Extra nuclear inheritance

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Extra nuclear inheritance

- It is universally accepted that genes showing **Mendlian inheritance** are located in chromosomes of eukaryotic nuclei. Hence, this form of inheritance pattern is sufficient evidence for a gene to be located on chromosomes.
- Such genes are called nuclear genes.
- A distinct subset of the genome is found in the mitochondria, and, in plants, also in the chloroplasts. These subsets are inherited independently of the nuclear genome.
- While working with *Mirabilis jalapa* Carl Correns (1908) observed that leaf color was dependent only on the genotype of the maternal parent. He determined that the trait was transmitted through a character present in the cytoplasm of the ovule.
- Later research by Ruth Sager and others identified DNA present in chloroplasts as being responsible for the unusual inheritance pattern observed.

Nature of organellar inheritance

- Peculiar feature of organelle genes is that they are present in large number of copies present in a cell.
- They DNA is folded within the nucleoid but does not have the type of histone-associated coiling shown by nuclear chromosomes.
- Most genes concern the chemical reactions taking place within the organelle itself: photosynthesis in chloroplasts and oxidative phosphorylation in mitochondria.

- According to the **endosymbiont theory**, mitochondria and chloroplasts were once free living organisms that were each taken up by a eukaryotic cell. Over time, mitochondria and chloroplasts formed a symbiotic relationship with their eukaryotic hosts. Although the transfer of a number of genes from these organelles to the nucleus prevents them from living independently, each still possesses genetic material in the form of double stranded DNA.
- It is the transmission of this organellar DNA that is responsible for the phenomenon of extranuclear inheritance.
- Both chloroplasts and mitochondria are present in the cytoplasm of maternal gametes only.
- Paternal gametes (sperm for example) do not have cytoplasmic mitochondria. Thus, the phenotype of traits linked to genes found in either chloroplasts or mitochondria are determined exclusively by the maternal parent.

Cytoplasmic/extranuclear/extrachromosomal/maternal inheritance (Non mendelian inheritance)

- The sum total of all genes present in the cytoplasm of a cell or an individual is known as *plasmon*, while all the genes in a plastic constitute a *plastome*, by analogy all genes present in mitochondria constitute a *chondriome*.
- All the available evidence indicates that plasmagenes are located in DNA present in mitochrondria (mtDNA) or chloroplast (cpDNA).
- Characteristic features of this type of inheritance are:
  1. Reciprocal differences
  2. Lack of segregation
  3. Irregular separation in biparental inheritance
  4. Somatic segregation
  5. Association with organelle DNA
  6. Mutagenesis
  7. Lack of association with a parasite, symbiont or virus.

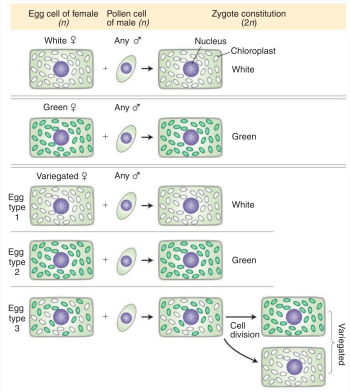

Figure 1: The results of the *Mirabilis jalapa* crosses can be explained by autonomous chloroplast inheritance. The large, dark spheres represent nuclei. The smaller bodies represent chloroplasts, either green or white. Each egg cell is assumed to contain many chloroplasts, and each pollen cell is assumed to contain no chloroplasts. The first two crosses exhibit strict maternal inheritance. If, however, the maternal branch is variegated, three types of zygotes can result, depending on whether the egg cell contains only white, only green, or both green and white chloroplasts. In the last case, the resulting zygote can produce both green and white tissue, and so a variegated plant results.

Figure 2: Many cases of white leaves are caused by mutations in chloroplast genes that control the production and deposition of the green pigment chlorophyll.

- It is the incapacity of flowering plants to produce or release functional pollens.
- Non functional pollen is caused by genetic or cytoplasmic factors.
- This phenomena is exploited in producing hybrids.

Genetic ♂sterility

- While CMS is controlled by an extranuclear genome, nuclear genes may have the capability to restore fertility.
- Genetic (nuclear, genic) ♂sterility is widespread in plants. The gene for sterility has been found in species including barley, cotton, soybean, tomato, potato, and lima bean.
- It is believed that nearly all diploid and polyploidy plant species have at least one ♂sterility locus.
- May be manifested as pollen abortion (pistillody) or abnormal anther development.
- Genetic ♂sterility is often conditioned by a single recessive nuclear gene, *ms*, the dominant allele, *Ms*, conditioning normal anther and pollen development.
- In alfalfa, however, two independently inherited genes have been reported
- The expression of the gene may vary with the environment. But to be useful, the system must be stable

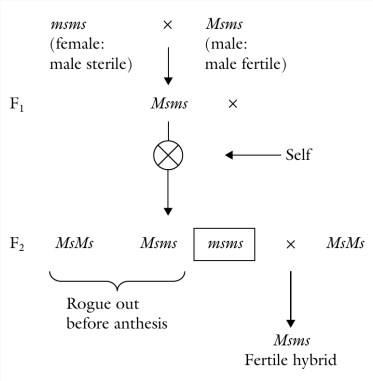

Figure 3: Genetic ♂sterility as used in practical breeding

Cytoplasmic ♂sterility

- Sometimes, ♂sterility is controlled by the cytoplasm (mitochondrial gene) but may be influenced by nuclear genes.
- A cytoplasm without sterility genes is described as normal (N) cytoplasm, while a cytoplasm that causes ♂sterility is called a sterile (*s*) cytoplasm or said to have cytoplasmic ♂sterility (CMS).
- Transmitted through the egg only (maternal factor).
- Has been found in species including corn, sorghum, sugar beet, carrot, and flax.
- The condition has been induced in species such as sorghum by transferring nuclear chromosomes into a foreign cytoplasm.
- Has real advantages in breeding ornamental species because all the offspring is ♂sterile, hence allowing them to remain fruitless.

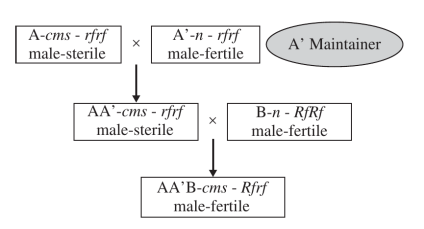

Figure 4: Cytoplasmic ♂sterility as applied in plant breeding (N, normal cytoplasm; s, sterile cytoplasm).

- Hybrid seed production using CMS requires three types of genotypes;
- ♂fertile lines (called *B* lines; maintained by selfing) with no cytoplasmic ♂sterility genes and which are homozygous for a dominant restorer gene (i.e. normal (*n*) cytoplasm, *RfRf*);
    - cytoplasmic sterile ♀lines with ♂sterile cytoplasm but with no restorer genes (called *A* lines; maintained by crossing with isogeneic cytoplasmic ♂fertile line);
    - '♂-fertile' ♀lines (called *A'* lines or *A'* maintainer lines; maintained by selfing) with normal cytoplasm and no restorer genes.

- Cytoplasmic ♂sterility may be modified by the presence of fertility-restoring genes in the nucleus.
- CMS is rendered ineffective when the dominant allele for the fertility-restoring gene (*Rf*) occurs, making the anthers able to produce normal pollen.
- CMS is transmitted only through the egg, but fertility can be restored by *Rf* genes in the nucleus.
- Three kinds of progeny are possible following a cross, depending on the genotype of the pollen source.
- The resulting progenies assume that the fertility gene will be responsible for fertility restoration.

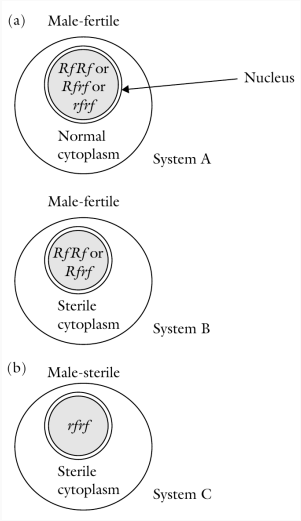

Figure 5: The three systems of cytoplasmic genetic ♂sterility. The three factors involved in CMS are the normal cytoplasm (N), the ♂sterile cytoplasm (S), and the fertility restorer (Rf, rf).

Features of organellar genomes

- They are circular molecules of DNA. In few exceptional case, generally in lower eukaryotes, mtDNA is linear.
- They are present in multiple copies in each organelle. In higher plants, cpDNA is present in 20-40 copies per chloroplast. Yeast cells have ~4 genomes per mitochondrion.
- They encode all the RNA species and some of the proteins required for organelle function.
- They are transcribed and translated within the organelles.
- In case of biparental inheritance, recombination does takes place between organellar genomes.
- Organelle DNA is replicated by a different DNA polymerase from that of nucleus.
- The DNA repair systems and other events that impinge on the fidelity of DNA sequences are different in organelles from those in nuclei.
- Accumulation of mutation is much faster in mtDNA than in nuclear genome in case of mammals, while in plants the reverse is the case.

Genes in organelles

- *Poky* phenotype mutants in *Neurospora* is caused by a mutation of a ribosomal RNA gene in mtDNA.

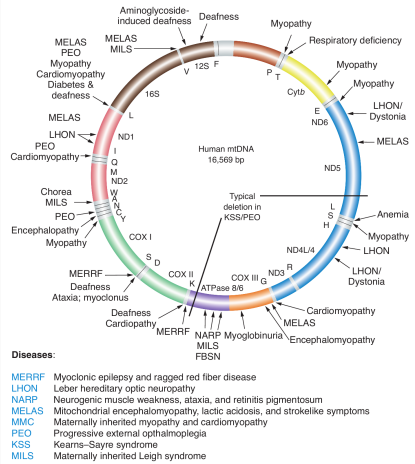

Figure 6: Map of human mtDNA shows loci of mutations leading to cytopathies

Maternal effects

- The development of some characters in several organisms is either goverened or markedly influenced by the genotype of the ♀parent; this is known as **maternal effect**.
- Such characters are governed by **nuclear genes**. But due to the maternal effect, they show the following features:
  1. Reciprocal differences in F_1
  2. Which, in most cases, disappear in F_2
  3. Considerably smaller variation in F_2 as compared to that in F_3.
- Examples of maternal inheritance:
  1. Coiling in Limnaea: The direction of shell coiling in an individual is governed by the genotype of its ♀parent and not by its own genotype. As a result, reciprocal crosses show differences in coiling in F_1 and there is no phenotypic segrgation in F_2. The phenotypic effect of segregation is observable in F_3 only.
  2. Some economically important traits as seed size, protein content in seeds, plant height, etc. show marked difference for F_1 progeny from reciprocal crosses.

	DD(Dextral ♀) × *dd*(Sinistral ♂)	
	↓	
F_1	*Dd*(Dextral)	
	↓	
	Dd × *Dd*	
	↓	
F_2	1*DD*	(Dextral)
	2*Dd*	(Dextral)
	1*dd*	(Dextral)
F_3	*DD*	(Dextral)
	1*DD*	(Dextral)
	2*Dd*	(Dextral)
	1*dd*	(Dextral)
	dd	(Sinistral)

	dd(Sinistral ♀) × *DD*(Dextral ♂)
	↓
F_1	*Dd*(Sinistral)
	↓
	Dd × *Dd*

- What differences are seen in reciprocal cross ?

- All embryos develop inside maternal tissue
- Some maternal genes affect embryo development
- Maternal effects can be genetic or environmental
- Can result from expression of genes in maternal tissue
- Can result from inheritance of maternal cytoplasm (and organelles)
- Can result from maternal environment (not genetic)