DEFINITION OF PLANT BREEDING

Plant breeding is the conscious human efforts needed to improve and develop new plants, which are called crop varieties in order to satisfy the demand for human food and animal feeds.

It is a type of selection made possible when there is genetic variability. It is specifically aimed at improving certain yield related character (traits) in a crop plant. It is very important for a potential plant breeder to know and understand the reproductive system of the plant; he/she wants to work with.

It is also very important to know the people to work with. Plant breeders will work with geneticists, physiologists, pathologists, biometricians, botanists, biochemists, seed technologist and nutritionist.

ROLE OF PLANT BREEDING IN INCREASING GLOBAL FOOD SUPPLY

1. Production of crops that have definite improvement over the existing or local varieties.
2. Production of crops that give increase yield per unit area at minimum cost of production.
3. Production of crops that are adapted to the need of the growers and consumers.
4. Production of crops that gives high quality yield or product.
5. Production of crops that are resistant to insect pest and diseases.
6. Faster crop breeding methods compared with traditional methods.
7. Production of crops that are adapted to specific environments or peculiar weather such as drought, water logging, salinity etc.

QUANTITATIVE AND QUALITATIVE CHARACTERS IN PLANT BREEDING

Quantitative characters are also known as metric characters. They are controlled by many genes. Such characters are agronomic in nature and have complex inheritance. They are easily influences by the environment. They are continuous in their phenotypic expression and they segregate in the second filial generation F_2. Such characters cannot be grouped into distinct classes but they can be improved by recurrent selection leading to small but steady genetic gain in each selection cycle. They are responsive to high temperature and water and are physiological in nature. Examples are grain yield, total dry matter, plant height, protein and oil content in plants and general disease resistance.

Qualitative characters are traits that show simple Mendelian inheritance. They are controlled by one or two pairs of genes. They are easily measured and their phenotype in the second filial generation F_2 has close resemblance with their parents. E.g. flower or leaf colour, leaf shape, fruit shape, etc.

It should be noted that selection is faster when dealing with qualitative traits compared with quantitative traits because unfavourable traits can be easily eliminated.

P= G+ E

$V^2p = V^2g + V^2e$

Where P =Phenotype, G = genotype and E = environment, V^2 = variance

HERITABILITY

Heritability is a measure of the genetic contribution to phenotypic variability

Types:

Broad-Sense Heritability: this expresses that proportion of variance due to the genetic component:

$\mathbf{H^2 = V_G/V_P}$

Where V_G is the genetic variance and V_P is the phenotypic variance

Narrow-Sense Heritability:

$\mathbf{h^2 = V_A/V_P}$

Because $V_P = V_E + V_G$ and $V_G = V_A + V_D$, we obtain:

$\mathbf{h^2 = V_A / V_E + V_A + V_D}$

Where V_A =additive variance, V_D =dominance variance,

Example

The mean and variance of corolla length in two highly inbred strains of Nicotiana and their progenies are shown in table below. One Parent (P1) has short corolla length and the other (P2) has a long length.

Strain	**Mean (mm)**	**Variance**
P1	40.47	3.12
P2	93.75	3.87
F_1 (P1xP1)	63.90	4.47
F_2 (F1xF1)	68.72	47.70

Calculate the heritability for corolla length

Solution

$\mathbf{H^2 = V_G/V_P}$, $\mathbf{V^2p = V^2g + V^2e}$

Because the strains breed true, they are assumed to be homogenous and the variance 3.12 and 3.87 is considered to be as a result of the environmental influences.

The average = (3.12 + 3.87)/2 = 3.50

F_1 is also genetically homogenous; hence it gives us an additional estimate of the environmental factors. By averaging over the two parents, we have:

(3.50 + 4.47)/2 =4.12

$\mathbf{V^2p = V^2g + V^2e}$

$47.70 = V^2g + 4.12$

$\mathbf{V^2g}$ =43.58

$\mathbf{H^2 = V_G/V_P}$,

=43.58/47.70

=0.91

=91%

This implies that about 91% of the variation in corolla length is due to genetic influences.

ROLE OF THE ENVIRONMENT IN PLANT BREEDING

Environment affects selection and progress from selection. The genetic gain or response to selection is the difference between the mean phenotypic value of selected offspring from parental population and that of the parental population before selection. Response to selection is used to compare selection methods and to predict environments.

Response to selection = rg[hx/hy]

Where rg =genetic correlation between trait (x) and yield (y),

hx = heritability for character x

hy = heritability for yield

The bigger the response to selection the better it is. It has no unit.

Heterosis

Heterosis, or hybrid vigor or outbreeding enhancement, is the increased function of any biological quality in a hybrid offspring. It is the occurrence of a genetically superior offspring from mixing the genes of its parents.

Heterosis is the opposite of inbreeding depression, which occurs with increasing homozygosity. The term often causes controversy, particularly in terms of the selective breeding of domestic animals, because sometimes it's inaccurately claimed, that all crossbred plants are genetically superior to their parents. It's only true in certain circumstances. When a hybrid is seen to be superior to its parents, this is known as hybrid vigor. When the opposite happens, and a hybrid inherits traits from its parents that makes it unfit for survival, the result is referred to as outbreeding depression.

Hybrid vigour is measured in two ways:

(1) Mid-parent heterosis (Hmp)

=(F – mp)/mp

(2) Hetero-betiosis (better parent heterosis) Hbp

= (F – bp)/bp

Where F = Mean of F1

mp = mean of the two parents

bp = better parent

Example:

Giving the mean yield of two inbred strains A=80kg , B= 50 and F1 is 90kg, calculate

i. Hmp

ii. Hbp

Solution:

1. mp =(80+50)/2

= 65

Hmp = (F – mp)/mp

= (90 – 65)/65

=0.3846

This implies that the hybrid vigour is 38.46%

2. Hbp = (F – bp)/bp

= (90 – 80)/80

=0.125

Herobetiosis is 12.5%

The better parent heterosis is more significant as far as breeding is concerned because individual progenies are more superior to the better parent.

Manifestations of Heterosis

1. increased heterozygosity
2. increased size and productivity in plants
3. Greater resistance to diseases, insects and environmental factors
4. Early maturity when compared to either of the parents.

INCOMPATIBILITY SYSTEMS

There are various forms of incompatibility. Araso (1998) defined incompatibilityas the inability of a plant to produce functional gametes or inability of a plant producing functional gametes to set seed when self-pollinated.

Causes of Incompatibility

1. Failure of the pollen tube either to penetrate the stigma and;
2. To grow normally the full length of the style so that fertilization may occur.

In the later above, the pollen tube grows sowly that it may never get to reach the ovule and if it does, it would be so late that the ovule would have either been pollinated by compatible pollen or would have withered. Incompatibility restrics self fertilization and inbreeding but it fosters cross fertilization.

Genesis of incompatibility

1. Protandry: Stamen maturing before the stigma
2. Protogyny: Stigma matures before the stamen
3. Hercogamy: This involves the physical arrangement of male and female organs on the same plant preventing self pollination in the absence of an insect.

Apart from the morphological mechanism, which ensures open pollination, there are also some genetic and physiological mechanisms which ensure incompatibility. Based on this, incompatibility can be divided into two groups:

A. Heteromorphic Incompatibility

B. Homomorphic Incompatibility

A. Heteromorphic Incompatibility

This system is based on the difference in the length between the stamen and the style. The flower with long style and short filament is called PIN where as the flower with long filament and short style is called THRUM.

In PIN the pollen grains contains the gene labeled (ss) while that of THRUM has heterozygous gene (Ss).

Consequently, pollination is possible only between the anther and stigma of the same height i.e. between stamen of PIN and stigma of THRUM or between the stima of Pin and stamen of THRUM.

PIN		THRUM	
ss		Ss	parents
s	x	Ss	gametes
	Ss	ss	F1- generation

In addition to the floral differences or floral morphology, PIN and THRUM plants also differ in other characteristics such as pollen size and the size of stigmatic cells. Consequently a combination of PIN x PIN is incompatible and THRUM x THRUM is also incompatible. It means that homozygous SS will not exist.

B. Homomorphic Incompatibility

Under this condition, differences in floral morphology are excluded. We therefore have gametophytic and sporophytic incompatibilities.

i. Gametophytic Incompatibility: This system is also known as the opposition factor system and it depends on a series of alleles on a single locus i.e. the ability of a pollen to fertilize the stigma depends on the type of gene in each locus. Under this system, pollen tube growth is usually very slow within a style that contains similar alleles e.g. S_1S_1 or S_2S_2.

Consequently, plants are virtually always heterozygous at this locus S_1S_2 or S_2S_3 or S_1S_3 for compatibility to be possible.

A situation with two alleles with gametophytic control with no dominance is impossible because all plants could be incompatible and sterile. The phenomenon of incompatibility gives rise to three types of pollination.

1. Fully compatible ($S_1S_2 \times S_1S_2$)

In this case both alleles are common in the male and the female. All gametes are non-functional and so, no offspring is produced.

2. Half of pollen is compatible ($S_1S_2 \times S_1S_3$)

Half of the pollen is compatible in which one allele is different in both the male and female gametes. S_3 is the functional male and S_1 is non-functional male.

$S_1S_2 \times S_1S_3$

S_1S_1 **S_1S_3** S_1S_2 **S_2S_3** ----- **F_1**

4. All pollen are compatible ($S_1S_2 \times S_3S_4$)

In this case both alleles differ giving the progenies:

S_1S_3 S_1S_4 S_2S_3 S_2S_4

ii. Sporophytic Incompatibility:

This is similar to the gametophytic system in that genetic control is by a single gene with multiple alleles. However, unlike gametophytic type, the functionality of pollen is determined by the genetic constitution of the plant producing it. It also differs from the gametophytic system in that the alleles may show dominance. Thus, individual action or competition in either pollen or style is according to the allele combination involved. The main feature of sporophytic system that differentiates it from the gametophytic system are:

a. There are frequent reciprocal differences

b. Incompatibility can occur within the female parent

c. A family can consist of three incompatible groups or more

d. Homozygosity is a normal part of the system

e. An incompatible group may contain two genotypes.

STERILITY

Sterility covers all cases of infertility or bareness in plants resulting from irregularities with the sexual reproductive system. Infertility may be caused by abnormal or imperfect development of the reproductive organs. The stamen or pistil may be malformed, pollen may be defective or the ovules aborted. Infertility may also result from failure of viable pollen to function after germination. The pollen tube may not penetrate the stigmatic surface or the pollen tube growth in the style may be reduced so that the spermatic cells do not reach the ovule.

In some cases even though fertilization occurs, the embryo may not develop normally so no viable seeds are formed. After seed formation, infertility in hybrid may result from chromosomal an irregularity that inhibits chromosomal pairing or normal division at meiosis of from other genetic causes. Regardless of the specific causes, infertility is a hindrance that should be understood and overcomed by the breeder if he is to obtain genetic recombination through inter-specific or intra-specific crosses.

TISSUE CULTURE AND PLANT BREEDING

Plant tissue culture is a practice used to propagate plants under sterile conditions, often to produce clones of a plant. Different techniques in plant tissue culture may offer certain advantages over traditional methods of propagation, including:

- The production of exact copies of plants that produce particularly good flowers, fruits, or have other desirable traits.
- To quickly produce mature plants.
- The production of multiples of plants in the absence of seeds or necessary pollinators to produce seeds.
- The regeneration of whole plants from plant cells that have been genetically modified.
- The production of plants in sterile containers that allows them to be moved with greatly reduced chances of transmitting diseases, pests, and pathogens.
- The production of plants from seeds that otherwise have very low chances of germinating and growing, i.e.: orchids and nepenthes.
- To clean particular plant of viral and other infections and to quickly multiply these plants as 'cleaned stock' for horticulture and agriculture.

Plant tissue culture relies on the fact that many plant cells have the ability to regenerate a whole plant (totipotency). Single cells, plant cells without cell walls (protoplasts), pieces of leaves, or (less commonly) roots can often be used to generate a new plant on culture media given the required nutrients and plant hormones.

Techniques

Modern plant tissue culture is performed under aseptic conditions under filtered air. Living plant materials from the environment are naturally contaminated on their surfaces (and sometimes interiors) with microorganisms, so surface sterilization of starting materials (explants) in chemical solutions (usually alcohol or bleach) is required. Mercuric chloride is seldom used as a plant sterilant today, as it is dangerous to use, and is difficult to dispose of. Explants are then usually placed on the surface of a solid culture medium, but are sometimes placed directly into a liquid medium, particularly when cell suspension cultures are desired. Solid and liquid media are generally composed of inorganic salts plus a few organic nutrients, vitamins and plant hormones. Solid media are prepared from liquid media with the addition of a gelling agent, usually purified agar.

In-vitro tissue culture potato explants

The composition of the medium, particularly the plant hormones and the nitrogen source (nitrate versus ammonium salts or amino acids) have profound effects on the morphology of the tissues that grow from the initial explant. For example, an excess of auxin will often result in a proliferation of roots, while an excess of cytokinin may yield shoots. A balance of both auxin and cytokinin will often produce an unorganised growth of cells, or callus, but the morphology

of the outgrowth will depend on the plant species as well as the medium composition. As cultures grow, pieces are typically sliced off and transferred to new media (subcultured) to allow for growth or to alter the morphology of the culture. The skill and experience of the tissue culturist are important in judging which pieces to culture and which to discard.

As shoots emerge from a culture, they may be sliced off and rooted with auxin to produce plantlets which, when mature, can be transferred to potting soil for further growth in the greenhouse as normal plants.[1]

Choice of explant

The tissue obtained from the plant to culture is called an explant. Based on work with certain model systems, particularly tobacco, it has often been claimed that a totipotent explant can be grown from any part of the plant. However, this concept has been vitiated in practice. In many species explants of various organs vary in their rates of growth and regeneration, while some do not grow at all. The choice of explant material also determines if the plantlets developed via tissue culture are haploid or diploid. Also the risk of microbial contamination is increased with inappropriate explants. Thus it is very important that an appropriate choice of explant be made prior to tissue culture.

The specific differences in the regeneration potential of different organs and explants have various explanations. The significant factors include differences in the stage of the cells in the cell cycle, the availability of or ability to transport endogenous growth regulators, and the metabolic capabilities of the cells. The most commonly used tissue explants are the meristematic ends of the plants like the stem tip, auxiliary bud tip and root tip. These tissues

have high rates of cell division and either concentrate or produce required growth regulating substances including auxins and cytokinins.

Some explants, like the root tip, are hard to isolate and are contaminated with soil microflora that become problematic during the tissue culture process. Certain soil microflora can form tight associations with the root systems, or even grow within the root. Soil particles bound to roots are difficult to remove without injury to the roots that then allows microbial attack. These associated microflora will generally overgrow the tissue culture medium before there is significant growth of plant tissue.

Aerial (above soil) explants are also rich in undesirable microflora. However, they are more easily removed from the explant by gentle rinsing, and the remainder usually can be killed by surface sterilization. Most of the surface microflora do not form tight associations with the plant tissue. Such associations can usually be found by visual inspection as a mosaic, de-colorization or localized necrosis on the surface of the explant.

An alternative for obtaining uncontaminated explants is to take explants from seedlings which are aseptically grown from surface-sterilized seeds. The hard surface of the seed is less permeable to penetration of harsh surface sterilizing agents, such as hypochlorite, so the acceptable conditions of sterilization used for seeds can be much more stringent than for vegetative tissues.

Tissue cultured plants are clones, if the original mother plant used to produce the first explants is susceptible to a pathogen or environmental condition, the entire crop would be susceptible to the same problem, conversely any positive traits would remain within the line also.

Applications

Plant tissue culture is used widely in plant science; it also has a number of commercial applications. Applications include:

- Micropropagation is widely used in forestry and in floriculture. Micropropagation can also be used to conserve rare or endangered plant species.
- A plant breeder may use tissue culture to screen cells rather than plants for advantageous characters, e.g. herbicide resistance/tolerance.
- Large-scale growth of plant cells in liquid culture in bioreactors for production of valuable compounds, like plant-derived secondary metabolites and recombinant proteins used as biopharmaceuticals [2].
- To cross distantly related species by protoplast fusion and regeneration of the novel hybrid.
- To cross-pollinate distantly related species and then tissue culture the resulting embryo which would otherwise normally die (Embryo Rescue).
- For production of doubled monoploid (dihaploid) plants from haploid cultures to achieve homozygous lines more rapidly in breeding programmes, usually by treatment with colchicine which causes doubling of the chromosome number.
- As a tissue for transformation, followed by either short-term testing of genetic constructs or regeneration of transgenic plants.
- Certain techniques such as meristem tip culture can be used to produce clean plant material from virused stock, such as potatoes and many species of soft fruit.
- micropropagation using meristem and shoot culture to produce large numbers of identical individuals.

Laboratories

Although some growers and nurseries have their own labs for propagating plants by the technique of tissue culture, a number of independent laboratories provide custom propagation services. The Plant Tissue Culture Information Exchange lists many commercial tissue culture labs. Since plant tissue culture is a very labour intensive process, this would be an important factor in determining which plants would be commercially viable to propagate in a laboratory.