Lecture 1: Origin and history of agriculture; conservation and agricultural development- the central role of agrobiodiversity – Methods to estimate biodiversity- trends and challenges

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Origin and history of agriculture

Agriculture is the science and art of cultivating plants and livestock. Agriculture was the key development in the rise of sedentary human civilization, whereby farming of domesticated species created food surpluses that enabled people to live in cities. The history of agriculture began thousands of years ago.

Time line of development of Agriculture

- 9500 BCE (Earliest evidence for domesticated wheat)
- 8000 BCE (Evidence for cattle herding)
- 7000 BCE (Cultivation of barley; animals are domesticated)
- 6500 BCE (Cattle domestication in Turkey)
- 6000 BCE (Indus Valley grows from wheat to cotton and sugar)
- 5500 BCE (Sumerians start organized agriculture)
- 5400 BCE (Archaelogical proof for domestication of chicken)
- 5400 BCE (Linearbandkeramik Culture in Europe)
- 5000 BCE (Africa grows rice, sorghum)
- 4000 BCE (Ploughs make an appearance in Mesopotamia)
- 3000 BCE (Maize is domesticated in Americas)
- 3000 BCE (Turmeric is harvested at Indus Valley).
- 2737 BCE Tea is discovered
- 2000 BCE 1st windmill in Babylon
- 1000 BCE sugar processing in India
- 500 BCE Row cultivation in China
- Year 200 (Multi-tube seed drill invented in China)
- Year 700 (Arab Agriculture Revolution)
- Year 1000 (Coffee originates in Arabia)
- Year 1492 (Columbian exchange changes agriculture)
- Year 1599 1st Practical Green House is created
- Year 1700 (British Agricultural Revolution)
- Year 1700 (Charles Townshend popularizes)

- 14/3/1794 (Cotton gin is invented)
- Year 1800 (Chemical fertilizer began to be used)
- Year 1837 (John Deere invents steel plough)
- Year 1860 (Hay cultivation changes)
- Year 1866 (Gregor Mendel describes Mendelian inheritance)
- Year 1879 (Milking machine replaces hand milking)
- Year 1892 (First practical gasoline-powered tractor)
- Year 1900 (Birth of industrial agriculture)
- Year 1930 (First aerial photos for agriculture)
- Year 1930 (First plant patent is given)
- Year 1939 (DDT becomes a rage)
- Year 1944 (Green Revolution begins in Mexico)
- Year 1972 (Organic movement starts taking roots)
- 1996 (Commercial cultivation of genetically modified plants)

History

- The first use of plant genetic resources dates to more than 10,000 years ago, when farmers selected from the genetic variation they found in wild plants to develop their crops. As human populations moved to different climates and ecosystems, taking the crops with them, the crops adapted to the new environments, developing, for example, genetic traits providing tolerance to conditions such as drought, water logging, frost and extreme heat. These traits - and the plasticity inherent in having wide genetic variability - are important properties of plant genetic resources.
- In recent centuries, although humans had been prolific in collecting exotic flora from all corners of the globe to fill their gardens, it wasn't until the early 20th century that the widespread and organized collection of plant genetic resources for agricultural use began in earnest. Russian geneticist Nikolai Vavilov, considered by some as the father of plant genetic resources, realized the value of genetic variability for breeding and collected thousands of seeds during his extensive travels to establish one of the first gene banks. Vavilov inspired the American Jack Harlan to collect seeds from across the globe for the United States Department of Agriculture (USDA). David Fairchild, another botanist at USDA, successfully introduced many important crops (e.g. cherries, soybeans, pistachios) into the United States.

- It wasn't until 1967 that the term *genetic resources* was coined by Otto Frankel and Erna Bennett at the historic International Conference on Crop Plant Exploration and Conservation, organized by the FAO and the International Biological Program (IBP). "The effective utilization of genetic resources requires that they are adequately classified and evaluated" was a key message from the conference.
- Historically, mankind has used only about 5,000 plant species worldwide to meet food and other needs. This number is just a fraction of the total world flora. With population growth, we are increasingly dependent on most productive plants. Today, only about 150 plant species are important in meeting the food (calories) needs of humans worldwide. The short list of the most commonly used foods is what stands between us and the estimated worldwide carrying capacity in pre-agricultural times (Wilkes, 1984). This short list contains:

Cereals	: Wheat, rice, maize, barley, oats, sorghum, millets, rye.
Oilseeds	: Coconut, cotton seed, sunflower.
Legumes	: Soybean, peanut, common beans (*Phaseolus* spp.), pea, chickpea, cowpea.
Root crops	: Potato, sweet potato, cassava, yam and taro.
Sugar crops	: Sugarcane, sugarbeet.
Vegetables	: Tomato, cabbage, onion, squash.
Fruits	: Banana, orange, apple, pear, melon, mango.

- The cereals represent twice the tonnage of all the other crops (if the potato with its high water content is discounted) and nearly three times the calories. Both tea and coffee are major world crops but these caffeine containing beverages are not included because they add essentially no calories to human nutrition. This list is primarily a calorie list and does not recognise the important role of low calorie vegetables and fruits in supplying vitamins, minerals and proteins to human nutrition. The list also does not include regional foods that locally may supply more than half of the calories consumed. In addition, pasture forages and fibre crops have been omitted (Wilkes, 1984).
- Hence, greater dependence on fewer plant species, 20 to 30 in global context (Harlan, 1975), gradually, has resulted in the loss of native genetic resources which are otherwise essential as building blocks of genetic diversity. In order to safeguard and

conserve this diversity, the large share of which is held by the developing world, different countries/national and international organisations have in recent past shown their concern for proper conservation of genetic resources. The cultivated plants truly form the very basis of modern civilization and their domestication in historical context constitutes the agricultural revolution, the signs of which are still visible in traditional cultivation sites in the developing world. In this chapter, emphasis is laid on some of these findings/concepts relating to the origin of agriculture, the process of plant domestication and the geographical regions where genetic richness in plant resources occurs. Further, the importance to safeguard and conserve such- genepools has been highlighted.

Change from nomadic life to settled agriculture

- To quote the great scientific philosopher, Dr. Jacob Bronowski, 'the genesis of cultivated plants is a true fairy tale of genetics as if coming of civilization had been blessed in advance by the spirit of the abbot Gregor Mendel'. The change from nomadic life to settled agriculture has had a fascinating past. What were the forces that led to domestication of plants? Where were the sources/centres which provided the initiation of agriculture? When did the science of plant breeding begin and blossom to guide the crop evolutionary processes through man's intervention? Why does agricultural research give so much emphasis on the importance of crop plant diversity? These are some of the basic questions, answers to which can apprise the students of botany and agriculture of the value of plant genetic resources our 'Mother Earth' is so greatly endowed with. These points have been discussed in the context of plant genetic diversity, largely in the Indian perspective.
- Conclusions drawn from circumstantial evidences show that agriculture started about 10,000 years ago. A well known hypothesis for the origin of agriculture is the Rubbish-Heap hypothesis. It says that early humans gathered nutritious roots and seeds for their food. Such plants actively colonized the bare areas around their dwellings, which were rich with the discarded rubbish. This natural process was obviously based on man's known food gathering activities and selection of only those useful plants which he found most suitable in tune with local habitats.
- The plants selected by man must have been preadapted to agriculture and they must be of particular interest to man because of their large food reserves. Three stages seemed to have operated in this continuous process. In the first stage, the preadapted

wild plants with weedy tendencies and large reserves of food began to colonize the open ground or kitchen middens around man's dwellings. Also, people probably accidentally dropped seeds from the natural habitats on the same ground and thus reinforced the process. In the second stage, perhaps the seeds were regularly harvested from the plots around the dwellings, and fenced to protect them from domesticated cattle and wild herbivores. At this stage, the early man was also selecting mutants for increased yields, palatibility and other desirable traits, and the plants might have evolved a series of better adapted types that were able to take advantage of the richer soil conditions. The third stage of sowing/placement of seeds in soil at the right time and carefully guarding them at all stages until harvest must have come very late at a time when man really began to know his plants. This stage marks the end of pre-agricultural phase and perhaps led to considerable increase of human population as a result of increased food supplies. From here, the human families would have begun to move away from their original areas, eventually reaching regions where the wild progenitors of crop plants no longer grew. These families could continue to harvest the food plants in the new region only if they had taken some seeds with them. As the population continued to spread, the new tradition of keeping and saving seeds, a tradition born out of necessity, may have been established. This explanation can obviously account for both seed and tuber/root crops (Hawkes, 1983; Paroda *et al*, 1986).

Biodiversity

- The term Biodiversity was first coined by Walter G. Rosen in 1986.
- The biosphere comprises of a complex collections of innumerable organisms, known as the Biodiversity, which constitutes the vital life support for survival of human race.
- Biological diversity, abbreviated as biodiversity, represent the sum total of various life forms such as unicellular fungi, protozoa, bacteria, and multi cellular organisms such as plants, fishes, and mammals at various biological levels including genes, habitats, and ecosystem

Concept and Types of Biodiversity

- Biodiversity is the variety of life forms on earth and the essential interdependence of all living things.
- As defined in Convention on Biological Diversity (CBD) singed at Rio De Jenerio (Brazil) in 1992 by 154 countries, the Biodiversity defined as “the variability among

living organisms from all sources including, inter alia, terrestrial, marine and other aquatic eco-systems and the ecological complexes of which the area part- this include diversity with in species, between species and of ecosystem."

There are three types of biodiversity

1. Diversity of Species
2. Diversity of Genes
3. Diversity of Ecosystem

1. Species diversity

- Species diversity refers to biodiversity at the most basic level and is the 'variety and abundance of different types of individuals of a species in a given area'.
- It includes all the species on Earth, ranging from bacteria, viruses, fungi, algae, bryophytes, pteridophytes, gymnosperms, angiosperms and all the species of animals including unicellular protozoans to mammals.
- Certain regions support a more diverse populations than others. Regions that are rich in nutrients and have well balanced climatic factors, such as moderate temperature, proper light and adequate rainfall, show high degree of diversity in their life forms.
- The tropical areas support more diverse plant and animal communities than the desert and polar areas
- The regions that are rich in species diversity are called hotspots of biodiversity

2. Genetic diversity

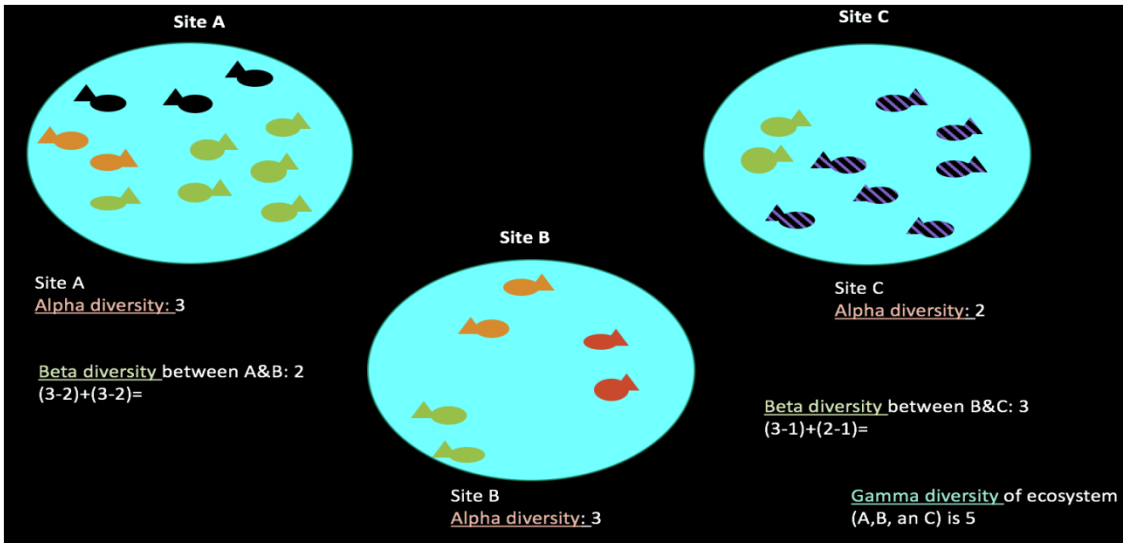
- Genetic diversity pertains to the range of diversity in the genetic resources of the organisms. Every individual member of a plant or animal species differs from other individuals in its genetic constitution. Each individual has specific characters, which is due to the genetic makeup
- Eg. There are many varieties within the same species such as rice, wheat, apples, mangoes, etc. that differ from one another in shape, size, colour of flowers and taste of fruits and seeds due to the variations at the genetic level

3. Ecological / Ecosystem Diversity

- Ecological diversity refers to the 'variability among the species of plants and animals living together and connected by flow of energy and cycling of nutrients in different ecosystems or ecological complexes'.
- It also includes variability within the same species and variability among the different species of plants, animals and microorganisms of an ecosystem.

Methods for computing biodiversity

- ***Alpha diversity*** refers to the average species diversity in a habitat or specific area. Alpha diversity is a local measure
- ***Beta diversity*** refers to the ratio between local or alpha diversity and regional diversity. This is the diversity of species between two habitats or regions. It is calculated by the following equation (number species in habitat 1- number of species habitat 2&1 have in common)+(number of sp in H2- number of sp H1&2 have in common)
- ***Gamma diversity*** is the total diversity of a landscape and is a combination of both alpha and beta diversity



Role of Agro-biodiversity

- Increase productivity, food security, and economic returns
- Reduce the pressure of agriculture on fragile areas, forests and endangered species
- Make farming systems more stable, robust, and sustainable
- Contribute to sound pest and disease management
- Conserve soil and increase natural soil fertility and health
- Contribute to sustainable intensification
- Diversify products and income opportunities
- Reduce or spread risks to individuals and nations
- Help maximize effective use of resources and the environment
- Reduce dependency on external inputs
- Improve human nutrition and provide sources of medicines and vitamins
- Conserve ecosystem structure and stability of species diversity.

Questions

1	The term Biodiversity was first coined by	(Walter G. Rosen)
2	How many types of biodiversity available?	(Three)
3	The regions that are rich in species diversity are called	(hotspots)
4	..... is a combination of both alpha and beta diversity	(Gamma diversity)
5	Who is considered as the father of plant genetic resources?	(N.I. Vavilov)

Lecture 2: Crop Diversity – Centres of crop plant origin and diversity, Concepts of gene pools

Centres of origin:

Some thousands years ago man might have selected some of the plants for his use. He might have started cultivating these plants and it might have become major occupation for him. In this way, some plants became cultivated crops. So by the end of 18^{th} century everybody started questing about origin of cultivated plants.

Darwin in 1868 stated that cultivated plants arose by profound modifications in the wild plants.

Alphonse de Candole in 1863 studies 247 plants species of cultivated plants and wrote a book "Origin of cultivated plants". He classified the plants into six classes.

1. Plants cultivated 4000 years ago.
2. Plants cultivated 2000 years ago.
3. Plants cultivated less than 4000 years
4. Plants cultivated 2000 - 4000 years
5. Plants cultivated before the time of Columbus
6. Plants cultivated after the time of Columbus.

Nikolai Ivanovich Vavilov (1926 - 1951) is a Russian Geneticist and Plant Breeder who realized the importance of genetic diversity for crop improvement. So N. I. Vavilov and his coworkers visited several countries and collected vast number of plants and stored at Institute of Plant Industry, Leningrad. Based on his global exploration and collection, he proposed the concept of **'Centres of origin'.** He was the Director of this Institute from 1916 till 1936. He proposed the following concept.

1. Primary centre of origin:

Crop plants evolved from wild species in the area showing great diversity of forms and that place is termed as primary centre of origin. Later on from the primary centre, the crops moved to other places due to the activities of man.

2. Secondary centre of origin:

There are certain areas where some crops exhibit maximum diversity of forms but this may not be the centre of origin for that particular crop and such areas are known as secondary centre of origin.

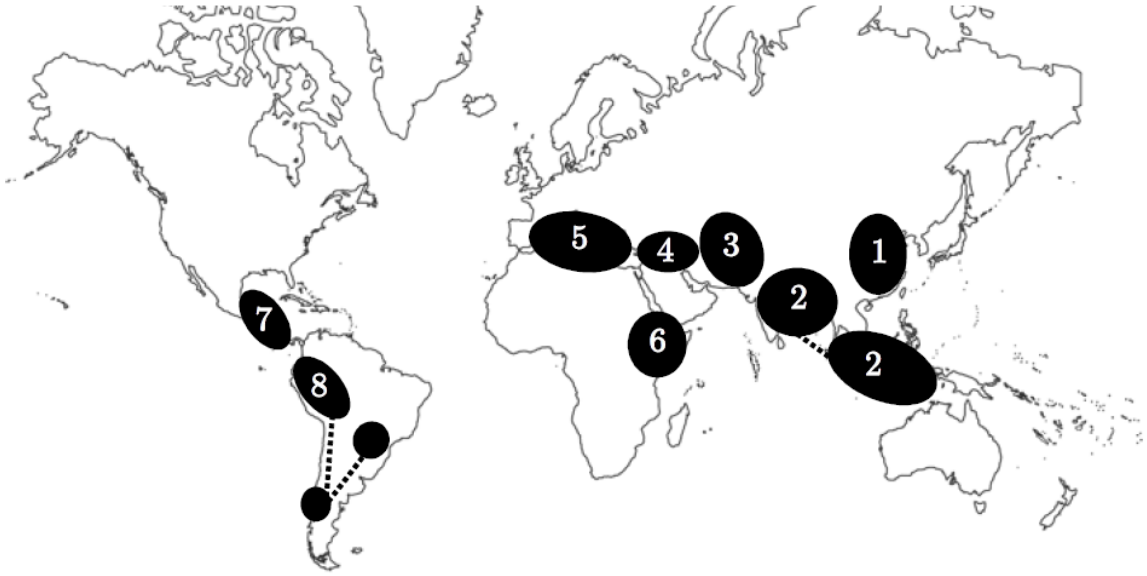
Eg. The primary centre of origin for Sorghum is Africa. But Indian shows the maximum diversity for this crop. So India is secondary centre of origin for sorghum.

N. I. Vavilov originally proposed eight main centres of origin

1. The China Centre:

   It consists of mountainous regions of central and western China. It is the largest and oldest independence centre.
2. The Hindustan Centre

   It includes Burma, Assam, Malaya, Java, Borneo, Sumatra and Philippines which exclude northwestern India, Punjab.
3. The Central Asia Centre / Afghanistan centre of origin. North western India, Afghanistan, Tadjikistan and Tianshan.
4. The Asia Minor Centre / Near East (or) Persian centre of origin: Asia minor, Transcaucasia, Iran and Turkmenistan
5. The Mediterranean Centre
6. The Abyssinian Centre: Ethiopia and hill country of Eritera
7. The Central America / Mexico centre of origin: South mexico, Central America
8. The South America: Peru, Bolivia, Ecuador, Colombia, Chile, Brazil and Paraguay



1: China
2: India and Malaya
3: Central Asia
4. Near East
5. Mediterranean
6. Ethiopia
7. Mexico and Central America
8. South America

Centre of Origin	Area	Primary Centre of Origin	Secondary Centre of Origin
1. The China Centre (largest and oldest independence centre)	Mountainous region of central and western China	Soybean, Radish, Prosomillet, Brassica, Onion	Maize, cowpea, Turnip, sesame and rajma
2. The Hindustan Centre	Burma, Assam, Malaya, Java, Borneo, Sumatra, Philippines excludes North west India and Punjab	Rice, Redgram Chickpea, Greengram, Cowpea, Turmeric, Cucumber, Radish Noblecane (*Saccharum officinarum*) Cotton (*G. arboreum*), coconut	-
3. The Central Asia (or) Afghanistan centre of origin	North west India, Afghanistan, Tadjikistan, Tian Shan	Wheat, Onion, Pea, Garlic, Broad bean, linseed, sesame, safflower, Greengram, cotton (*G. herbaceum*)	Rye
4. The Asia minor centre or Near east / Persian centre of	Asia minor Transcaucasia, Iran, Turkmenistan	Triticum, Rye, Alfalfa, cabbage, oats	Rape seed, Black Mustard, Turnip.

origin			
5. Mediterranean centre	-	Durum wheat, Emmer wheat, Barley, Lentil, pea, Broad bean, Chickpea, Beets and Peppermint	-
6. The Abyssinian centre	Ethiopia & hill country of Eritrea	Barley, sorghum, pearllmillet, Lentil, Khasari, safflower, castor, coffee, okra.	Broad Bean
7. Central America centre / Mexican centre of origin	South Mexico, Central America	Maize, Lema bean, Melons, pumpkin, sweet potato, Arrow root, cotton, (*G. hirsutum*), chilly, papaya, Guava	-
8. The south America Centre	Peru, Bolivia, Ecuador, Colombia, Chile, Brazil and Peraguay	Potato, maze, Lima bean, Peanut (Ground nut)	-

Later, in 1935, N.1.Vavilov divided the Hindustan Centre of origin into two centres viz.,

1. Indo-Burma Centre of origin
2. Siam-Malaya - Java centre of origin

The South American centre was divided into three centres

1. Peru
2. Chile
3. Brazil - Peraguay Centre of origin

At the same time, he introduced a new centre of origin called USA centre of origin. The two plant species, sunflower, Jurusalem artichoke originated in this centre.

Centres of origin may be more appropriately called the centre of diversity.

Microcentre**:** Within the large centre of diversity, a small area exhibits much greater diversity than the centre as a whole is called microcenter.

N.I. Vavilov proposed law of homologous series or law of parallel variation

The characters found in one species also observed in other related species.

Eg. Series of identical characters are found in diploid, tetraploid and hexaploid wheat.

Series identical characters are found in diploid andtetraploid cotton.

Objections to N.I. Vavilov's theory:

1. According to N.I.Vavilov, whenever a crop exhibits maximum diversity that place is called centre of origin for that crop. But it is not valid for maize and tomato

   Eg. For maize, Peru is the centre of origin. But archeological evidence shows Mexico is the centre of origin. Similarly for tomato, South America is the centre of origin. But archeological evidence shows Mexico in the centre of origin.
2. N.I.Vavilo stated that in the primary centre, dominant genes exist in the centre and recessive genes towards the periphery. But it is not so in maize and wheat.
3. N.I.Vavilov claimed that centre of origin is confined to mountaneous region only. But it is not so. Eg. Maize exhibits maximum diversity in plains.
4. Many crops have more than one centre of origin. Eg. Sorghum
5. In some crops, centre of domestication cannot be determined for want of suitable evidence.

Zhukovsky:

He was the student of N.I. Vavilov and proposed "Mega centre theory". He divided the world into 12 regions.

Mega gene centre is the place where cultivated plant species exhibit diversity.

Micro gene centre is the place where wild species occur.

Harlan:

He stated that each crop may have been repeatedly domesticated in different times in different location (or) may have been brought into cultivation in several regions simultaneously. So we cannot pinpoint single centre of origin.

Harlan developed the idea of centre and non centre. According to him

Centre is the place of Agricultural origin

Non centre is the place where Agriculture has been introduced.

Harlan divided the world into three centres and three non centres.

Main features of Primary and Secondary Centres

Sl.No.	Primary centre of Diversity	Secondary centre of Diversity
1.	Have wide genetic diversity	Have lesser genetic diversity
2.	Have large no. of dominant genes	Have large no. of recessive gene
3.	Mostly have wild characters	Mostly have desirable traits
4.	Exhibits less crossing over	Exhibits more crossing over
5.	Natural selection operates	Both natural and artificial selection operates

Gene Pool Concept

Gene pool concept was developed by Harland and Dewet (1971). Gene pool consists of all genes and their alleles in crops species which can hybridize with each other.

There are three groups of gene pool.

1. Primary Gene Pool (GP_1)

- It includes plants of the same species or closely related species.
- Members of primary gene pool hybridize readily with each other and produce fertile hybrids.
- The members of primary gene pool are most commonly used in plant breeding programmes

2. Secondary Gene Pool (GP_2)

- It includes plants of related species.
- Members of secondary gene pool hybridize with members of primary gene pool with some difficulty and produce partially fertile hybrids. So gene transfer from secondary gene pool to primary gene pool is possible with difficult.
- The members of secondary gene pool are often used in plant breeding programmes.

3. Tertiary Gene Pool (GP_3)

- The members of tertiary gene pool hybridize with the members of primary gene pool with great difficulty and produce sterile hybrids. Hence, gene transfer from tertiary gene pool to primary gene pool is very difficult which requires special techniques. However, gene transfer from tertiary gene pool to secondary gene pool is relatively easier.
- The members of tertiary gene pool are occasionally used in plant breeding programme.

Questions

1 Who did write a book "Origin of cultivated plants"
a) Darwin b) **Alphonse de Candole** c) N. I. Vavilov d) Mendal

2 Who did propose the concept of 'Centres of origin'
a) Darwin b) Alphonse de Candole c) **N. I. Vavilov** d) Mendal

3 Crop plants evolved from wild species in the area showing great diversity of forms and that place is termed as .....
a) **Primary centre of origin** b) Secondary centre of origin
c) Tertiary centre of origin d) Microcenter

4 There are certain areas where some crops exhibit maximum diversity of forms but this may not be the centre of origin for that particular crop and such areas are known as .....
a) Primary centre of origin b) **Secondary centre of origin**
c) Tertiary centre of origin d) Microcenter

5 How many centres of origin were originally proposed by N. I. Vavilov?
a) **Eight** b) Nine c) Ten d) Twelve

6 Primary centre of origin for soybean is .....
a) **China Centre** b) Hindustan Centre c) Central Asia d) Asia minor

7 Primary centre of origin for rice is .....
a) China Centre b) **Hindustan Centre** c) Central Asia d) Asia minor

8 Primary centre of origin for Sorghum is .....
a) China Centre b) Asia minor c) Central Asia d) **Abyssinian centre**

9 Primary centre of origin for Maize is .....
a) China Centre b) Asia minor c) **Central America** d) South America

10 Primary centre of origin for Potato is .....
a) China Centre b) Asia minor c) Central America d) **South America**

11 Sunflower originated in ..... centre
a) **U.S.A.** b) Abyssinian c) Hindustan d) Mediterranean

12 Centres of origin may be more appropriately called .....
a) Primary centre of origin b) Secondary centre of origin
c) **Centre of diversity** d) Microcenter

13 Within the large centre of diversity, a small area exhibits much greater diversity than the centre as a whole is called .....
a) Primary centre of origin b) Secondary centre of origin
c) Centre of diversity d) **Microcenter**

14 Who did propose law of homologous series?
a) Darwin b) Alphonse de Candole c) **N. I. Vavilov** d) Mendal

15 Who did propose Mega centre theory?
a) Darwin b) N. I. Vavilov c) **Zhukovsky** d) Harlan

16 Who did develop the idea of centre and non centre?
a) Darwin b) N. I. Vavilov c) Zhukovsky d) **Harlan**

One mark
1. Define primary centre of origin
2. Define secondary centre of origin
3. State law of homologous series
4. Differentiate between Mega gene centre and Micro gene centre
5. Differentiate between centre and non centre

Two marks
1. Differentiate between Primary centre of Diversity and Secondary centre of Diversity

Five marks
1. Who did propose the concept of 'centres of origin'? Explain eight main centres of origin

Lecture 3: Biodiversity hotspots - Global – Indian- Regions of agro-biodiversity

- Biodiversity is referred to as the variation of plant and animal species in a particular habitat. Species evenness and species richness form the major components of biodiversity
- India is known for its rich biodiversity and has 23.39% of the geographical area covered by forests and trees
- the country has 66 National Parks, 333 Wildlife Sanctuaries and 35 Zoological Gardens which comprises of a wide variety of fauna
- Biodiversity hot spot is defined as the regions which are known for their high species richness and endemism.
- Norman Myers coined the term "Biodiversity hotspot" in 1988

Conservation International (CI)

- Conservation International (CI) is an American nonprofit environmental organization headquartered in Arlington, Virginia
- Conservation International was founded in 1987 with the goal of protecting nature for the benefit of people.
- In 1989, CI formally committed to the protection of biodiversity hotspots, ultimately identifying 36 such hotspots around the world and contributing to their protection. The model of protecting hotspots became a key way for organizations to do conservation work
- Biodiversity Hotspot regions are blessed with a variety of exceptional plant species and habitat, but facing endemism and serious habitat loss.
- Hence, it is our duty to protect and conserve the endemic species and their habitat.
- We can conserve biodiversity in two ways- first is in-situ and second is ex-situ.

- In-situ conservation involves in the maintenance of bio-diversity rich area in its natural form, whereas in ex-situ conservation, the endangered species are kept in a specially protected area which is separated from its natural habitat region

Two criteria to qualify as a hotspot

1. It must have at least 1,500 vascular plants as endemics — which is to say, it must have a high percentage of plant life found nowhere else on the planet. A hotspot, in other words, is irreplaceable.
2. It must have 30% or less of its original natural vegetation. In other words, it must be threatened. (greater than 70 percent habitat loss)

Four biodiversity hotspots in India

1. The Himalayas
2. Indo-Burma Region
3. The Western Ghats
4. Sundaland

1. Himalaya:

- Includes the entire Indian Himalayan region (and that falling in Pakistan, Tibet, Nepal, Bhutan, China and Myanmar).
- Considered as the highest in the world, the Himalayas comprises of North-East India, Bhutan, Central and Eastern parts of Nepal. This region holds a record of having 163 endangered species which includes the Wild Asian Water Buffalo, One-horned Rhino and as many as 10,000 plant species, of which 3160 are endemic. This mountain range covers nearly 750,000 km^2.

2. Indo-Burma:

- Includes entire North-eastern India, except Assam and Andaman group of Islands (and Myanmar, Thailand, Vietnam, Laos, Cambodia and southern China)
- The Indo-Burma Region is stretched over a distance of 2,373,000 km^2. In the last 12 years, 6 large mammal species have been discovered in this region: the Large-antlered Muntjac, the Annamite Muntjac, the Grey-shanked Douc, the Annamite Striped Rabbit, the Leaf Deer and the Saola.
- This hotspot is also known for the endemic freshwater turtle species, most of which are threatened with extinction, due to over-harvesting and extensive habitat loss. There are also 1,300 different bird species, including the threatened White-eared Night-heron, the Grey-crowned Crocias, and the Orange-necked Partridge.

3. Western Ghats and Sri Lanka:

- Includes entire Western Ghats (and Sri Lanka).
- The Western Ghats are present along the western edge of peninsular India and covers most of the deciduous forests and rain forests. This region consists of 6000 plant species of which 3000 are endemic. Originally, the vegetation in this region was spread over 190,000 km^2 but has been now reduced to 43,000 km^2. The region is also known for 450 species of birds, 140 mammals, 260 reptiles and 175 amphibians.

4. Sundalands:

- Includes Nicobar group of Islands (and Indonesia, Malaysia, Singapore, Brunei, Philippines).
- The Sundaland hotspot lies in South-East Asia and covers Singapore, Thailand, Indonesia, Brunei and Malaysia. In the year 2013, the Sundaland was declared as a World Biosphere Reserve by the United Nations. This region is famous for its rich terrestrial and marine ecosystem. Sundaland is one of the biologically richest hotspots in the world which comprises of 25,000 species of vascular plants, of which 15,000 are found only in this region.

Biodiversity Hotspots of the World

Africa

1. Eastern Afro-Montane
2. The Guinean forests of Western Africa
3. Horn of Africa
4. Madagascar and the Indian Ocean Islands
5. Maputoland, Podoland, Albany hotspot
6. Succulent Karou
7. East Malanesian islands
8. South Africa's Cape floristic hotspot
9. Coastal forests of Eastern Africa

Asia and Australia

1. Himalayan hotspot
2. The Eastern Himalayas
3. Japan biodiversity hotspot
4. Mountains of South-West China
5. New Caledonia

6. New Zealand biodiversity hotspot
7. Philippine biodiversity hotspot
8. Western Sunda (Indonesia, Malas and Brunei)
9. Wallace (Eastern Indonesia)
10. The Western Ghats of India and Islands of Sri Lanka
11. Polynesia and Micronesian Islands Complex including Hawaii
12. South-Western Australia

North and Central America

1. California Floristic Province
2. Caribbean islands hotspot
3. Modrean pine-oak wood lands of the USA and Mexico border
4. The Mesoamerican forests

South America

1. Brazil's Cerrado
2. Chilean winter rainfall (Valdivian) Forests
3. Tumbes-Choco-Magdalena
4. Tropical Andes
5. Atlantic forest

Europe and Central Asia

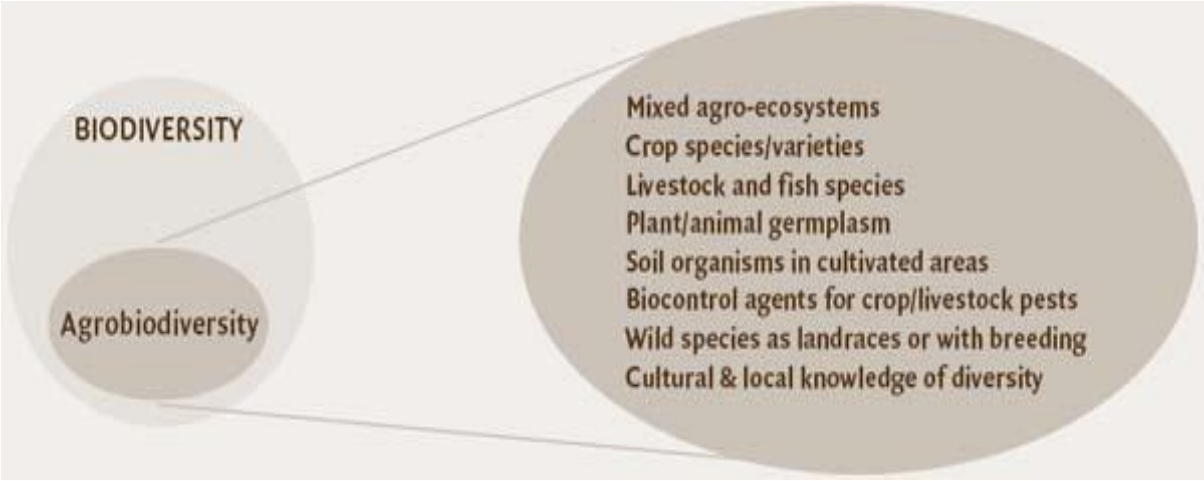
1. Caucasus region
2. Iran-Anatolia region
3. The Mediterranean basin and its Eastern Coastal region
4. Mountains of Central Asia

- In 2011, the Forests of East Australia region was identified as the 35th biodiversity hotspot.
- The North American Coastal Plain (NACP) – was recognized only recently as meeting the criteria for a global biodiversity hotspot
- Therefore, 36 biodiversity hotspots cover 2.3% of the Earth's land surface, yet more than 50% of the world's plant species and 42% of all terrestrial vertebrate species are endemic to these areas.

AGROBIODIVERSITY

Agricultural biodiversity, also known as agrobiodiversity or the genetic resources for food and agriculture, includes

- Harvested crop varieties, livestock breeds, fish species and non domesticated (wild) resources within field, forest, rangeland including tree products, wild animals hunted for food and in aquatic ecosystems (e.g. wild fish);
- Non-harvested species in production ecosystems that support food provision, including soil micro-biota, pollinators and other insects such as bees, butterflies, earthworms, greenflies; and
- Non-harvested species in the wider environment that support food production ecosystems (agricultural, pastoral, forest and aquatic ecosystems).



It comprises the diversity of genetic resources (varieties, breeds) and species used for food, fodder, fibre, fuel and pharmaceuticals.

Distinctive features of agrobiodiversity

- Agrobiodiversity is actively managed by male and female farmers;
- many components of agrobiodiversity would not survive without this human interference; local knowledge and culture are integral parts of agrobiodiversity management;
- many economically important agricultural systems are based on ‘alien’ crop or livestock species introduced from elsewhere (for example, horticultural production systems or Friesian cows in Africa). This creates a high degree of interdependence between countries for the genetic resources on which our food systems are based;
- as regards crop diversity, diversity within species is at least as important as diversity between species;

- because of the degree of human management, conservation of agrobiodiversity in production systems is inherently linked to sustainable use - preservation through establishing protected areas is less relevant;
- in industrial-type agricultural systems, much crop diversity is now held ex situ in gene banks or breeders' materials rather than on-farm.

Role of Agro-biodiversity

- Increase productivity, food security, and economic returns
- Reduce the pressure of agriculture on fragile areas, forests and endangered species
- Make farming systems more stable, robust, and sustainable
- Contribute to sound pest and disease management
- Conserve soil and increase natural soil fertility and health
- Contribute to sustainable intensification
- Diversify products and income opportunities
- Reduce or spread risks to individuals and nations
- Help maximize effective use of resources and the environment
- Reduce dependency on external inputs
- Improve human nutrition and provide sources of medicines and vitamins
- Conserve ecosystem structure and stability of species diversity.

Distribution of Agrobiodiversity in India

- According to Chatterjee (1939), India divided into 8 phytogeographical regions
- 8 agro-climatic regions by ICAR
- 15 agro-climatic zones by Planning commission
- In 1990, 20 agro-ecological zones were recognized on the basis of micro-climate, physiography, type of soil, temperature, soil depth, soil texture, available water capacity and crop growing period

Distribution of major crop diversity in different phytogeographical regions of India

SN	Phytogeographical regions	Areas	major crop diversity
1	Western Himalayas	Jammu & Kashmir, H.P, Part of U.P	Rice, Wheat, maize, finger millet, potato and fruits

2	Eastern Himalayas	West Bengal & Assam	Rice, wheat, maize, chickpea, jute, tea
3	North-Eastern	NE states	Rice, Maize, Barley, pineapple, citrus, tea, banana, sugarcane
4	Gangetic plains	Punjab, UP, Bihar	Rice, wheat, maize, millets, chickpea, sugarcane
5	Indus plains	Gujarat, Rajasthan, Haryana	Wheat, chickpea, oilseeds, millets
6	Eastern Ghats / Deccan plateau	MP, Orissa, AP	Rice, millets, wheat, oilseeds
7	Western Ghats / Malabar	Karnataka, TN, Kerala,	Rice, sorghum, finger millet, groundnut, plantation crops, tobacco
8	Islands region	Andaman-Nicobar & Lakshadweep	Rice, Plantation crops

Lecture 4: Crop wild relatives – domestication of crops

Crop Wild Relatives (CWR)

Crop wild relatives (CWR) collectively constitute an enormous reservoir of genetic variation that can be used in plant breeding and are a vital resource in meeting the challenge of providing food security, enhancing agricultural production and sustaining productivity in the context of a rapidly growing world population and accelerated climate change. They occur in a wide range of habitats but as numerous assessments testify, habitats continue to be lost or degraded across the world, putting many of these species at risk. It is therefore essential that urgent steps are taken to conserve them both in the wild (*in situ*) and in genebanks (*ex situ*) while the genetic diversity they contain is still available.

What is CWR ?

In general terms, a crop wild relative (CWR) may be defined as a wild plant species that is more or less closely related to a particular crop and to which it may contribute genetic material, but unlike the crop species has not been domesticated (Heywood et al, 2007). There are two ways of describing this relationship –

i. **Genecological** – based on the extent to which they can exchange genes with thecrop – and
ii. **Taxonomic** – based on their taxonomic relationship with the crop

The genecological approach often uses the Harlan and de Wet (1971) gene pool concept to define the degree of relatedness, based on the relative ease with which genes can be transferred from them to the crop (Box1).

Genetic resources

Genetic resources were traditionally defined as genetic material (alleles) of known value used in plant or animal improvement, but the meaning has been widened by the Convention on Biological Diversity (CBD) to mean *any material of plant, animal, microbial or other origin containing functional units of heredity, of actual or potential value*. Crop Wild Relatives are a key component of plant genetic resources for food and agriculture.

Gene Pool

Gene pool is based on the taxonomical and evolutionary relationship between cultivated species and their wild allied species. Gene pool concept was proposed by Harlan and de Wet (1971) based on hybridization among species. Gene pool is totality of genes occurring in populations, cultigens and progenitor species and wild allied species.

Primary gene pool (GP1) consists of biological species and crossing within the gene pool is easy. The resulting hybrids are vigorous, exhibit normal meiosis, complete chromosome pairing and show high fertility and free gene exchange with normal genetic segregation. In subspecies A of GP1, cultivated races and in subspecies B, spontaneous races are included. A race is a biological unit with some integrity, originated in some geographical region at some time of the history of the crop. It is not clearly separable as a species but has distinct cohesion in morphology, adaptation, distribution and frequently of breeding behaviour.

Secondary gene pool [GP 2] comprises related species and taxa and successful hybrids can be obtained between them with GP 1 showing low / poor fertility and gene transfer is possible but with difficulty. The GP2 in wheat, cotton and rice is substantially large. The tertiary gene pool (GP3) is the extreme outer limit of potential genetic resource. Hybrids between GP1 and GP3 are difficult to produce, require in vitro technique and show non homology of chromosome and complete sterility. Sometimes the hybrids are inviable. In

rice, GP 3 is very small. Soybean and barley have no GP 2 and GP 1 and GP 3 are very limited.

Cytogenetics approaches for gene pools would indicate high degree of chromosome homology and gene exchange between members of primary gene pool, partial chromosome homology or homoeology between members of primary and secondary gene pool. Hybrids between tertiary gene pool and the primary and secondary gene pools invariably show often complete sterility and high degree of non homology of chromosome. Amphiploidy mediation is often effective to restore fertility for gene transfer. In general, introgression of trait by wide hybridization present difficulties that are not easily resolved.

Techniques for alien gene transfer

Different techniques are followed to overcome barriers to wide hybridization and to obtain viable hybrids to effect gene transfer:

1. Embryo rescue and in vitro techniques.
2. Involving bridge species which are crossable with both the parental species.
3. Application of exogenous plant growth regulators and immuno suppressors at post pollination stage.
4. Backcrossing the hybrids with agronomically acceptable base as recurrent parent
5. Chromosome doubling when genome non homology is present. (4n or 6n pathway) and backcrossing
6. chromosome techniques such as translocations, alien additions lines [MAAL and DAAL], substitutions, homoeologous pairing and also irradiation to induce interchanges and gene transfer.

Wild species of crop plants

Wheat

T.boeoticum: forms with one to two seeded spikelets occur. The brittle ears shatter at maturity into individual spikelets armed with awns which provide an effective means of seed dispersal. It is probably the ancester for all the cultivated wheats

- *T.monococcum*: Primitive diploid form domesticated, evolved from *T.boeoticum* by mutation and selection..
- *Aegilops speltoides*: (2n=14;B genome). It is naturally cross-pollinating. It is the recognized donor of the B genome.
- *T.dicoccoides*:It is an amphidiplod form resulting from the hybridization of *T.boeoticum* and *Ae. speltoides*.
- *T.dicoccum*: The spikes are dense, bearded and laterally compressed, the spikelets are two grained and the grains are retained within the glumes after threshing (speltoid). It is the oldest of the cultivated wheat.
- *T.durum*: Free threshing wheat with naked grains, important of the tetraploid wheats. Grains contain high gluten.
- *Ae. squarrosa*: (2n=14; D genome) It is the source of D genome in the cultivated hexaploid wheat, high adaptability.
- *T.spelta*: Hexaploid species, considered an amphidiploid from hybridization between *T.dicoccoides* and *Ae.squarosa.*

Sorghum

S.halapense	:	Both *2n = 20* and *2n = 40* forms are available utilized for forage sorghum improvement.
S.sudanense	:	Utilized for improvement of forage sorghum.
S.nitidum	:	Found in Kodai Hills. Processes shoot fly resistance and dormancy.
S.staffii	:	Found in Southern districts, used for inducing dormancy.

Redgram

Cajanus kerstingii

Cajanus lineate

C. scaraboides

Bengalgram

C.soongaricum - cultivated in Afghanistan, Western Himalayas and Tibet.

C.microphyllum Grown in higher elevations for food as well as for cattle feed

C.reticulatum which crosses readily with *arietinum* is probable ancestor for chick pea.

C. pinnatifidum, C.judaicum - Having wilt resistance

Greengram

V.umbellata - resistant to bean fly

V.radiata var. *sublobata* - resistance to bruchids

Blackgram

V.mungo var.*sylvestris* - YMV resistant

Cowpea

V.unguiculata ssp m*enensis* – Putative parent

V.v*exillata* - having tuberous roots which is edible

Soy bean

Glysine usuriensis - Probable ancestor

Groundnut

Arachis batizoccoi – Disease resistance

A.*monticola* - for thin shelled conditions

A.*villoulicarpa* - for increased number of pods

Gingelly

S.alatum - Resistant to phyllody and it is having dormancy.

S.malabaricum - Occurs in Travancore of Kerala. It freely crosses with cultivated gingelly. It is utilised to transfer male sterility in cultivated sesame.

S.laciniatum - Tolerant to phyllody, drought and jassid resistant.

S.prostratum - Tolerant to drought.

Sunflower

H. hirsuta - moderately resistance to *Alternaria*

Safflower

Carthamus oxycanthus - having 28% oil were utilised in hybridization programme to increase yield and oil content

Cotton

G. raimondii - Jassid resistance.

G. anamalum - Jassid resistance.

G. thurberi - Boll worm resistance

G. harknessi - For transferring male sterility

Potato

Solanum ajanhuiri & S.curtilobium - Frost resistant

S.phureja - Sort duration. 4 month no dormancy

S.stenotomum - Longer in duration 6 months dormancy

Solanum tuberosum ssp andigena - High altitude potato

S.demissum and S.acaule ssp. *andigena* – Resistant yo Early blight, late blight, powdery scab., *verticillium* wilt, virus diseases

Solanum tuberosum ssp andigena – Tolerant to Nematode

S.verineii - resistant to Aphids, Colorado beetle

Tapioca

Manihot glaziovii - Resistant to YMV

Tobacco

N. debneyi - Resistant to Black root rot

N. longiflora - Black shank resistant

N. glutinossa - Mosaic resistant

N. plumbaginifolia - Leaf curl, black shank resistant.

N. digluta - Bridging species & resistance to mosaic virus

Rice

Species	2*n*	Genome	Number of accessions	Distribution	Useful traits
O. sativa complex					
O. sativa L.	24	AA	96,564	Worldwide	Cultigen, high yielding
O. glaberrima Steud.	24	A^gA^g	1,562	West Africa	Cultigen; tolerance to drought, acidity, iron toxicity, P-deficiency; resistance to BB, blast, RYMV, African gall midge, nematodes, weed competitiveness
O. nivara Sharma et Shastry	24	AA	1,260	Tropical and subtropical Asia	Resistance to grassy stunt virus, BB
O. rufipogon Griff.	24	AA	858	Tropical and subtropical Asia, tropical Australia	Resistance to BB, blast, BPH, tungro virus; moderately tolerant to Shb, tolerance to aluminum and soil acidity, increased elongation under deep water; source of CMS and yield-enhancing loci

Species	2*n*	Genome	Number of accessions	Distribution	Useful traits
O. breviligulata A. Chev. et Roehr. *O. barthii*	24	A^gA^g	218	Africa	Resistance to GLH, BB; drought avoidance; tolerance to heat and drought
O. longistaminata A. Chev et Roehr	24	A^lA^l	203	Africa	Resistance to BB, nematodes, stemborer, drought avoidance
O. meridionalis Ng	24	A^mA^m	56	Tropical Australia	Elongation ability; drought avoidance; tolerance to heat and drought
O. glumaepatula Steud.	24	$A^{gp}A^{gp}$	54	South and Central America	Elongation ability; source of CMS; tolerance to heat
O. officinalis complex					
O. punctata Kotschy ex Steud.	24, 48	BB, BBCC	71	Africa	Resistance to BPH, BB, zigzag leafhopper; tolerance to heat and drought
O. minuta J.S. Presl. ex C.B. Presl.	48	BBCC	63	Philippines and Papua New Guinea	Resistance to BB, blast, BPH, GLH
O. officinalis Wall ex Watt	24	CC	265	Tropical and subtropical Asia, tropical Australia	Resistance to thrips, BPH, GLH, WPH, BB, stem rot; tolerance to heat
O. rhizomatis Vaughan	24	CC	19	Sri Lanka	Drought avoidance, resistance to blast; tolerance to heat
O. eichingeri A. Peter	24	CC	30	South Asia and East Africa	Resistance to BPH, WBPH, GLH
O. latifolia Desv.	48	CCDD	40	South and Central America	Resistance to BPH, BB, high biomass production
O. alta Swallen	48	CCDD	6	South and Central America	Resistance to striped stemborer; high biomass production
O. grandiglumis (Doell) Prod.	48	CCDD	10	South and Central America	High biomass production
O. australiensis Domin.	24	EE	36	Tropical Australia	Resistance to BPH, BB, blast; drought avoidance; tolerance to heat and drought
O. meyeriana complex					
O. granulata Nees et Arn. ex Watt	24	GG	24	South and South Asia	Shade tolerance, adaptation to aerobic soil
O. meyeriana (Zoll. et (Mor. ex Steud.) Baill.)	24	GG	11	Southeast Asia	Shade tolerance; adaptation to aerobic soil
O. ridleyi complex					
O. longiglumis Jansen	48	HHJJ	6	Irian Jaya, Indonesia, and Papua New Guinea	Resistance to blast, BB
O. ridleyi Hook. F.	48	HHJJ	15	South Asia	Resistance to blast, BB, tungro virus, stem borer, whorl maggot
Unclassified					
O. brachyantha A. Chev. et Roehr	24	FF	19	Africa	Resistance to BB, yellow stemborer, leaf folder, whorl maggot; tolerance to laterite soil
O. schlechteri Pilger	48	KKLL	1	Papua New Guinea	Stoloniferous
O. coarctata Tateoka	48	KKLL	1	Asian Coastal Area	Tolerance to salinity, stoloniferous
Leersia perrieri A. Camus	24	UNKNOWN	1	Africa	Shade tolerance, stoloniferous

BPH brown plant hopper, ***GLH*** green leaf hopper, ***WBPH*** whitebacked plant hopper, ***BB*** bacterial blight, ***Shb*** sheath blight, ***CMS*** cytoplasmic male sterility, ***RYMV*** rice yellow mottle virus

Lecture 5

Dynamics of crop domestication with special reference to Rice, Wheat, Maize and Tomato

Dynamics of plant domestication

Domestication is an evolutionary process operating under the influence of human activities. Being evolutionary, obviously it is relatively a slow process and exhibits gradual progression from the wild state to a state of incipient domestication. Diverse forms that differ more and more from their progenitors develop. The possible changes in plant species (in different directions) due to domestication are listed below:

1. Adapting to a greater diversity of environments and a wider geographical range;
2. Different/specific ecological preference;
3. Flowering and fruiting simultaneously/uniformly;
4. Lack of shattering or scattering of seeds and sometimes may have lost the dispersal mechanism completely;
5. Increased size of fruits and seeds which often reduces the dispersal efficiency;
6. Change from a perennial to annual habit;
7. Loss of seed dormancy;
8. Loss of photoperiodic response;
9. Lack of normal pollinating organs;
10. Change in breeding system (may result from a change in flower morphology, or a change from self-incompatibility to self-compatibility);
11. Loss of defensive adaptations, such as hairs, spines, thorns, etc.;
12. Loss of protective coverings and sturdiness;
13. Improvement towards palatability, chemical composition rendering them more likely to be eaten by animals;
14. Increased susceptibility for diseases and pests;
15. Developing of seedless parthenocarpic fruits;
16. Multiplied vegetatively.

For prominent characters, the evolutionary changes that take place during plant domestication are listed in Table 1 (Hawkes, lecture delivered at the NBPGR, 1978).

Table 1. Evolutionary changes during plant domestication

Character	Wild forms	Domesticated forms
1. Viability in competition with other species	Good	Poor
2. Food reserves (size of fruit, etc.)	Medium, not very succulent	Large, succulent
3. Variability of storage organ used by man (size, shape, colour)	Small	Great
4. Physiological adaptation	Medium to narrow range	Wide range
5. Dispersal mechanisms such as		
(a) Rachis or rachilla of cereals	Brittle	Non-brittle
(b) Stolons in potato	Long	Short
(c) Explosive dehiscence (legume-pods etc.)	Present	Absent
(d) Pores for seed dispersal (*Papaver somniferum*)	Present	Absent
(e) Cereal awns	Present	Absent or reduced
6. Protective devices, such as		
(a) Thorns or spines	Present	Absent
(b) Bitter or poisonous flavour	Present	Absent
(c) Dense indumentum of hairs	Present	Absent
7. Sexual reproduction (as in potato, sweet potato, etc.)	Present	Absent or reduced
8. Habit	Perennial	Annual
9. Seed germination uniformity	Not synchronous	Synchronous and uniform
10. Breeding mechanism	Outbreeding	Inbreeding

Cultivation practices adopted by man also had a significant role in the domestication process, the cultivated field presenting a different environment from the wild habitat. The crop

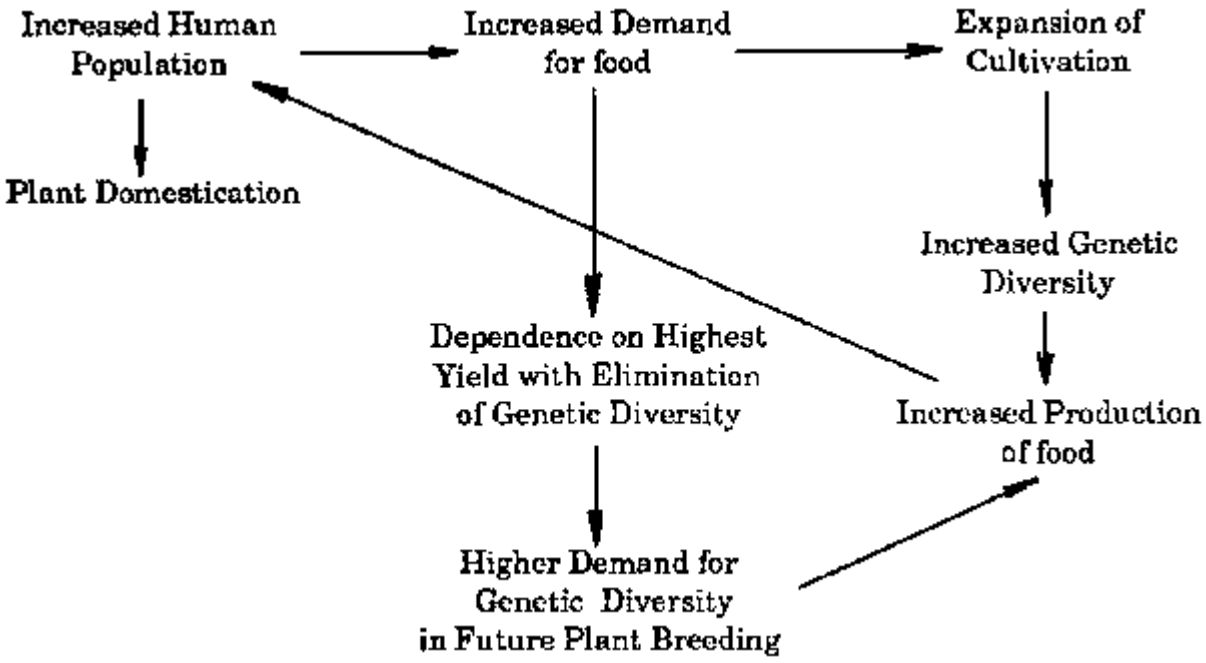
evolutionary process obviously includes changes as affected by changed environment of a cultivated field. Not only this, the selection pressure associated with cultivation practices also results in production of weedy races (plants which are competitive with cultivated races but retain some important characters of the wild races) and consequent occasional crossing between the two, leading to a setting up of differentiation-hybridization cycle and release of more potential variability. This is one remarkably elegant evoloutionary process wherein barriers to geneflow maintain identity of the two types and, at the same time, limited exchange of genes releases variability. Deliberate selection practices by man from the released variability provide a new order of selection pressure making the population an array of deliberately chosen components. The total potential range of variation is also fragmented into landrace populations or primitive cultivars. Different cultivars are grown for different purposes or to fit different ecological niches of the agricultural system. For example, the man selects glutinous and non-glutinous rice, long and short grained rice, aromatic rice, etc. In maize, the man's selection is for popping, boiling, eating tender cob, flour quality, etc.

Broadly, three factors that operate in the selection process of domesticated species are: (i) selection of desirable traits by the cultivator while sowing; (ii) changed micro-environment through cultivation practices; and (iii) differentiation - hybridization cycles between crop-weed pairs and man's selection from them. **So the dynamics of domestication has resulted in great morphological changes without substantial change in the genetic background**. However, speciation rarely occurs under domestication. Under domestication, modification(s) induced ultimately lead to the end products which are generally radically different in appearance from their wild progenitors.

Thus, most domesticated plants and all the food plants are, by and large, the product of a long selection process. As already elaborated, we call this evolutionary process as domestication. In the process of domestication, food plants have quite literally crossed a threshold. Their survival is keyed to preparation of the ground, decreased competition with other plants, sowing of the seed in the proper season, protection of plants during their growth and finally collecting seed. Thus, the process of domestication has 'tamed' these plants to make them dependent on humans.

On the global scene, the human population has enormously increased such that we are held captive by our domesticated food plants that is we are totally dependent on the high yields of these few selective cultivated plants. By and large, a dependent, though viable relationship exists among plant domestication, genetic diversity and human population growth (Wilkes, 1984; Fig.1).

Fig. 1. Plant domestication, genetic diversity and human population growth (Wilkes, 1984)



Morphological and Genetic Changes During Domestication

In the "Origin of Species", Darwin used domesticated plants and animals as evidence to support his theory of evolution:

- "Domesticated races show adaptation, not indeed to the animal's or plant's own good, but to man's use or fancy."
- "Very many of the most strongly-marked domestic varieties could not possibly live in a wild state."
- Gigantism of harvested organs: e.g., seeds of domesticated plants.
- Artificial selection has created tremendous diversity within crop species for the parts of the plant that have economic value (flowers, leaves, pods, or tubers). In comparison, there is little variation within species for parts of the plant that are not of interest to man

The process of plant domestication occurs as early wild-type crops are sown from seed gathered from wild stands. The key to domestication is the selective advantage of rare mutant alleles, which are necessary for survival in cultivation, but unnecessary for survival in the wild. The process of selection continues until the mutant phenotype dominates the population.

Cultivation also creates selection pressure, resulting in allele frequency changes, gradations within and between species, fixation of major genes, and improvement of quantitative traits.

Early domestication and important plant traits

Seeds from domestic crops (inner circle) are usually larger, lighter in color, and more uniform than their wild relatives. Clockwise from top: Peanuts, corn, rice, coffee, soybean, hops, pistachio, and sorghum.

Selection associated with cultivation, harvesting, and food uses

Loss of seed dispersal mechanisms and seed dormancy traits are most important in the domestication process.

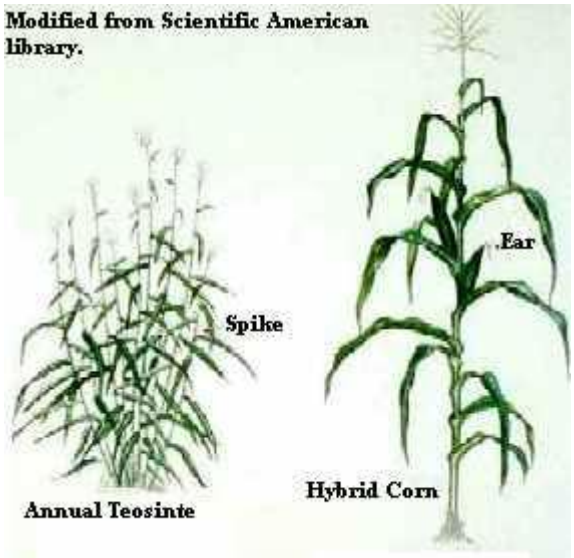
Non-shattering - crop seeds remain attached to the plant until harvest

Non-brittle rachis - the rachis (central axis of the inflorescence) remains intact in crop species

Non-dehiscence - fruits do not split open to release contents at maturity

Free threshing

- the seed is easily removed from other parts of the plant



Changes in growth habit

Compact growth habit

Reduction in branching

Synchronous tillering

Synchronous flowering

Example: climbing to bush habit in beans

In the wild, a climbing habit allows plants to access limited light. More compact plants are often favored by domestication.

Reduction in internode length

Reduction in number of nodes, branches

Suppression of twining reponse

Determinacy (simultaneous flowering)

Harvesting: Increases in seed yield

Reduction in daylength sensitivity - provides broader adaptation (plants will flower at wider latitudes); there is an adaptive value for daylength sensitivity in wild plants (ensures that they germinate at the right time of the year)

Increased number of seeds

Reduced sterility

Larger inflorescence size

Increased number of inflorescences

Increased harvest index (weight of harvested portion of the plant to the weight of the whole plant)

Planting: increased seedling vigor

- Larger seeds
  - More carbohydrates; increased reserves
  - Fewer number, larger seeds
- Non-dormant seeds
  - Dormancy has an adaptive value for the wild type, ensuring that it germinates when environmental conditions are most favorable (e.g. there is enough water or temperatures are

stable.) However, it is not a desirable character for a crop. A farmer wants the seeds that he plants to germinate quickly and uniformly throughout the field.

- Conflict – lack of dormancy may cause premature germination (e.g. sprouting of a cereal head before harvest)
- Correlated response: reduced chaff

Reproductive system

- Shift from outcrossing to predominantly self-pollination for many crops
- Reduced or absence of sexual reproduction in some crops - banana, plantain, navel orange
- Vegetatively propagated crops - instant domestication, because the selected plants can be reproduced without further changes occuring through meiosis

Adaptation for taste and food utilization

Color, flavor, texture, storage quality, cooking quality, uniformity, etc.

Reduced toxic compounds

Cyanogenic glucoside: cassava and lima bean

Bitterness; phenols, etc., in wild seeds and plants

Processing and cooking quality

Selection for starch, protein and oils

Genetic control of domestication is relatively simple:

- There are few genes and genomic regions involved
- Several genes have major phenotypic effects
- Genes for domestication represent a small subset of genes/traits for that species
- Domestication could occur quite rapidly
- In some cases only a limited amount of the available genetic diversity is carried through the domestication process - wild relatives represent an important reservoir of genetic diversity for the crop

Collectively, the changes that frequently occur with domestication are known as "**the domestication syndrome**".

Attributes of Domesticated Plants vs Wild Relatives

Attribute	**Wild/Weedy Relative**	**Domesticate**
Ecogeographical	Sometimes restricted, may be	For major crops, often rathermore

distribution and microenvironmental niche	intolerant of periodically disturbed soils. Many exceptions known (*Avena*, *Sorghum*).	widespread than wildrelative, adapted to survivalunder cultivation
Dispersal mechanism	Usually present (shattering)	Often absent
"Domesticated" organ	Often smaller, fewer, and more uniform	Often larger, more numerous and more highly variable; attractive patterns andcolors; better processing quality
Defense mechanism	Better-developed (spines, thorns, anti-nutritional factors)	Reduced or absent
Growth pattern	In herbs, often indeterminate and resource-limited	In herbs, often determinate; less branching
Maturity	Irregular	Uniform; shorter life cycle
Seed and seedling	Often smaller, dormancy mechanism well developed	Often larger, dormancy mechanism absent (e.g. photoperiod and vernalization requirements)
Sexual reproduction	Present	Mechanisms may be lost
Breeding systems	Often more allogamous (outcrossing)	More autogamous (self-pollinating)

History of domestication and cultivation – RICE

Origins in China

The current scientific consensus, based on archaeological and linguistic evidence, is that rice was first domesticated in the Yangtze River basin in China. Because the functional allele for nonshattering, the critical indicator of domestication in grains, as well as five other single-nucleotide polymorphisms, is identical in both *indica* and *japonica*, Vaughan *et al.* (2008) determined a single domestication event for *O. sativa*. This was supported by a genetic study in 2011 that showed that all forms of Asian rice, both *indica* and *japonica*, sprang from a single domestication event that occurred 13,500 to

8,200 years ago in China from the wild rice *Oryzarufipogon*.[38] A more recent population genomic study indicates that *japonica* was domesticated first, and that *indica* rice arose when *japonica* arrived in India about ~4,500 years ago and hybridized with an undomesticated proto-*indica* or wild *O. nivara*.

There are two most likely centers of domestication for rice as well as the development of the wetland agriculture technology. The first, and most likely, is in the lower Yangtze River, believed to be the homelands of the pre-Austronesians and possibly also the Kra-Dai, and associated with the Kauhuqiao, Hemudu, Majiabang, Songze, Liangzhu, and Maquiao cultures. It is characterized by pre-Austronesian features, including stilt houses, jade carving, and boat technologies. Their diet were also supplemented by acorns, water chestnuts, foxnuts, and pig domestication.

The second is in the middle Yangtze River, believed to be the homelands of the early Hmong-Mien-speakers and associated with the Pengtoushan, Nanmuyuan, Liulinxi, Daxi, Qujialing, and Shijiahe cultures. Both of these regions were heavily populated and had regular trade contacts with each other, as well as with early Austroasiatic speakers to the west, and early Kra-Dai speakers to the south, facilitating the spread of rice cultivation throughout southern China.

Rice was gradually introduced north into early Sino-Tibetan Yangshao and Dawenkou culture millet farmers, either via contact with the Daxi culture or the Majiabang-Hemudu culture. By around 4000 to 3800 BC, they were a regular secondary crop among southernmost Sino-Tibetan cultures. It did not replace millet, largely because of different environment conditions in northern China, but it was cultivated alongside millet in the southern boundaries of the millet-farming regions. Conversely, millet was also introduced into rice-farming regions.

By the late Neolithic (3500 to 2500 BC), population in the rice cultivating centers had increased rapidly, centeredaround the Qujialing-Shijiahe culture and the Liangzhu culture. There was also evidence of intensive rice cultivation in paddy fields as well as increasingly sophisticated material cultures in these two regions. The number of settlements among the Yangtze cultures and their sizes increased, leading some archeologists to characterize them as true states, with clearly advanced socio-political structures. However, it is unknown if they had centralized control.

Liangzhu and Shijiahe declined abruptly in the terminal Neolithic (2500 to 2000 BC). With Shijiahe shrinking in size, and Liangzhu disappearing altogether. This is largely believed to be the result of the southward expansion of the early Sino-Tibetan Longshan

culture. Fortifications like walls (as well as extensive moats in Liangzhu cities) are common features in settlements during this period, indicating widespread conflict. This period also coincides with the southward movement of rice-farming cultures to the Lingnan and Fujian regions, as well as the southward migrations of the Austronesian, Kra-Dai, and Austroasiatic-speaking peoples to Mainland Southeast Asia and Island Southeast Asia.

Southeast Asia

The spread of *japonica* rice cultivation to Southeast Asia started with the migrations of the Austronesian Dapenkeng culture into Taiwan between 3500 and 2000 BC (5,500 BP to 4,000 BP). The Nanguanli site in Taiwan, dated to ca. 2800 BC, has yielded numerous carbonized remains of both rice and millet in waterlogged conditions, indicating intensive wetland rice cultivation and dryland millet cultivation.

From about 2000 to 1500 BC, the Austronesian expansion began, with settlers from Taiwan moving south to colonize Luzon in the Philippines, bringing rice cultivation technologies with them. From Luzon, Austronesians rapidly colonized the rest of Island Southeast Asia, moving westwards to Borneo, the Malay Peninsula and Sumatra; and southwards to Sulawesi and Java. By 500 BC, there is evidence of intensive wetland rice agriculture already established in Java and Bali, especially near very fertile volcanic islands.

However, rice (as well as dogs and pigs) did not survive the first Austronesian voyages into Micronesia due to the sheer distance of ocean they were crossing. These voyagers became the ancestors of the Lapita culture. By the time they migrated southwards to the Bismarck Archipelago, they had already lost the technology of rice farming, as well as pigs and dogs. However, knowledge of rice cultivation is still evident in the way they adapted the wetland agriculture techniques to taro cultivation. The Lapita culture in Bismarck reestablished trade connections with other Austronesian branches in Island Southeast Asia. They also came into contact with the non-Austronesian (Papuan) early agriculturists of New Guinea and introduced wetland farming techniques to them. In turn, they assimilated their range of indigenous cultivated fruits and tubers, as well as reacquiring domesticated dogs and pigs, before spreading further eastward to Island Melanesia and Polynesia.

Rice, along with other Southeast Asian food plants, were also later introduced to Madagascar, the Comoros, and the coast of East Africa by around the 1st millennium AD by Austronesian settlers from the Greater Sunda Islands.

Much later Austronesian voyages from Island Southeast Asia succeeded in bringing rice to Guam during the Latte Period (AD 900 to AD 1700). Guam is the only island in Oceania where rice was grown in pre-colonial times.

Within Mainland Southeast Asia, rice was presumably spread through river trade between the early Hmong-Mien-speakers of the Middle Yangtze basin and the early Kra-Dai-speakers of the Pearl River and Red River basins, as well as the early Austroasiatic-speakers of the Mekong River basin. Evidence for rice cultivation in these regions, dates to slightly later than the Dapenkeng settlement of Taiwan, at around 3000 BC. Southward migrations of the Austroasiatic and Kra-Dai-speakers introduced it into Mainland Southeast Asia. The earliest evidence of rice cultivation in Mainland Southeast Asia come from the Ban Chiang site in northern Thailand (ca. 2000 to 1500 BC); and the An Sơn site in southern Vietnam (ca. 2000 to 1200 BC).

Origin and history - Wheat

Cultivation and repeated harvesting and sowing of the grains of wild grasses led to the creation of domestic strains, as mutant forms ('sports') of wheat were preferentially chosen by farmers. In domesticated wheat, grains are larger, and the seeds (inside the spikelets) remain attached to the ear by a toughened rachis during harvesting. In wild strains, a more fragile rachis allows the ear to easily shatter and disperse the spikelets.[17] Selection for these traits by farmers might not have been deliberately intended, but simply have occurred because these traits made gathering the seeds easier; nevertheless such 'incidental' selection was an important part of crop domestication. As the traits that improve wheat as a food source also involve the loss of the plant's natural seed dispersal mechanisms, highly domesticated strains of wheat cannot survive in the wild.

Archaeological analysis of wild *emmer* indicates that it was first cultivated in the southern Levant, with finds dating back as far as 9600 BCE. Genetic analysis of wild *einkorn* wheat suggests that it was first grown in the Karacadag Mountains in southeastern Turkey. Dated archeological remains of einkorn wheat in settlement sites near this region, including those at Abu Hureyra in Syria, suggest the domestication of einkorn near the Karacadag Mountain Range.[20] With the anomalous exception of two grains from Iraq ed-Dubb, the earliest carbon-14 date for einkorn wheat remains at Abu Hureyra is 7800 to 7500 years BCE.

Remains of harvested emmer from several sites near the Karacadag Range have been dated to between 8600 (at Cayonu) and 8400 BCE (Abu Hureyra), that is, in the Neolithic

period. With the exception of Iraq ed-Dubb, the earliest carbon-14 dated remains of domesticated emmer wheat were found in the earliest levels of Tell Aswad, in the Damascus basin, near Mount Hermon in Syria. These remains were dated by Willem van Zeist and his assistant Johanna Bakker-Heeres to 8800 BCE. They also concluded that the settlers of Tell Aswad did not develop this form of emmer themselves, but brought the domesticated grains with them from an as yet unidentified location elsewhere.

The cultivation of emmer reached Greece, Cyprus and Indian subcontinent by 6500 BCE, Egypt shortly after 6000 BCE, and Germany and Spain by 5000 BCE. "The early Egyptians were developers of bread and the use of the oven and developed baking into one of the first large-scale food production industries." By 3000 BCE, wheat had reached the British Isles and Scandinavia. A millennium later it reached China.

The oldest evidence for hexaploid wheat has been confirmed through DNA analysis of wheat seeds, dating to around 6400-6200 BCE, recovered from Çatalhöyük. The first identifiable bread wheat (*Triticumaestivum*) with sufficient gluten for yeasted breads has been identified using DNA analysis in samples from a granary dating to approximately 1350 BCE at Assiros in Macedonia.

From Asia, wheat continued to spread across Europe. In the British Isles, wheat straw (thatch) was used for roofing in the Bronze Age, and was in common use until the late 19th century.

History -Maize

Pre-Columbian development

Most historians believe maize was domesticated in the Tehuacán Valley of Mexico.[10] Recent research in the early 21st century has modified this view somewhat; scholars now indicate the adjacent Balsas River Valley of south-central Mexico as the center of domestication.

An influential 2002 study by Matsuoka *et al*. has demonstrated that, rather than the multiple independent domestications model, all maize arose from a single domestication in southern Mexico about 9,000 years ago. The study also demonstrated that the oldest surviving maize types are those of the Mexican highlands. Later, maize spread from this region over the Americas along two major paths. This is consistent with a model based on the archaeological record suggesting that maize diversified in the highlands of Mexico before spreading to the lowlands.

Archaeologist Dolores Piperno has said:

A large corpus of data indicates that it [maize] was dispersed into lower Central America by 7600 BP [5600 BC] and had moved into the inter-Andean valleys of Colombia between 7000 and 6000 BP [5000–4000 BC].

According to a genetic study by Embrapa, corn cultivation was introduced in South America from Mexico, in two great waves: the first, more than 6000 years ago, spread through the Andes. Evidence of cultivation in Peru has been found dating to about 6700 years ago.[15] The second wave, about 2000 years ago, through the lowlands of South America.

The earliest maize plants grew only small, 25 millimetres (1 in) long corn cobs, and only one per plant. In Jackson Spielvogel's view, many centuries of artificial selection (rather than the current view that maize was exploited by interplanting with *teosinte*) by the indigenous people of the Americas resulted in the development of maize plants capable of growing several cobs per plant, which were usually several centimetres/inches long each. The Olmec and Maya cultivated maize in numerous varieties throughout Mesoamerica; they cooked, ground and processed it through nixtamalization. It was believed that beginning about 2500 BC, the crop spread through much of the Americas. Research of the 21st century has established even earlier dates. The region developed a trade network based on surplus and varieties of maize crops.

Mapuches of south-central Chile cultivated maize along with quinoa and potatoes in Pre-Hispanic times, however potato was the staple food of most Mapuches, "specially in the southern and coastal [Mapuche] territories where maize did not reach maturity". Before the expansion of the Inca Empire maize was traded and transported as far south as 40°19' S in Melinquina, Lácar Department.[21] In that location maize remains were found inside pottery dated to 730 ±80 BP and 920 ±60 BP. Probably this maize was brought across the Andes from Chile.[21] The presence of maize in Guaitecas Archipelago (43°55' S), the southernmost outpost of Pre-Hispanic agriculture, is reported by early Spanish explorers. However the Spanish may have misidentified the plant.

Columbian exchange

After the arrival of Europeans in 1492, Spanish settlers consumed maize and explorers and traders carried it back to Europe and introduced it to other countries. Spanish settlers far preferred wheat bread to maize, cassava, or potatoes. Maize flour could not be substituted for wheat for communion bread, since in Christian belief only wheat could undergo transubstantiation and be transformed into the body of Christ. Some Spaniards worried that by eating indigenous foods, which they did not consider nutritious, they would

weaken and risk turning into Indians. "In the view of Europeans, it was the food they ate, even more than the environment in which they lived, that gave Amerindians and Spaniards both their distinctive physical characteristics and their characteristic personalities." Despite these worries, Spaniards did consume maize. Archeological evidence from Florida sites indicate they cultivated it as well.

Maize spread to the rest of the world because of its ability to grow in diverse climates. It was cultivated in Spain just a few decades after Columbus's voyages and then spread to Italy, West Africa and elsewhere.

Lecture 6&7:

- Germplasm exploration and collection – Eco-Geographical issues to be considered in planning explorations- – use of GIS and GPS principles during explorations
- Planning the logistics and execution of collection missions- Global collection missions and achievements

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There are over a quarter million plant species available on the earth. It is difficult to predict which of these species would be required to fulfill future needs. Hence, more the diversity is conserved and made available for future use, better the chances of fulfilling future demand. Generally, the exploration for germplasm collecting is conducted for desired genetic material (primitive and advanced) or capturing maximum variability to use in the crop improvement programme and also to study the genetic variability within the crops. Depending on the needs and objectives, crop specific or multi-crop exploration missions can be executed for capturing maximum variability from a wide agro-ecological/phyto-geographical region as well as for fulfilling the needs of breeders and conservation. In case of multi-crop/species collecting mission, a region is targeted and an attempt is made to sample as much as possible of the diversity of as many species as possible. Usually, they are planned when no systematic collecting in the area has been conducted before and/or when the area is difficult to reach and future visits are therefore unlikely.

For any collecting mission, the under-mentioned steps including prioritization of area/species, thorough gap analysis studies needs to be followed before execution.

- Planning

- Making contacts with local research organization
- Gathering equipment and preparation
- Meeting with local researchers in area to be surveyed
- Sorting out of collected samples
- Reporting to the Headquarters
- Preparation and publication of reports
- Distribution/ conservation of collected samples

Planning of exploration mission: principles and practices

Depending upon the priorities, gathering a prior knowledge of the crops/species before launching a mission is important. The areas to be explored and crops/ species to be collected should be prioritized after thorough gap analysis based on information from different sources including database/ National Genebank status. Priority should be given to the areas which have been inadequately covered/surveyed. Because, genetic variation in genepools is associated with variation in environmental factors, ecological conditions which are not represented are given high priority along with missing genotypes and taxa. The explorer should be well-versed with the nature and extent of diversity and breeding behaviour of the crop/species to be collected and plan well in advance to facilitate the preparations of the proposed missions except those to be carried out under special situations like rescue collecting. Visit to herbaria is essential to know the range of distribution, localities, diversity pattern and period of collection particularly for wild species. Collaborating institute/University should be communicated to depute a scientist well in advance with details of preparations/tour itinerary/tentative programme. Information on topography, climatic conditions, vegetation, crops in cultivation and their maturity, etc. needs to be gathered to finalize the itinerary of collecting mission. Besides, explorers should also establish local contacts especially at grass root level to seek the social, cultural, ethnic and other information of interest.

Tour itinerary: A tentative tour itinerary should be drawn up at an early stage of the planning, showing the main target areas (or even precise localities) to be visited within the overall target region, the roads/tracks to be followed and the proposed timings of each visit. The mode of transport should also be specified. Prior permission should be obtained from the concerned authorities for collecting in

protected (biosphere reserves, sanctuaries, national parks) and restricted areas (border areas/some states in NEH region). Collecting/innerline permits may also require specific areas to be mentioned. Letters of introduction to local government officials are often useful, and their preparation will require some rough idea of the itinerary to be followed. Maps will clearly be needed in planning the itinerary, but local contacts are essential for advice on the feasibility of following particular routes at different times of the year.

Period of collecting: For seed producing cultivated crops/species, exploration should be undertaken when crops/species are physiologically mature and ready for harvest. In case of species with shattering nature because ripe seeds are generally quickly shed (crop wild relatives/wild species) are usually not available to the collector once this happens (though in some cases some collecting from the ground may be possible). For such species, missions are executed rather earlier (7-10 days depending on crop/ species) before their maturity. Further, longer duration (2-3 weeks) mission and repeat visits are suggested for collection of wild species. For vegetatively propagated crops/species, the targeted areas should be surveyed first for identification and marking of elite types at the time of flowering/fruiting and subsequently the collections are made at appropriate time. For conducting explorations within the country, the period should be of at least 10-15 working days and more than a month when conducted in foreign countries.

Team composition**:** The collecting team should be familiar with basics of agriculture/plant genetic resources to meet the objective of the mission. Team consisting of 2-3 members including a collaborator and need-based local-aid be formed preferably a botanist/ breeder as leader. Area and route of explorations should be fine-tuned in consultation with the subject experts of local organizations as soon as the team reaches to the starting point keeping in view the targeted species and areas of the proposed mission.

Items and equipments required**:** As per the nature of the germplasm to be collected (fruit/ seed/ vegetative propagule/ in vitro/ live plants) and the area(s) to be explored, the required items and equipments needs to be gathered before execution of exploration.

List of items and equipments for collecting

Survey / collecting items	Global Positioning System (GPS), digital camera with additional memory card, binocular, magnifying glasses, handheld microscope, digital Vernier calliper and portable balance, Haversack/ kitbag, seed envelopes, cloth bags, polythene bags, aluminium & tag labels, drying sheets, old newspapers, plant press, moss, rubber bands, packing tape, *sutli* (thick and thin), secateurs, scissors, knife, digger, torch light, measuring tape, passport data book, field note book, pencil, ballpoint pen and permanent marker.
Reference material	Regional/ national flora, digital herbarium, lap-top and accessories, list of local names of plants, road-map, vegetation/climate map, list of rest-houses/ lodges, hotels, resting/ stay places and list of local contacts (phone, fax, e-mail).
First Aid-Box	Anti-malaria pills, anti-allergen tablets, pain killers, anti- amoebic and anti-diarrhoeal tablets, mosquito repellent, antifungal/ antibacterial/ antiseptic creams or lotions, cotton-packs, band-aid, dettol, dressing gauze, water-purifying tablets, etc.

Collecting strategies and sampling method

At the actual collecting sites, there is a need to apply sampling method which will ensure that the genetic diversity of crop/species represented in the sample collected. For sampling in any region/site, inaccessible areas of valleys, isolated hills, villages at the edge of deserts, forests, mountains and isolated coastal belts which may hold rich genetic diversity, potential/ trait-specific germplasm and wild relatives should be approached for collecting. While for cultivated species, farmers' field, backyard/ kitchen garden, threshing yard, farm store, local village market, etc. are ideal sites to collect the germplasm. Drier tracts (vs. humid), un-irrigated areas (vs. irrigated), valleys (vs. hills) should be approached to capture maximum diversity and sites having stress situations viz. saline habitat, un-irrigated/ drought conditions, desert (cold and hot), flood prone areas should be identified as target areas for collection of trait-specific material. For biotic stress tolerant material, hot-spot areas should be visited to collect healthy plants in fields where severe pest damage is evident. The

frequency of sampling (number of samples per site) should be decided based on on-the-spot observations on the variability available. In general, more sites per target area are preferred to sample the targeted species rather than sampling from a few sites.

***Sampling method*:** While collecting seeds, the explorer should keep in mind the required quantity of material to be sampled for long-term conservation (2,000 and 4,000 seeds for self- and cross-pollinated crops, respectively) besides meeting the requirement of characterization, evaluation and related studies. The optimum sample size per site would be the number of plants required to obtain, with 95% certainty, all the alleles at a random locus occurring in the target population with frequency greater than 0.05. In case of species with extremely small-sized seeds, low seed-set, asynchronous maturity and low seed viability, care should be taken to collect adequate sample size. Such species have been increasingly focused on from 1998 onwards. Of nearly 320 species of CWR considered a priority for collection. In case of extremely variable populations, one can either make larger samples (bulking), or take as sub-samples if observed interesting variants, and be given separate collecting numbers. In general, random sampling should be followed by collecting single spike/panicle or fruit/berry/pod from at least 50 plants along a number of transects throughout the field to obtain a representative and adequate sample. In a situation when wild population with few individuals occur, one should collect from all the plants so as to make the representative sample from that site. In case of certain wild and semi-domesticated species occurring in small pocket with scattered populations (treated as sampling site) having specific use/traits, the seed should be bulked. However one should not deplete the populations of farmers' planting stocks or wild species, or remove significant genetic variation. In case of large tubers, only a portion, e.g. head or proximal ends in yams, crown or tuber in taro and other aroids should be collected. In case of scion collection, the sample size will depend upon the number of rootstocks available but not less than ten per sample. In case of cuttings and rooted suckers (e.g. grapes, ornamentals, passion fruits, black pepper, beetle vine, banana, cardamom, etc.) 15-20 cuttings may be sufficient. Material with dubious identity or unidentified material, vernacular name should be collected along with herbarium specimen and photographs for authentication. The detailed guidelines for preparation and processing herbarium specimen should be followed as per Jain and Rao (1977).

***Recording of information*:** Information on both the essential and optional fields needs to be recorded in the passport data sheet at the site of the collection. However, in any circumstances, the explorer should not leave the information blank on essential fields namely sample labelling; sample identification; sampling information and collecting sites. Information on genetic erosion should also be gathered particularly on the depletion of landraces cultivated over the time and the reasons for their loss in general using a unstructured format. Observations on the distribution pattern and frequency status of crop wild relatives, rare, endangered and threatened species of PGR importance should be recorded for their sustainable management. In addition, on-site observations on some important quantitative and qualitative characters/traits should also be recorded using descriptors developed. Ethnobotanical observations and new uses of plants, especially those collected from tribal dominated tracts, are currently recorded as a database which would be available for reference in future collections

Post collection handling: The extraction and cleaning of seed should be done preferably on the same day or immediately after completing the expedition and process for their drying under shade/ sun/ controlled conditions. The seeds with short longevity (recalcitrant type) should be processed at the earliest and care should be taken during threshing/ cleaning to avoid damage. In a situation, when delay in processing is anticipated, all precautions should be taken to maintain its viability. The observations on variability parameters on fruit/ pod/ seed should be recorded along with photographs for report writing, documentation and publication. The clean and dried material should be kept in the envelopes with proper label specifying its botanical name and collector number. One set of the material along with passport data should be sent for accessioning, conservation (LTS/MTS) and another set be sent to the collaborating institute for initial seed increase (if required), maintenance, characterization and evaluation. The vegetatively propagated material should be sent for establishment/ maintenance in field genebank or at suitable site. The material for *in vitro* and cryo-genebank should be handed over to the concerned curators. The elite material, if any, should be studied in detail to generate supporting information as well as for validation of the known trait(s) for its registration with NBPGR.

Do's and Don’ts

Do's

- Get acquainted with the International Code of Conduct for Plant Germplasm Collecting and Transfer of FAO (1993).
- Always keep a route map of the target area with list of important places and the distance covered during travel to facilitate report writing.
- Before entering into a forest take the help of forest guards to have forehand knowledge of possible dangers in the target area. If needed, help of a gunman is taken during survey in dense forest.
- Explain the purpose and get consent from the farmers for collecting germplasm**.**
- Keep important telephone numbers of concerned officers including district authorities, hospitals, dispensaries and police station.
- Keep your identity card and a certificate from Head of Organization for proposed mission.
- Honour social customs of local inhabitants of the target area.
- While talking and discussing with ladies, be polite and respectful to them
- After day's collection and before retiring to bed, have a glance at your equipments, passport data and collected material for need-based updating.

Don'ts

- Do not provide lift to strangers in your vehicle under any pretext.
- Do not indulge in unnecessary discussion related to politics, religion and local beliefs with the local people.
- Do not make false promises with donors.
- Do not plan the expedition during important festivals and peak election campaign in the target area.
- Do not enter any house for seed collection in absence of male members of the family.
- Do not eat unknown wild fruits since some of them may be toxic or internally infected.
- Do not collect the seed in large quantities from any household if the farmers wish so.
- Over-collecting of the genetic diversity with similar attributes should be avoided to save time and energy in collection and evaluation and to save space in the genebank.

Lecture 8: Sampling strategies to be adopted in collections – Data recording and handling including passport data, collection of herbaria of samples etc during collection missions

Sampling Method

- In general, random sampling should be made by collecting single spike / panicle or fruit / berry / pod from at least 50 plants along a number of transects throughout the field
- While collecting the seed, the required quantity of material to be sampled for long term conservation (2000 and 4000 seeds for self & cross pollinated crops respectively) besides meeting the requirement of characterization, evaluation, etc.
- The optimum sample size per site would be the number of plants required to obtain, with 95 percent certainty, all the alleles at a random locus occurring in the target population with frequency greater than 0.05 (Marshall and Brown,1975)
- In case of species with extremely small sized seeds / low seed set / asynchronous maturity / low seed viability, care should be taken to collect adequate sample size.
- In case of extremely variable populations, one can either make larger samples (bulking), or take as sub samples if observed interesting variants, and be given separate collecting numbers.
- In a situation when wild population with few individuals occur, one should better collect from all the plants so as to make the representative sample from that site
- In case of certain wild & semi domesticated species occurring in small pocket with scattered populations (treated as sampling site) having specific use / traits, the seed should be bulked.
- However one should not deplete the populations of farmers' planting stocks or wild species, or remove significant genetic variation.
- In case of large tubers, only a portion, e.g. head or proximal ends in yams, crown or tuber in taro and other aroids should be collected.
- Since vegetative propagules are subject to rapid deterioration after harvest and damage during transportation care should be taken while sampling and in transportation.
- In case of scion collection for budding and grafting the sample size will depend upon the number of root stocks available but not less than ten per sample so that at least eight grafts may survive.

- In case of cuttings and rooted suckers (e.g. grapes, ornamentals, passion fruits, black pepper, beetle vine, banana, cardamom, etc.) 15-20 cuttings may be sufficient.

Sampling strategies: salient points

The general strategy is summarised below (Hawkes, 1980).

A. For seed collections (cultivated and wild species)

1. Collect from (30-) 50 (-100) individuals per site (50 seeds of each as one sample or less, if necessary, at random. One inflorescence per plant is generally suitable.
2. Sample as many sites as possible according to availability of time.
3. Choose sampling sites over as broad an environmental range as possible. This should capture all alleles with frequency of 5 percent or more in the population.
4. Change tactics, where necessary, for wild species, that is, where individuals are scattered, you may need to consider that a population for sampling spreads over several square kilometres.
5. If considerable morphological variation is present in a population, make separate samples of each type.
6. Add biased sampling if some morphotypes are not included in random sampling.
7. Take whole inflorescences, as well as seeds, where necessary, as vouchers.
8. Make herbarium specimens, where possible.
9. Take photographs.
10. Write meticulous field notes.

B. For vegetatively propagated plants

i) For vegetatively propagated cultivated species

1. Sample each distinct morphotype in a village.
2. Repeat at intervals over an area.
3. Supplement with seed collections, where possible, and give same collection numbers if seeds come from the same plants as the vegetative samples. If they do not or are bulked samples, give separate collection numbers.

ii) For collecting vegetatively propagated wild species

Collect just a single propagule from each of 10-15 individuals as a bulk sample (less if organs are very large, more if smaller, from area of about 100 x 100 m).

Recording of information:

Information on both the essential and optional fields needs to be recorded in the passport data sheet at the site of the collection. However, in any circumstances, the explorer should not leave the information blank on essential fields namely sample labelling; sample identification; sampling information and collecting sites. Information on genetic erosion should also be gathered particularly on the depletion of landraces cultivated over the time and the reasons for their loss in general using a unstructured format. Observations on the distribution pattern and frequency status of crop wild relatives, rare, endangered and threatened species of PGR importance should be recorded for their sustainable management. In addition, on-site observations on some important quantitative and qualitative characters/traits should also be recorded using descriptors developed. Ethno botanical observations and new uses of plants, especially those collected from tribal dominated tracts, are currently recorded as a database which would be available for reference in future collections

Passport data: Passport data are important source for the enhanced utilization of PGR and studying the variation in distributional pattern with respect to ecological and socio economic factors. It is advisable to record information on both the essential and optional fields in the passport data sheet at the site of the collection itself by the explorer.

Herbarium Collection: The herbarium specimens in general and especially of the wild types and wild relatives should be collected to help in identification / authentication. Wherever possible efforts be made to collect economic products of local and wider use as supportive material.

Post collection handling:

The extraction and cleaning of seed should be done preferably on the same day or immediately after completing the expedition and process for their drying under shade/ sun/ controlled conditions. The seeds with short longevity (recalcitrant type) should be processed at the earliest and care should be taken during threshing/ cleaning to avoid damage. In a situation, when delay in processing is anticipated, all precautions should be taken to maintain its viability. The observations on variability parameters on fruit/ pod/ seed should be recorded along with photographs for report writing, documentation and publication. The clean and dried material should be kept in the envelopes with proper label specifying its botanical name and collector number. One set of the material along with passport data should be sent for accessioning, conservation (Long term / medium term storage) and another set be sent to the collaborating institute for initial seed increase (if required), maintenance, characterization and evaluation. The vegetatively propagated material should be sent for establishment/

maintenance in field gene bank or at suitable site. The material for in vitro and cryo gene bank should be handed over to the concerned curators. The elite material, if any, should be studied in detail to generate supporting information as well as for validation of the known trait(s) for its registration with NBPGR.

Geographical Information System

GIS technology can be effectively used in planning field explorations for collecting agro-biodiversity, design and management of *in-situ* conservation sites, identify eco-geographical gaps in existing *ex-situ* germplasm collections, site identification for germplasm evaluation and regeneration; identifying geographic regions which are likely to contain specific desired traits, taxa or habitats of interest. Potential uses of Geographical Information system (GIS) tools for managing Plant Genetic Resources have been reviewed and discussed. GIS has been successfully used for diversity analysis to locate rich diversity, yield and oil quality attributes, in several annual oilseed crops in India, which are briefly discussed. Future strategies and priority areas where GIS could be integrated to enhance crop production through effective management of plant genetic resources are also discussed.

This geo-informatics technology in conjunction with the passport / herbarium / NGB database could serve as a potential information treasure house to the scientific community in general and agriculture in particular. In PGR studies geo-informatics technology could be of great use in the management of plant genetic resources particularly in the following thematic area of studies

i. Integrated geo-informatics technology can be used in gap analysis, planning and execution of future exploration programme at National level.
ii. Germplasm passport data information, satellite data spectral signature and climate analogue tools can be use in diversity distribution mapping and prediction of diversity rich areas for different crops and their species.
iii. Hyper spectral remote sensing can be used in distinguishing and identification of crop wild relatives of cultivated plants.
iv. High spatial resolution (60 cm) satellite data can be used in mapping of disease symptoms in crops and their wild relatives at fine grid level.

Global Positioning System (GPS)

The Global Positioning System (GPS) is a satellite-based positioning and navigation system that offers 24-hour, worldwide, three-dimensional positioning.

The GPS, also known as NAVSTAR, began in 1973 when the United States Department of Defence developed a satellite-based three-dimensional positioning system

with 24-hour worldwide coverage. The initial design was four satellites to be in view from any position on the Earth's surface at any time. The concept was based on a receiver's distance from a satellite being estimated by measuring the time for the signal to travel from the satellite to a GPS receiver. Measuring the time from each of the four satellites (of known positions) allows three-dimensional position fixing (latitude, longitude and altitude) to be determined at the GPS receiver.

Application of GPS in Agriculture

- **Soil sampling:** GPS provides the necessary data to accurately determine soil variability and to establish whether a given type of soil is ideal for the growth of a particular crop. Soil sampling also helps in profiling of soils to distinguish between soils that are viable and those that are not.
- **Weed location:** Using linear sampling techniques, GPS can be used to single out weed patches in vast areas of lands. Weed usually hinders the effective growth of a crop and hampers the eventual yields over a given period of time.
- **Accurate planting:** GPS also comes in handy when planning the planting of a given crop. Each seed has specific spacing and depth required depending on the soil type. Using GPS, it is easier to tell what spacing a given seed requires and to what depth the seed should be planted in order to return maximum yields.
- **Determination of planting ratios:** GPS can also be used in the determination of planting ratios of seeds. Some seeds have specific spaces in between them while others may be planted together with other seeds. GPS helps in determining the ratio of this type of planting.
- **Creation of yield maps:** GPS plays an important role in the creation of yield maps for specific types of crops. For instance, during harvests, GPS can be used to map out expected yields of a given crop from one piece of land based on the land characteristics and the seed characteristics.
- **Harvesting:** GPS plays an important role in the determination of what area of a farm is ready to be harvested and how the harvesting will take place. The GPS will also give an estimate of the size of the area being harvested and the expected returns from the area.
- **Locating a yield map:** GPS can also be used to locate a yield map by mounting a GPS receiver on a farm machinery and then collecting the data.
- **Environmental control:** Applying herbicides or pesticides based on the capacity of each square meter reduces the application amount of the pesticide being used. This allows the soil to absorb all the pesticide hence reducing the chances of runoff.
- **Farm planning:** GPS plays an important role in the planning of a farmland ready for planting. GPS will give the overall size of the area and help in determining what crop will be planted on what part of the farmland using various factors such as soil characteristics and crop characteristics.

- **Field mapping:** GPS gives an exact estimate of the field that is being prepared for farming. Through this, experts can tell what part of the field will be used for farming activities and what area will be used for other non-farming related activities.
- **Soil sampling:** Soil sampling is one of the most important uses of GPS in agriculture. It is important to know what type of soil is available on a given farmland as this will help in determining the type of crop to be planted on that farm.
- **Crop scouting:** GPS gives an exact mapping of an area helping when scouting for crops that are grown in a particular area. Through this, experts are able to tell the nature and type of crops that thrive within a given locality and help in improving the quality of that crop.
- **Yield mapping:** After a crop has been planted and is ready for harvesting, GPS can be used to make an estimation of the yield of a given farmland. This can be achieved through aerial mapping where experts can tell the quantity of a yield based on the area covered by the crop.
- **Correlation of production techniques with crop yields:** GPS can be used to make a correlation of the production technique that was used over a given piece of land and the crop yields after a given period of time. This information can then be used to determine the viability of a given technique
- **Soil property mapping:** GPS plays an important role in determining the soil property of a given soil to establish its variability and suitability for a given crop. It also helps researchers identify which area of a farmland contains what type of soil and what area is suitable for a given crop.
- **Machinery location:** It is easier to locate any farm machinery on a vast piece of land thanks to GPS. The farmer does not need to physically go out and locate farm equipment especially in cases where the number is high. GPS can pinpoint the exact location of these farm machineries.
- **Machinery direction:** Technology has necessitated the use of autonomous farm machinery for use in farming. GPS is used to direct these machineries into deciding what direction the seeds will be placed and the spaces in between each seed
- **Identification of areas suitable for cultivation:** GPS plays an important role in deciding what areas in a given farmland are suitable for cultivation. This is done through aerial mapping of the area under cultivation and the analysis of the soil samples to determine the viability of the soil.
- **Classification of areas for cultivation based on various characteristics:** GPS can be used to classify different areas for cultivation based on various characteristics such as soil types and the terrain maps. Areas that are not suitable for cultivation can be identified and alienated while those that are suitable can then be developed.
- **Assessment for the availability of water in an area:** GPS has been used in the assessment of the availability of water or water sources within a given locality. Water sources such as rivers or canals can easily be singled out using GPS.
- **Identification of irrigated crops:** GPS can also be used to identify areas where there are crops that have been irrigated and those that have not been irrigated. This helps in

creating a profile between irrigated crops and non-irrigated crops to help in making comparisons

- **Identification of swamps and other water logged areas:** GPS can be used to identify swampy areas and waterlogged areas that may not be ideal for certain types of crops. This helps in determining the suitability of these types of lands for certain crops and their non-suitability for other types of crops
- **Rivers mapping:** GPS helps in creating a map of all rivers within a locality which builds a profile of the area with regards to the water flow. Farmers and researchers can be able to tell the presence of rivers and help in determining the crops that will be grown in that locality.
- **Land usage in the locality:** GPS can also be used to monitor the land usage within a given locality. Through GPS, it is easier to tell what area of the land has been put under cultivation and what part of the land has been left bare.
- **Contour mapping:** In cases where the land is irregular, GPS has been instrumental in determining the contours within the specific locality. This is because some crops may not do well in contoured lands while others may thrive in these lands.
- **Irrigation systems mapping such as dams or canals:** In cases where the land needs to be irrigated, GPS can help locate some irrigations systems such as dams and canals. This will make it easy as it will avail the necessary water needed for irrigating the lands.
- **Meteorological mapping such as climatic patterns:** GPS plays an important role in mapping out some climatic conditions which may determine the type of crop that can grow in a given region.
- **Personnel mapping:** GPS may also play an important role in mapping out the number of personnel in a given farmland at specific times of the day. This is important if a farmer wants to measure the productivity of the personnel in a farm
- **Plantation mapping:** GPS can help in creating a map of a plantation and establishing the crop yields in a given plantation.
- **Water bodies mapping:** GPS can also be used to map out the existing water bodies within a given area to assess the viability of crop growth and crop yields in a given area.

Lecture 10 & 11:

- Historical issues related to PGR conservation, scientific basis of PGR conservation – Types :*In situ* and *ex situ* conservation
- *In Situ* Conservation methods : concept of biosphere reserves, gene sanctuaries,and on-farm conservation

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Methods of PGR conservation

A species or a population sample and its genetic variation can be maintained through *in situ* or *ex situ* conservation.

***1. In situ* conservation**

This type of conservation refers to the conservation of germplasm in ecosystems and natural habitats and the maintenance and recovery of viable populations of species in their natural

surroundings. In the case of domesticated or cultivated species, it refers to their conservation in the surroundings where they have developed their distinctive properties. This is generally done in protected areas mostly for the conservation of wild relatives, and on-farm or in home gardens for the conservation of cultivated species. This type of conservation is not described further the Crop Genebank Knowledge Base.

2. Ex situ conservation

This type of conservation is the storage of seeds or plant material under artificial conditions (other than their natural environment), to efficiently and effectively guarantee its longevity viability and availability. It is the type of conservation mostly used in genebanks. It covers a range of methods suitable for various types of seeds or plant materials. It ranges from cold storage of seeds or propagules, *in vitro* (tissue culture or cryopreservation), field, pollen or DNA conservation. With *ex situ* conserveration two types of storage are recognized: storage of samples for long-term security – referred to as **base collections** – and storage of samples for immediate use – referred to as **active collections**. The storage conditions and distribution arrangements of these stores vary.

Base collections

A base collection is a set of accessions in which each is distinct and as close as possible to the original sample in terms of genetic integrity. Normally, material is not distributed from base collections directly to users. Base collections are only used to regenerate active collections (FAO, 2013). In seed banks, samples in base collections are stored for long periods at below 0°C – usually at -18° to -20°C – to maintain seed viability and, in cryobanks, specially prepared *in vitro* culture samples are stored for long periods at -196°C, usually in liquid nitrogen. Engels and Visser (2003) introduced the term ‘most-original sample’ (MOS) to qualify the samples in base collections. A MOS consists of genetic material that has undergone the lowest number of regenerations since the material was acquired by the genebank; it may be a sub-sample of the original seed lot or a seed sample from the first regeneration cycle if the original seed lot required regeneration before storage or a cryopreserved sub sample of the first *in vitro* culture cycle.

Active collections

Active collections consist of accessions that are immediately available for distribution. These accessions are accessed frequently and storage of active collections can be in seed banks, vegetative banks, field banks and *in vitro* banks. Seeds are maintained in conditions that ensure at least 65% viability for 10-20 years (FAO, 2013) and *in vitro* cultures are maintained in slow growth conditions. Samples in vegetative banks are only stored for a few months but perennial living plants in field banks can be maintained for 20 years or more.

***In situ* conservation**

In situ conservation is the conservation of species and populations of living organisms in a natural state in the habitat where they naturally occur. This method conserves both the population and the evolutionary processes that enable the population to adapt by managing organisms in their natural state or within their normal range. For example, large ecosystems may be left intact as protected reserve areas with minimal intrusion or alteration by humans.

The "*in-situ* conservation" term is usually applied to naturally occurring plant species, progenitors of crop plants, forest trees and other species. It also includes on farm conservation of weedy/wild relatives of crops and landraces of crops as well as artificial regeneration of obsolete cultivars in their original habitats without conscious selection.

Importance of in situ conservation

In situ conservation is an important component of the conservation and management of genetic resources. It supplements the ex situ conservation efforts of local, national, and international germplasmcollections.Insituconservationsites preserve potentially important and useful genes, many of which may be unrecognized today. Their existence enables the selective and adaptive processes that give rise to new genetic traits to continue in response to environmental stresses. These areas can be sources of genetic traits not already captured in ex situ collections. In situ reserves can also provide living laboratories for studying the genetic diversity of the wild species that are the progenitors of modern crops.

The most commonly referred *in-situ* conservation sites include:

1. Biosphere reserves
2. Gene sanctuaries
3. Sacred groves etc.,

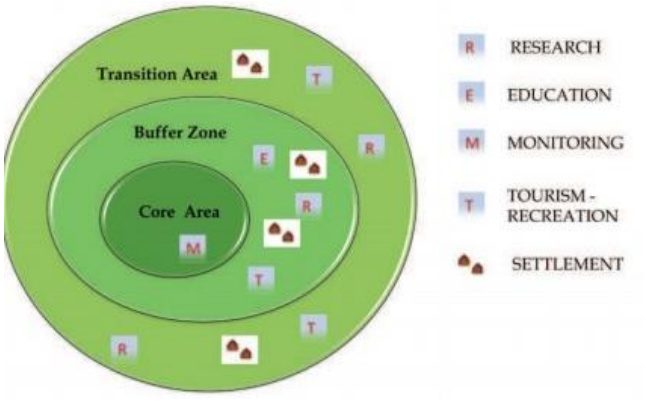
Genesis of Biosphere Reserves Concept

The UNESCO's 'Man and Biosphere' (MAB) programme was launched in 1971. It aimed to 'develop within the natural and social sciences a basis for the rational use and

conservation of the resources of the biosphere and for the improvement of the relationship between man and the environment'. A further objective of this programme concentrated on 'to predict the consequences of to-day's actions on to-morrow's world and thereby increase Man's ability to manage efficiently the natural resources of the biosphere'. One of the themes of the MAB programme was the 'conservation of natural areas and the genetic material they contain'. From this theme evolved the concept of biosphere reserves to conserve various representative ecosystems of the earth. Through *in-situ* conservation of biodiversity, the concept emphasizes the need for conserving ecosystems of a size large enough to ensure self-perpetuation and unhindered evolution of the living organisms. It envisages international co-operation dealing with people-environment interaction in the areas of operation within the bio-climatic zones, from islands and coastal areas to high mountain regions and sparsely populated regions to dense human settlements. The world's first biosphere reserve was designated in 1976 and since then the international network of such reserves has steadily grown to 651 biosphere reserves in 120 countries including 15 transboundary sites.

Basic structure of biosphere reserves

Biosphere reserves are demarcated into following 3 inter-related zones:



Core Zone

Core zone must contain suitable habitat for numerous plant and animal species, including higher order predators and may contain centres of endemism. Core areas often conserve the wild relatives of economic species and also represent important genetic reservoirs having exceptional scientific interest. A core zone being National Park or Sanctuary/protected/regulated mostly under the Wildlife (Protection) Act, 1972. Whilst realizing that perturbation is an ingredient of ecosystem functioning, the core zone is to be kept free from human pressures external to the system**.**

Buffer Zone

The buffer zone, adjoins or surrounds core zone, uses and activities are managed in this area in the ways that help in protection of core zone in its natural condition. These uses

and activities include restoration, demonstration sites for enhancing value addition to the resources, limited recreation, tourism, fishing, grazing, etc; which are permitted to reduce its effect on core zone. Research and educational activities are to be encouraged. Human activities, if natural within BR, are likely to continue if these do not adversely affect the ecological diversity.

Transition Zone

The transition area is the outermost part of a biosphere reserve. This is usually not delimited one and is a zone of cooperation where conservation knowledge and management skills are applied and uses are managed in harmony with the purpose of the biosphere reserve. This includes settlements, crop lands, managed forests and area for intensive recreation and other economic uses characteristics of the region.

Merits:

- It conserves the existing genetic variability in the population and allows evolution to continue. As a result, new alleles and gene combinations would appear.
- Risks associated with *ex situ* Germplasm conservation are eliminated.

Demerits:

- It is difficult to establish and maintain gene sanctuaries in highly populated countries like India
- This is a costly method of Germplasm conservation.

Questions

1 Gradual loss of genetic variability is called .....
a) Genetic b) **Genetic erosion** c) d) corruption

2 Germplasm may be collected through
a) Expeditions to centres of origin b) Personal visit to gene banks
c) Exchange of materials d) **All the above**

3 Gene sanctuary for *in situ* germplasm conservation of citrus is located at .....
a) North Eastern region b) **Meghalaya** c) Tamil nadu d) Kerala

4 Gene sanctuary at Meghalaya is meant for *in situ* germplasm conservation of .....
a) Banana b) Rice c) Mango d) **Citrus**

Lecture 12 & 13:

- *Ex Situ* conservation methods : Field gene banks and seed gene banks
- *Ex Situ* conservation methods : Cryo conservation, *in vitro* conservation, DNA banks, conservation of microspores and mega spores

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- Conservation of germplasm away from its natural habitat is known as *ex situ* germplasm conservation.
- This is achieved by
  1. Seed banks
  2. Plant (or) Field bank
  3. Shoot tip bank
  4. Cell and organ bank
  5. DNA bank

i. Seed Bank

- Germplasm is stored as seeds of various accessions
- It is easy, safe and needs minimum space to store.
- Seeds of many species can be stored up to 50 - 100 years in a glass, tin (or) plastic covers.

ii. Plant / Field Bank:

- It is an orchard or a field in which accessions of fruit or vegetatively propagated crops are grown / maintained.

Limitations:

1. Require larger area
2. Expensive to establish and maintain
3. Prone to pest and diseases, manmade / natural disasters

iii. Shoot tip Banks:

- Germplasm is conserved as slow growth cultures of shoot tip and node segments.
- Regeneration is done by sub culturing in every 6 months to 3 years.

Advantages

- Can be conserved free from pest and diseases.
- It is suitable for crops which do not produce seeds or produce recalcitrant seeds.

iv. Cell (or) Organ Bank:

- It is cryopreserved (-196º C in liquid nitrogen) embryonic cell culture, shoot tip, somatic / zygotic embryos.

v. DNA Banks:

DNA segments of genome of germplasm accessions are maintained as cosmid clones, phage lysates (or) pure DNA.

CRYO CONSERVATION

Cryo-conservation is widely used for long-term storage of seeds and *in vitro* cultures and is the method of choice for ensuring cost-effective and safe storage of germplasm of species which particularly have recalcitrant seeds or are vegetatively propagated. Storage is usually done in liquid nitrogen (-196°C), whereby all metabolic processes and cell divisions are arrested. Thus, plants can be stored for very long time and the problems such as genetic instability and the risk of losing accessions due to contamination or human errors during multiplication either in the field or during sub culturing under *in vitro* conditions can be overcome.

The most commonly applied cryopreservation methods are:

1. **Air drying (flash drying, normal drying)**

This method is directly applicable to orthodox seed, zygotic embryos and pollen of many common agricultural and horticultural species. Some of these orthodox seeds can even withstand drying below 3%moisture content, without any damage and reduction of viability. Flash (or ultra-rapid) drying proved to be beneficial for recalcitrant zygotic embryos of some plant species.

2. **Classical slow-cooling or rate controlled freezing**

This was the first 'standard' protocol that was developed for hydrated plant tissues. It is based on slow cooling of specimens at a rate of 0.5-2°C/min in the presence of a cryoprotectant solution, generally containing DMSO at 5-15% concentration. When a temperature of about –40°C is reached during the slow-cooling process, the intra-cellular solution is considered to be concentrated enough to vitrify upon a subsequent liquid nitrogen plunging. Now, this method is mainly used for cryopreservation of non-organized tissues, like cell suspensions and calli.

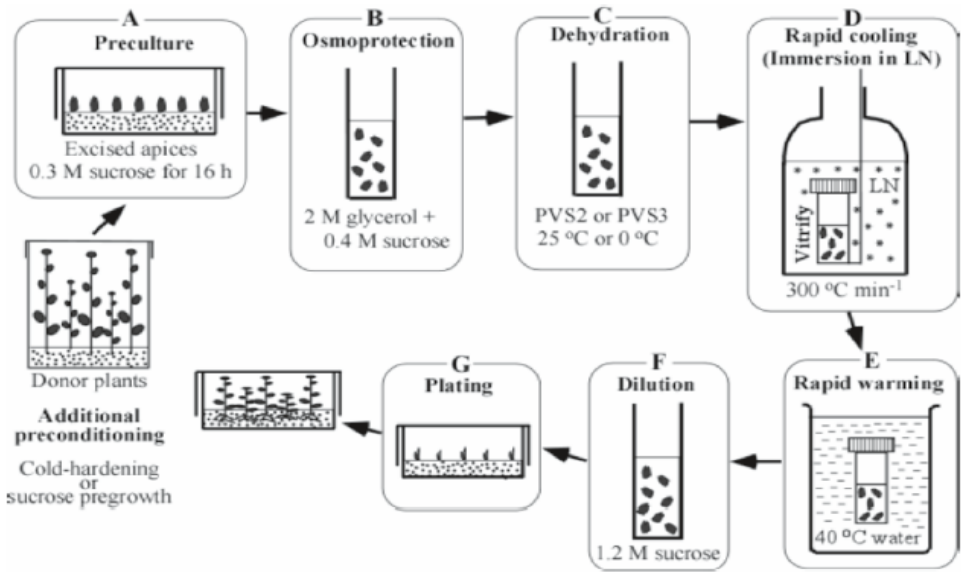
3. **Encapsulation/dehydration**

In this method, developed by Fabre and Dereuddre, explants (usually meristems or embryos) are first encapsulated in alginate beads (which can contain also mineral salts and organics), thus forming "synthetic seeds" (artificial seeds). Then, the synseeds are treated with a high sucrose concentration, dried down to a moisture content of 20-30% (under airflow or using silica gel) and subsequently rapidly frozen in liquid nitrogen. Although the procedure can be considered rather lengthy and labour-intensive, it is observed that the

presence of a nutritive matrix (the bead) surrounding the explant can promote its regrowth after thawing.

4. Vitrification

Vitrification can be defined as the transition of water directly from the liquid phase into an amorphous phase or glass, whilst avoiding the formation of lethal crystalline ice. The technique relies on treatment of explants with a concentrated vitrification solution for variable periods of time (from 15 minutes up to 2 hours), followed by a direct plunging into liquid nitrogen. This results in both intra- and extra-cellular vitrification. The vitrification solution consists of a concentrated mixture of penetrating and non-penetrating cryoprotectant substances. The most commonly applied solution, named "PVS2" (Plant Vitrification Solution 2), consists of 30% glycerol, 15% ethylene glycol, 15% DMSO (all v/v) and 0.4 M sucrose . Vitrification is the most widely used cryopreservation protocol today. The success of the procedure can be attributed to its easiness, high reproducibility and to the fact that it can successfully be applied to a wide range of tissues and plant species.



5. Droplet vitrification

A modification of vitrification technique that further reduces the chance for lethal ice-crystal formation through the application of ultra-fast cooling and rewarming rates is called "droplet vitrification". In this method, shoot tips are treated with PVS2 solution and then inserted individually in 5–10 µl droplets of PVS2, which are placed on a piece of aluminum foil, and then are immersed directly in LN. The main advantage of this technique is the

possibility of achieving very high cooling/warming rates owing to the tiny volume of cryo protective medium in which the explants are placed.

Each species requires specific protocols that must be carefully followed for preparation of samples to ensure maximum survival.

General considerations

- Tissues and recalcitrant seeds generally cannot be thawed and refrozen without damage.
- Orthodox seeds and pollen behave differently and can usually be thawed and refrozen
- Transfer cryopreserved material quickly between vessels to avoid rewarming.
- Ensure good air circulation in the room where LN storage tanks are placed because nitrogen gas is constantly boiling from the tanks. Oxygen monitors should be placed around the room for detection of oxygen content of the air.
- Use emergency fans that are triggered by the oxygen monitors or emergency buttons to increase air exchange in case of build up of nitrogen gas

Storage containers

- Storage container will vary with the size of the seeds or tissues. Store seeds and tissues in 1.8 and 2.0 ml cryogenic vials for cryopreservation
- For meristems and shoot tips, 10-25 tissues can be placed in one vial; For small seeds from 1500 to 3000 can be placed in one vial
- Larger vials will be needed for storage of larger seeded orthodox seeds
- Place multiple vials into aluminum cans or metal boxes for storage.
- Liquid nitrogen storage containers vary with tissue and size of collection
- Small 20-30 liter tanks with no vapor phase for direct tissue storage.
- Five-foot-diameter steel tanks that allow a vapour phase for seed storage.
- Use well insulated containers to reduce loss of liquid nitrogen. Containers with narrow necks reduce loss of liquid nitrogen but are inconvenient for access.
- Use an alarm system to indicate low liquid nitrogen levels.
- Top up storage dewars once in a week.
- Cryogenic vials may be stored directly in the liquid nitrogen at -196°C or suspended in trays within the vapour phase of the liquid nitrogen at -160°C

IN VITRO CONSERVATION

Seedgene banks are not feasible for germplasm from clonal crops which are either vegetatively propagated and/or do not produce seeds, or for species with short lived recalcitrant seeds. Clonally propagated plants require special approaches for their conservation. Since field/clonal gene bank approaches have limitations regarding efficiency, costs, security and long-term maintenance, *In vitro* conservation, which involves maintenance of explants in a sterile, pathogen-free environment is therefore preferentially applied to clonal crop germplasm. It also supports safe germplasm transfers under regulated phytosanitary control. This modern technique has already been applied for multiplication, storage and collection of germplasm of more than 1000 species.

Cultures in the active genebank are maintained by successive subculturing allowing culture renewal and distribution. For medium term storage, sub-culture intervals are extended, reducing processing costs by arresting growth using cold treatments, adapted light conditions, culture medium modifications (osmotic active compounds, growth retardants). This increases efficient use of resources and staff time and offsets selection risks and contamination.

Practical considerations

Security

Security should ensure:

- Purity: freedom from contaminating organisms.
- Authenticity: correct identity.
- Stability: fit-for-purpose and true-to-type.

Good laboratory practices, application of aseptic techniques with careful containment strategies, clear and accurate documentation and avoiding practices that increase risks of genetic variation are all essential to ensure security of cultures.

Culture facilities

Some general guidelines necessarily followed to ensure the appropriate environment to successfully culture and grow materials of different species in *in vitro* cultures are:

- Use culture growth rooms with temperature control, lighting and shelving.
- Aim for a room where the humidity is 40–50%. High humidity increases fungal growth, while low humidity dries cultures and creates dust problems.
- Use an isolated growth room for *in vitro* explants of materials taken directly from the field to allow time to detect insect infestations and prevent their spread to other cultures.

- Ensure a light intensity in the range from 10 to 1000 μmol S^{-1} m^{-2}. Most plant cultures require 50–200 μmol S^{-1} m^{-2}.
- Use ventilation systems or air-conditioning units to regulate temperature. Air should not flow directly onto the cultures. Common growth room temperatures range from 22ºC to 28ºC, depending on species requirements.
- Back-up generators are advisable for areas with frequent power cuts to control temperature and light.

Genetic stability during storage

Somaclonal variation, a problem usually associated with plants regenerated from single cells, callus or adventitious buds, is not common in plants micropropagated from axillary buds. The frequency of somaclonal variation occurring, gross chromosomal aberrations and *in vitro* selection are enhanced in prolonged tissue culture. Exposure to minimal growth conditions over long periods of time can also be expected to lead to genetic changes. It is significant that asexually propagated species for germplasm conservation may display a higher frequency of somaclonal variation as compared to those where the propagule is a seed. Great care should be taken to select culture practices to reduce this variation and ensure genetic integrity.

Preferred practices are:

- Avoid using germplasm propagated via dedifferentiated and adventitious routes for conservation.
- Select germplasm from young cultures because somaclonal variation increases and totipotency decreases during prolonged culture.

Medium term storage using slow growth*in vitro*

The objective of slow growth (or minimal growth) is to reduce the sub-culture interval to a critical level which does not impose a long-term deleterious effect on the germplasm, or the stability of regenerated/regrown plants. However, slow growth treatments incur some level of stress and it is essential to optimise regimes for each species for timing of sub-culture and regeneration. Minimal growth storage is achieved via several following treatments, applied singularly or in combination:

- Physical growth limitation
- Low temperature
- Low light/restricted photoperiod
- Minimal containment

- Minimal O_2
- Osmotic (water) stress
- Chemical growth limitation
- Growth regulator retardation
- Growth inhibitors
- Minimal nutrition
- Low macro nutrient levels
- Low micro nutrients levels

Choice of treatment is largely species-dependent and dictated by the ability of specific cultures to withstand the stresses incurred.

Culture and storage protocols have been developed for several important vegetatively propagated crops, including banana, cassava, potato, sweet potato, yam.

Questions

1 *Ex situ* method suitable for conservation of crops producing recalcitrant seed is .....
a) Seed bank b) Field bank c) **Shoot tip bank** d) DNA bank

2 *Ex situ* method suitable for conservation of vegetatively propagated crops is .....
a) Seed bank b) **Field bank** c) Shoot tip bank d) DNA bank

3 Suitable *Ex situ* method for conservation of crops which do not produce seeds is .....
a) Seed bank b) Field bank c) **Shoot tip bank** d) DNA bank

4 An example for crop producing recalcitrant seeds is .....
a) Coffee b) Mango c) Jack d) **All the above**

5 Germplasm accessions of various crops are evaluated based on .....
a) Basic record b) Germplasm record c) **Descriptors** d) Field note

6 ..... deals with germplasm activities at global level
a) CGIAR b) **IPGRI** c) FAO d) NBPGR

7 Who has developed descriptors for various crops?
a) CGIAR b) **IPGRI** c) FAO d) NBPGR

Lecture 14: Concept of base, active and working collections, core collections and reference sets

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Based on duration of storage, seed bank collections are classified into.

1. Base collection
2. Active collection
3. Working collection

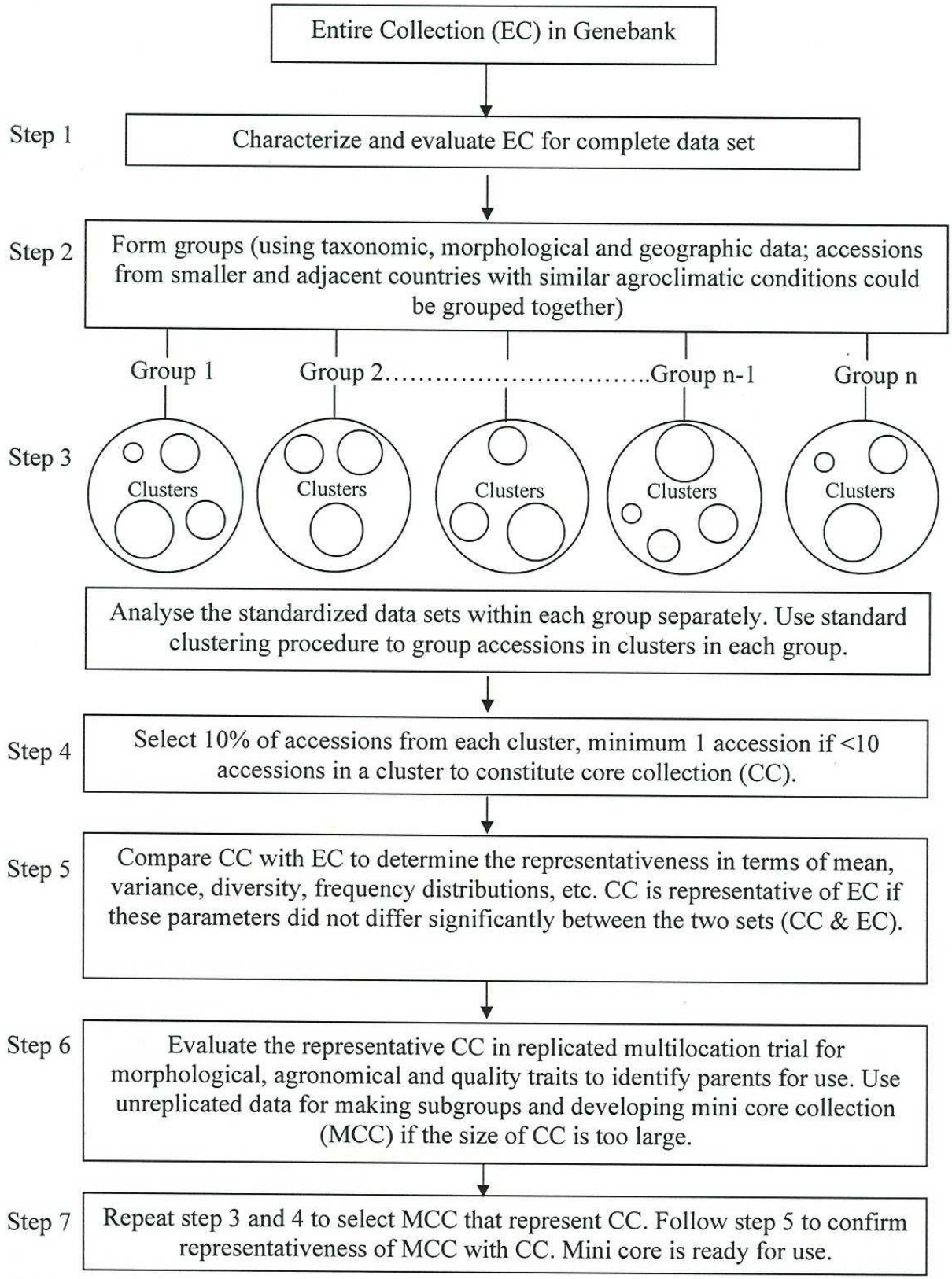
	Base collection	Active collection	Working collection
1.	This source of collection is utilized for plant breeding programme only when other source of germplasm is not available	This source of collection is actively utilized in plant breeding programmes.	This source of collection is frequently utilized in plant breeding programme
2.	Seeds are stored at -20ºC with 5% moisture content	Seeds are stored at 0ºC with 5 - 8% moisture content	Seeds are stored at 5 -10ºC with 10% moisture content
3.	It is meant for long term conservation (up to 50 years or more)	It is meant for medium term conservation (10 - 15 years)	It is meant for short term conservation (3 - 5 years)

Procedure of development of core and mini-core collection

Creating a core collection can be very simple. It can be done for any germplasm collection. It does not require complete documentation or fully reliable data. There is no need to have data on genetic markers or to have specialist knowledge of mathematics. All that is needed is a germplasm collection, someone with some basic knowledge about the collection and the species involved, and some time for selecting the core.

A general procedure for the selection of a core collection can be divided into five steps, which are depicted in a sequential order in the Figure 1.

1. Identify the material (collection) that will be represented.
2. Decide on the size of the core collection.
3. Divide the set of material used into distinct groups.
4. Decide on the number of entries per group.
5. Choose the entries from each group that will be included in the core



Flow chart to establish the core and mini-core collections in a crop species

(Upadhyaya*et al.*, 2009)

Validating the core collection

Once a core/mini core collection has been established, an important question for gene bank managers is to test the extent to which the core or mini core collection meets its original objectives in terms of the representation of diversity and lack of repetition. This process of validating the core collection usually involves comparing it in some appropriate way with the original collection from which it was developed.

The evaluation of core collection along with that of original collection is carried out statistically for means and variances of the quantitative traits measured, the frequency distribution of the accessions, traits correlations, and using the range retention index. This validation process uses the statistical parameters to assess how accurately each core represented the total variability in the entire collection.$\chi 2$ test is done to verify whether the frequency of the traits in the accessions in each stratum of the core collection remained similar to the frequency in the entire collection and to verify the homogeneity in the frequency distribution of the traits between the entire collection and each core collection. The classes of each trait were determined by dividing the range in the entire collection by 20, which was empirically considered adequate for the studied traits. These ranges can also be used within each core collection. If the class in the core collections contained fewer than five accessions, the Yates correction can be used.

To determine the proportion of the entire collection range retained by each core collection, a range retention index can be calculated for each of the quantitative traits. The range retention index is the proportion of the range of the entire collection maintained in a core collection (Diwan*et al.*, 1995). The mean range retention index is calculated according to Diwan*et al.* (1995), using the following equation:

$$Mean\ RR = \frac{\sum_{i=1}^{t} AiCN/AiCB}{t}$$

where RR = mean range retention index; AiCN = amplitude of trait i in the core collection; AiCB = amplitude of trait i in the entire collection; t = number of traits.

A core collection is considered to be representative of the entire collection and, therefore acceptable, if 30% or fewer of the trait means and ranges were significantly different ($P \leq 0.05$) from those of the entire collection. A core collection is taken as representative of the entire collection as a resource for plant breeders when means, ranges and phenotypic correlations between the trait are maintained and when variances and kurtosis

were unequal, that is the variance of core > variance of entire collection and the kurtosis of the core < kurtosis of entire collection. Frankel and Brown (1984) suggested that the sampling strategy is efficient when the constructed core collection retains, in average, at least 80% of the original trait range.

Questions

1 The following source of collection is frequently utilized in plant breeding programme
a) Base collection b) Active collection
c) **Working collection** d) All the three

2 Which one of the following is meant for long term conservation
a) **Base collection** b) Active collection
c) Working collection d) All the three

3 Which one of the following is meant for medium term conservation
a) Base collection b) **Active collection**
c) Working collection d) All the three

4 Which one of the following is meant for short term conservation
a) Base collection b) Active collection
c) **Working collection** d) All the three

5 Who did give concept of core collection?
a) Mendel b) Vavilov
c) **Frankel** d) Karpechenko

Lecture 15 & 16:

- International framework and PGR networks; International treaties and policies in relation to agrobiodiversity conservation and sustainable use; CBD and UPOV convention
- National polices: National Biodiversity Authority, PPV & FR authority, IP issues with respect to ITKs and communities safe guarding biodiversity

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The Convention on Biological Diversity (CBD) is the international legal instrument for "the conservation of biological diversity, the sustainable use of its components and the fair and equitable sharing of the benefits arising out of the utilization of genetic resources" that has been ratified by 196 nations.

The objectives of the Convention on Biological Diversity are expressed in its article 1:

- the conservation of biological diversity;
- the sustainable use of its components; and
- the fair and equitable sharing of the benefits arising out of the utilization of genetic resources, including by appropriate
    - access to genetic resources,
    - transfer of relevant technologies,
    - funding.

The Convention is thus the first agreement to address all aspects of biological diversity: species, ecosystems and genetic resources. It is indeed the first time that genetic diversity is specifically covered in a binding global treaty.

The Convention also recognises - for the first time - that the conservation of biological diversity is "a common concern of humankind" and an integral part of the development process. In other words, the Convention recognises that all humanity has an interest ensuring the conservation of biological diversity, including poor nations, women and indigenous people, and that it needs to be addressed by concerted international action.

International Union for Protection of New Plant Varieties (UPOV Convention)

- The International Union for the Protection of New Varieties of Plants (UPOV) is an intergovernmental organization with headquarters in Geneva (Switzerland).
- UPOV was established by the International Convention for the Protection of New Varieties of Plants. The Convention was adopted in Paris in 1961 and it was revised in 1972, 1978 and 1991.
- UPOV's mission is to provide and promote an effective system of plant variety protection, with the aim of encouraging the development of new varieties of plants, for the benefit of society.
- The UPOV Convention provides the basis for members to encourage plant breeding by granting breeders of new plant varieties an intellectual property right: the breeder's right.
- In the case of a variety protected by a breeder's right, the authorization of the breeder is required to propagate the variety for commercial purposes. The breeder's right is granted by the individual UPOV members.
- Only the breeder of a new plant variety can protect that new plant variety. It is not permitted for someone other than the breeder to obtain protection of a variety.

- There are no restrictions on who can be considered to be a breeder under the UPOV system: a breeder might be an individual, a farmer, a researcher, a public institute, a private company etc.
- India is not a member.

PPV&FRA

In order to provide for the establishment of an effective system for the protection of plant varieties, the rights of farmers and plant breeders and to encourage the development of new varieties of plants it has been considered necessary to recognize and to protect the rights of the farmers in respect their contributions made at any time in conserving, improving and making available plant genetic resources for the development of new plant varieties.

The Government of India enacted "The Protection of Plant Varieties and Farmers' Rights (PPV &FR) Act, 2001" adopting ***sui generis*** system. Indian legislation is not only in conformity with International Union for the Protection of New Varieties of Plants (UPOV), 1978, but also have sufficient provisions to protect the interests of public sector breeding institutions and the farmers.

The legislation recognizes the contributions of both commercial plant breeders and farmers in plant breeding activity and also provides to implement TRIPs in a way that supports the specific socio-economic interests of all the stakeholders including private, public sectors and research institutions, as well as resource-constrained farmers.

To implement the provisions of the Act the Department of Agriculture and Cooperation, Ministry of Agriculture established the Protection of Plant Varieties and Farmers' Rights Authority on 11th November, 2005.

The Chairperson is the Chief Executive of the Authority. Besides the Chairperson, the Authority has 15 members, as notified by the Government of India (GOI).

Eight of them are ex-officio members representing various Departments/Ministries, three from SAUs and the State Governments, one representative each for farmers, tribal organization, seed industry and women organization associated with agricultural activities are nominated by the Central Government. The Registrar General is the ex-officio Member Secretary of the Authority.

Objectives of the PPV & FR Act, 2001

1. To establish an effective system for the protection of plant varieties, the rights of farmers and plant breeders and to encourage the development of new varieties of plants.

2. To recognize and protect the rights of farmers in respect of their contributions made at any time in conserving, improving and making available plant genetic resources for the development of new plant varieties.
3. To accelerate agricultural development in the country, protect plant breeders' rights; stimulate investment for research and development both in public & private sector for the development new of plant varieties.

Facilitate the growth of seed industry in the country which will ensure the availability of high quality seeds and planting material to the farmers.

General functions of the Authority

- Registration of new plant varieties, essentially derived varieties (EDV), extant varieties;
- Developing DUS (Distinctiveness, Uniformity and Stability) test guidelines for new plant species;
- Developing characterization and documentation of varieties registered
- Compulsory cataloging facilities for all variety of plants
- Documentation, indexing and cataloguing of farmers'varieties;
- Recognizing and rewarding farmers, community of farmers, particularly tribal and rural community engaged in conservation, improvement, preservation of plant genetic resources of economic plants and their wild relatives
- Maintenance of the National Register of plant Varieties and
- Maintenance of National Gene Bank

Rights under the Act

Breeders' Rights

Breeders will have exclusive rights to produce, sell, market, distribute, import or export the protected variety. Breeder can appoint agent/ licensee and may exercise for civil remedy in case of infringement of rights.

Researchers' Rights

Researcher can use any of the registered variety under the Act for conducting experiment or research. This includes the use of a variety as an initial source of variety for the purpose of developing another variety but repeated use needs prior permission of the registered breeder.

Farmers' Rights

- A Farmer who has evolved or developed a new variety is entitled for registration and protection in like manner as a breeder of a variety;
- Farmers variety can also be registered as an extant variety;
- A farmer can save, use, sow, re-sow, exchange, share or sell his farm produce including seed of a variety protected under the PPV & FR Act, 2001 in the same manner as he was entitled before the coming into force of this Act provided farmer shall not be entitled to sell branded seed of a variety protected under the PPV&FR Act, 2001;
- Farmers are eligible for recognition and rewards for the conservation of Plant Genetic Resources of land races and wild relatives of economic plants;
- There is also a provision for compensation to the farmers for non-performance of variety under Section 39 (2) of the Act, 2001 and
- Farmer shall not be liable to pay any fee in any proceeding before the Authority or Registrar or the Tribunal or the High Court under the Act.

Registration

A variety is eligible for registration under the Act if it essentially fulfills the criteria of Distinctiveness, Uniformity and Stability (DUS). The Central Government issues notification in official Gazettes specifying the genera and species for the purpose of registration of varieties.

So far, the Central Government has notified 57 crop species for the purpose of registration. The PPV & FR Authority has developed "Guidelines for the Conduct of Species Specific Distinctiveness, Uniformity and Stability," tests or "Specific Guidelines', for individual crop species. These include bread wheat, rice, maize, sorghum, pearl millet, chickpea, pigeon pea, green gram, black gram, field pea/garden pea, kidney bean/French bean, lentil, diploid cotton (two species), tetraploid cotton (two species), jute (two species), sugarcane, ginger, turmeric, Indian mustard, karan rai, rapeseed, gobhi sarson, sunflower, safflower, castor, sesame, linseed, groundnut, soybean, black pepper, small cardamom, rose, chrysanthemum, mango, potato, eggplant, tomato, lady's finger, cauliflower, cabbage, onion, garlic, durum, dicoccum and triticum species of wheat, jsabgol, menthol mint, damask rose, periwinkle brahmi, orchids (Venda, cymbidium & Dendrobium) and 20 different crops are to be notified very soon.

Publications of Authority

- Plant variety journal of India
- General and crop specific DUS test guidelines

- Technical Bulletin
- Gene Bank Manual
- Agro-biodiversity (Hotspots Book (Two Volumes)
- A video CD entitled 'Seed of Sustenance' highlighting various provisions of the PPV & FR Act, 2001
- Annual Reports
- A video CD on Krishak Adhikar
- A compendium of varieties registered under PPV & FR Act 2001 (from 2009 to 2012)
- A book entitled 'Cultivated plants & their wild relatives in India" an Inventory

Fees for registration

Application for registration of plant varieties should be accompanied with the fee of registration prescribed by the authority. Fee for registration for different types of variety is as under:

Type of variety	**Fees of Registration**
Extant variety notified under section 5 of the seeds Act, 1996	Rs.1000/-
New variety /Essentially Derived Variety (EDV)	IndividualRs.5000/- EducationalRs.7000/- Commercial Rs.10000/-
Extant variety about which there is common knowledge (VCK)	IndividualRs.2000/- EducationalRs.3000/- Commercial Rs.5000/-

The Registration of a variety is renewable subject to payment of annual fee as notified in the Plant Variety Journal of India of the Authority.

DUS Test Centers

Authority has 122 DUS test Centers for different crops with a mandate for maintaining and multiplication of reference collection, example varieties and generation of database for DUS descriptors as per DUS guidelines of respective crops. The list of DUS test Centers is available on the official website of the Authority.

Plant Variety Journal of India

Authority publishes its official journal "Plant Varieties Journal of India" (PVJI) as a monthly bilingual (Hindi & English) publication and made available to public on the first working day of each month on its official website. This journal has the equivalent status of a gazette under

the Regulations, 2006. The contents of Journal includes official and public notices, passport data of plant varieties, DUS test guidelines of crop species, details of certificate of registration and other related matters.

Certificate of Registration

Applications which have fulfilled all requirements and have been finally accepted by the Registrar for registration were issued Certificates of Registration. 747 Certificates have been issued, out of which 91 have been issued for new varieties, 633 for extant varieties notified under the seeds Act, 1966, 22 for farmers' varieties and 1 for Essentially Derived Variety (EDV). The certificate of registration issued will be valid for nine years in case of trees and vines and six years in case of other crops. It may be reviewed and renewed for the remaining period on payment of renewal fees subject to the condition that total period on payment of renewal fees subject to the condition that total period of validity shall not exceed eighteen years in case of trees and vines from the date registration of the variety, fifteen years from the date of notification of variety under the Seeds Act, 1996 and in other cases fifteen years from the date registration of the variety. So far the Authority has received 4934 applications as on October, 2013 for registration for different categories of varieties including farmer's varieties.

National Register of Plant Varieties

National Register of Plant Varieties has been kept at the head office of the Registry, containing the names of all the registered plant varieties with the names and addresses of their respective breeders, the rights of such breeders in respect of the registered varieties, the particulars of the denomination of each registered variety, its seed or other propagating material along with specification of salient features thereof and such other matters as may be prescribed.

Lecture 17: Utilization of Plant Genetic Resources – Pre-breeding concepts for use of adapted and un-adapted germplasm in crop improvement programmes

Pre-breeding refers to all activities designed to identify desirable characteristics and genes from un-adapted materials that cannot be used directly in breeding programme and to transfer these traits to an intermediate set of materials. The breeders can use further this material in producing new varieties for farmers. The term "enhancement" was first used by Jones (1983) which according to him can

be defined as transferring useful genes from exotic or wild types into agronomically acceptable background. Rick (1984) used the term pre-breeding or developmental breeding to describe the same activity. Thus "genetic enhancement" or "pre-breeding" refers to the transfer or introgression of genes or gene combinations from un-adapted sources such as landraces, wild species of crops and semi-wild relatives into breeding materials. It is an emerging concept emphasizing the use of plant genetic resources.

Importance of pre-breeding

- Pre-breeding aims to reduce genetic uniformity in crops through the use of a wider pool of genetic material to increase yield, resistance to pests and diseases, and other quality traits.
- It also aims at base broadening which is achieved by either identification of genes that control traits of interest or moving these genes from un-adapted germplasm to adapted background.
- It plays an important role through genetically improving the yield performance, enhancement of agronomic, physiological and biotic stress tolerance in the germplasm.
- Germplasm enhancement should be regarded as a long term activity, because exotic /wild germplasm seldom has immediate use without selection for local adaptation and enhanced yield potential.
- Thus, these programmes are independent of local crop genetic base until they become sources of parental material in normal breeding pool. Lack of pre-breeding programme is the most limiting factor for using landraces and crops wild relatives.

Linking gene banks with plant breeders

Genebanks are repositories of genetic diversity of cultivated as well as their wild relatives and other wild species. The ultimate role of genebanks is to ensure the long term availability of crop germplasm to sustain agricultural production, by providing pre-breeder and breeder with new genetic diversity that adds value to the future varieties. Pre-breeding helps in building a bridge that brings together the people who understand the scope of germplasm collections (genebank managers)

with those who introduce new traits into their varieties (plant breeders). Pre-breeding acts as a link between plant genetic resources PGR (gene bank managers) and breeding (plant breeders). Plant breeders and genebank managers must find ways to make it easier to effectively use germplasm from genebanks to produce new varieties with the traits the world needs.

Aims of pre-breeding programs

- Enhancement of genetic variability in the germplasm for its further use in regular breeding programme.
- To reset the genetic diversity of crops by reintroducing genetic variability left behind.
- To use genetic diversity that was not previously accessible due to genetic in-compatibilities or non-overlapping geographic range.
- Gene banks mainly focused on the conservation aspects of Plant Genetic Resources and there is urgent need for active engagement with all stakeholders to enhance their utilization.

Major Activities of Pre-breeding

- ✓ Characterization of unadaptedpopulation and Identification of desirable traits / genes
- ✓ Identification new traits from other sources
- ✓ Creation of new parent population for transferring these traits into well-adapted lines
- ✓ Creation of novel traits through mutation
- ✓ Creation of polyploidy for new genetic variation
- ✓ Development of new biotechnological and molecular techniques

Planning for a pre-breeding programme

When planning to utilize the unadaptedgermplasm or exotic parents for germplasm enhancement via pre breeding, the order of preference should be:

1. Improved cultivars and breeding lines

2. Landraces or older cultivars

3. Closely related species

4. More distantly related species and genera

Procedure of pre-breeding