Faculty Name: Dr. Kumari Sushma Saroj

Department: Zoology

College: Dr. L. K. V. D College, Tajpur, Samastipur

Class: B.Sc. Part –II (Hons.)

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Topic: Cytoplasmic Inheritance or non-chromosomal inheritance

Cytoplasmic Inheritance or non-chromosomal inheritance

Extra-chromosomal inheritance, **extra-nuclear inheritance** and **maternal inheritance** are all synonyms. All these terms can be defined as the inheritance of characteristics of only one of the two parents, usually the female parent to the progeny.

The reciprocal crosses show consistent differences as well as there is a lack of segregation in F_2 and subsequent generations.

The genes controlling cytoplasmic inheritance are present outside the nucleus and, in the cytoplasm, they are known as **plasma** genes, **cytoplasmic** genes, **extra nuclear** genes or **extra chromosomal** genes.

The sum total of the genes present in cytoplasm of a cell is known as **Plasmon**. All the genes present in a plastid are known as **plastoms.** Similarly, all the genes present in a mitochondrion are known as **chondrioms.**

The genes present in plastid and in mitochondrion are located in their own DNAs and are known as **cp DNA** and **mt DNA**, respectively. These DNAs are collectively termed **organelle DNA**.

Characteristics and Detection of Cytoplasmic Inheritance:

They show the following characteristic features:

i. Hereditary traits which are transmitted by cytoplasm do not show Mendelian segregation in crosses and in reciprocal crosses with respect to a particular set of characteristics controlled by a set of cytoplasmic genes produce dissimilar hybrids.

ii. Most of the recorded cytoplasmically inherited characteristics would follow the maternal line, i.e., uniparental mode of transmission.

In higher plants and animals, ovum or egg cell is comparatively large and contains large amount of cytoplasm. But male gametes or sperms have very little amount of cytoplasm. So, under this situation, most of cytoplasmic factors are transmitted to the progeny through the ovum of mother. It is known as **maternal** inheritance or **trans-ovarian** transmission.

In this mode of transmission, all the offspring's of the parents have maternal condition and only female progeny can transmit the cytoplasmic characteristics to the succeeding generations. Hence the reciprocal crosses yield different or non-Mendelian results.

Examples of extra nuclear inheritance in eukaryotes :

Maternal Inheritance:

Maternal inheritance means the inheritance controlled by extra-chromosomal, i.e., cytoplasmic, factors that are transmitted to the succeeding generation through the egg of female organism.

They following features are:

i. reciprocal differences in F_1

ii. Which in most cases disappears in F_2

iii. A smaller variation in F_2 as compared to that in F_3.

Maternal inheritance mainly two kinds:

I. Some treatments (chemical poison, heat shock etc.) are applied to the female parent; it may affect the egg's cytoplasm. As a result subsequent offspring's are modified in some way. Effects of this kind are called Dauer-modifications or persisting modifications.

It is observed that when protozoa are treated experimentally with chemical poisons or heat shocks, the treatments induce several morphological abnormalities in them. Such abnormalities go on decreasing generation after generation and, eventually, disappear completely through cell division if the treatments are removed.

II. Other kinds of maternal inheritance are also known which do not depend upon the repeated application of an external stimulus to the cytoplasm. In this case, maternal inheritance is truly controlled by independent cytoplasmic genes.

Maternal effects reflect the influence of the mother's gene on developing tissues. Many important characteristics of both animal and plants show maternal effects of which some examples are:

Coiling of Snail Shells (Limnaea Peregra):

One of the earliest and classical examples of a maternal effect is that of the direction of coiling in shells of the water snail Limnaea peregra. In this snail, the shell is spirally coiled.

Usually the direction of coiling of the shell is clockwise if viewed from the top of the shell. This type of coiling is called **dextral**. However, in some snails the coiling of shell is anticlockwise. This type of coiling is **sinistral.**

The direction of shell coiling of both types of snail is governed by genotype of the female parent and not by their own genotype. Further investigation suggests that coiling depends upon the early clearage in the zygote.

If the mitotic spindle is tilted to left of the median line of zygote, the successive cleavages will produce a spiral to left (sinistral) and if the orientation of spindle is tilted to the right of the median line of zygote, the successive cleavages will produce a spiral to right (dextral).

The spindle orientation is controlled by the genotype of oocyte from which the egg develops.

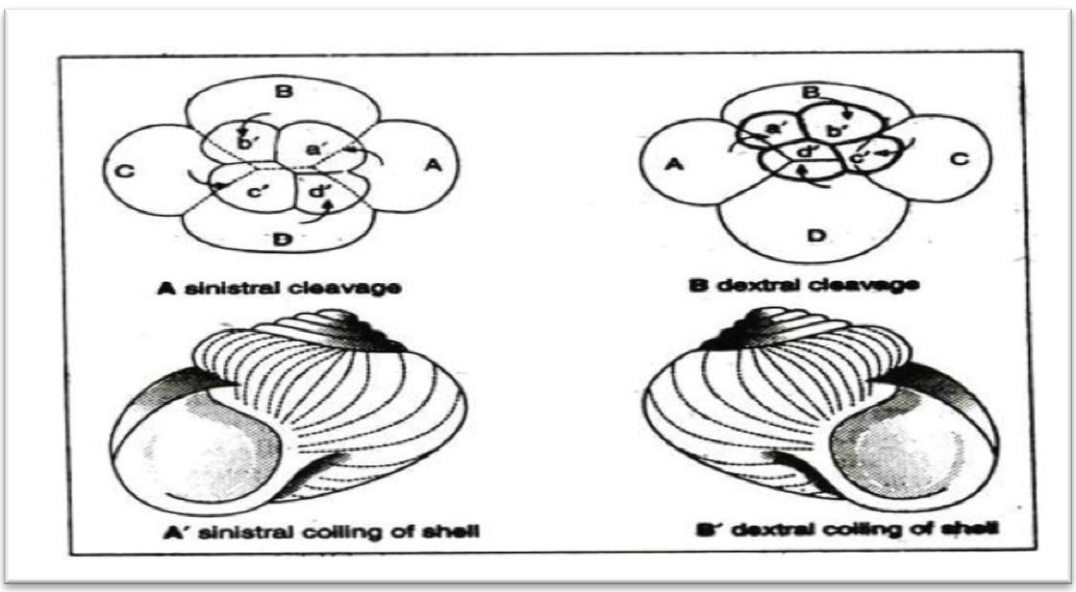

Fig. A. Sinistral coiling of shell and B. Dextral coiling of shell

In a cross between dextral (female) snail and sinistral (male), (follow the left side coloum of the) all the Fi progeny have dextral coils like their mother and also indicates that dextral character (RR) is dominant over sinistral coiling (rr).

However, in the F_1 x F_1 cross (i.e., inbreeding or self fertilization) all the F_2 snails are also dextral. The F_3 progeny from F_2 individuals with the genotype RR and R_r will show dextral coiling while those from rr F_2 individual will exhibit sinistral coiling of their shell; this produces the typical 3:1 ratio in F_3 generation.

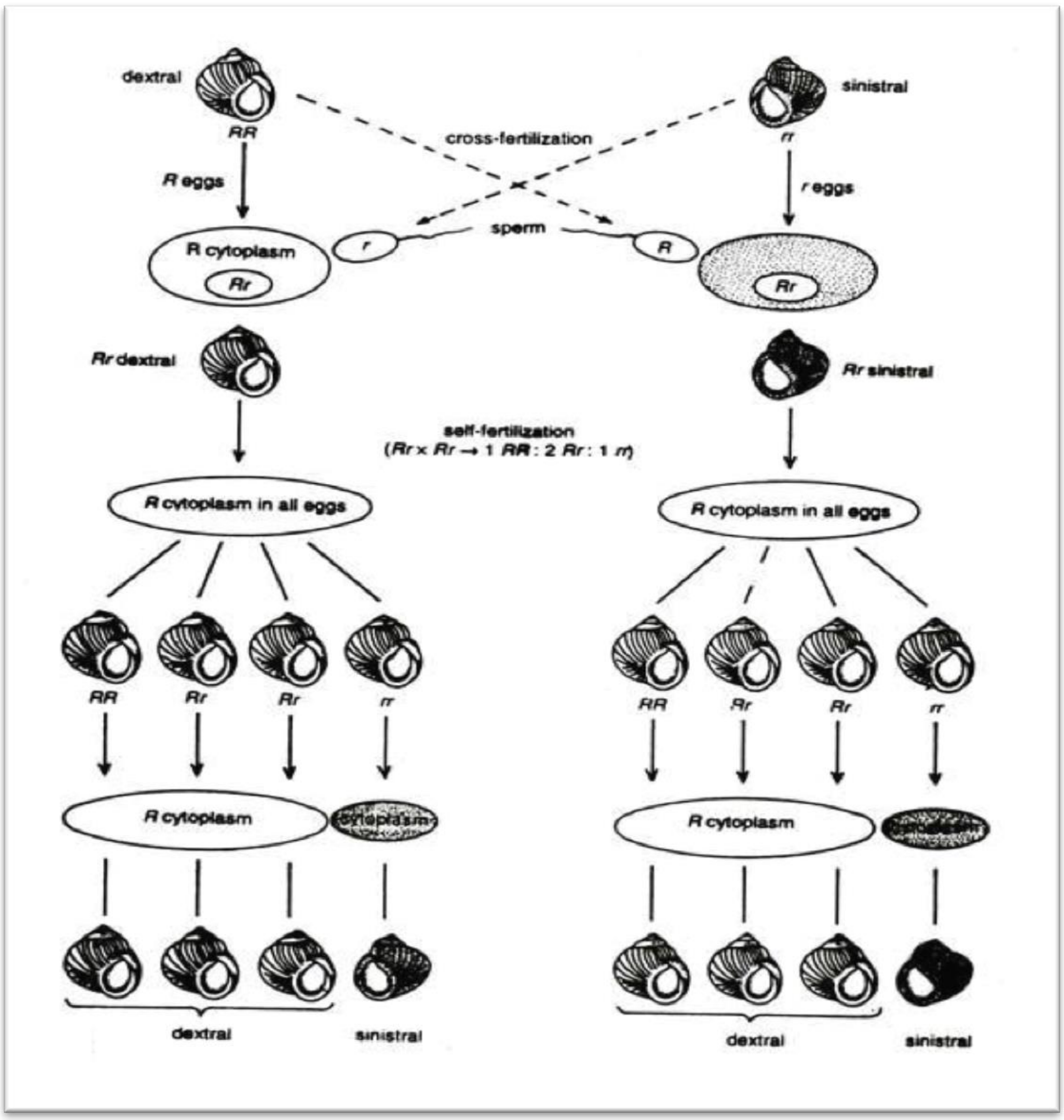

Fig. Maternal effect in direction of coiling of the shell in Limnaea Peregra.

In reciprocal cross (right side column of the) between dextral (male) and sinistral (female), all the F_x progeny have sinistral coiling (Rr) instead of dextral coiling. In this case, F_1 x F_1 cross, all the F_2 snails are, again, dextral. This F_3 progenies from F_2 also exhibit the typical monohybrid ratio of 3:1.

Thus the features of inheritance of coiling of Limnaea shells may be summarised as:

i. F_1s from reciprocal crosses show differences in coiling pattern.

ii. No segregation in F_2.

iii. Appearance of the typical 3: 1 ratio in F_3 in place of F_2.

The 3:1 ratio, although in F_3, clearly indicates that coiling of shell is governed by a single nuclear gene. But the segregation of this nuclear gene is apparently delayed by one generation and is visible in F_3 instead of F_2 as in all other cases of Mendelian inheritance.

This is because the direction of coiling in this snail is primarily determined by some substances already present in the cytoplasm or ooplasm of the egg cell. Obviously these substances are produced by the female parent. As a result the offspring would produce the phenotype (in F_1) of the maternal parent since its nuclear gene product is possibly active after one generation later and shows delayed segregation in F_3.

Maternal Inheritance in Drosophila:

i. Abnormal growth in the head region of Drosophila melanogaster was produced sporadically in a sample from a wild population collected at Acahuizotla, Mexico. Development of abnormal growth in the head region is called Tumorous head (Tu

– h). Tu – h is governed by two major genes. But the frequency of tumour development in progeny is markedly influenced by the maternal effect.

When a cross is made between a normal female fly and a male fly with head tumour, less than 1% of the progeny exhibit head tumour. In contrast, when a reciprocal cross is made between a female having head tumour and a normal male, about 30% of the progeny show tumour development.

ii. In Drosophila, fertility and survival are occasionally influenced by maternal effect. A recessive nuclear gene, grandchild-less, affects the fertility of progeny in Drosophila subobscura. In this fly a female homozygous for which is fertile but all her offspring's are sterile.

The reason of this effect arises from cytoplasmic dependent pathway for the development of many organs, the egg cytoplasm formed by a female fly is not uniform and various parts of the egg appear to be specifically assigned for the formation of different tissues.

Thus the fate of Drosophila germ cells to produce either various or testes are determined early in development.

A daughterless (da) gene in Drosophila causes death of all XX zygotes derived from eggs of da da females. It is reported that the cytoplasm of eggs of da da females affects the two X-chromosomes and does not inhibit the development of the female phenotype.

It should be noted that the action of da is determined by the genotype of the female producing egg and not by the genotype of the egg cells themselves. It is also reported that interaction of da gene product is evident if the zygote is XX but there is no such action affecting the survival of XY zygote.

Plastid Inheritance in Mirabilis:

Plastid inheritance means the inheritance of plastid characteristics due to plasma genes located in plastids. Plastid inheritance was first described by C. Corens (1908) in the four o'clock plant, Mirabilis Jalapa.

Leaves of Mirabilis Jalapa may be green, white or variegated and some branches may have only green, only white or only variegated leaves. Variegation means the presence of white or yellow spots of variable size on the green background of leaves.

Thus it forms the mosaic pattern of coloration on a leaf. Due to certain inheritable defects chloroplast of all cells or some cells of leaf often are unable to synthesize the chlorophyll pigments.

Such cells remain non- green and form white or yellow coloured leaf, or white or yellow patches, interspersed with areas containing normal green cells with healthy chloroplasts.

Variegation may be produced by:

(a) Some environmental factors,

(b) Some nuclear genes,

(c) Plasma-genes in some cases.

Since the first and second causes of leaf variegation do not concern cytoplasmic inheritance, the inheritance of variegation due to plasma-genes will be discussed in this article.

Correns made reciprocal crosses in all combinations among the flowers produced on these three types of branches.

Table: Plastid inheritance in variegated four O'clock Plant

Leaf phenotype of branch used as male plant	Leaf phenotype of branch used as female plant	Leaf phenotype of the progeny (F_1)
Green	Green	Green
	White or yellow	White or Colourless
	Variegated	Green, White or Colourless, Variegated
White or Colourless	Green	Green
	White or Colourless	White or Colourless
	Variegated	Green, White or Colourless, Variegated
Variegated	Green	Green
	White or Colourless	White or Colourless
	Variegated	Green, White or Colourless, Variegated

The results obtained from various crosses of leaf phenotypes of Mirabilis jalapa, as shown in Table, clearly indicates that leaf phenotype of the progeny is the same as that of the female parent. The phenotype of male parent did not contribute anything to the progeny.

This phenomenon is referred to as uniparental transmission. Again, the results of the crosses of Mirabilis Jalapa cannot be explained by sex-linkage.

The inheritance of different leaf colours in Mirabilis Jalapa might be explained if the plastids are somehow autonomous and are never transmitted through male parent.

For an organelle to be genetically autonomous, it must be provided with its own genetic determinants that are responsible for its phenotype.

Since the bulk amount of cytoplasm containing many plastids is contributed by the egg and the male gametes contribute negligible amount of cytoplasm, therefore plastids present in the cytoplasm of egg is responsible for the appearance of maternal colour in the offspring and the failure of male plant to transmit its colour to offspring is reasonable.

In the offspring from variegated female parents, green, white and variegated progeny are recovered in variable proportions. The variegated parent produces three kinds of egg- some with colourless plastids, some contains only green plastids, and some are with both chloroplasts and leucoplasts.

As a result, zygotes derived from these three types of egg cells will develop into green, white and variegated offspring's, respectively.

Extra-Nuclear Inheritance by Mitochondria of Yeast:

Yeast, Saccharomyces cerevisiae, are unicellular ascomycetes fungi. In these fungi, sexual reproduction takes place by the fusion of two somatic cells to form a diploid zygote nucleus.

Next follows two successive nuclear divisions forming four haploid daughter nuclei, all of which take part in ascospore formation. Now the mother cell, i.e., zygote cell, is called **ascus**.The diploid zygote can also be grown vegetatively as a diploid strain that will later sporulate.

Respiration of yeast cell takes place both aerobically and anaerobically (fermentation). Certain mutant yeast cells are unable to utilise oxygen and are comparatively small- sized and slow growing producing small colonies on agar medium. These small colonies forming mutant strains of yeast are known as petites.

In petite strains, the necessary components (cytochrome b, c_1) and some enzymes (cytochrome oxidase a, a_3) for aerobic terminal respiration activity are absent. But these components are present in the cell of normal strain where they are associated with the inner membrane of mitochondria.

Petite strain can be maintained indefinitely in the vegetative state and can be mated with normal yeast cells. When such mating are carried out, three petite varieties can be classified.