the anther. The stigma is receptive throughout the day, but it has been established that fruit setting frequency following artificial self pollination is much higher when pollination occurs between 6 and 9 A.M. than when it occurs later in the day. High atmospheric humidity favors fruit setting. The ovary, which is inferior, is readily apparent, and its relative size is an important factor in fruit setting.

Small and poorly developed ovaries rarely set, whereas pollination of flowers that have large ovaries results in a high percentage of success. The largest ovaries are usually found on flowers near the tips of the most vigorous branches of a plant. In watermelon crosses, higher seed set is observed when pollination occurs in early morning immediately after flower opening. Seed set is considerably lower when pollination is carried out in the afternoon. Pollens kept at room condition for 5 hr gave a lower seed set than freshly collected pollens and after 30 hr, they lost viability. It is essential to place colonies of bees hive on the perimeter of watermelon fields. This is done to increase seed yield and it is also claimed that by supplying a high population of pollinating insects adjacent to, or within the seed production plot or field, the incidence of cross-pollination with other fields of watermelon which may be a different seed category or cultivar is minimized.

Breeding objectives:

1. Earliness
2. Pistillate flowers at lower node number
3. Tough skinned fruits for long distance transportation
4. Dark red flesh
5. Firm and non-fibrous flesh texture
6. Black seed
7. Proper sugar to acid ratio
8. TSS content not less than 10%, higher TSS greater preference, >12% very good, <9% not desirable
9. Fruits with smaller and fewer seeds with attractive deep red flesh
10. Firm flesh
11. Intermediate fruit shape between typical long and round ones as most elongated cultivars have a tendency to produce so called gourd neck fruit, whereas round-fruited cultivars tend to be susceptible to 'hollow heart'. The intermediate fruit shape is the advantage of F_1 hybrids between long and round-fruited parental lines.
12. Development of seed less watermelon
13. High yield
14. Resistance to diseases, viz., Virus, *Fusarium* wilt (race 0, 1, 2) Anthracnose, gummy stem blight Powdery mildew

15. Resistance to insects (cucumber aphid, fruit fly, cucumber beetle, red pumpkin beetle)

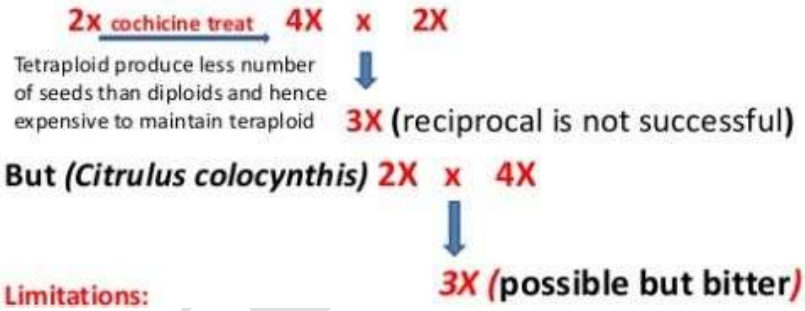
Heterosis breeding:

Hybrid watermelons have been developed which are early, high yielding, disease resistant and are with excellent fruit quality. At the IARI, New Delhi, **Sugar Baby × Asahi Yamato, Sugar Baby × Pusa Rasal, Russian × Shakarchini and Asahi Yamato × Russian** have been found promising with yield and fruit quality improved over best commercial variety. Private seed companies in India have entered into the programme of developing F_1 hybrids in watermelon. **Nath 101, Nath 102, MHW 6 and MHW 11** are a few such hybrids. **Other hybrids :**

NDWMH 15, NDWMH 14, Apoorva, Black Magic and Super Dragon are popular hybrid in cultivation.

Seedless watermelon:

First reported by Dr. Kihara (1939), in 1951-52 succeed in producing commercial triploid. Diploid pollen on triploid stigma stimulates parthenocarpy, but ovules fail to develop.



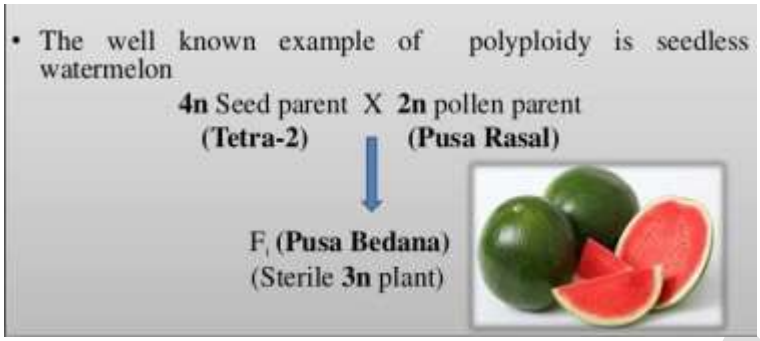
Limitations :

- Triploid seed cost is 20 times of that of OP seeds
- Difficult to germinate (removal of seed coat), require high temperature **Pusa Bedana**:

It is a seedless triploid variety of watermelon developed at IARI, from a cross of Tetra-2 (4X) x Pusa Rasaal (2X). The fruits have dark green skin with faint stripes. Fruits are somewhat triangular in shape with tough rind, red flesh and white remnants of false seed. TSS is 12-13%. Average fruit weight is 5-6 kg. The number of fruits per vine varies from 3 to 6. It takes 115-120 days for first fruit harvest. It could not become popular due to irregular fruit shape and high cost of seed. Now it is not available.

Polyploidy breeding:

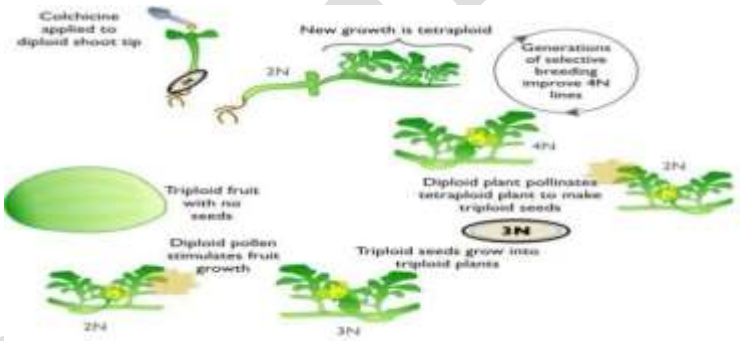
Seedless watermelons are developed by application of colchicine (0.2-0.4%) in growing point of young seedlings/ soaking of seed for development of tetraploid lines (4X).



It is not successful because of difficulty in:

- Maintenance of tetraploid parent
- Deforming in hybrid fruits
- Less seed set
- Germination problems

Development of seedless watermelon:



The credit of production of seedless watermelon goes to Japanese scientist. Kihara (1951) who gave an exceptionally clear account of various steps in production of triploid fruits. The triploids are the resultant of a cross of tetraploid and diploid parent. The steps involved in triploid seed productions are as under:

(a) Production of parental line (tetraploid and diploid) :

1. Application of colchicine 0.2% to 0.4% to growing points of young seedling at 1 to 2 true leaf stages for 2 to 3 days successively to induced tetraploids (44 chromosomes).
2. The treatment is given under controlled conditions avoiding direct sunlight. The terminal growth will be slow and promoted carefully.

3. The tetraploid plants are characterized by broad thick leaves and bigger pollen grain and at flowering pollen fertility and pollen size be tested. The seed size will be broad and bigger.
4. The maintenance of tetraploid lines at stable level is important and continuous selection for improvement of quality and vigour in tetraploid line has to be done for at least 4-5 generation.
5. The seed of diploid lines is produced in isolation.

(b) Seed production of Triploid (3X):

Triploid seed are produced by two ways:

a) Hand pollination in female tetraploid by diploid male and pinching of male of tetraploid before anthesis.
b) Pinching of male of tetraploid line and allow to open or natural cross pollination with diploid.

The planting of tetraploid and diploid is done in 1:1 ratio. Seed yield from 4:5 to 6: 8 Kg/acre under open pollination. The cost of triploid is very high; germination is very poor due to hard thick seed coat. Seed germination is to be done in controlled conditions which enhance the cost of production. The triploid will not set the fruit alone; therefore stimulation of fruit development has to be brought about by n pollen through bee pollination. Hence, as polarizer, a diploid cultivar has to be planted in the field with triploid field.

Triploid varieties from KAU, Trichur, Kerela:

KAU have been developed 2 triploid hybrids *i.e.* Shonima and Swarna using tetraploid line namely CL-4 and CL-5 (red and yellow fleshed) through crossing with diploid males.

CHAPTER – 23 CABBAGE BREEDING

Introduction:

Cabbage is the second most important crop of the cole group in India. Barring one or two months of intense heat, it is produced throughout the year. The word cabbage was derived from the French word '*caboche*', meaning head. The Latin name *Brassica* was derived from the Celtic word '*bresic*' also meaning cabbage.

Head cabbage [*Brassica oleracea* L. var *Capitata*, 2n = 2x = 18] commonly called cabbage is a member of one *Brassica oleraceae*, belonging to Brassicaceae family; the most important vegetables grown for its tender heads and consumed as a green leafy vegetable throughout the world. *Brassica oleraceae* show amazing diversity in form with different botanical variety names which generally describe the origin of the crop, or the edible part that has been accentuated.

Cabbage, known as a highly nutritious vegetable, is used in slaw, sauerkraut, and cooked dishes and its outer leaves are also used as animal fodder. Cabbage has wide adaptability, high disease and stress resistance, high yield potential and strong transporting tolerance, which makes it the most widely growing vegetable in the world. Cabbage is cultivated in more than eighty countries in according to the FAO (1999).

The classification of cabbage is mostly based on the botanical characteristics and the shape of head. According to its botanical characteristics, cabbage can be classified as:

1. ***Common cabbage* (*Brassica oleracea* L. var. *capitata* f. *alba*),** smooth leaves, green to dark green with protruding central rib, no apparent crinkle. It is the most common cultivated variation of *Brassica oleracea*.
2. ***Purple cabbage*** (***Brassica oleracea* L. var. *capitata* f. *rubra***), the leaf blade is the same as common cabbage, but its outer leaves and the inner leaves are purple. Usually for fresh use and far less cultivated than common cabbage.
3. ***Savoy* (*Brassica oleracea* L. var. *capitata* f. *sabauda*),** with crinkled or curling outer leaves that have deep veins, but the color of leaves looks the same as common cabbage, good flavor and can be used as a cooked dish, also less cultivated.

Commonly grown varieties of cabbage in India belong to the white cabbage group, which has three head shapes namely round, conical and flat, or drumhead. These varieties are also classified as early, medium and late on the basis of time required from transplanting

to reach marketable maturity. The common cabbages are of three types based on head shape:

1. ***Drum head***, most of the drum headed varieties are medium or late maturing, resistance to immature bolting, diseases, and heat. When they are cultivated in spring, they hardly show any immature bolting.
2. ***Round head***, round head type has round and nearly round head with characteristics of early or mid-early maturing, hard and crisp head of good quality. But this type is prone to immature bolting than pointed type if it is sown early or improperly managed in early spring.
3. ***Pointed head*****,** pointed head cultivars are mostly early maturing, have strong immature bolting tolerance and chilling resistance, but are susceptible to disease and heat stress.

Origin and Distribution:

Cabbage has originated from a wild non-heading type, colewort *(Brassica sylvestris)*. The genus *Brassica* includes about 100 species. Majority of which are native to the Mediterranean region. The crop is attributed to Mediterranean region. It is also considered that the red headed cabbage was evolved in Germany. The Savoy cabbage had probably originated in Italy and spread to France and Germany in the sixteenth and seventeenth centuries. At present cabbage are grown in Caribbean countries, Indonesia, Malayisa, Central East and West America, the Philippines and tropics in general. Sikka (1940) discussed the role played by gene mutations, structural changes of chromosomes and hybridization in species formation of Brassica. Of these, hybridization has played the most important part; as amphiploidy has frequently occurred in the genus.

Taxonomy:

It belongs to family Brassicaseae (earlier Cruciferae), genus Brassica, *B.oleracea* L. convar *capitata* (L.) Alef. var. *capitata*. Bailey (1930) classified the cultivated *oleracea* into 7 divisions.

The cabbage is also classified on the basis of these following aspects:

Botanical colour and form of heads:

(a) *B. oleracea* var. *capitata* L. f. *alba* ***e.g.*** white cabbage;

(b) *B. oleracea* var. *capitata* L. f. *rubra* ***e.g.*** red cabbage;

(c) *B. oleracea* var. *capitata* L. f. *sabauda* ***e.g.*** savoy cabbage **Place of origin:**

(a) *B. oleracea* var. *capitata* ssp. *mediterranea* ***e.g.*** Mediterranean cabbage;

(b) *B. oleracea* var. *capitata* ssp. *orientalis* ***e.g.*** Oriental cabbage;

(c) *B. oleracea* var. *capitata* ssp. *Europe* ***e.g.*** European cabbage **Head Shape (Choudhary, 1976):**

1. Round shape, head or ball head type (Golden Acre, Pride of India, Copenhagen Market and Mammoth Rock Red);
2. Flat head or drum head type (Pusa Drum Head);
3. Conical head type (Jersey Wakefield);
4. Savoy type (chieftain)

Myer's classification based on size and shape of head (Allen, 1914):

1. Wakefield and Winnings Kedt group – heads are small, conical and very early – Jersey Wakefield, Charleston Wakefield
2. Copenhagen market group – round heads, early, large heads – Copenhagen Market, Goulden Drum Head, Globe, Bonanza
3. Flat head or drum head group – Heads flattened from both ends – Pusa Drum head, Early round Dutch, All Head Early, Succession, All Seasons, Sure crops
4. Savoy group – leaves are wrinkled and heads are of very high quality but limited commercial use – Drum Head Savoy, Improved American Savoy, Chieftain
5. Danish ball head group – leaves are thin, heads are compact, solid, medium sized and are of good keeping quality, fine texture – Danish Ball Head, Hollander, Wisconsin Ball Head
6. Alpha group – the earliest group, heads are very small, solid head are of limited commercial use – Miniature Marrow
7. Volga group – thick leaves, shining blue coloured leaves, loose bottom – Volga
8. Red cabbage group – similar to Danish ball head except red colour leaves – Red Rock, Red Dutch, Large Red

In India Copenhagen market group and Flat Dutch group are common.

Floral biology:

Inflorescence is a raceme. Flowers are actinomorphic and bisexual. Calyx is gamosepalous with 4 sepals and corolla is gamopetalous with 4 petals and is cruciform. Pollination is entamophilous. Cabbage is highly cross-pollinated due to sporophytic self incompatibility, determined by up to 10 alleles at the S locus. Anthesis occurs in 8.00 to

10.00 hr. Pollen fertility is maximum on the day of anthesis. Stigma is receptive 2-3 days before to the day of anthesis and four days after anthesis. The period from pollination to fertilization generally takes 24-48 hrs, depending on the temperature. The ideal temperature has been 12-48 ˚C but continuous foggy weather with lower temperature affects both fertilization and development of seeds. Higher day temperature is harmful for fertilization since this causes pollen sterility. Fruit is a siliqua and is often called a pod.

Chromosome number:

Cabbage is diploid with 2n=18. Studies on secondary associations have been interpreted as showing a basic number of cabbage as x=5, making it a modified amphidiploid from a cross between two primitive 5 chromosome species with subsequent loss of one pair of chromosomes. Other authors have suggested that x=6; based on an observation of 3 groups of bivalent each in a normal cell of cabbage. The constitution of a haploid set is thus ABBCCDEEF.

Breeding objectives:

1. High yield
2. Longer staying capacity in field after head formation
3. Narrow short & soft core
4. Short stem
5. Self incompatible but cross compatible inbreds to be used in development of hybrids
6. Resistance to black rot, cabbage yellows
7. Resistance to cabbage butterfly, caterpillar, aphids & diamond black moth.
8. Breeding for low glucosinolates **Breeding methods:**

1. Introduction:

Many lines introduced to India have become promising and highly adaptable. They are Golden Acre, Red Acre, Perfection, August, September and Copenhagen Market.

2. Mass Selection:

This method has been successfully used to improve an existing variety. The characters based on which improvement has been thought to be achieved are (a) maturity days to 50 % heading (b) stalk length; (c) number of non-wrapper leaves (d) frame or plant spread (e) shape of head: polar and equatorial diameters. Kalimpong English Ball and Kalimpong Eclipse Drumhead have been developed through mass selection from exotic stock.

3. Pedigree method:

Pusa Mukta (Sel 8) is a selection developed at the IARI regional station, Katrain, by hybridization, followed by selection from the cross EC 24855 × EC 10109. It is resistant to black rot *(Xanthomonas campestris)*, and has been specially identified for the areas where this disease is a problem. Pusa Drum-head and Pusa Ageti are also selection from advance generation.

4. Heterosis Breeding:

Breeding new varieties is an important way to improve yield, quality, and wider adaptability of cabbage. Many countries, such as The Netherlands, Japan, USA, China, and Russia, pay more attention to breeding and utilization of heterosis in cabbage. Usually the Institutes and Universities focus on the study of the genetic resources and materials for breeding, and the seed companies use these materials to breed new varieties.

The phenomena of self incompatibility can be utilized to exploit heterosis. Heterosis has been observed for earliness, head size, uniformity in head shape, and above all, for yield. Two inbreed lines which are specific combiners and having desirable characters are planted in alternate rows to produce single cross hybrid. These two inbred lines are self-incompatible but cross-compatible due to the presence of different S alleles. Single dominant marker gene (e.g. purple stem pigmentation) can be tagged with male line. This would facilitate identification of F_1 seedlings before transplanting. Using redcoloured cabbage as male and collecting seeds from cabbage; the red coloured F_1 seedlings can be assured as their F_1s. Natural crossing is allowed and seeds are collected from female lines possessing recessive characters such as normal green stem, redcoloured seedlings etc.

***Double cross hybrids*:**

Double cross hybrids are also produced in cabbage using inbred lines. Four homozygous self-incompatible but cross-compatible lines are used. The F_1 hybrid is a double cross.

***Synthetics*:**

Synthetics are produced in cabbage by growing a set of inbred lines tested for their specific combing – ability effects, and differing in S alleles. These inbred lines are grown in alternate rows in isolation. Random mating is allowed and seeds collected from such a random mated population from synthetic seed (Hays, 1963).

Interspecific hybridization:

This is done to generate variability and to transfer desirable characters. The relationship of *Brassica* taxa based on the chromosome number is as follows:

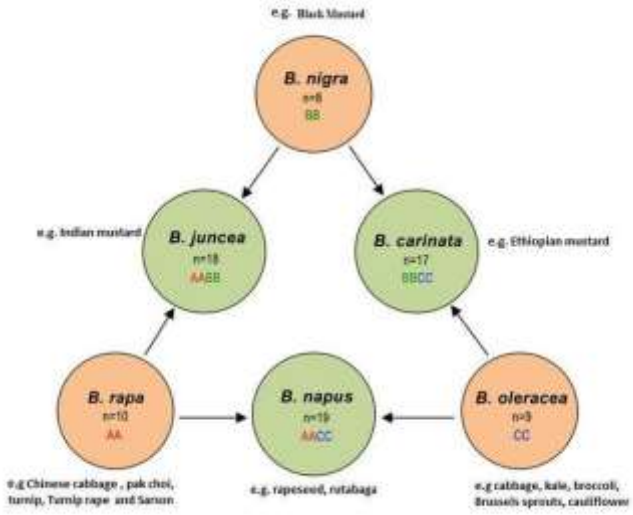


Fig: 1 Relationship of Brassica taxa based on chromosome numbers. B.rapa is also known as B. campestris

Self compatibility:

Wallace and Nasrallah (1968) identified a self compatible cabbage mutant in a self incompatible inbred line of cabbage homozygous for as S-allele. The self compatibility trait was determined by a dominant gene unrelated gene unrelated to the self incompatibility S-allele system.

Self-incompatibility:

Detjem (1927) described four types of incompatibility in cabbage:

Type A: Cross compatible and slightly self – incompatible

Type B: Fully cross-compatible and strongly self-incompatible

Type C: Highly cross-incompatible and self-incompatible

Type D: similar to type A but with as increased degree of cross-compatibility and self – incompatibility.

Using the Self-Incompatible Line for Hybrid Production:

As self-incompatibility widely exists in cabbage stable self-incompatible lines are used as the parents to produce hybrid. In the conditions of simultaneity in flowering time the seeds from parents are all high purity hybrid F_1 seeds, so it costs less and easy to use. Until now, almost all cabbage hybrid seeds have been produced using self-incompatible lines all over the world.

Male Sterility:

Hybrid seeds production can reach 100% purity at low cost by using male sterile line as female parents. The first recessive nuclear male sterility was reported by Cole (1959), Nicuwhof (1961), and Sampson (1966). However, no marker genes linked to male sterility were found, so it was difficult to use this kind of male sterility. The second type of male sterility controlled by nigra nuclear-cytoplasm interaction was reported by Pearson (1972). The defect of this type of material is that the petals cannot open fully and the nectar gland is less developed, and doesn't attract insect pollinators. The third type, Ogura male sterility, was transferred from radish cytoplasm.

The main problem of such type is chlorosis at low temperatures and suppressed nectar gland development. In recent years, scientists in France and US have used the protoplast fusion to improve male sterile lines with radish cytoplasm. While the chlorosis problem at seedling stage has been solved, the improved materials showed reduced nectar production, inability to attract insects and low seed setting by open pollination. The fourth type is the dominant male sterile gene in cabbage. The result from trials of several years verified that a pair of dominant nuclear genes controls this type of male sterility gene. This male sterile material has been used to develop homozygous dominant male sterile lines. Several superior hybrids from male sterile lines have been developed and used for commercial seed production. By now, the most widely used male sterile lines in the hybrid seed production are improved radish CMS and dominant GMS.

Cytoplasmic male sterility system can also be used for producing hybrids. This trait was found in Japanese radish by Ogura. That is controlled by interaction between homozygous recessive nuclear genes *ms ms* and cytoplasm *S*. Male sterile lines were developed in cabbage by crossing *Rapahanus* and *B. oleracea* followed by repeated back crossing with cabbage but there was problem of chlorosis which was solved by protoplast fusion by replacing radish chloroplasts with *brassica* chloroplasts.

Using Male Sterility for Hybrid Seed Production:

The instability and complex inheritance of the self-incompatibility mechanism makes its use difficult. Pollination by hand in bud stage to propagate parent lines may cost mass labour force and the parent lines after repeated self-pollination may lose vigour, but use of male sterile lines can remove all these disadvantages. There are four types of male sterile lines in cabbage, two types of male sterility–cytoplasmic male sterility and dominant genetic male sterility–have recently become economically significant, and are used by plant

breeders in some countries. The main advantage to use male sterile line lies in two aspects: the low labour cost and high purity hybrid.

5. Mutation breeding:

A spontaneous mutant characterized by lack of wax-layer on leaves has been located. The absence of wax is associated with a significant higher content of ascorbic acid, dry matter and coarse fibres compared with normal type. This mutant can be sued for breeding for high ascorbic acid content and for production of F_1 hybrid seed. Mutant 19p-2 of variety Kjure 17 induced by irradiating seeds with 60 kr gamma rays has been semi-sterile. Mutation breeding is restored to induced characters like male sterility.

6. Polypoidy breeding:

Polyploids are produced using cochicine and colchamine; the latter requiring higher dose than former. A few tetraploids developed had larger compact heads with the interior stalk shorter than the diploids.

Breeding for disease resistance:

In breeding for disease resistance, the backcross method of breeding is commonly used, especially in transferring one or two genes to an otherwise desirable cultivar. Club root, downy mildew, yellows and black rots are the major diseases of cabbage against which resistance breeding programme is done.

Breeding Achievements:

In India, Copenhagen market group (round and compact head) and Flat Dutch group (flat heads) are common.

Institution	**Variety/Hybrid**
IARI Regional Station, Katrain	Golden Acre and Copenhagen Market (Introduction), Pusa Drum Head, Pusa Mukta, Pusa Synthetic, Pusa Sambandh (Synthetic), KGMR-1 and KTCBH-81 (Hybrid)
IARI, New Delhi	Pusa Ageti
YSPUH&F, Solan	Pride of India
TNAU, Coimbatore	September, Drumhead Savoy, Red Acre

CHAPTER – 24 CAULIFLOWER BREEDING

Introduction:

Cauliflower (*Brassica oleracea* L.var. *botrytis* L. 2n=2x=18) is one of the most popular cool season vegetable grown for its curd which is pre-floral fleshy apical meristem. The word cauliflower comes from Latin term *caulis* and *floris*, means stem or stalk and flower, respectively. The curds are used in making curries, soups and pickles. The curd contains a good amount of Vitamin B and fair amount protein. Among cole crops, cauliflower follows cabbage in importance with regard to area and production in the world. In India, cauliflower is more widely grown than cabbage. In India it is grown both in hills and in plains. The crop is harvested from late August or early September to late February or early March in the north Indian plains and from March to November in the hills.

Origin and Distribution:

Cauliflower is an important member of the genus Brassica. Cauliflower, cabbage, kale and broccoli are related and have originated from wild cabbage coleworts (*Brassica sylvestris*). Wild coleworts are still found in wild in seacoasts of England and Denmark and in North-west France and in various localities from Greece to Great Britain. Cyprus and areas around Mediterranean coast are considered as primary center of origin of cauliflower. It is reported that cauliflower has originated from a related species *B. cretica*. According to Boswell (1949), it originated in the Island of Cyprus from where it moved to other areas like Syria, Turkey, Egypt, Italy, Spain and north – western Europe. Cauliflower was introduced to India in 1882 when Dr. Jemson, a botanist from Kew, took charge of the company Bagh (United Provinces, Saharanpur in the northern plains) to carry out some horticultural experiments during the period of the East India Company (Swarup and Chatterjee, 1972).

There are four major groups of cauliflower as under:

(a) Italian types which includes both biennial and annual types. Consist of white, Romanesco, various green, purple, brown and yellow cultivars. This type is the ancestral form from which the others were derived.

(b) Northwest European biennial used in Europe for winter and early spring harvest. This group was developed in France in the 19th century. It includes old cultivars like Roscoff and Angers.

(c) Northern European annuals used in Europe and North America for summer. This group was developed in Germany in the 18th century. It includes old cultivars like Erfurt and Snowball.

(d) Asian Tropical cauliflower used in China and India. This group was developed in India during the 19th century from the now-abandoned Cornish type. It includes old varieties like Early Patna and Early Benaras.

The Indian cauliflower has further divided on the basis of temperature requirement of curd development and maturity as, (a) Early (20-27 ^{0}C), (b) Mid (16-20 ^{0}C), (c) Mod-late (12-16 ^{0}C).

Major types of cauliflower:

European cauliflower:

Systematic and extensive cultivation of cauliflower occurred first in Italy where the 'Originals' or 'Italians' were developed. Broadly, on the basis of suitability of growing conditions, the European cauliflowers have been grouped into winter type; that is, winter cultivation ('Originals' or 'Italians', 'Cornish', 'Northerns', 'Roscoff', 'Angers') and summer type; that is, summer cultivation ('Erfurt' and 'Snowball').

Indian cauliflower:

The Indian/tropical cauliflowers grown in India are characteristically different from European types and are tolerant to high temperature and humid conditions—the earliest maturing types known—and do not require vernalization for bolting. In India, most cauliflower varieties are called by the name of the month in which the curds become ready to harvest; that is, Kunwari, Katki, Agahani, Pusi, and Maghi. These are highly heterozygous for maturity, plant growth, and curd traits.

Differences between Indian type and European type cauliflower:

Sr.No.	Indian types	Sr.No.	European types
1.	Tolerant to heat	**1.**	Not tolerant to heat

2.	Curd formation at and above 20 ˚C	**2.**	Curd formation at 5-20 ˚C
3.	Annual	**3.**	Biennial
4.	Yellow curd with loose strong flavour	**4.**	Snow white curd with mild or no flovour
5.	Early	**5.**	Late
6.	Less juvenile phase	**6.**	Long juvenile phase
7.	No need vernalization but need cold treatment at 10-13 ˚C for 6 week	**7.**	Need vernailzation at 7 ˚C for 8-10 week

History in India:

Cauliflower was introduced to India by Dr. Jemson, a botanist at Kew Garden, London, in charge of Company Bagh (renamed the Government Botanical Garden) at Saharanpur, Uttar Pradesh, in 1822. The Royal Agri- Horticultural Society, Calcutta, West Bengal, introduced seed of European vegetables from South Africa in 1824. Seed imported from England and South Africa was given to growers in northern India. From 1822 to 1929, through selection, these growers unconsciously evolved present-day Indian cauliflowers that have the ability to grow under conditions of high temperature and high humidity, tropical in nature, with potential to produce seed in the north Indian plains. The first four Indian varieties listed by Sutton and Sons, India, in 1929 were Early Crop Patna, Main Crop Patna, Early Crop Benaras, and Main Crop Benaras. It is likely that the Cornish type contributed most of the genes, including a long stalk, open growth habit (plant type 2), and yellowish, uneven, and strongly flavored curds. Some leaves and curd characteristics were contributed by Roscoff, Italian, and Northern types.

Botany:

It belongs to family Brassicaceae (Earlier Cruciferae) and genus *Brassica*, *B. oleracea* L. convar. *botrytis* (L.) Alef. var. *botrytis* (syn. *B. botrytis*, *B. florida botrytis*, *B. cauliflora*). Cultivated forms of *Brassica oleracea B. oleracea* var. *botrytis* sub var. *cauliflora* (Cauliflower).

Floral Biology:

Basically cauliflower is classified as early (August-September), mid (November- December) and late (January-march) maturity groups vegetable. Many of the early and midseason varieties

are day-neutral and tolerant to high temperature (> 22.2 ˚C) and humidity. Self-incompatibility is more pronounced in early-maturing cultivars than in late-maturing types. Male sterility is another reason for allogamy in cauliflower. Cauliflower is characterized by both self-incompatibility and protogyny so it is considered as cross pollinated. The self-incompatibility is of sporophytic type. The long receptivity of flowers, as reported earlier, is due to protogynous nature of flower. Considering these two conditions, breeding techniques and methods have been developed suitable for its improvements.

Chromosome Number:

Somatic chromosome number of cauliflower is 2n = 18. According to a study, 3 groups of 2 bivalents each and 3 groups of one bivalent each have repeatedly been found. From this secondary pairing of chromosomes, it has been concluded that they all are derived from a basic species with x=6. The six chromosome are designated as A, B, C, D, E and F. Later it was indicated that minimum number of secondary association groups which included all chromosomes was three. This implies that basic chromosome number is three.

Breeding Objectives:

1. To obtained higher yield
2. To bred varieties for non-riceyness, compact, bract free protected curds with retentive cream/white colour
3. To obtain suitable varieties for curd formation in summer and rainy season in the hills
4. To have better seeding quality
5. To obtain self-incompatibility but cross-compatible inbreds to produce hybrids of tropical type
6. To produce variety resistance to disorder like rosseting of curd
7. To develop biotic resistance (black rot, *sclerotinia* rot, *alternaria* blight, *erwinia* rot)
8. To develop resistance against abiotic stress like heat etc.

Breeding methods:

1. Mass Selection:

This method is effective in improving qualities or highly heritable characters. Pusa Katki and Early Kanwari have been developed by this method from indigenous stock.

2. Pedigree Method:

Hybridization, followed by pedigree selection, has been commonly used for cauliflower improvement. Pusa Shubhra (MGS2-3× 15-1-1) × D 96) and Pusa Snowball 1 (C 12012× EC 12013) have been developed through this method.

3. Heterosis breeding:

This breeding utilizes mainly dominance variance. Cauliflower shows pronounced heterosis in earliness, net weight of head or curd, yield per unit area, besides combining resistance to disease, hardiness, uniformity. Self incompatibility and cytoplasmic male sterility are commonly exploited for heterosis breeding programme in cole crops. By utilizing the phenomena of self incompatibility (Sporophytic self incompatibility), double cross and synthetics have been developed. Some important synthetic varieties are Pusa Early Synthetic, Synthetic 78-1, Pant Gobi 3 and Pusa Synthetic.

Breeding Achievements:

First Variety: Pusa deepali release from AICRP, New Delhi

Developing institution	**Variety**
IARI , New Delhi	Pusa Early Synthetic, Pusa Synthetic, Improved Japanese, Pusa Shubra, Pusa Deepali, Pusa Sharad, Pusa himjyothi
IARI Regional Station, Katrain	Pusa Snowball Kt-25, Pusa Snowball K-1, Pusa Snowball-1
GBPUA&T, Pantnagar	Pant Gobi-4
TNAU, Coimbatore	Ooty 1
PAU Ludhiana	Early Kunwari, Punjab Giant 35
GBPUA&T	Pant Gobhi 4, Pant Gobhi 2, Pant Gobhi 3

CHAPTER – 25 BROCCOLI BREEDING

Introduction:

Broccoli [*Brassica oleracea var. Italica,* 2n=18] belongs to the family Brassicaceae; is an important cole crop grown in tropical countries. It is originated at Eastern Mediterranean and Asia minor (italy). Sprouting broccoli is less important in India and is grown by some people in the kitchen garden. It has been originated in Italy, as the name broccoli as been derived from Italian word "brocco" refers to development of young shoots, which have been used as vegetables. Sprouting broccoli producing green heads consisting of green buds and thick, fleshy flower stalks. In broccoli, the head or sprouts are a mass of fully differentiated flower buds. Broccoli is high in vitamin C and dietary fiber.

It also contains multiple nutrients with potent anti-cancer properties, such as diindolylmethane (DIM) and small amounts of selenium. Broccoli is also an excellent source of indole-3-carbinol, a chemical which boosts DNA repair in cells and appears to block the growth of cancer cells. Broccoli has the highest levels of carotenoids in the *brassica* family. It is particularly rich in lutein and also provides a modest amount of beta-carotene. The stem are mostly consumed as a cooked vegetable, sometimes they are cut into small pieces and used raw in mixed salads or in pickles. Broccoli also processed in mixtures of dried vegetables.

Floral Biology:

Broccoli display a typical flower consisting of four sepals, six stamens, two carpels and four symmetrical, equal petals takes place which may be yellow or white. The carpels form a superior ovary with a "false" septum. There are two short and four long stamens. The buds open under the pressure of the rapidly growing petals.

The anthers open a few hours later being slightly protogynous. Under normal conditions, the anthesis starts at 5 am and continues up to 11:30 am. Peak hours of anthesis are between 8 to 9 am. The anther dehiscence begins at the time of anthesis, however maximum dehiscence occurs between 10 am and 12 noon. The pollen fertility is considerably high at the time of anthesis and one day before anthesis. The fertility is reduced one day after anthesis. The stigma becomes receptive two days before and remains upto two days after anthesis.

The central growing point along with the axillary buds clusters form thick, fleshy flower stem, which is the actual consuming parts in broccoli. The length of the flower stem is

small and the flower primordia develop into normal buds, which are united into a cluster, commonly called as head. Heads of broccoli becomes loose quickly and the buds start opening. The process of flowering starts at low temperature. Flowering starts from down upwards in all the branches, first at the main axis. The flowering is even and the whole crop flowers simultaneously. Between 20-30 ^{0}C day temperature; flowering, pollination and seed setting go on satisfactorily. Higher temperatures result in pollen sterility and low seed setting.

The flowering season is February-April.

Breeding objectives:

Criteria for selecting an ideal type:

- Vigorous, healthy growth under organic growing conditions, competitiveness with weeds, and resistance to any pests or pathogens are present.
- Clean leaf abscission – growers need to be able to strip leaves quickly in the field without using trimming knives.
- Even maturity
- Good flavour and attractive color.
- Medium size un-branched heads with tight, refined beads (Beads are the individual unopened flower buds that make up a broccoli head).
- Develop varieties which can form heads during summer and rainy season in the hills for markets in the plains.
- Varieties with better head quality.
- Varieties with better seedling quality.

Varieties:

Broccoli is of 2 types, heading and purple or green sprouting. Sprouting broccoli is more popular in India. Heading broccoli forms curds like cauliflower, while sprouting broccoli contains a group of green, immature buds and thick fleshy flower stalk forming a head. There are several varieties of broccoli :

Pusa Broccoli Kt 1 :

Compact head, light green with small buds weighing 250-400 g, maturity 85-95 days, yield 125 q/ha.

Palam Samridhi :

Green sprouting broccoli is tender, fresh and full of flavour. Terminal head weight 300-400 g.

Palam Haritia :

It is a sprouting broccoli with dark green upright leaves having purple reddish tinge. Maturity is 145-150 days. Yield 230-250 q/ha.

Palam vichitra :

The head is purple and compact. The variety is rich in nutrients especially vitamins and minerals with high cosmetic appeal. Maturity is 115-120 days. Yield 230-260 q/ha.

Palam Kanchan :

The head is large in size, compact, attractive yellowish-green in colour. It is rich in vitamin – A. Maturity 140-145 days. Yield 250-275 q/ha.

Punjab broccoli 1 :

It is compact, attractive and succulent, suitable for salad and cooking and average yield 70 q/ha.

CHAPTER – 26
BRUSSEL'S SPROUT BREEDING

Introduction:

Brussel's sprout is the same as the cabbage. Their existence was first recorded in 1587, and they were apparently developed in 15th century in northern part of Europe that is now Belgium. Whether they originated in Brussel's or not, they were cultivated there for centuries and rapidly spread to other countries around the world. In England they are popular vegetable served with holiday meals. Brussel's sprout first became popular in Europe after world war-1. The consumption of vegetable increased considerably, but they are still among the minor vegetable in United States. On the day of the Christmas, especially Christian people made a special dish from the Brussel's sprout. The original family name of brassicas was cruciferae, which derived from the flower petal pattern resembling a crucifix. Brussel's sprout is dark green colour leafy vegetable with small sized group of many fruits.

Morphology:

Brussels sprout is cool season biennial with axillary bud produced in the leaf axils during the 1st year growth &seed produce 2nd year of growth.

Stem : Light grayish green in colour.

Root : shallow with 80% of the roots growing in the upper 8-12 inches of soil.

Leaves : simple, alternate round to heart shaped with long petioles, they are light green to deep grayish in colour.

Floral Biology:

Flowers are perfect & borne in terminal racemes. Flowering is stimulated by temperature below 45 ^{0}F for 1 to 2 months. The flowers are pollinated by insect. Many rows of sprouts are produced on a single long stem. This leafy green buds resemble miniature cabbages with forms popular for food ranging from ½ inches in diameter.

Emasculation and pollination:

Brussels sprout is naturally cross pollinated species. Stigmas are normally pollinated by bees and flies. In breeding programme hand emasculation is frequently used to produce self pollinated or cross pollinated seeds. In certain cases, bud pollination is used if neither self- incompatible nor male sterile is available for parental lines. The flower buds, expected to open 12 days, are emasculated. The stigma is then pollinated with the desired pollen using a brush or bee stick. When S.I or M.S. plant is used as female parent emasculation can be avoided. Pollinated buds should be labelled and

covered with paper bags. If crosses are made in Green house remove the bags 10 days after pollination. If in open field, leave the bag until young siliqua are developed. Pollen can be stored at -20 to -25 ºC for 20-70 weeks.

Self incompatibility:

- Brassica plants have sporophytic system of self incompatibility.
- Controlled by S locus having several alleles.

Commercial hybrid Seed Production:

Single Cross:

For production of single cross F_1 hybrids, two self incompatible inbred lines with different S alleles are planted in alternate rows. Seeds produced by both lines are identical except the characters that are maternally inherited. These single crosses are more uniform than hybrids produced by double or top crosses.

Breeding Objectives:

1. Early maturity
2. Higher yield
3. Compact Bract free, protected head
4. Suitable for the mild winter
5. Small size of the head
6. Number of the head per spike is more with uniform size of head
7. Resistant to club rot and leaf spot
8. Also resistant to aphid pest
9. Light green colour of the head Breeding achievements:

CHAPTER – 27 CARROT BREEDING

Introduction:

The carrot [*Daucus carota* L., 2n=18] belongs to the family Apiaceae. It is a cool season vegetable grown round the year in temperate region and during winter in sub-tropical climates.

Initially the roots were long and thin, and either purple or yellow in colour. The mature root colour is white or orange; among which the orange or orange red colour is most popular today. Many shapes of roots also exist, from rather long and thin to shorter and thick.

Roots are used for making soups, stews, curries, pies, pickles and for salad purposes. Sweet preparation 'gajar halwa' prepared out of carrot is delicious and popular. Roots are also canned. Carrot roots are rich sources of α and β carotenes (1890 μ g/100g) and contain sucrose 10 times that of glucose or fructose. Carrot leaves are a good source of leaf protein. It is sued as fodder and for preparation of poultry feeds.

Temperature is the single environmental factor affecting root shape and colour in this crop. The optimum temperature required by carrot is 15 to 22 ^{0}C. In India, it is mainly cultivated in Uttar Pradesh, Assam, Karnataka, Andhra Pradesh, Punjab and Haryana.

Origin:

According to Mackevic (1929) Afghanistan is the primary centres of origin of carrot since a large diversity for morphological and root characters occur. Considerable variability for root also exists in India, indicating India also as a centre of origin. Root colour varies from absolutely colourless through light lemon light orange, deep orange, light purple, deep purple to almost black.

Botany and Floral Biology:

Carrot is andromonecious consisting of hermaphrodite flowers in the peripheral and central zones in the umbel and male flowers in the intermediate zones. Male sterility is controlled by a cytoplasmic factor and one or more recessive genes have been reported. Closed anther mutants and types with unrolled stamen filaments have also been observed. This type of functional male sterility is useful in hybrid seed production. Pollens mature 3-4 days before stigma receptivity. This phenomenon of protandry is also responsible for crosspollination. The stigma becomes receptive on the fifth day after anthesis and remains active

for another 8 days. Better fruit sets are from pollination on 6 to 11 days after flower opening. Over 95 per cent of cross pollination has been observed in carrot.

Breeding objectives:

1. Early rooting
2. Higher yield
3. White, long root and non branching habit
4. Non pithy roots
5. Pungency of roots as per consumers preference **Male Sterility:**

There are two distinct types of male sterility in carrot, depending on the source of sterility inducing (S) cytoplasm. One is brown anther type, in which the anther degenerate and shrivel before anthesis, is expressed in domestic cytoplasm from cv. Tender sweet and in cytoplasm from commercial cultivars. Other type is known as petaloid type, where the stamens are replaced by five petals. In hybrid production, petaloid types are commonly used, but brown anther types are preferred as they give better seed yield. Most of the brown anther types are genetically environmentally unstable.

In carrot, the Indian Agricultural Research Institute (IARI) regional station, Katrain has developed one hybrid, "Pusa Nayanjyoti" which is based on petaloid CGMS.

Breeding methods:

1. Introduction:

Introduction is an important method of breeding in carrot. The varieties successfully introduced in India are Imperator, Danvers, Nantes and Perfection.

2. Mass selection:

Spontaneous mutation coupled with selection mainly responsible for development of cultivated carrot. Mass selection for root length has resulted in the selection of high yielding lines.

3. Bulk population method:

This method has been successfully used to evolve "Pusa Kesar" as a selection from a cross between Nantes and Local Asiatic.

4. Mutation Breeding:

Chemical mutagen NEU and NMU were successfully used to develop male sterile lines in carrot.

5. Polyploidy Breeding:

Tetraploids (2n=36) and octaploids (2n=72) have been developed in carrot. The polyploids have only limited utility in carrot.

6 Heterosis Breeding:

Heterosis has been reported for earliness, root length, root yield, carotene content, top weight, core diameter and root diameter in carrot. Male sterility is used in heterosis breeding programme. Honey bees prefer male fertile plants over male sterile plants and a population of eight honey bees/sq.yard is required for effective pollination.

Breeding achievements:

Sr.No.	Developing Institute	Varieties
A	**Tropical varieties**	
1	IARI, New Delhi	Pusa Kesar, Pusa Meghali
2	HAU, Hisar	Hisar Gairic
B	**European varieties**	
1	IARI Regional Station, Katrain	Nantes, Early Nantes, Pusa Yamadagini
2	SKUA&T, Srinagar	Chaman
3	TNAU, Coimbatore	Ooty – 1
4	IIHR, Bangalore	Arka Suraj
5	State Department of Horticulture, Tamil Nadu	Zino

CHAPTER – 28 RADISH BREEDING

Introduction:

Radish [*Raphanus sativus* L., 2n=18], commonly known as *Mooli*; is an edible root vegetable grown throughout the world. It is a quick growing and short duration vegetable crop. Small radish is short duration type and it is strictly a cool season vegetable. The larger radish has a wide range of adaptability. It can withstand relatively high temperature and is grown as

an important vegetable in Japan, Korea, China, India and other Eastern countries. Radishes were first cultivated thousands of year ago in China, then Egypt and Greece. In India, it is grown in all states. The earliest radishes to be cultivated were the black varieties. Fodder radish bears little or no fleshy roots and is grown for its foliage and used as fodder or green manure. It has high nutritive value. It is a good source of ascorbic acid and trace elements. Pink-skinned radish is generally richer in ascorbic acid than the white skinned. Radish is known as an ancient vegetable. Inscriptions in Pyramids in Egypt showed its existence about 2000 B.C.

Origin and Distribution:

Egyptian writing reports that radishes were a common food in ancient Egypt even before the pyramids were built. In Greece, radishes were so highly valued that imitations of them were made of gold. Radishes were grown by the first English colonists in America. The recent studies indicated that east of Mediterranean; most probably China is the centre of origin of the crop. The globular forms of salad radish were developed from *radicula* variety in 19th century. The large rooted radishes are cultivars of *niger* and *radicula* varieties.

Botany:

Radish belongs to family Brassicaceae. Cultivated radishes are included under *Raphanus sativus* L. Four botanical varieties are recognized within species *Raphanus sativus* L. They are *radicula, niger, mougri* and *oleifera*; among witch first two are grown for their tuberous roots and *oleifera* is grown primarily for oil in its seeds.

Cultivated radishes are put under 3 different species based on the plant morphology and ecological requirements.

1. ***Indian types*** which are heat-tolerant, pungent and mostly used for pickle-making are called *R. indicus*.
2. ***European types*** which are frost-tolerant, rich in carotene, long-day plants, and strictly annuals, are called as *R. sativus* L.
3. ***Japanese types*** which are intermediate to Indian and European types, growing in the coastal regions of Japan and neighboring regions, and turnip shaped giant radishes cultivated in Sakurjuna Island of Japan are called *R. raphnistroides*.

R. caudatus L. non-tuber forming rat-tail radish, is closely related to Indian types of radishes. Indian type of radishes got evolved in the near Eastern and Indo-Burma centre of origin. The European types have originated directly or through hybridization from a few wild

species like *R. maritimus*, *R. landra* and *R. rostratus*. The Japanese types are derived from *R. sativus* f. *raphanistroids*.

Floral Biology:

Edible portion of radish develops from primary root and hypocotyls. Inflorescence is a typical terminal raceme. Flowers are small, usually white in colour. Sepals are erect and four in number. Four petals are clawed. Radish is cross pollinated due to sporophytic self incompatibility. It is mainly pollinated by honey bees.

Flowers are homogamous. Anthesis occurs during 9.00 to 10.00 hrs. Pollen fertility is maximum on the day of anthesis. When stored at 3 ^{0}C, pollen is viable for 60 days. Stigma is receptive at anthesis and that lasts 4 days after anthesis. Seed set was 3-12 times greater after open pollination than selfing.

Breeding Objectives:

1. Early rooting
2. High Yield
3. White, long/stump roots with thin tap root and non-branching habit
4. Nonpithy roots
5. Pungency of roots as per consumers' preference
6. Slow bolting habit
7. Heat tolerance
8. Drought resistance
9. Wet tolerance
10. Resistance to *alternaria* blight, white rust, radish mosaic virus
11. Tolerance to aphids **Breeding Methods:**

1. Introduction: Variety Mino Early is an introduction from Japan and large quantity of imported seed is marketed in India by Pvt. Sector seed companies.

2. Mass selection:

This method is effective in improving highly heritable characters like colour and shape of roots in radish. Pusa Desi, Punjab Safed, Arka Nishant and Co 1 was developed through this method.

3. Pedigree method:

This is another method commonly used in radish. Variety Pusa Himani has been developed as selection from cross between Black Radish and Japanese White. Pusa Rashmi is also such a selection from a cross between Green Top x Desi.

4. Polyploidy breeding:

Polyploid radishes with 2n=36 was produced through colchiploidy. They had no distinct advantages over diploids. Two polyploidy varieties Sofia Delicious (2n=36) and Semilong Red Giant (2n=36) have yielded more than diploids.

5. Heterosis breeding:

There is a predominance of non-additive genetic variance for majority of the characters including yield in radish and this can be exploited by developing F_1 hybrids. F_1 hybrids which are early and high yielding have been developed using phenomenon of incompatibility and male sterility.

Breeding Achievements:

Sr.No.	Institute	Varieties/Hybrids
1	IARI, New Delhi	Pusa Deshi, Pusa Chetki, Pusa Reshmi, Pusa Himani, Japanese White, White Icicle
2	PAU, Ludhiana	Punjab Safed (Resistant to *alternaria* leaf spot), Punjab Pasand, Punjab Agethi
3	IIHR, Bangalore	ArkaNishant
4	TNAU, Coimbatore	Co-1
5	HPAU, Palampur	Palam Hriday
6	IIVR, Varanasi	Kashi Sweta
7	CSUA&T,	Kalyanpur No.1
8	HAU, Hisar	Hisar Mooli

CHAPTER – 29
ONION BREEDING

Introduction:

Onion [Allium cepa L., 2n=16] is cool season vegetable grown for its bulbs which are used as salad, cooked in various ways in curries, fried, boiled, used in soup making, in pickles, and for many other purposes. They are daily used in many homes primarily for seasoning curries. Onion is extensively grown in South and Central India. In India, the most important onion growing states are Maharashtra, Tamil Nadu, Andhra Pradesh, Bihar and Punjab. Onion is one of the crops which exported from India.

Origin and Distribution:

Onion has primary centre of origin in Central Asia and Mediterranean as the secondary centre. The onion is originated from the region comprising north-west India, Afghanistan, the Soviet Republic of Tazik and Uzbek and Western Tiensen. Western Asia and area around Mediterranean Sea is its secondary centre of origin.

Botany:

It belongs to family Alliaceae, genus Allium, Species cepa. The species is divided into 3 groups which are sometimes given rank of botanical varieties as follows:

- Allium cepa L. : Common onion group
- A. cepa var. aggregatum G. Don: Aggregatum group multiplier onion, potato onion, shallots
- A. cepa var. proliferum (Moench) Aschers : Tree onion Horticultural classification:

Horticultural forms of Allium cepa are placed in three groups viz., the common onion group, the aggregatum group and the proliferum group.

Common Onion Group:

Bulbs large, usually single, inflorescence typically lacking bulbils and plants always produced from seed.

Aggregatum Group:

Bulb with many lateral bulbs or shoots, inflorescence typically lacking bulbils, producing seed or sterile, multiplication by vegetative means. Three distinct forms viz., potato onion, everready onion and shallot are available in this group.

Proliferum Group:

Bulb sometimes poorly developed, inflorescence bearing bulbils, true seed usually lacking, reproduced vegetatively by inflorescence bulbils. Two botanical varieties A. cepa var. viviparum and A. cepa var. proliferum are included here.

Types of Onion:

Four types of onion are observed which are as under:

1. Yellow Onion:

They are sweet onions. They are best for caramelizing. They are also used for curry, soup, stew, roast, stir-fry and onion rings.

2. Red onion:

Red onions, sometimes called (incorrectly) Spanish Onions have purplish red skin and white flesh tinged with red. These onions tend to be medium to large in size and can have a mild to sweet flavour, but after being stored for short time can become quite pungent.

3. Brown onion:

Brown onions which have a brown or almost yellow skin and creamy flesh are usually strongly flavoured and are suitable for cooking. This is the most widely used onion. With its pungent aroma and strong flavour it is a good all-round onion. Choose firm, blemish-free onions and avoid any that have green shoots.

4. White onion:

White onions are considered to be the strongest in flavour after brown onions. On average the Australian consumer buys less white and more brown and red onions. The varieties vary in size, skin characteristics and flavour.

Floral Biology:

In onion, flowers are borne in simple umbels at the apex of floral stem. The inflorescence may consist of a few to more than 2000 flowers per umbel. Plants grown from seed usually produce only one seed stem. Plants grown from bulbs may produce six or more seed stems. The flowering structure is called an umbel. It is an aggregate of many small inflorescences (cymes) of 5-10 flowers, each of which opens in a definite order, causing flowering to be irregular and lasts for two or more weeks.

Each individual flower is made up of six stamens, three carpels united with united with one pistil, and six perianth segments. The pistil contains three locules, each of which contains two ovules. The flowers contain nectarines, which secrete nectar to attract insects and they are protandrous, the

inner stamens shed their pollen first followed by the outer stamens. Anthesis occurs in early morning (6 to 7 hr). Anther dehiscence is between 7.00 to 17.00 hr and on the next day also with peak between 9.30 to 17.00 hr. Pollen fertility is maximum on the day of anthesis. Onion is highly cross pollinated and pollinators are bees and other insects. The reasons for cross pollination are heteromorphism and male sterility.

Male Sterility:

The chromosome number of onion is 2n = 16. Natural tetraploid plants with 2n = 32 have been observed. Male sterility is a natural phenomenon observed in onion which is governed by the interaction of nuclear and cytoplasmic gene. History of all hybrid onion seed can be traced back to single male sterile plant observed in the vegetable breeding plots of University of California at Davis in 1925.

Breeding Objectives:

- Higher bulb yield
- Long storage life
- Resistance to abiotic stresses
- Developing early maturing varieties and hybrids
- Better bulb quality character (colour, size, shape, narrow neck thickness, dry matter content, etc)
- Free from bolting
- Disease & pest resistance
- High total soluble solid content
- Breeding varieties for dehydration purpose Selfing:

Onion is a self-incompatible crop so selfing induces reduction in vigour and appearance of sterile plants in the populations. Therefore sufficient amount of seeds cannot be produced. Thus, selfing in onion done only on a limited scale as it becomes difficult to maintain the inbred lines beyond S_2 generation. Selfing is done by putting individual cages over the plants. Flies are generally used to ensure pollination within cages. Sometimes it is convenient to enclose 2-3 umbels of the same plant in a muslin cloth bag before anthesis. After anthesis, the umbels are rubbed against each other daily for a few days to ensure self pollination.

Crossing:

As soon as few buds in an umbel open, the whole umbel of the female parents is bagged in a muslin cloth bag. The flowers are removed daily for a few days until the peak flowering has reached after which buds are emasculated as they open and when sufficient buds have been emasculated the remaining young flower buds are removed. The umbel of pollen parents covered by a muslin cloth bag is cut off and its stalk placed in glass bottle filled with water. This bottle is fastened to a bamboo/wooden stake and fixed in soil close to the female parent. Female parent umbel and the pollen parent umbel are now enclosed in the same common bag. For a few days in the morning, the male umbel is gently rubbed over the emasculated umbel to ensure pollen shedding and cross pollination. A few common house flies can also be introduced into the bag for pollen transfer.

Research stations:

- ꕥ International : Asian Vegetable Research and Development Center (AVRDC), Shanhua, Taiwan
- ꕥ National : National Research Center for Onion and Garlic, Rajgurunagarm, Pune, MH
- ꕥ Stale level : Vegetable Research Station, JAU, Junagadh Breeding Achievements:

Sr.No.	Developing Institute	Varieties
1	IARI, New Delhi	Pusa Red, Pusa Ratnar, Pusa White Flat, Pusa White Round, Pusa Madhavi, Early Grano
2	IIHR, Bangalore	Arka Niketan, Arka Kalyan, Arka Bindu, Arka Pragathi, Arka Peethamber, Arka Lalima, Arka Keerthiman
3	NHRDF, Nasik	Agrifound Dark Red, Agrifound Light Red, Agrifound White, Agrifound Rose, Agrifound Red
4	VPKS, Almora, UP	VL 3
5	MPKV, Rahuri	N-2-4-1, N-257-9-1, Nishad 53 (N-53), Baswant-780
6	HAU, Hisar	Hisar 2
7	PAU, Ludhiana	Punjab Naroya, Punjab Selection, Punjab Red Round, S-148
8	RAU, Rajasthan	Udaipur 102
9	CSAUA&T, Kanpur	Kalyanpur Red Round
10	TNAU, Coimbatore	Co 1, Co 2, Co 3, Co 4, Co On 5. MDU 1
11	JAU, Junagadh	

CHAPTER – 30
GARLIC BREEDING

Introduction:

Garlic [Allium Sativum L., 2n = 26] is an important bulb crop which belongs to the family Alliaceae. It is highly cross pollinated crop. The centre of origin for this crop is Central Asia & Southern Europe. Related wild species of these crops are A.vineale, A.canadense, and A. oleraceum.

It is used as a spice. It is important because of its medicinal properties carminative. It is useful to reduce cholesterol level in the blood. Garlic used in the case of TB, rheumatism, sterility, cough, red eyes etc in the form of garlic juice. One percent garlic extract protect from mosquito and flies. Extract of garlic acts as fungicidal action. Garlic kills the colonies of food poisoning bacteria, clostridium perfringens.

Floral biology:

The garlic inflorescence can be described as an umbel like flower arrangement, whose branches arise from a common meristem. An initial elongation of the flower stalk precedes the spathe (a large sheathing bract enclosing the flower cluster of certain plants) formation and the swelling of the floral meristem. The differentiation of floral initials begins only after the scape (a long flower stalk coming directly from a root) reaches 5-7 mm length and the apex diameter exceeds 0.5 mm.

The apical meristem subdivides form several swellings, each of which gives rise to a number of individual flower primordial (an organ, structure, or tissue in the earliest stage of development). Leaf-like membranous bracts appear at the periphery of the inflorescence, and grow faster than the developing floral primordia. The differentiation of individual flowers begins when the inflorescence meristem reaches a diameter of about 2-3 mm and in the individual flower.

Each perianth (the outer part of a flower, consisting of the calyx (sepals) and corolla (petals)) lobe and the subtended stamens arise simultaneously from a single primordium. The outer perianth lobes and stamens, the inner whorl is differentiated. The carpels are initiated when the outer perianth lobes overarch the stamens.

Types of garlic:

1. Rocambole
2. Porcelain
3. Purple stripe
4. Artichoke
5. Asiatic
6. Silver skin

Breeding Objectives:

- Higher bulb yield
- Long storage life

- Resistance to abiotic stresses
- Developing early maturing varieties and hybrids
- Better bulb quality characters
- Free from bolting
- Disease & pest resistance Research stations:
- International : Asian Vegetable Research and Development Center (AVRDC), Shanhua, Taiwan
- National : National Research Center for Onion and Garlic, Rajgurunagarm, Pune, MH
- Stale level : Vegetable Research Station, JAU, Junagadh Varieties released by JAU, Junagadh:

Variety	Released Year	Yield (q/ha)
Gujarat Garlic-2	1993	74.57
Gujarat Garlic-3	1999	75.35
Gujarat Garlic-4	2007	89.33

CHAPTER – 32
TURNIP BREEDING

Introduction:

The turnip [Brassica rapa subsp. rapa, 2n=20] formerly B. campestris subsp. Rapifera; is a root vegetable commonly grown in temperate climates worldwide for its white, bulbous taproot. Small, tender varieties are grown for human consumption, while larger varieties are grown as feed for livestock. The most common type of turnip is mostly white-skinned apart from the upper 1-6 cm, which protrude above the ground and are purple, red, or greenish wherever sunlight has fallen. This above ground part develops from stem tissue, but is fused with the root. The entire root is roughly globular, about 5-20 cm in diameter & lacks side roots. The taproot is thin & 10 cm or more in length. The leaves grow directly from the above ground shoulder of the root. Turnip leaves are sometimes eaten as “turnip greens “or “turnip tops (in UK)” & they resemble to mustard greens in flavor.

Turnip greens are a common side dish in southeastern U.S. cooking, primarily during late fall & winter. Smaller leaves are preferred; however, any bitter taste of larger leaves can be reduced by

pouring off the water from initial boiling & replacing it with fresh water. Turnip roots weigh up to about 1 kg, although they can be harvested when smaller. Size is partly a function of varieties & partly a function of the length of the time the turnip has grown. Most very small turnips are specialty varieties. These are only available when freshly harvested & do not keep well. Most baby turnips can be eaten whole, including their leaves. Baby turnips come in yellow-, orange- & red- fleshed varieties as well as white-fleshed. Their flavor is mild, so they can be eaten raw in salads like radishes and other vegetables. The turnip roots are high in vitamin C. The green leaves of the turnip top are a good sparse of vitamin A, foliate, vitamin C, vitamin K & calcium. Turnip greens are high in lutein contain (8.5mg/100g). Turnip contains bitter cyanoglucosides that release small amounts of cynide.

Sensitivity to the bitterness of these cyanoglucosides is controlled by a paired gene. Subjects who have inherited two copies of the "sensitive" gene find turnips twice as bitter as those who have "insensitive" genes, & thus may find turnips & other cyanoglucoside containing foods intolerably bitter.

Origin:

Turnips are believed to have originated as a crop in the cooler parts of Europe, presumably from biennial oilseed forms. There is evidence that the turnip was domesticated before the 15thcentury BC; it was grown in India at this time for its oil- bearing seeds. The turnip was a well established crop in Hellenistic & Roman times, which leads to the assumption that it was brought into cultivation earlier. It was introduced into Britain from France by the Romans and into North America by the early European setters in the 17th century. Wild form of the hot turnip found over west Asia and Europe.

Floral Biology:

Brassica rapa is a biennial growing to 0.5 m height. It is in flower from May to August and the seeds are ripening from July to September. The flowers are hermaphrodite (have both male and female organs).It is pollinated by Bees. The plant is self-fertile.

Growth habit:

Turnip is a biennial which generally forms seed in the second year or even late. Turnip leaves are usually light green, thin & sparsely pubescent (hairy). In addition, a white-fleshed, large global

or tapered root develops at the base of the leaf petioles. The storage root varies in size but usually 3 to 4 inch wide and 6 to 8 inch long.

The storage root consists mainly of the hypocotyls, the plant part that lies between the true root & the first seedling leaves (cotyledons). The storage not generally has little or no neck and a distinct taproot. The flowers are clustered at the top of the raceme & are usually raised above the terminal buds. Turnip flowers are small & have four light-yellow petals.

Subspecies of turnip:

- Brassica rapa subsp. Chinensis
- Brassica rapa subsp. Chinensis var. parachinensis
- Brassica rapa subsp. Chinensis var. purpuraria
- Brassica rapa subsp. Dichotoma
- Brassica rapa subsp. Japonica
- Brassica rapa subsp. narinosa
- Brassica rapa subsp. Nipposinica
- Brassica rapa subsp. Nipposinica var. perviridis
- Brassica rapa subsp. Oleifera
- Brassica rapa subsp. Oleifera forma biennis
- Brassica rapa subsp. Oleifera forma annua
- Brassica rapa subsp. Pekinensis
- Brassica rapa subsp. Rapa
- Brassica rapa subsp. trilocularis Breeding Objectives:

1. Early days to attain marketable root size
2. Root colour as per consumers' preference, white, purple types more liked in India than golden ball types
3. Stump rooted varieties with thin tap root and non-branching habit
4. Slow bolting habit
5. Appropriate dry matter (8-9%) in roots
6. Resistance to club root, powdery mildew, turnip mosaic virus, white rust, phyllody, cabbage root fly, turnip root fly and aphids Breeding methods:

Mass selection:

This method of breeding has been commonly employed to breed several open-pollinated cultivars. Plants from selected roots are allowed mass-pollinated in isolation.

Hybrid Breeding:

There has been greater interest among breeders to produce hybrid cultivars of fodder Swedes utilizing self incompatibility. However, the same has not been achieved in case of horticultural types. Heterosis has been reported for several characters including the yield of root and leaf. Japanese breeders have been successful in developing several F_1 hybrid cultivars of white turnip.

Breeding Achievements:

Turnip root cultivars can be categorized into two groups: white-fleshed varieties and yellow-fleshed varieties (Ware and McCollum, 1980). The outer skin can range from white to green to purple (Duke, 1998). Today, turnips are most widely cultivated as a vegetable crop and there is a wide selection of available varieties. Vegetable breeding programs tend to focus on small tender roots and vigorous leaf production. While these varieties can be used for livestock fodder, they do not produce maximum yield as compared to older fodder varieties.

Varieties:

There are two distinct groups of turnip (i) biennial or temperate or European type, (ii) annual, tropical or Asiatic type. The seed of former group can be produced in the hills and that of latter in plains. Many good varieties differing in shape and colour are now available for cultivation in both the groups. Some of the commonly grown varieties of the two groups are.

Temperate Types:

Pusa Chndrima:

It is developed by hybridization between Japanese Whit and Snowball. It is early (matures in 50-55 days), high yielding and suitable for the area where growing period is very short. It has been released by IARI, Regional Station, Katrain.

Pusa Swarnima:

It is developed by hybridization between Japanese White and Golden Ball which matures in 65-70 days. It has been released by IARI, Regional Station, Katrain.

Purple Top White Globe:

This is most popular variety of the temperate group. The roots are nearly round with purple colour at the top and white lower half. The roots are nearly round with purple colour at the top and white lower half. It is an introduction and recommended by IARI, Regional Station, Katrain.

Golden Ball:

The roots are bright creamy yellow skin and pale, amber coloured flesh of fine texture and flavor.It has 65-70 days of maturation and recommended by IARI, Regional Station, Katrain. Snowball:

It takes about 60-65 days from sowing to root formation. The roots are globe shaped with pure white skin and mildly sweet flavor. This is also an introduction and has been replaced by Pusa Chandrima.

Asiatic Types:

Pusa Kanchan:

This variety has been developed from a cross between tropical type (Local Red Round) and a temperate type (Golden Ball) and was released in early sixties. The skin is red and the flesh is creamy yellow and it has excellent flavor and taste.

Pusa Sweti:

This variety was developed by selection from indigenous collection from Punjab and was released by IARI, New Delhi in 1976. It takes 40-50 days to attain harvest maturity.

Early Milan Red Top:

This is an extra early and high yielding cultivar reaching maturity in 45 days. The roots are deep flat with purplish red top and white underneath. The flesh is pure-white, well grained, crisp and mildly pungent.

CHAPTER – 33
SWEET POTATO BREEDING

Introduction:

Sweet potato [Ipomoea batatas (L.) Lam, 2n = 90] is an important tuber crop belongs to Convolvulacea family. The cultivated sweet potato is hexaploid in nature. It is commonly known as Sweet potato, Spanish potato, Sakkariya etc. It is originated in South America. In sweet potato, chromosome numbers are in multiple of x = 15 with diploid (2n = 2x = 30), tetraploid (2n = 4x = 60) and hexaploid (2n = 6x = 90) species.

Since, prehistoric time sweet potato has been cultivated in two widely separated areas, tropical America and Polynesia. Most reference assign an American origin to sweet potato, and finding in caves of Peru provides that it was grown there long before the advent of agriculture in Polynesia. Genetic evidence in the form of wild populations of closely related Ipomoea species suggests the center of origin was in northern South America and southern part of Central America. Sweet potato was already widely grown in tropical areas of the Americas when the European arrived, and it was rapidly introduced to Europe, first perhaps by Columbus. It was late introduced to Africa, perhaps from Spain or directly from tropical America. It is not known how sweet potato was introduced in Polynesia. The sweet potato is dicotyledonous perennial plant, cultivated as annual. The stem has trailing and vining habit. Leaves are variable in appearance and the morning glory like flowers may produce one to four seeds. Sweet potato is cultivated for its roots (tubers).

Flower biology:

Flowers occur in inflorescences, clusters of up to 22 buds growing out of the leaf axils. Each flower opens once, soon after daybreak, and usually fades by noon. It contains one stigma on top of the pistil (the female part) and 5 anthers on top of the 5 stamens (the male parts). The height of the stamens varies in different clones. If the stamens are shorter than the pistil, it is easy to find and pollinate the stigma, but if the stamens are the same height as or taller than the pistil, it is difficult to find and pollinate the stigma. The enlarged base of the pistil contains 2 ovaries, and each ovary has the potential of producing 2 seeds. Therefore each fruit, which is called a capsule, can contain a maximum of 4 seeds. Hand-pollinated capsules usually contain only 1 or 2 seeds, and most open pollinated capsules contain 2 to 3 seeds. Self-fertilisation in sweet potato is rare, because all clones have a high degree of self-incompatibility. Similarly, it may be difficult to obtain seed from crosses between certain parents, because cross incompatibility also occurs.

Breeding Objectives:

- Pest resistance (Sweet potato weevil)
- Diseases resistance (Feathery mottle disease)
- Yield improvement
- Good keeping quality
- Desirable characters of tubers for processing.
- Quality improvement (Shape, size, colour of flesh and skin)
- Less fibre and high Carotene content
- Nutritional improvement
- Resistance to abiotic and biotic stress Germplasm collection:
- IITA – International Institute of Tropical Agriculture, Ibadan, Nigeria
- AVRDC – Asian Vegetable Research and Development Center, Tainan, Taiwan
- CATIE – Centro de Agricultura de Investigacion y Ensenanza, Turriala, Costa Rica
- CIP – International Potato Center, Peru
- CTCRI - Central Tuber Crops Research Institute, Thiruvananthapuram
- NBPGR – National Bureau of Plant Genetics Resources, New Delhi Breeding methods:

Selection:

The incompatibility system in sweet potato offers to maintain high level of heterozygosity and thus provide ample scope of selection even among the collection of local cultivars. Selection criteria chosen to sieve out phenotypes, possessing high yield potential, desirable under diverse eco-edaphic conditions, resistance to biotic and abiotic stress and according to local quality demand. Varieties developed through selection are like Cross -4 and Bhukanti (Beta Carotene rich variety) developed through selection method which was endorsed NAU.

Hybridization:

The presence of self and cross incompatibility coupled with shyness of flowering act as barrier in hybridization programme in sweet potato, the parent chosen should posses high cross incompatibility and are of profuse flowering types, besides the desirable agronomic attributes. As the sweet potato flowers are bisexual, emasculation is required for hybridization. The flowers when matured, open before dawn (in darkness), even from 2 AM onwards. The flower remains open for few hours and wilt after some time. Dehiscence of anthers occurs before anthesis and hence

emasculation is done the previous day evening and pollination is done in the early hours of the day from 4 -7 AM to ensure maximum fruit set.

Breeding Achievements:

Sr.No.		Variety
A.	Through Selection	Goutam, Kalinga, Kishan, Sourin, Sree Vardhini, Sree Arun, Sree Varun, Sree Bhadra, Sree Nandini
	NAU, Navsari	C-71, Bhukanti (Endorsed)
B.	Through Hybridization	Gouri, H – 41 Hybrid, H – 42 Hybrid, Sankar, Sree Kanaka, Sree Retna, Varsha

CHAPTER – 34
TAPIOCA BREEDING

Introduction:

Tapioca [Manihot esculenta Crantz, 2n = 36] belongs to family Euphorbiaceae; is an important root crop. The common name of this crop is Cassava, Tapioca etc. It is originated in Brazil. There is little published information on cassava genetics. Cassava has the karyotype 2n = 36 and is probably alloploid (x = 9). Abraham produced several 'tetraploids' (2n = 72) which gave a poorer yield than the original (2n = 36) parents while 'triploids' (2n = 54) were superior to the tetraploids. It is cultivated for its tuber as well as sago is also well known product made from cassava. Cassava is a shrub with upright stems marked by leaf scars, reaching to a height of about 5 m. The leaves are palmate and rarely seen flowers, resemble a trumpet. The roots form thick tubers rich in starch. The species is native to tropical America. Indonesia is becoming the second centre of diversity.

Flower biology:

Cassava is diclinous, flowers of different sex being separated on the same inflorescence. Female flowers at the base of the inflorescence open first and apical male flowers normally open about a week later. During the flowering season there is great activity among nectar gathering insects and pollen collecting wild bees. In India many cultivars rarely or never flower. Cassava has a short day flowering response, but the effect of temperature and its interaction with day length on flowering has not yet been studied. At IITA most cassava clones flower during the period August to January with the peak of flowering occurring during the period October to December. The stigma remains receptive for up to twenty-four hours, and dried pollen remains viable for six days. Eight to nineteen

hours are required for fertilization to occur. Structurally and functionally therefore the cassava flower is well adapted to cross-pollination. Both the stigma and pollen are sticky and pollination is effected mainly by insects, although wind and rain may also be agents. Wild bees are probably the principal pollen vectors as cassava nectar is very attractive to them. Some plants have been observed to attract more bees than others, and this has been found to be associated with greater nectar production which is sometimes so prolific that it can be found on the petioles. Wild bees are most active at high temperature, low humidity and high light intensity. Seed matures in about 75-90 days. The fruit has three locules and three seeds, and on average 100 seed weigh 10g.

Breeding Objectives:

- High yield (>35 t/ha fresh root)
- High starch (> 25%)
- High harvest index
- Responsive to additional inputs
- Un-branching or late branching plant type
- Low HCN content
- Good cooking and eating quality
- Early harvest-ability
- Better root storage quality
- Shade tolerance for use as an intercrop under coconut etc.
- Wide adaptation
- Compact branches
- Compact root system
- Resistance to major diseases (cassava bacterial blight, anthracnose, brown leaf spot, cassava mosaic virus)
- Tolerance to adverse soil and climatic conditions Germplasm collection:
- IITA – International Institute of Tropical Agriculture, Ibadan, Nigeria
- AVRDC – Asian Vegetable Research and Development Center, Tainan, Taiwan
- CIAT – International Center for Tropical Agriculture, Columbia
- CIP – International Potato Center, Peru
- CTCRI - Central Tuber Crops Research Institute, Thiruvananthapuram

- NBPGR – National Bureau of Plant Genetics Resources, New Delhi Breeding methods:

Selection:

In India, considerable amount of variability exists in crop and much more available in other Cassava growing regions, particularly in tropical south Latin America, Which is the birth place of Cassava.

Varieties developed through selection are as under: -

Variety	Pedigree	Avg. Yield (t/ha)	Maturity (Months)	Cooking Quality	Features & Reco. area
Sree Jaya (CI649)	Selection from Indigenous germplasm	26-30	6-7, Early maturing	Excellent	Short duration suitable for low and becoming popular in rain fed plains of AP.
Sree Prakash (S-856)	Selection from Indigenous germplasm	30-35	7, Early maturing	Good	Short duration suitable as sequential cropping in rice fallows.
Sree Vijaya (CI731)	Selection from Indigenous germplasm	25-28	6-7, Early maturing	Excellent	Suitable for low land and becoming popular in irrigated plains of TN. Suitable as inter crop in coconut garden.

Varieties developed through Clonal Selection at TNAU are as under: -

Varieties	Pedigree	Yield (t/ha)	Duration (months)	Starch (%)	Year of release
CO 1	Clonal Selection (ME 7) from a local type collected from Tiruchirapalli district.	29.97	8.5-9	35.0	1977
CO 2	Clonal selection (ME167) from an OP seedling progenies raised from the seeds collected from Thiruvarur type in Thanjavur district.	35.37	8-8.5	34.50	1984

CO 3	Clonal Selection (ME 120-1) from seedling progenies of OP seeds obtain from IITA, Ibandan, Nigeria.	42.58	8	35.60	1993
CO (TP) 4	Clonal Selection from one of the seedling of the hybrid SM 1679 (CM 2766-5 x CM 4843) obtained from CIAT.	50.60	8.5	40.0	2002

Hybridization:

Cassava is monoecious. On a given branch, female flowers always open first and the male flowers follow after 1 or 2 weeks. Both self and cross-pollinations occur naturally in cassava. There seems to be no physiological or genetic mechanism to prevent self-fertilization in normally flowering types. No cross-incompatibility has been found so far. The pollen are relatively large in size and sticky, therefore, natural pollination by wind is unlikely. Several species of wasps and bees are the main pollinators. Self-pollination varies between 0 and 100%, depending upon the genotypes and planting distance. A distance of 30 m between pure stands of different genotypes is sufficient to prevent cross-pollination between two populations. However, 500 m is suggested for a perfect isolation of two populations in genetic studies.

Emasculation is not needed because female and male flowers are separate. Male flowers open 1 to 2 weeks after the female flowers opened within the same inflorescence. By the time male flower open, the female flowers of the same inflorescence have developed into fruits or have died. Female and male flowers usually begin to open from 12:00 to 14:00 hours and remain open about 1 day. To prevent stray pollinations, the flower branches are covered by large cloth bags which also identify the female flowers to be pollinated during the day. Recently opened male flowers are picked off the branch during the first hours of the afternoon and carried in small bottles. Pollination can be done most efficiently between 13:00 and 17:00 hours. Because both female and male flowers are large and the pollen is sticky, pollination is easy and requires no special tool. One male flower can be used for the pollination of three female flowers.

If the female flowers are exposed after pollination, they must be covered with a small bag 1 or 2 weeks after pollination. By this time the pollinated female flowers will have developed into young fruits. The bag protects young fruits from fruit fly attack and catches mature seeds which fall off naturally about 3 months after pollination. One female flower can produce up to three seeds;

however, it is difficult to obtain an average of 2.0 seeds per female flower. Cassava is a highly heterozygous species and has extremely high inbreeding depression. After one cycle of selfing, some plants are so weak that they cannot produce enough male and female flowers for further hybridization. Thus, selfing is not a major part of hybridization programs in cassava.

Varieties developed through Hybridization are as under: -

Variety & Year of Release	Pedigree	Avg. Yield (t/ha)	Maturity (Months)	Cooking Quality
H 97 (1971)	Manjavella x Brazillian seedling selection	23-35	10	Good
H 165 (1971)	Chadyamangalam Vella x clone similar to Kalikalan	33-38	8-9	Good
H 226 (1971)	Ethankkakaruppan x M4	30-35	10	Good
Sree Visakham (1977)	Acc No. 1501 x S-2312	35-38	10	Good
Sree Harsha	Triploid OP-4(2x) x H-2304(4x)	35-40	10	Good
Sree Prabha	Top cross hybrid	40-45	10	Excellent
Sree Rekha	Top cross hybrid	45-48	10	Excellent
Sree Sahya (11-2304)	Multiple (Acc No. 468, 174, 3024, 1310, 82, 3939, 3588 & M4)	35-40	10-11	Good

Inter Specific Hybridization:

To enhance the protein content and to incorporate diseases resistance in cultivated Cassava, hybridization between Cera rubber (Manihot glaziovii) and selected clones of Cassava was attempted at CTCRI, Thiruvananthapuram. Repeated backcrossing of interspecific hybrid of Cassava was carried out, but acceptable root quality was not recovered.

Heterosis Breeding:

Cassava is highly heterozygous and this heterozygosity is perpetuated through years of asexual propagation. Through selfing, good inbred lines could be developed and promising hybrids could be obtained by crossing of superior inbreds. A project on these lines was initiated at CTCRI in 1981. Marked inbreeding depression was noted in S_1, S_2, S_3 and S_4 generations for root characters, shoot weight, total biomass and harvest index. Six selected S4 lines were crossed in a diallel fashion and hybrids were reported to be in the seedling stage.

Polyploidy Breeding:

Induce tetraploids by colchicine treatment was attempted at CTCRI, Thiruvananthapuram and found that they were poor yielding and less adapted to the normal field condition. To produce triploids, a number of tetraploid clones are crossed with diploids. However, successful production of triploids in large enough numbers to be able to exert selection pressure is possible only in a limited number of combinations, probably due to the operation of cytological diploidization over a period of time in some tetraploids. The triploid plants derived from OP-4 (2x) X S-300 (4x) and OP-4 (2x) x H-2304 (4x) consistently produced roots with high DM in the seedling and succeeding clonal generations, which ranged from 34 to 43%. Some of the triploids recorded high starch content from the eighth month onwards, being significantly higher than that of the control. Among these, the triploid 76-9 had a yield similar to that of H-2304, the released cultivar, at CTCRI. A spontaneous triploid was identified from a cross involving the two released diploid varieties H-165 and Sree Sahya.

Mutation Breeding:

Mutation with gamma irradiation has been employed successfully on single node cutting of cassava but no economic mutant has been isolated so far. A mutant with short petiole has been reported to have practical application on the basis of research at CTCRI. Successful induction and recovery of more than 50 mutants could be accomplished at CTCRI by single-node cutting propagation of acute gamma-irradiated stakes of M-4 and pruning of the MV 1 plants. A preliminary evaluation of 19 of these showed that there was considerable variation in root yield, DM and starch content, as well as the HCN and chlorophyll contents. The photosynthetic rate, measured in terms of ppm CO2 uptake/m^2/sec of 15 mutants showed a variation from 16.56 to 97.58, compared to 28.00 in the control during the fifth-month growth stage. Similarly, the proline content, considered to be a major constituent in controlling drought resistance, varied from 16.0 mg/g to 53.0 mg/g compared to 18 mg/g in the control.

Biotechnology:

Techniques for the elimination of cassava mosaic disease, developed first in Canada by Kartha and Gamborg in the year 1978 were modified by scientists to suit the local conditions. Disease- free plants of M4, H-97, H-165, H-226, Sree Visakham, Sree Sahya and Sree Prakash have been produced and multiplied, and are now being distributed to farmers in India. In field trials these plants out-yielded the normal symptom-free plants to the extent of 10 to 25%, depending on the cultivars. Sero-diagnostic tests showed that the meristem derived plants were free from cassava mosaic disease during the initial stages.

CHAPTER – 35
AMARANTH BREEDING

Introduction:

Amaranth is one of the ancient groups of plants and has a great potential for combating under-nutrition and malnutrition. It belongs to the family Amaranthaceae consists of hardy, weedy, herbaceous, fast growing cereal like plants. The family Amaranthaceae is comprised of 65 genera and 850 species. Amaranth leaves and grains are utilized as food by humans as well as animals. Vegetable amaranth has been rated equal or superior in taste to spinach but still it is under exploited plant with promising economic and nutritive value. There are six vegetable species which are used as leafy vegetables viz., A. tricolor L. (syn.A. melancholicus, A. tristis, A. mangostanus and A. gangeticus), A. blitum L.(syn. A. blitum L. var. oleraceus, A. lividus L.), A. spinosus L., A. dubius Mart. Ex Theil., A. viridis L.(syn. A. gracilis) and A. cruentus L.(syn. A. paniculatus). The grain amaranthus includes A. hybridus,
A. caudatus, A. retroflexus, A. albus, A. hypochondriacus and A. graecizens (syn. A. blitoides, A. angustifolius). The important leaf amaranth species are Amaranthus tricolor, A. dubius and A. lividus where as the important grain amaranthus is A. hypochondriacus. Amaranth is an excellent vegetable due to following reasons:

(i) It is a very fast growing crop with extremely high yield potential (around 30 tonnes of fresh greens or 4.5 tonnes of dry matter per hectare) and easy to grow.

(ii) It is very much suitable to be fitted in crop rotations.

(iii) It shows highly favourable response to added fertilizers and organic manure.

(iv) It is considered to be the cheapest leafy vegetable in the market due to low production cost and high productivity. Hence, it is considered to be as “poor man’s vegetable”.

(v) It is good source of carotene, Vit-C, folic acid, other micronutrient and protein & it is a cheap source of nutrient as well.

The genus Amaranthus is classified in to two sections viz., Amaranthotypus Dumort and Blitopsis Dumort among which, the former consisting important grain types and the latter consisting of green types. The section Amaranthotypus Dumort was later renamed as Amaranthus Sauer (Sauer, 1967). The section Amaranthus Sauer has only terminal flower cluster and it includes many of the domesticated ornamentals, grain-types, dye-amaranthus and weeds. The section Blitopsis flower clusters in axils.

Majority of leaf cultivars (green type) grown in India belong to Amaranthus tricolor. Major species found in India are:

Sr.No.	Name of Species	Particulars
1.	A. tricolor (syn:A. gangeticus, A. mangostanus)	Cultivated - leaf type
2.	A. polygonoids	Cultivated - leaf type
3.	A. dubius	Cultivated - leaf type
4.	A. Blitum (syn: A.lividus)	Cultivated - leaf type
5.	A. spinosus	Cultivated – leaf type
6.	A. tristis	Wild type
7.	A. viridis	Wild type
8.	A. cruentus	Cultivated – Grain type
9.	A. caudatus	Cultivated – Grain type

Origin and Distribution:

The main vegetable type Amaranth is Amaranthus tricolor L. is believed to be originated in south or south-east Asia, particularly in India. A. lividus is reported to be a native of south or central Europe; whereas A. dubius is a native from Central America. A. dubius shows diversity in Central America, Indonesia, India and Africa; whereas A. lividus is popular vegetable in Southern and Central Europe. As a hot season vegetable, it is cultivated throughout the year in tropics.

Botany:

Amaranth is an annual herb with erect growth and scarce to profuse branching habit. Plant gets rough or prickly appearance while mature. Plant height is varies from 1 m to 3 m depends on different species, its growth habit and environment. Stem is succulent with green or purple or mixed shades of these two. Some species like A. spinosus have spines on its stem. Stem is thick and tough similar to those of sunflower.

Floral Biology:

The presence of three tepals (petals+sepals) is an important characteristic of amaranthus. The arrangement and development of individual flowers within a flower cluster has been described by Murray. Most of the amaranthus species are monoecious in nature due to this it is considered as cross-pollinated. The flowers can be terminal or axial, but are always organized into glomerules within the inflorescence. Within the glomerules, the first flower is generally

staminate and the later flowers are pistillate. In grain amaranth, each glomerule contained one male flower and about 250 female flowers. In A. tricolor, glomerules contained up to 30% male flowers. The percentage of male flowers per glomerule was reported as 0.5-1% in grain types and 10-25% in the green types. Therefore the process of emasculation is restricted to the topping off of the upper part of the panicle carrying male flowers above the female flowers. The anthesis time in amaranthus is 8:30 to 9:30 a.m.

Cytology:

The genus Amaranthus is dibasic with x = 16 and x =17; in which A. tricolor is with 2n=2x=34 and A. cruentus and A. tristis have 2n=2x=32 while the tetraploid species, A. dubius has 2n=4x=64.

Breeding objectives:

Grain Amaranths:

- To increase yield
- To increase harvestability
- To increase seedling vigour
- To develop resistance/tolerance against pest
- To produce bold seeds
- To develop cold tolerance Vegetable Amaranths:
- To develop erect and multicut variety
- To improve seedling establishment
- To identify suitable vegetable type with high potential coupled with nutritional qualities and without anti-nutrient factor (like oxalate which causes kidney stone)
- To develop resistance to disease and insects
- To develop heat and drought tolerance
- To develop a dual amaranth type i.e., grain cum leafy Multicut cultivars:

Multicut cultivars give more yields compared to unicut cultivars. A cultivar Co – 3 (A. tricolor) was selected from local materials at Tamil Nadu Agricultural University, Coimbatore, India; this cultivar is especially suitable for rationing, and is mainly used in vegetable slurry preparations.

Hybridization:

The small, closely arranged flowers of the monoecious species make emasculation very difficult. The most satisfactory method of making crosses in monoecious species was to remove staminate flowers by hand and pollinate heavily as soon as the stigmas were receptive. Even so,

5-25% self-pollination usually occurred. Hybrids were easily distinguished from the monoecious parent and in several crosses dominant genes were used to distinguish hybrids in seedling stage.

Breeding methods:

Mass selection:

Mass selection is a common method of breeding in Amaranths. The line A 25, later named Co-2, is a selection from a local material. The cultivar Co-2 is a typical A. tricolor. Other lines developed through selection at TNAU, Coimbatore are Co-1 (A. dubius) and Co-3 (A. tricolor).

Breeding Achievements:

Sr.No.	Institute Name	Name of Varieties
1	TNAU, Coimbatore	Co-1 (A.dubius), Co-2 (A.tricolor), Co-3 (A.tristis), Co-4 (A.hypochondriacus), Co-5 (A.tricolor)
2	IARI, New Delhi	Pusa Chotti Chaulai (A. blitum), Pusa Badi Chaulai (A. tricolor), Pusa Kirti (A. blitum), Pusa Kiran (A. tricolor), Pusa Lal Chaulai (A. tricolor)
3	IIHR, Bangalore	Arka Suguana (A. tricolor) Arka Arunima (A. tricolor)
4.	SDAU, S.K.Nagar	Grain Amaranth (GA 1), Grain Amaranth (GA 2), Grain Amaranth (GA 3), Grain Amaranth 6 (GA 6)

Sirukeerai (A. polygonoides) :

It is a traditional cultivar in Tamil Nadu suited for uprooting at 25 days after sowing. Leaves are small, ovate with blunt tip and have long petiole. Collar region is dark pink. At leaf axil a miniature branch initiates.

CHAPTER – 36
BLACK PEPPER BREEDING

Botanical Name : Piper nigrum

Family : Piperaceae

Origin : Western ghats of India

C.N : 2n = 52

Mode of pollination : Self pollination Introduction:

Black pepper, christened as “King of spice” and “Black gold” is the most important and the most widely used spice in the world occupying a position that is supreme and unique. It was the lure of Indian pepper that brought the western world to Indian subcontinent. Apart from black pepper the genus also includes economically important species like

P.longum – long pepper,

P. betle – betel leaf,

P.chaba – Java long pepper and

P.cubeba – Cubeb, Tailed pepper.

Pepper originated in the tropical evergreen forests of the Western Ghats. The Malabar coast of India was the centre of pepper trade from time immemorial. Black pepper was essentially a minor forest produce in the past. Domestication of pepper appears to be a much later event. The history shows that Arabs, followed by the Portuguese, the Dutch and the British traders took pepper to all over the world and spread its use and cultivation. Initially black pepper was taken from the Malabar Coast to the Indonesian islands, and then it spread to various pacific islands, South East Asian countries and later to tropical Africa and America. Currently pepper is grown in about 26 countries, major being India, Indonesia, Brazil, Malaysia and Srilanka. In India pepper is grown mainly in Kerala, Karnataka, Tamil Nadu and to a little extent in Goa, Orissa, Assam and Andaman group of islands. Kerala is the original home of pepper. The state accounts for 95% of country’s area and production.

Botany and Floral Biology:

Black pepper is a predominantly self pollinated while various degree of protogyny is encountered. Positive geotropism, spatial arrangement of flowers, sequential ripening of the stigma and non-chronological dehiscence of anthers stimulate selfing. Selfing with occasional out-crossing is the predominant mode of pollination in cultivated bisexual black pepper. It is adapted for pollination by gravitational descending of pollen grains combined with action of rain water or dew drops (Geitonogamy).

Breeding Objectives:

The main objectives of pepper breeding are higher yields, resistance to diseases (mainly foot rot and virus diseases), higher quality (piperine and piperidine content), tolerance to abiotic stresses and evolving low input responsive varieties. Pepper being a vegetatively propagated in addition to viable seed reproduction offer much scope for crop improvement work, especially for selection, breeding and exploitation of hybrid vigour. Existing genetic variability can be

exploited through clonal selection, as there are more than 100 pepper cultivars known to exist in India with substantial amount of inter and intra cultivar variability.

Genetic Diversity:

Diversity of pepper is great in evergreen forests of Western Ghats. Out of 17 species of Piper occurring, 11 are endemic. Through the process of natural evolution, domestication and selection, a lot of cultivars originated in its centre of origin. Cultivar diversity is the richest in Kerala, followed by Karnataka. Most of the cultivars are bisexual.

Selection in OP progenies

Pepper being heterozygous and propagated mainly through cuttings, there exist segregation in open pollinated and selfed progenies. Selection in OP progenies was carried out at Pepper Research Station, Panniyur. Two varieties Paniyur-2 and Panniyur -5 were developed through selection from OP progenies of cvs. Balankotta and Perumkodi, respectively.

Hybridization

Great variability that exists among cultivars is utilized in hybridization. Hybridization work in pepper was started at Pepper Research Station, Panniyur as early as 1959 and the first ever hybrid pepper variety in the world Panniyur-1 was released in 1971. It is a selection from F1 of a cross between cv. Uthirankotta x Cheriyakaniakkadan. The average yield of the variety is 1242kg/ha of dry berries. Interspecific hybridization was reported between P. nigrum x P. attenuatum and P. nigrum x P.barberi.

Breeding for quality

In pepper quality is mainly decided by content of piperine, essential oil and oleoresin. Piperine is responsible for pungency. Piperine content varies from 2- 7.4% among the cultivars. Essential oil ranges from 0.4-7 %. The property of piperine as bioavailability enhancing agent is being exploited by pharmaceutical industry. Diversification of value added products from pepper also demands high quality varieties. The existing cultivar diversity can be utilized for locating high quality varieties which can be subjected to selection as well as intercultivar hybridization.

Resistance breeding

The main objective is to evolve black pepper variety resistant/ tolerant to Phytophthora foot rot disease.

Polyploidy & mutation breeding

Polyploidy plays an important role in crop improvement. However, the success is very much limited in black pepper. A natural triploid (2n = 3x = 78), Vadakkan having bold fruits and less fruit setting and large leaves was identified. The progenies of the cultivar exhibited wide morphological variations and varying chromosome numbers, however none of these

exhibited horticulturally useful traits. The plants produced through mutation breeding were slow in growth. Varieties Developed:

Variety	Parentage	Institution	Salient features
Panniyur 1 1971	Inter- cultivar hybrid of Uthirankotta x Cheriyakaniyakadan	Pepper Research Station, Panniyur	Vigorous growing vine. Do not tolerate shade. Long spikes, close setting of berries, bold berries, oleoresin 11.8 % piperine 5.3%, essential oil 3.5% dry recovery 35.3% with an average yield of 1242kg/ha (dry)
Panniyur 2 1991	Clonal selection from open pollinated progeny of Balankotta	Pepper Research Station, Panniyur	Shade tolerant, suitable for intercropping, medium maturity group, medium quality, oleoresin 10.9%, high piperine (6.6%), essential oil 3.4%, dry recovery 35.7% with an average yield of 2570 kg/ha (dry)
Panniyur 3 1991	Inter cultivar hybrid of Uthirankotta x Cheriyakaniyakadan	Pepper Research Station, Panniyur	Suitable for all pepper growing regions, performs well under open situation, late maturity group, Long spikes and bold berries, piperine 5.2%, oleoresin 12.7%, essential oil 3.1%, dry recovery 27.8% with an average yield of 2570 kg/ha (dry)
Panniyur 4 1991	Clonal selection from Kuthiravally type II	Pepper Research Station, Panniyur	Stable yielder, performs well under adverse condition also, tolerant to shade, late maturity, 4.4% piperine, 9.2% oleoresin, 2.1% essential oil and 34.7% dry recovery.
Panniyur 5 1996	Clonal selection from open pollinated progeny of Perumkodi	Pepper Research Station, Panniyur	Suitable for both mono and mixed cropping in coconut/arecanut gardens, shade tolerant, medium maturity, tolerant to nursery disease, long spikes, piperine 5.3%, oleoresin 12.33% ,essential oil 3.8%

Panniyur 6 2000	Clonal selection from Karimunda type III	Pepper Research Station, Panniyur	A vigorous vine, tolerant to drought and adverse climatic conditions, stable and regular bearer, medium maturity group. Suitable for ope condition as well as partial shade, spike 6-8cm, more number of spikes/unit area, close setting and attractive bold berries, piperine 4.9%, oleoresin 8.27% and essential oil 1.33% and 33.0% dry recovery with an average yield of 2127kg/ha (dry)
Panniyur 7 2000	Open pollinated progeny of Kalluvally	Pepper Research Station, Panniyur	Vigorous vine and a regular bearer, long spike, a hardy type vine, tolerant to adverse climatic conditions, suitable for open and shaded conditions, very long spike (1624cm) high piperine content (5.6%), oleoresin 10.6%, essential oil 1.5% and 34.0% dry recovery with an average yield potential of 1410 kg/ha (dry).
Sree kara	Clonal selection from Karimunda	Indian Institute of Spices Research, Calicut	Suitable for all pepper growing regions including high elevations as well as for intercropping. Medium maturity, gives high quality pepper
Subhakara 1990	Clonal selection from Karimunda	Indian Institute of Spices Research, Calicut	Wide adaptability to all pepper growing tracts. Suitable for intercropping as well as for high elevations, high quality, medium maturity, piperine 3.4%, oleoresin 12.4%, 6.0% essential oil and 35.0% dry recovery with an average yield potential of 2352kg/ha (dry)
Panchami 2001	Clonal selection from Aimpiriyan	IISR, Calicut	High yielding, spike twisting, late maturing, suitable for high elevation, excellent fruit set, piperine 4.7%, oleoresin 12.4% essential oil 6.0% and 35.0% dry recovery. Average yield potential is 2828kg/ha (dry)

Pournami 2001	Clonal selection from Ottaplackal	IISR, Calicut	Tolerant to root knot nematode and shade. Medium maturity, suitable for intercropping with arecanut and banana.Piperine 4.1 % and dry recovery of 31.0%. Average yield potential is 2333 kg/ha (dry)
IISR Thevam	Clonal selection from germplasm of Thevammundi	IISR, Calicut	Stable yielding, grow vigorously, field tolerant to phytophthora, medium maturity, suitable to high altitude areas of South India up to 3000 ft MSL in coffee and tea estate. Piperine 1.6%, oleoresin 8.15%, essential oil 3.1% and dry recovery 32.5%.
IISR Malabar Excel	A hybrid of Cholamundi x Panniyur 1	IISR, Calicut	Recommended for rainfed condition including coffee and tea plantation. Oleoresin 11.7%, piperine 2.4%, essential oil 2.8%, dry recovery 32.3%. suitable for high elevations and plains. The average yield is 1453kg/ha (dry).
IISR Girimunda	A hybrid of Cholamundi x Panniyur 1	IISR, Calicut	Recommended for rainfed condition including coffee and tea plantation. A medium maturity group. Piperine 2.2%, oleoresin 9.65%, essential oil 3.4% and dry recovery 32.0%. The average yield is 2880kg/ha (dry)
IISR – Sakthi (P-24)	Open pollinated seedling progeny of cv. Perambra mundi a clonal cultivar	IISR, Calicut	Tolerant to P.capsici, piperine 3.3%, oleoresin 10.2%, essential oil 3.7% and driage 43.0%. The average yield is 5.2kg/vine fresh/ha
PLD -2 1996	Clonal selection from Kottanadan	NRC for Oil palm, Palode	Late maturity high quality cultivar contains piperine 3.0%, oleoresin 15.45%, essential oil 4.8%. Suitable for plains and higher elevations. The average yield is 2475kg/ha (dry)

CHAPTER – 37
CINNAMON BREEDING

Botanical Name : Cinnamomum verum (syn: C.zeylanicum)

Family : Lauraceae

Origin : Malabar coast

Chromosome No. : 2n=2x=24

Mode of pollination : Cross pollination Introduction:

The genus, a native of South- Western tropical India and Sri Lanka, consists of more than 250 species distributed in South East Asia, China and Australia. Seychelles and Malagasy Republic are the major producing countries of Cinnamon besides Sri Lanka. In India, cinnamon is mainly cultivated in Kenmore, south Karana, Nilgiris, Lower Pulneys, Courtallamand Kanyakumari. The genus cinnamomum has two centre of diversity in India, the north east region and the Western ghats, South India.

The introduction of C. verum from Srilanka and C. cassia from China to India in due course enhanced cinnamon production in India. The conservation of available variability of cinnamon in India and from exotic sources is carried out at IISR, Calicut, RRL, Bhubaneswar, KAU and TNAU.

The existence of wide variability for number of peeler shoots per plant, plant height, plant girth and tree spread indicated that the further improvement in the genotype may be made through Selection.

Cinnamon is commonly propagated through seeds. Seeds are extracted from ripe fruits from selected mother trees with desirable characters like smooth bark, erect stem, easy peeling of bark, vigorous growth, free from pests and diseases and having good qualities like sweetness, pungency and flavour. The seeds are sown immediately after collection, otherwise viability is reduced. Highest germination of 94 percent can be obtained by sowing seeds on the third day of harvesting. Under normal conditions, seeds germinate within 20 days.

Flowers are small; numerous in terminal and axillary panicles on current seasons growth. Peduncles are creamy white and five to seven cm long. Individual flowers are three mm in diameter with fetid smell. Flowering is from November to March. On an average 13.83 days are required for the flower bud development from the stage of its visible initiation. Peak anthesis is from 11 am to 12 noon. Stigma receptivity is maximum on the day of anthesis. Cinnamon flowers are cross pollinated. Insects are the pollinating agents.

Varieties developed:

Navashree & Nithyashree

Two high yielding and high quality cinnamon selections were released from IISR, Calicut.

S.No.	Character	Navashree (Sl.63)	Nithyashree (Sl.189)
1.	Regeneration capacity (shoots/plot of 4 plants)	25.45	18.90

2.	Fresh weight of bark (g)	488.95	511.15
3.	Dry weight of bark (g)	201.1	194.6
4.	Yield of bark /ha (kg)	55.56	54.16
5.	Recovery of bark (%)	40.6	30.7
6.	Bark oil (%)	2.70	2.70
7.	Yield of bark oil (l/ha)	1.50	1.46
8.	Bark oleoresin (%)	8.0	10.0
9.	Yield of oleoresin (kg/ha)	4.44	5.42
10.	Leaf oil (%)	2.80	3.00

Varieties Developed:

Name and year of release	Released by	Av. yield t/ha (Fresh)	Salient features
Yercaud -1	Horticultural Research Station, Yercaud,TNAU.	It gives a bark yield of 359.75 kg quills and 3800 kg of dried leaves/ha	It comes to harvest from third year onwards and can be maintained economically for 20 years. It gives high bark recovery of 35.3 per cent. It has got 2.8 and 3 per cent volatile oil in quills and leaves respectively. It gives a high regeneration capacity of 19.2 harvestable shoots. Quills are sweet and light pungent in taste.
Konkan Tej Clonal selection	Konkan Krishi Vidyapeeth, Dapoli	Fresh bark yield 789.75 g and 3.56 kg leaf per plant.	High oil (3.2%), cinnamaldehyde (70.23%) and eugenol (6.93%)
Sugandhini selection	Aromatic and Medicinal Plant Research Station, Odakkali, Kerala Agricultural University	Average leaf yield is 18kg/tree/year and average bark yield is 1.2 kg/tree/year.	It is recommended for cultivation in the midlands and highlands of Kerala both in open and as an intercrop in coconut gardens for cinnamon leaf oil. Leaf oil yield is 295ml/tree/year or 125kg/ha and the eugenol content is 94 per cent in leaf oil.

PPI (C)-1 selection	Horticultural Research Station, Pechiparai, Tamil Nadu Agricultural University.	It gives a fresh bark yield of 980kg/ha	Bark recovery is 34.22%, leaf oil recovery 3.3% and bark oil recovery 2.9%
RRL (B) C-6 selection	Regioanl Research Laboratory, CSIR, Bhubaneswar	Bark oil yield is 250kg/ha.	Bark is of high quality with 83.0% cinnamaldehyde in the oil. Leaf oil contains 94.0% eugenol.

CHAPTER – 38
NUTMEG BREEDING

Scientific Name	: Myristica fragrans
Family	: Myristicaceae
Chromosome No.	: 2n = 42
Origin	: Indonesia
Pollination system	: Cross Pollination
Type of inflorescence	: Umbellate cymes

Introduction:

The genus Myristica consists of about 120 species of which five have been described from India. They are M. fragrans, M. malabarica, M. magnifica, M.beddomei and M. contorta. The main difficulties are the long juvenile phase, the difficulty in propagating vegetatively, the dioecy and the single ovule in female flower.

Wide variation was reported in growth rate, productivity, size and shape of the leaf, flower size and shape and size of the fruit and nut. Nutmeg is a dioecious tree and the chief agent of pollination is wind. Selection will be effective in improving fruit number in nutmeg and selecting nutmeg trees with optimum fruit number and moderately good seed weight.

Native of Indonesia, nutmeg tree grows there abundantly and is now naturalized in West Indies, Sri Lanka, India, Philippines, Tropical America and Pacific Islands. In India the plant is grown in certain pockets of Kerala, Tamil Nadu, Karnataka, Goa, Maharashtra, North East India and Andaman. It is also grown in a small scale in Srilanka, Trinidad, China, Tobago, Zanzibar and Mauritius.

It is propagated sexually and asexually (cuttings or grafting). Sexual propagation yields 50% male seedlings, which are unproductive. As there is no reliable method of determining plant sex before flowering in the sixth to eighth year, and sexual reproduction bears inconsistent yields, grafting is the preferred method of propagation. Origin and Distribution

- Nutmeg is a native of Moluccas Island (Indonesia) and was introduced in India towards the end of the 18th century.
- It is now grown in certain areas in Kerala, Tamil Nadu and Karnataka.

Floral biology:

Plant :

The nutmeg is a medium sized, spreading and conical, thickly-leaved evergreen tree that attains the average height 4-10 m but sometimes may reach heights of 20 m and over.

Flower:

Inflorescences with male and female flowers are structurally similar and are axillary and glabrous, bearing flowers in umbellate cymes with the male 1-10 usually outnumbering the female 1-3. its quite commone to find in the male inflorescence flower in various stages of development. The pedicels 1-1.5 cm long are pale green with a minute caducouse bracteole at the base of flower.

The flowers are creamish yellow in appearance, waxy and fleshy, fragrant and may measure up to 1 cm in length. Petals are absent so the, fragrant and may measure up to 1 cm in length. Petals are absent so the dominant calyx is bell shaped, nectiferous at the base with 3-reflexed triangular lobes. The female flowers, up to 1 cm long, exhibit a puberulous, superior, sessile, one called ovary about 7 mm long and topped by a very short, white two lipped stigma.

The male flower consists of an androecium 1 cm long, glabrous, with 2 mm stalk, with 8-12 stamens, with anthers adnate to the central column and attached to each other by their sides. The male flowers are born in cluster were as female flower are often solitary.

Fruit:

The fruit is a flashy pendulous, one seeded drupe suspended by greenish brown fruit stalk about 1.5 cm long. It is broadly pyriform, yellow, smooth, 6-9 cm long and almost as broad.

Breeding objectives

- High yield
- Earliness
- Good processing qualities
- Resistance to disease and pest

Varieties Developed:

Name and year of release	Released by	Av. yield t/ha (Fresh)	Salient features

Konkan Sungandha	Dr. Balasaheb Sawant Konkan Krishi Vidyapeeth at Regional Fruit Research Station, Vengurla.	526 nuts /tree @ age of 15 years	This is the only hermaphrodite variety released. It yields 2.63 kg dry nuts . The nut size is 5g with 1.2g mace.
Konkan Swad	Regional Coconut Research Station, Bhatye, Ratnagiri, Maharashtra	761.36kg fruits/tree	It gives an average yield of 761.38 kg fruits/tree. Seeds contain 39.8% essential oil and mace 10.9%.
IISR-Vishwasree High yielding selection	IISR, Calicut	It gives an average yield of 3122 kg nut/ha (dry) and 480 kg mace (dry)/ha.	This variety possesses 7.1 per cent oil in nut and mace, 13.0 per cent oleoresin in mace and 2.5 per cent oleoresin in nut. Butter content is 30.9 per cent in nut.

CHAPTER – 39
GINGER BREEDING

Botanical name : Zingiber officinale Roscoe

Family : Zingiberaceae

Chromosome no. : 2n = 22

Center of origin : Southeast Asia Mode

of pollination : Cross pollination

Introduction:

Ginger is a herbaceous perennial grown as an annual crop. The family Zingiberaceae consists of 47 genera and about 1400 species. Among these, 22 genera and 178 species are endemic to India. Apart from cultivated ginger, the other important economic species of the genus are Z. zerumbet, Z.odoriferum, Z. spectabile, Z. squarrosum and Z.casumunnar, which are used as medicine and aromatic purposes.

It is used in both fresh and dried forms. Ginger is an ancient and the third most important spice of the world and is prized for its flavor and medicinal properties. In addition to its use as spice and condiment, it is also used to treat liver complaints, flatulence, anemia, rheumatism,

piles, and jaundice in Indian and Chinese systems of medicines. The genus Zingiber, consisting of about 150 species, is widely distributed in tropical and subtropical Asia.

Origin and Distribution:

Ginger is not found in the truly wild state. It is believed to have originated in Southeast Asia, but was under cultivation from ancient times in India. The main areas of ginger cultivation are India, China, Nigeria, Indonesia, Jamaica, Taiwan, Sierra Leone, Fiji, Mauritius, Brazil, Costa Rica, Ghana, Japan, Malaysia, Bangladesh, the Philippines, Sri Lanka, Solomon Islands, Thailand, Trinidad and Tobago, Uganda, Hawaii, Guatemala, and many Pacific Ocean islands.

Exotic Germplasm

In India, many exotic ginger cultivars have been introduced and some of them got adapted well to conditions and performed well in terms of yield and quality. Some of them are:

Rio-de-Janeiro (Brazil)	:	bold rhizome, fair skin, pungency, flavour and less fibrous
China (China)	:	extra bold rhizome, yellowish white skin, good pungency, flavour and fibrous
Jamaica (Jamaica)	:	bold rhizome, white skin, moderately pungent, high flavour and less fibrous.
Sierra- Leone (Sierra- Leone)	:	slender rhizome, buff skin, pungent, moderately flavoured and fibrous
Taffingiva (Nigeria)	:	a moderately high yielder, which is under commercial cultivation in the ginger growing tracts of Nigeria.

Botany:

- The genus Zingiber, the type genus of the family Zingiberaceae, forms an important group of the order Zingiberales.
- Among these Z. officinale, Z. zerumbet, and Z. montanum are medicinal species; Zingiber mioga is a vegetable; and Z. officinale is the cultivated ginger.

Zingiber officinale Rosc. :

Ginger is an herbaceous perennial having an underground branched rhizome with small scales. The inner core of the rhizome is pale yellow to bluish tinge while the outer is light yellow. Adventitious roots and storage roots arise from among the nodes of these scales. The ancillary buds shoot up as a leafy stem known as a pseudostem, which dies out annually; however, the plant continues to live through its rhizome. Leaf sheathing is arranged alternatively; there is a linear lanceolate gradually becoming acuminate and glabrous. Flowers

are borne on a spike produced in a peduncle, different from the aerial leafy stem, arising directly from the rhizome.

Zingiber americanus Bl.:

It is native to Malaysia. It is an attractive, medicinally important garden plant widely grown in the United States. The rhizomes are used as an ingredient in various traditional medicines. The pounded rhizome is used as a poultice for women after delivery. In Java, young rhizomes are eaten as a vegetable.

Zingiber aromaticum Val. :

A native of tropical Asia, the rhizome of this species is strongly aromatic and fibrous, resembling Z. americanus in taste and aroma. It is widely cultivated in kitchen gardens and as an ornamental plant. Its fresh and tender shoots and flowers are eaten and used to flavor foods. The rhizomes are used as an ingredient in folk medicines as well as for poultices The rhizomes contain zerumbone, which has HIV-inhibitory and cytotoxic activities.

Zingiber bradleyanum Craib. :

This plant is cultivated in the United States as attractive foliage plant with a beautiful silvery stripe on the midrib of the leaves. The plant has a natural dormancy and is winter hardy.

Other species:

- Zingiber chrysanthum Rosc.
- Zingiber citriodorum J. Mood & I. Theilade
- Zingiber clarkei King ex Benth.
- Zingiber collinsii J. Mood & I. Theilade
- Zingiber corallinum Hance
- Zingiber eborium J. Mood & I. Theilade
- Zingiber gramineum Noronha
- Zingiber griffithii Baker Breeding Objectives:
- Higher rhizomes yield
- Early maturity
- More storage life
- Resistance to insect pests
- Resistance to abiotic stresses
- Resistance to diseases
- Desirable rhizomes weight
- high quality (high oil, high oleoresin, low fibre etc.)

- Rhizomes quality (rhizomes size, shape and colour, rhizomes firmness) Crop Improvement:

Crop improvement work in ginger is limited to clonal selection, mutation breeding and polyploidy breeding. Conventional recombination breeding programmes were handicapped by relatively shy flowering behaviour and absence of seed set. The main objectives of breeding are high yield, higher driage, wide adaptability, high quality (high oil, high oleoresin, low fibre etc.) and resistance to fungal and bacterial pathogens (bacterial wilt and rhizome rot).

Introduction and Selection

Crop improvement work carried out so far has been confined to collection of cultivars from different localities and their comparative yield evaluation and selection. The cultivars differ considerably in their rhizome characters and production potential. In ginger, yield and quality are influenced by various factors. Most of the improved varieties of ginger are the result of direct selections from germplasm. Nine varieties of ginger have been released. Varieties Suprabha, Suruchi, and Suravi have bold and plump rhizomes and are suitable for both rainfed and irrigated conditions. Varada is the most promising, with bold rhizomes, wide adaptability, and tolerance to rhizome rot. Mahima has low fiber content and is resistant to root knot nematode. Rejatha has round and bold rhizomes with low fiber content and high oil content. Himagiri is best for green ginger and less susceptible to rhizome rot.

Mutation breeding

Induction of variability through mutations, chemical mutagens, and ionizing radiation has been attempted by various workers. Use of chemical mutagen ethyl methane sulfonate (EMS) resulted in reduced growth and increased cytological irregularities. Almost all the induced changes appearing in the R1 generation were in chimeric form, expressed a stunted or semi dwarfing effect, and were inhibitory on production of rhizomes. Mohanty and Panda (1991) developed and released a high-yielding yellow-fleshed mutant, Suravi, that is suitable for both rainfed and irrigated conditions. Two more mutant selections, V3S1-8 and V1E8-2, using mutagens sodium azide and ethyl methyl sulfonaste, respectively. Both have wide adaptability and are moderately tolerant to disease and pests.

Polyploidy breeding

Ramachandran (1982) and Ramachandran and Nair (1992) reported successful induction of stable tetraploids having 2n=4x = 44 in ginger (cultivars Maran and Mananthody) by treating the sprouts with 0.25% aqueous colchicines. The polyploids were more vigorous than the diploids and flowered during the second year of induction. These autotetraploids had

larger rhizomes and high yield (198.71 g/plant). However, oil content of these rhizomes was lower (2.3%) than that of the original diploid cultivar (2.8%).

Varieties Developed:

Name and year of release	Pedigree/parentage & Plant type	Salient features
Suprabha 1988, OUAT, Pottangi	Clonal selection from Kunduli local	Plumpy rhizomes, less fibre, wide adaptability, suitable for early and late sowing with a duration of 229 days, 8.9% oleoresin, 4.4% crude fibre, 1.9% essential oil and 20.5% dry recovery. Suitable for Orissa and adjoining states.
Suruchi 1990, OUAT, Pottangi	Clonal selection from Kunduli local	Profuse tillering, bold rhizome, suitable for rainfed/irrigated conditions with a duration of 218 days, 10.9% oleoresin, 2.0% essential oil, 3.8% crude fibre with a dry recovery of 23.5%. Suitable for Orissa, Central and South India.
Surabhi 1991, OUAT, Pottangi	Induced mutant of Rudrapur local	Plumpy rhizome, dark skinned yellow fleshed, suitable for both irrigated/ rainfed with a duration of 225 days. 10.2% oleoresin, 2.1% essential oil, 4.0% crude fibre with 23.5% dry recovery.Suitbale for Orissa.
V_3S_1-8, OUAT, Pottangi	Sodium azide mutant	A mutant line moderately tolerant to diseases and pests. Having an oleoresin content of 10.8%, essential oil 1.8%. crude fibre 3.2%, dry recovery 22.2%, suitable for green and dry ginger, wide adaptability, suitable for both hills and plains
V_1E_8-2 OUAT, Pottangi	An EMS mutant	A mutant line moderately tolerant to diseases and pests.Contains 10.8% oleoresin, 1.8% essential oil, 3.5% crude fibre, 21.4% dry recovery, suitable for green ginger, late planting under rainfed conditions in hills and plains.

Himgiri 1996, Solan, Himachal Pradesh	Clonal selection from Himachal collection	Best for green ginger, less susceptible to rhizome rot disease, suitable for rainfed condition, 4.29% oleoresin, 1.6% essential oil, 6.05% crude fibre, 20.2% dry recovery with a duration of 230 days.
IISR Varada 1996, IISR	Selection form germplasm	High yielder, high quality bold, low fibre content (3.29% to 4.50%), essential oil 1.7% , 6.7% oleoresin and 19.5% dry recovery, tolerant to diseases, maturity 200 days.
IISR Rejatha 2004, IISR	Selection form germplasm	High yielder, plumpy and bold rhizome, 2.36% essential oil, 6.3%oleresin, 4.0% crude fibre, 20.8% dry recovery, maturity – 200 days. Suitable for Kerala and Karnataka
IISR Mahima 2004, IISR	Selection form germplasm	High yielder, plumpy bold rhizomes, 1.72% essential oil, 4.5% oleoresin, 3.26 crude fibre, dry recovery 23.0% , maturity 200 days. The variety is resistant to nematode (M. incognita and M. javanica)

CHAPTER

TURMERIC BREEDING

Botanical name : Curcuma longa

Family : Zingiberaceae

Chromosome no. : 2n = 22

Center of origin : Southeast Asia Mode of

pollination : Cross pollination

Introduction:

Turmeric "the golden spice of life" is one of the most essential spice crops. As early as 3000 B.C. the turmeric plants were cultivated by "Harappan" civilization. It belongs to the family zingiberaceae. It is a native to India. India is the largest producer and consumer of turmeric in the world.

Turmeric, the sacred spice of Asian countries is a herbaceous perennial native to Indo Malayan region. Turmeric is essentially a tropical crop grown in India, Pakistan, Malaysia, Thailand, Philippines, Japan, China, Sri Lanka, Africa and Central America. It is the third important spice crop of India, next to chilies and black pepper.

India is the largest producer and exporter of turmeric contributing about 80% of production and 45% of export. The crop occupies major share of area in Andhra Pradesh followed by Orissa, Tamil Nadu, West Bengal and Maharashtra.

Nearly 40 species of Curcuma are known to exist in India, while only one species C. longa contributes to commercial production of turmeric of commerce (96%). It is an herbaceous perennial with underground rhizomes. It is a sterile triploid (3n = 63) and do not normally set viable seeds. The other species are C. aromatica (Kasthuri manjal), C. caesia (Black turmeric), C. amada (mango ginger), C. zedoaria, C. purpurescens, C.mangga, C.heyneana, C. xanthorrhiza, C. aeruginosa, C. phaeocaulis and C. petiolata are also cultivated in different parts of India. C. aromatica is cultivated to a lesser extent for Kasturi turmeric used in cosmetics.

Turmeric types can be grouped into three based on maturity period as short, medium and long duration types. Short duration types are known as Kasturi. They mature in seven months, rhizomes possess pleasant aroma, good yielders of dried turmeric and rich in volatile oil content but low in curcumin and used in culinary preparation. Flowering is common in these types and seeds produce gametic seedlings. Medium duration Kesari types which mature in eight months are referred as intermediary types and are high yielders of fresh rhizomes than Kasturi types and rich in curcumin and volatile oil. Long duration types mature in nine months

and are moderately good both for rhizome yield and other quality constituents. Flowering and seed set are rare in medium and long duration types.

Origin & distribution:

- ✓ Turmeric is originated in South East Asia (India).
- ✓ Indian turmeric is considered to be the best due to high curcumin content.
- ✓ India accounts for about 80% of world turmeric and 60% of world exports.
- ✓ Other major producers are Pakistan, china, peru etc.

Nutritional and medicinal value:

- Turmeric contains curcumin, a substance with powerful anti-inflammatory and antioxidant properties.
- Curcumin can inhibit many molecules known to play major roles in inflammation.
- Turmeric increases the anti oxidant capacity of the body
- It boosts brain derived factors, lower risk of brain diseases.
- It decreases the risks of heart diseases.
- It helps to prevent cancer.
- Arthritis patients respond very well to curcumin supplementation.
- It has beneficial effects against depression.
- it is very popular as an anti aging supplement.

Species:

The important characteristics of C. longa, C.aromatica, C. amada, C. angustifolia and C. zedoaria are as under:

C. longa (Popularly known as Longa types)

Pseudostem is tall, robust with oblong elliptic leaves narrowed at the base. Plant reaches a height up to 1m with 8 to 10 leaves. Spike is apical, length ranges between 10-18 cm. with pale yellow flowers. Starchy root tubers are not produced at the end of fibrous roots.

Rhizomes are bigger in size with more curcumin content but moderate in volatile oil.

C.aromatica (Popularly known as Kasthuri types)

In this group, cultivars mature early, within 6-7 months. Pseudostem is short with elliptic/oblong leaves. Flowering is lateral, and being a tetraploid, fertile and viable seeds are produced. Plants produce peculiar root tubers at the end of the fibrous roots. Rhizomes possess pleasant unique aroma due to volatile oil but low in curcumin content. Rhizome production is less as compared to C. longa types. It is used in the preparation of dyes, cosmetics and drugs but not used as a spice or condiment.

C. amada (Mango ginger)

Popularly known as mango ginger cultivated in India for its rhizomes, which have the odour of raw mangoes and it is used for the preparation of pickles , chutneys etc.

C. zedoaria

It is considered to be native of north- eastern India and to have spread in cultivation throughout the Indian subcontinent and Malaysia. The interior of the rhizome is yellow and when dried has an agreeable musky odour with a slight smell of camphor and a pungent bitter taste. Zedoary rhizomes are used in indigenous medicines in Asia and in perfumery in India.

Plant morphology:

Plant :

- It is a perennial plant with roots or tubers.
- Leaves are 2 feet, long petioled, tapering at each end.

Flower :

- The inflorescence in turmeric is a compound spike which is terminal shoot.
- Flowers are yellowish white, zygomorphic and bisexual.

Breeding objectives:

- To identify turmeric types with high yield potential, high curing percentage and high curcumin content.
- Rhizome should be bold, bright orange in color and suitable for drought prone areas.
- Should be resistant to pest & diseases.
- Resistant to abiotic stress.
- Proper weight of finger & mother rhizomes should be maintained.

Breeding Methods:

Selection

Among the characters, plant height, rhizome yield, curing percentage , curcumin content, oleoresin content and resistance to leaf blotch and leaf spot diseases recorded higher percentage of genetic advance indicating scope for selection. Estimation of oil and curcumin contents in different cultivars of C. longa and C. aromatica indicated that variability for oil and curcumin content was high in C. longa compared to C. aromatic and for identifying cultivars with high curcumin and oil content, it may be worthwhile to carry out selection in C. longa alone. Hybridization

Hybridization work is limited in turmeric as commercial cultivars are sterile triploids of C. longa.

Mutation breeding

Efforts were made to evolve improved varieties through mutation breeding which resulted in release of a few varieties, such as BSR 1, BSR 2, CO 1 and Suroma.

Varieties Developed:

Name and year of release	Pedigree/parentage & Plant type	Av. Yield t/ha (Fresh)	Salient features
CO 1 1983, TNAU	Vegetative mutant by x-ray irradiation of Erode local	35.0	The crop duration 270 days. It yields 35t/ha. Rhizomes are bigger in size and bright orange coloured and better than Erode local. The curcumin content of rhizome is 3.2 per cent with 20 per cent processing recovery. Plants are robust, vigorous and taller (40-60cm) with more number of leaves (25-32) and tiller production 3.7 to 5.0.
BSR 1 1986, TNAU	Clonal selection from Erode local irradiated with xrays	39.6	The crop duration is 280 days. It yields 31t/ha of fresh rhizomes and 6tonnes of dried rhizomes. The rhizomes are attractive with yellow fingers and close internodes. The processing ratio is 20 per cent. The rhizome contains 4.2 per cent curcumin, which is higher than CO 1 and Erode local.
BSR 2 1994, TNAU	Induced mutant from Erode local	32.7	The crop yields 32t/ha in a duration of 240-250 days. The plants are medium stature, high yielding and resistant to scale insects. The variety is adaptable to Erode, Coimbatore, and Salem, Dharmapuri, Trichirapalli, thanjavur, North Arcot and South Arcot districts.
Roma 1988, Pottangi, Orissa.	Clonal selection	40.0	Suitable for both rainfed and irrigated condition, suitable for hilly areas and late season planting. Curcumin 9.3%, oleoresin 13.2%, essential oil 4.2% and dry recovery 31.0% with duration of 250 days.

Suroma 1989, Pottangi, Orissa.	Clonal selection	44.9	Round and rhizomes, field tolerant to leaf blotch, leaf spot and rhizome scale, curcumin 9.3% , oleoresin 13.1%, essential oil 4.4% and dry recovery 26.0% with a duration of 253days.
Rajendra sonia 1989, Dholi, Bihar	Selection from local germplasm	23.0	Bold and plumpy rhizome grows widely under all north Indian conditions. Curcumin 8.4%, essential oil 5.0% and dry recovery 18.0% with duration of 225 days.
Megha turmeric 1996, Meghalaya	Selection from Lakadong type	27.5	Suitable for North East hill and North West Bengal. Bold rhizomes, high curcumin content 6.8% and dry recovery 16.37% with a duration of 300-315 days.
Pant Peetabh 2001, Pant Nagar	Clonal selection from local types	29.0	Long attractive fingers, curcumin 7.5%, essential oil 1.0%, dry recovery 18.5%, resistant to rhizome rot.
Suranjana (TCP-2) 2000, West Bengal	Clonal selection from local types of North Bengal	29.0	Suitable for open and shade condition sole or intercrop, suitable for rainfed as well as high rainfall areas. Curcumin 5.7%, oleoresin 10.9%, essential oil 4.1%, dry recovery 21.2%, duration 235 days, tolerant to leaf blotch and rhizome rot. Resistant to rhizome scales and moderately resistant to shoot borer.
IISR Alleppy Supreme 2004, Calicut	A clonal selection from Alleppy turmeric	35.45	Shows tolerance to leaf blotch disease. Rhizome contains 5.5% curcumin, 16.0% oleoresin, 19.0% dry recovery with crop duration of 210 days.
IISR Kedaram 2004, Calicut	Clonal selection from germplasm	34.5	Tolerant to leaf blotch disease, Rhizome contain 5.5% curcumin, 13.6% oleoresin, dry recovery of 18.9% with duration of 210 days.
Kanthi 1996, KAU, Trichur	Clonal selection from Mydukur variety of Andhra Pradesh	37.65	Erect leaf with broad lamina, big mother rhizomes with medium bold fingers and closer internodes, Medium duration, Curcumin content (7.18%), oleoresin 8.25%, essential oil 5.15%, dry recovery 20.15% with a duration of 240-270 days.

Sobha 1996, KAU, Trichur	Clonal selection from local type	35.88	Mother rhizome big with medium bold and closer internodes. Inner core of rhizomes is dark orange like alleppey. More tertiary rhizomes. Dryage 19.38%, curcumin content (7.39%), oleoresin (9.65%), essential oil (4.25%) with a medium duration of 240-270 days.

Sona 2002, Trichur, Kerala	Clonal selection from local germplasm	4..02 (dry)	Orange yellow rhizome, medium bold with no tertiary fingers. Best suited for central zone of Kerala. Rhizome medium bold, field tolerant to leaf blotch. Curcumin 7.12%, essential oil 4.4%, oleoresin 10.25%, 18.8% dry recovery, medium duration of 240-270 days.
Varna 2002, Trichur, Kerala	Clonal selection from local germplasm	4.16 (dry)	Bright orange yellow rhizome, medium bold with closer internodes, tertiary fingers present. Suited to central zone of Kerala. Field tolerant to leaf blotch, curcumin 7.87 %, essential oil 4.56%, oleoresin 10.8%, 19.05% dry recovery with a medium duration of 240-270 days.