# Extra-chromosomal inheritance

**Contents:** Definition**;** Chromosomal (nuclear) *versus* cytoplasmic inheritance**;** Types of extra-chromosomal inheritance**;** Extra-chromosomal inheritance in *Paramecium*: Strains of *Paramecium;* Killer trait in *Paramecium*; Properties of *kappa* particles**;** Extra-chromosomal inheritance in *Paramecium***;** Extra-chromosomal inheritance in *Drosophila***;** Suggested reading.

## Definition

Inheritance of certain traits of organisms that are controlled by the genetic materials present in the cytoplasm is known as cytoplasmic inheritance, which is also referred to as extra-chromosomal or non- nuclear inheritance. The genetic materials present in the cytoplasm are called ‘plasmagenes’.

## Chromosomal (nuclear) genes *versus* plasmagenes

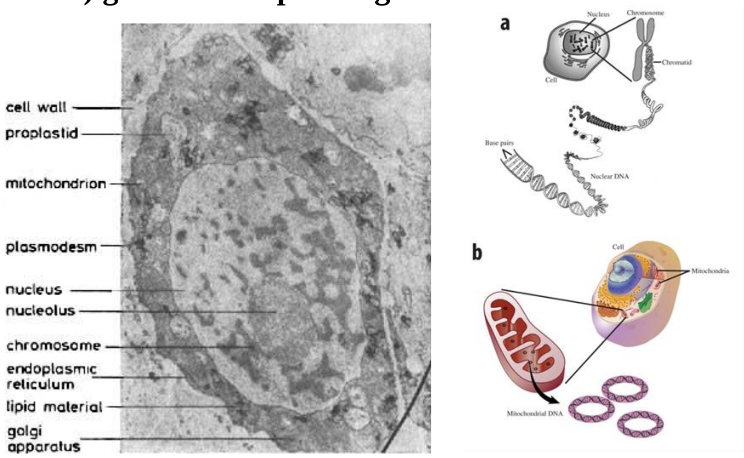


**Fig 12.1** Chromosomal (or nuclear) genes= DNA and RNA in the chromosomes; Plasmagenes= mitochondrial DNA (mtDNA) and chloroplast DNA (cpDNA) in the cytoplasm

## Differences between chromosomal (nuclear) and cytoplasmic inheritance

| Chromosomal inheritance | Cytoplasmic inheritance |
|---|---|
| 1. Traits are controlled by nuclear genes present in the nucleus. | Traits are controlled by plasmagenes present in the cytoplasm. |
| 2. Except for sex-linked traits, father and mother play equal role. | The role of mother is more important than that of father, because ova (eggs) contain more cytoplasm than that of spermatozoa (sperms). |
| 3. Reciprocal crosses between males and females produce Mendelian ratios. | Reciprocal crosses between males and females produce non-Mendelian ratios. |
| 4. Traits are transmitted through chromosomes. | Traits are transmitted through cytoplasm. |

**Types of extra-chromosomal inheritance**

There are three major types of extra-chromosomal inheritance as follows:

1. **Infectious particles:** Killer trait in *Paramecium aurelia*, $CO_2$ sensitivity in *Drosophila melanogaster*, milk factor in *Mus musculus* etc.
2. **Cell organelles:** Plastid (chloroplast) transmission in 4 o'clock plant, *Mirabilis jalapa.*
3. **Maternal factors:** Shell coiling in land snail, *Limnaea peregra*, eye colour variation in flour moth, *Ephestia cautella* etc.

**Infectious particles other than kappa (ϰ):**

(a) μ (mu) particles: Produce mate killer and mate sensitive strains;
(b) π (pi) particles: Mutant forms of kappa and do not produce poisonous substance;
(c) λ (lambda) particles: Cause lysis or disintegration of sensitive strains;
(d) σ (Sigma) particles: Cause unconsciousness to the sensitive strains;
(e) DNA viruses: Cause breast cancer (mammary carcinomata).

**Extra-chromosomal inheritance in Paramecium**

Extra-chromosomal or cytoplasmic inheritance in *Paramecium* was studied extensively by the American scientist T. M. Sonneborn and his colleagues at the University of Indiana, USA. They studied the strains of *Paramecium*, their properties and the mode of transmission of the extra-chromosomal substance the then called *kappa* particles in this ciliate protozoan.

**Fig 12.2** T. M. Sonneborn (1965) who contributed to our understanding of the extra-chromosomal inheritance in *Paramecium*

**Strains of *Paramecium***

There are two strains of *Paramecium*, characteristics of which are as follows:

1. The *killer* strain: Cytoplasm contains toxic and infectious particles called *kappa*, which produces a water soluble chemical (paramecin); cytoplasm is opaque and particulate; bears nuclear dominant genotypes *KK* (homozygous) or *Kk* (heterozygous).

2. The *sensitive* strain: Absence of *kappa* particles, so, cytoplasm does not contain any toxic or infectious particles and hence unable to produce paramecin; cytoplasm is transparent and non-particulate; bears nuclear recessive genotype *kk.*

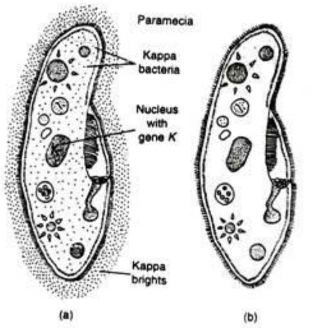


Fig. 22.8: (a) Killer strain Paramoecium with Kappa particles and nucleus with gene K; (b) Sensitive Paramoecium with no Kappa particles and nucleus with gene k.

**Fig 12.3** The *killer* (left) and *sensitive* strains of *Paramecium*

**Killer trait in *Paramecium***

- Certain *Paramecium* secretes toxic substance (paramecin) into the medium around them, which kill other paramecia;
- This killer trait is caused by kappa particles, which are symbiotic bacteria *Caedobacter taeniospiralis* (meaning killer bacterium with spiral ribbon);
- The kappa particles are found in natural populations of *Paramecium aurelia*.

**Properties of *kappa* particles**

1. Each *kappa* particle is about 0.2μ in size.
2. It undergoes cell division, *i.e*. it can multiply.
3. Killer strains may harbour up to 1600 *kappa* particles.
4. To be a killer, at least 400 *kappa* particles need to be present in the cytoplasm.
5. EM studies revealed that *kappa* particles are actually symbiotic bacterium, *Caedobacter taeniospiralis.*
6. *Kappa* particles can be destroyed by the physical and chemical mutagens like low temperature, X-rays, nitrogen mustard etc.

**Extra-chromosomal inheritance in *Paramecium***

Two types of reproduction take place in *Paramecium* (Fig. 12.4). These are:

(1) Asexual reproduction by binary fission; and
(2) Sexual reproduction by conjugation.

Conjugation is again of two types:

(1) Normal conjugation: Usual method; exchange of nuclear materials only; No cytoplasmic exchange takes place; so, exconjugant killer produces 50% killer and 50% sensitive; but exconjugant sensitive produces sensitives only. So, transmission of kappa particles through the killer strain does not take place.

(2) Rare conjugation: Unusual method; a cytoplasmic bridge is formed; exchange of both nuclear and cytoplasmic materials takes place; exconjugant killer produces 50% killer and 50% sensitive, whereas exconjugant sensitive produces 50% sensitive and 50% killer. That means, transmission of kappa particles through the killer strain takes place only through the rare conjugation.

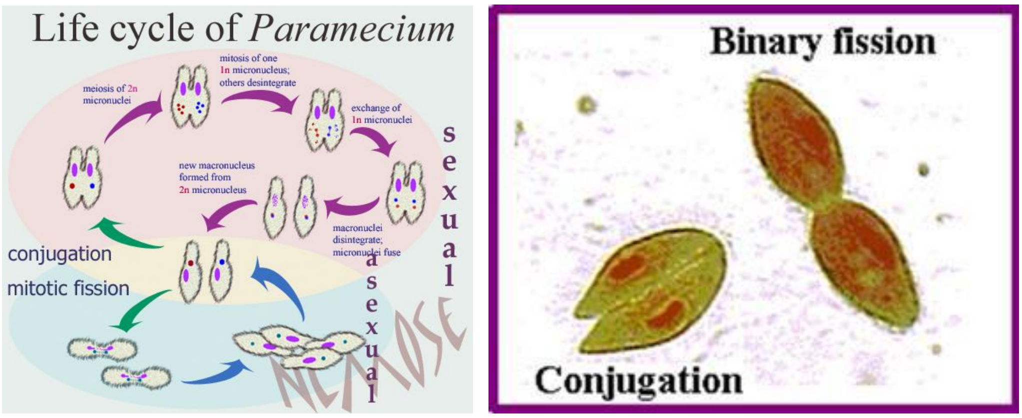


**Fig 12.4** Reproduction in *Paramecium* by conjugation and binary fission

**Normal and rare conjugations in *Paramecium***

In normal conjugations, when a killer strain conjugates with a sensitive strain, the resulting exconjugants are similar to their parents, both killer and sensitive, because the conjugation takes place for a brief period of time and the exchange of cytoplasmic materials does not occur. Then the exconjugants further divide asexually by binary fission. Here the sensitive strain produces only sensitives, but the killer strain produces both killer and sensitive strains because of the further dilution of kappa particles (Fig. 12.5 left).

In rare conjugations, however, when a killer strain conjugates with a sensitive strain, the resulting exconjugants are both killers, because the conjugation takes place for a long period of time and the exchange of cytoplasmic materials including kappa particles occurs. Finally, the exconjugants further divide asexually by binary fission, when the killer strain produces both killer and sensitive strains (Fig. 12.5 right).

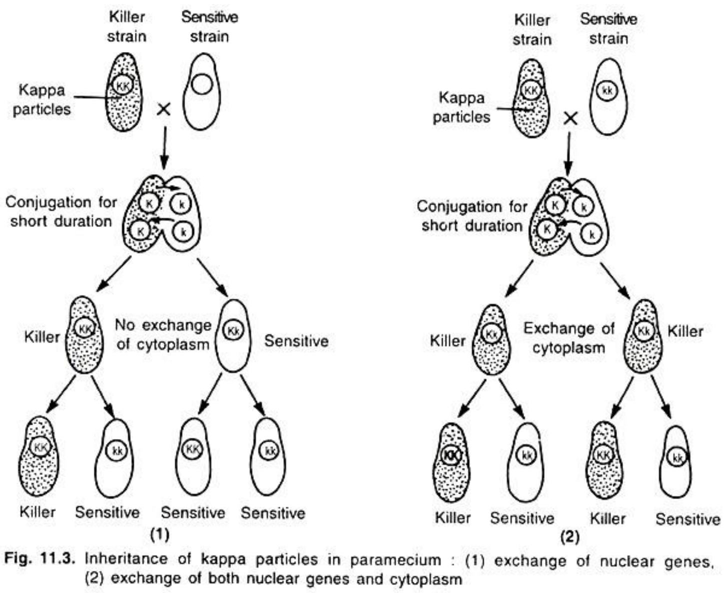


**Fig 12.5** Consequences of normal (left) and rare (right) conjugation in transmitting killer trait (kappa particles) in *Paramecium*

**Conclusions**

Extra-chromosomal inheritance of the killer trait (*kappa* particles) in *Paramecium* is dependent on the following three important conditions:

1. The *Paramecium* must carry KK or Kk (*i.e*. K-) nuclear genotype;
2. At least 400 *kappa* particles must be present in the cytoplasm; and
3. The kappa particles are transferred from the killer strain to the sensitive strain by rare conjugation, in which a cytoplasmic bridge is formed; the conjugation takes a longer period of time; and both nuclear and cytoplasmic materials are transferred.

**Extra-chromosomal inheritance in *Drosophila***

The following example shows the inheritance of extra-chromosomal substance (called sigma particles) in the fruit fly, *Drosophila*.

**Fig 12.6** The fruit fly, *Drosophila melanogaster* shows an extra-chromosomal inheritance of sigma particles

- Most *Drosophila* can tolerate an exposure of pure $CO_2$ for long hours without any injury.
- French geneticists Ph. L'Heritier and G. Teissier (1937) discovered a strain of *Drosophila melanogaste*r which was sensitive to $CO_2$.
- The sensitive flies, when exposed to $CO_2$ for a short period, become unconscious in a characteristic way, with their legs becoming paralyzed, and eventually they die.
- A sensitive fly retains its sensitivity trait, even when all its chromosomes are replaced by those of the normal fly, suggesting that the causal agent is located in the cytoplasm.
- Later on, the causal agent has been called sigma (σ) particles.

**Characteristics of sigma (σ) particles**

1. Sigma particles are DNA viruses, each particle is of ~0.07μm in diameter and are responsible for their hereditary transmission;
2. They transmit through egg cytoplasm, but occasionally through sperms;
3. Their reproduction depends on suitable temperature of 20°C;
4. They are heat labile, for example, destroyed by high temperatures;
5. They show properties of non-chromosomal gene or plasma gene.

**Crossing experiments on CO2 sensitivity in *Drosophila***

The crossing experiments with *Drosophila* revealed the following results:

1. P: Normal ♀♀ × Sensitive ♂♂
   $F_1$: Most offspring are normal
   (Only a few progeny are sensitive)

2. P: Sensitive ♀♀ × Normal ♂♂
   $F_1$: All offspring are sensitive

3. P: Cell-free extracts from sensitive ♀♀ → When injected into normal ♀♀
   $F_1$: All offspring are sensitive

**Conclusions:**

(a) The inheritance pattern of $CO_2$ sensitivity in *Drosophila* is non-Mendelian (Experiments 1 and 2);
(b) The $CO_2$ sensitivity trait shows cytoplasmic basis of inheritance (Experiment 3).

**Suggested reading:**

Burns, GW. 1980.
Gardner *et al*. 1991.
Islam, MS. (2018).
Sinnott *et al*. 1973.
Winchester, AM. 1966.
Wikipedia: www.wikipedia.com.
ইসলাম, ম.সা. ও অন্যান্য ২০১৭।