

## CYTOPLASMIC INHERITANCE

Inheritance of most of the characters in eukaryotic organisms shows the following characteristic features.

1. The contributions by both male and female parents are equal so that the results from reciprocal crosses are identical.
2. Segregation produces the characteristic 3:1 ratio in the F<sub>2</sub> generation of a monohybrid cross and a typical 9:3:3:1 in dihybrid crosses.

These features of inheritance were first demonstrated by Mendel: consequently, such an inheritance pattern is referred to as Mendelian inheritance. It is universally accepted that genes showing Mendelian inheritance are located in the chromosomes of eukaryotic nuclei. Therefore Mendelian inheritance pattern is regarded as a sufficient evidence for a gene to be located in the chromosomes, such genes are termed as nuclear genes or more commonly simply as genes.

### Non Mendelian Inheritance

But some characters in several organisms do not show Mendelian inheritance or they show a non Mendelian inheritance pattern. In such cases, the following characteristic features are observed.

1. There is consistent difference between the results from reciprocal crosses; generally only the trait from female parent is transmitted.
2. In most cases, there is no segregation in the F<sub>2</sub> and subsequent generations.

Characters showing non Mendelian inheritance may be grouped under three broad categories:

- (1) those related to cellular structures and patterns,
- (2) those produced by intracellular parasites, symbionts and viruses
- (3) those associated with DNA containing cell organelles viz., mitochondria and chloroplasts.

In addition to these cases of non Mendelian inheritance, some characters in several organisms exhibit a Mendelian inheritance pattern but the development of these characters in an individual is markedly affected by the genotype of the maternal parent of the concerned individual; such cases are classified as maternal effects.

The evidence for cytoplasmic inheritance was first presented by Correns in *Mirabilis jalapa* and by Baur in *Pelargonium zonale* in 1908. In case of cytoplasmic inheritance generally the character of only one of the two parents ( usually the female parent) is transmitted to the

progeny. As a result, reciprocal crosses exhibit consistent differences for such characters and there is a lack of segregation in the F<sub>2</sub> and the subsequent generations. Such inheritance is also referred to as extra nuclear inheritance, extrachromosomal inheritance and maternal inheritance.

Genes governing the traits showing cytoplasmic inheritance are located outside the nucleus and in the cytoplasm; hence they are referred to as plasma genes, cytoplasmic genes, cytogenes, extranuclear genes or extra chromosomal genes.

The sum total of all the genes present in the cytoplasm of a cell is known as Plasmon, while all the genes present in a plastid constitute a plastron.

### **Characteristics of cytoplasmic inheritance:**

**1. Reciprocal differences:** Reciprocal crosses show marked differences for the characters governed by plasmagenes. In most cases, plasmagenes from only one parent, generally the female parent are transmitted, this phenomenon is known as uniparental inheritance.

**2. Lack of segregation:** In general, F<sub>2</sub> F<sub>3</sub> and the subsequent generations do not show segregation for a cytoplasmically inherited trait. This is because the F<sub>1</sub> individuals generally receive plasma genes from one parent only.

**3. Irregular segregation in biparental inheritance:** In some cases, plasma genes from both the parents are transmitted to the progeny, this is known as biparental inheritance.

**4. Somatic segregation:** Plasma genes generally show somatic segregation during mitosis, a feature of rare occurrence in the case of nuclear genes.

**5. Association with organelle DNA:** Several plasma genes have been shown to be associated with cp-DNA or mt-DNA.

**6. Nuclear transplantation:** If nuclear transplantation reveals a trait to be governed by the genotype of cytoplasm and not by that of nucleus, cytoplasmic inheritance of the trait is strongly indicated. In nuclear transplantation, nucleus of a cell is removed and replaced by a nucleus of another genotype from a different cell. Generally nuclei of somatic cells are transplanted into zygotes before the first mitotic division is initiated.

**7. Transfer of nuclear genome through back crosses:** The nucleus of a variety or species may be transferred into the cytoplasm of another species or variety through repeated back crossing with the former, which is used as the recurrent male parent. Lines produced in this way are known as alloplasmic lines since they have nuclei and cytoplasms from two different species. A comparison of the various characters of alloplasmic lines with those of the corresponding euplasmic line (lines having nuclei and cytoplasms from the same species) demonstrates cytoplasmic effects, if any on these traits. This technique is time consuming, but

extremely powerful; it has been extensively used to study the cytoplasmic differentiation during evolution.

**8. Mutagenesis:** Some mutagens eg: Ethidium bromide are highly specific mutagens for plasma genes while nuclear genes are not affected by them. Induction of mutation by such agents in a gene indicates it to be a plasma gene.

**9. Lack of chromosomal location:** In many organisms, extensive linkage maps of nuclear genes are available. If a gene is shown to be located in one of these linkage groups, it cannot be a plasma gene. Failure to demonstrate the location of a gene in one of the linkage groups of an organism is indicative of its cytoplasmic location, but this is highly tentative.

**10. Lack of association with a parasite, symbiont or virus:** In many cases, a cytoplasmically inherited character is associated with a parasite, symbiont or virus present in the cytoplasm of the organism. Such cases cannot be regarded as cases of cytoplasmic inheritance. Only those cytoplasmically inherited characters which are not associated with parasites, symbionts or viruses can be regarded as governed by plasma genes.

The known cases of true cytoplasmic inheritance are concerned with either chloroplast or mitochondrial traits and are usually associated with their DNA. Such cases are therefore often referred to as organellar inheritance, plastid inheritance and mitochondrial inheritance.

**Plastid inheritance:**

The inheritance pattern of plastid characters due to plasma genes located in plastid is known as plastid inheritance. Plastid inheritance was first case of cytoplasmic inheritance to be discovered independently by Correns and Baur in 1908. Variegation refers to the presence of white or yellow spots of variable size on the green background of leaves. Variegation may be produced by some environmental factors, some nuclear genes and in some cases, plasma genes.

**Inheritance of plastids in *Mirabilis jalapa*:**

The inheritance of plastids in Four 'O' clock plant *Mirabilis jalapa* was first described by Correns (1908). In *M. Jalapa*, some of the branches may have normal green leaves, while in the same plant, some other branches may have only pale green or white leaves and still others may have variegated leaves. Flowers on branches with normal green leaves produce seeds that grow into plants with normal green leaves irrespective of whether they are pollinated by pollen from branches with normal green variegated or pale green leaves.

**Progeny of a variegated four 'O' clock plant**

|  |   |   |
|--|---|---|
| Type of branch from which flowers are chosen for | Type of branch from which pollen was obtained | Type of leaf in the progeny grown from seed |
|--|---|---|

|                  |                                     |                                      |
|------------------|-------------------------------------|--------------------------------------|
| pollination      |                                     |                                      |
| Green            | Green,<br>variegated,<br>pale green | Only green<br>“<br>“                 |
| Variegated Green | Green<br>Variegated<br>Pale green   | Green, variegated, or pale<br>“<br>“ |
| Pale green       | Green<br>Variegated<br>Pale green   | Green, pale green<br>“<br>“          |

It is clear that variegation is determined by agencies transmitted through the female and that it is not influenced by the type of pollen used. These agencies are the chloroplast. They are capable of self-duplication and are transmitted from generation to generation through the cytoplasm of the egg. Seeds borne on a green branch have three gene only green plastids, seeds borne on a pale green branch have three gene only pale green plastids and seeds borne on a variegated branch have green or pale green or a mixture of the two types of plastids.

Variegation is thus a heredity character determined by stable, self-duplicating, extra nuclear particles called plastids. Neither the nucleus of the female gamete nor the male gamete is involved in the control of this type of heredity character.

### **Maternal inheritance by 'iojap' gene in maize**

The egg regularly contributes much more cytoplasm to the next generation than does the sperm. It should therefore be expected that in cases of cytoplasmic inheritance, differences between reciprocal crosses would result.

Rhoades (1946) identified the 'iojap' gene (ijj) in maize located in chromosome VII controlling plastid inheritance in the plant. The gene 'lj' is responsible for the normal green colour of the plant.

When normal green plants with ljlj are used as female and pollinated by pollen from stripped with ijij, F1 plants are wholly green.

1.           Green                          x                          stripped

                  Ij Ij   ij ij  
                   F1   Ijij                          Green

                                  F2 3 green : 1 lojap.

When striped with Ijij are pollinated by pollen from the normal green plants with Ij Ij the F1 plants, all of which have the same genotype. Ijij are of 3 different phenotypes.

|               |      |                                 |   |
|---------------|------|---------------------------------|---|
| Stripped Ijij | X    | Green Ij Ij                     |   |
| □□            |      | (Iojap)                         | □ |
| F1            | Ijij | Green, striped or white (Iojap) |   |

When plants with same genotype Ijij have different phenotype viz., normal green, striped or white, the differences can be attributed only the differences in plastids.

**Cytoplasmic male sterility in Maize**

In case of male sterility in maize, pollen grains of such male sterile are aborted. This male sterility is transmitted only through the female and never by the pollen. When all of the chromosomes of the male sterile line were replaced with chromosomes of normal plants, the line still remained male sterile, showing thereby that male sterility is controlled by some agency in the cytoplasm. It was later recognized that cytoplasmic male sterility in maize results from alterations in the heredity units in the mitochondria (mitochondrial DNA).

**Inheritance of Kappa particles in Paramecium**

In *Paramecium aurelia*, two strains of individuals have been reported. One is called as ‘Killer’ which secretes a toxic substance ‘paramecin’ and the other strain is known as ‘sensitive’ and is killed if it comes in contact with the ‘paramecin’. In the cytoplasm of the killer strain the kappa particles (cytoplasmic – DNA) are present, kappa particles are absent in sensitive strains. The transmission of kappa particles is through cytoplasm but maintenance of kappa particles and production of paramecin is controlled by ‘k’ we assume that the killer strains carry dominant allele ‘kk’; and that sensitive ‘kk’. Conjugation Rare conjugation (cytoplasmic exchange)

On conjugation, conjugants exchange their nuclear material so that ex-conjugants ‘kk’ resulted from conjugants ‘kk’ and ‘kk’ when conjugation is for normal time, then only nuclear material is exchanged and therefore killer will produce killer daughters and sensitive will produce sensitive daughters. But if the conjugation is in longer period, there will be exchange of cytoplasm resulting in the inheritance of kappa particles by both the ex-conjugants so that all the daughter paramecia produced are killers because all inherit the kappa particles through the

mixing of cytoplasm. Therefore this trait is transmitted through cytoplasmic heredity. The trait is only stable in killer strains.

### **Inheritance through mitochondria**

Mitochondria can self-replicate and represent another genetic system in the cell. Of course, the amount of mitochondrial DNA is so small, representing less than 1% of the nuclear DNA in mammalian cells and it can code for a part of the protein in the mitochondria. The synthesis of the cytochrome found in mitochondria for example, is known to be present in minute amount in cytoplasm under the control of nuclear genes. Therefore, it is suggested that both mitochondria and chloroplast seem to have a semiautonomous existence and their DNA forms the basis for genetic systems separate from that in the nucleus.

### **Episome in Bacteria**

Some hereditary particles have been found to exist in two states, either in an autonomous state in the cytoplasm, where they replicate independently, of the chromosomes, or in an integrated state incorporated into the chromosome. Particles with such properties are known as episomes and include such things as the sex factor. The episomes are apparently not essential to the life of the bacteria, because they may or may not be present. If they are absent, they can be acquired only from an external source. In bacteria, *E. coli*, sex is determined by the presence or absence of the sex factor (F). Male bacterial cells (donor) have the sex factor and this factor is responsible for the transfer of DNA from male to female bacterial cells (Recipient). This sex factor is the cytoplasmic particle.

### **Significance of Cytoplasmic Inheritance**

1. Development of cytoplasmic male sterility several crop plants like maize, Pearl millet, sorghum, cotton etc.
2. Role of mitochondria in the manifestation of heterosis.
3. Mutation of chloroplast DNA and mitochondrial DNA leads to generation of new variation