Cytoplasmic Inheritance

Not all genetic information is located within the chromosomes in the nucleus. DNA is also found in mitochondria and chloroplasts.

The Origin of Cytoplasmic DNA

As described in the Diversity of Living Things unit (Unit 1), both mitochondria and chloroplasts originated as prokaryotic organisms. One theory about their origin, now widely accepted in the scientific community, is that over time, each of these organisms was independently taken in by eukaryotic cells and became organelles (**Figure 1**).

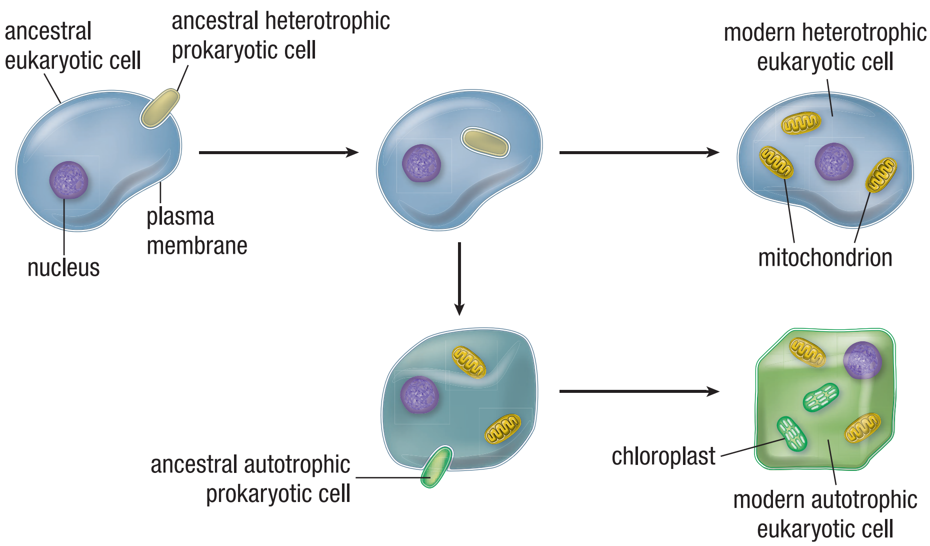

Figure 1 Mitochondria and chloroplasts originated as independent prokaryotes before becoming organelles within eukaryotic cells.

Like all prokaryotes, predecessors to modern mitochondria and chloroplasts contained their own simple chromosomes—genetic material in the form of one or more circular loops of DNA. This genetic material includes genes necessary for the proper functioning of the organelle. Without this DNA, mitochondria would not be able to carry out cellular respiration. Similarly, chloroplasts would not be able to carry out photosynthesis. Mitochondria and chloroplasts are able to reproduce independently within the cytoplasm, thereby producing copies of their DNA.

Asexual Reproduction and Cytoplasmic Inheritance

When a eukaryotic cell (or individual) is produced by asexual reproduction, each daughter cell inherits any genetic material contained within the organelles of the parent cell. As the parent cell divides, each daughter cell obtains approximately equal numbers of mitochondria and chloroplasts (if present). These organelles are assorted randomly into the daughter cells.

Sexual Reproduction and Cytoplasmic Inheritance

During sexual reproduction, each gamete contributes equal numbers of nuclear chromosomes to the zygote but does not always contribute equal amounts of cytoplasmic genetic material. Most male gametes are small and contain very little cytoplasm when compared to the large female egg cell. During fertilization, male gametes do not usually contribute organelles to the new zygote. The zygote inherits cytoplasmic DNA (mitochondria and chloroplasts) from the female gamete (**Figure 2**), a type of inheritance called **maternal inheritance**. In humans and most other animals, sperm do not contribute mitochondria to the zygote, and, as a result, the mitochondria in any individual are always genetic clones of the mitochondria of the mother.

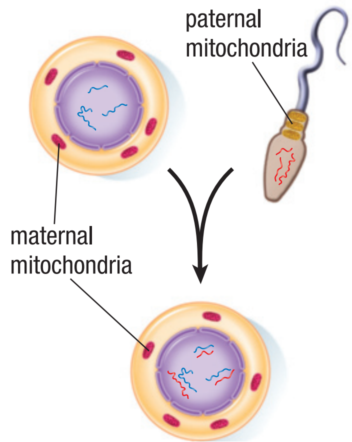

Figure 2 In sexual reproduction, human zygotes receive all of their mitochondria from the egg cell. The sperm contributes only nuclear material. This is an example of maternal inheritance of mitochondrial DNA.

maternal inheritance a type of inheritance in which a zygote formed from two gametes inherits cytoplasmic DNA from only the female gamete

paternal inheritance a type of inheritance in which a zygote formed from two gametes inherits cytoplasmic DNA from only the male gamete

Although mitochondria and chloroplasts are most often inherited maternally, this is not always the case. There are examples of **paternal inheritance**, the inheritance of cytoplasmic DNA from only the male gamete. There are also cases in which both gametes (male and female) contribute cytoplasmic DNA.

Cytoplasmic Inheritance and Genetic Variation

Although mitochondria (and chloroplasts) are normally inherited exclusively from the mother, the mitochondria (and chloroplasts) in the daughter cell are not necessarily genetically identical. For example, a plant cell might contain chloroplasts with two different sets of genetic information. These chloroplasts are separated at random during cell division, making it possible for each daughter cell to receive a different mix of chloroplasts. This genetic variability is not usually significant because, for the most part, organelles contain only a small number of genes with little or no variation.

Leaves with a variety of colours illustrate how cytoplasmic genetic variation can manifest itself. Some plants contain both normal green chloroplasts and chloroplasts with a genetic mutation that causes them to be colourless (**Figure 3(a)**).

During cell division, the random assortment of chloroplasts can produce daughter cells with a mixture of both types of chloroplasts and/or daughter cells with only a single type of chloroplast (green or colourless) (**Figure 3(b)**). When cells containing only colourless chloroplasts grow and divide, they can give rise to large patches of colourless cells in the leaf. The resulting large-scale mixture of both green cells and colourless cells is called variegation and illustrates how genetic variation and inheritance can occur within a single organism.

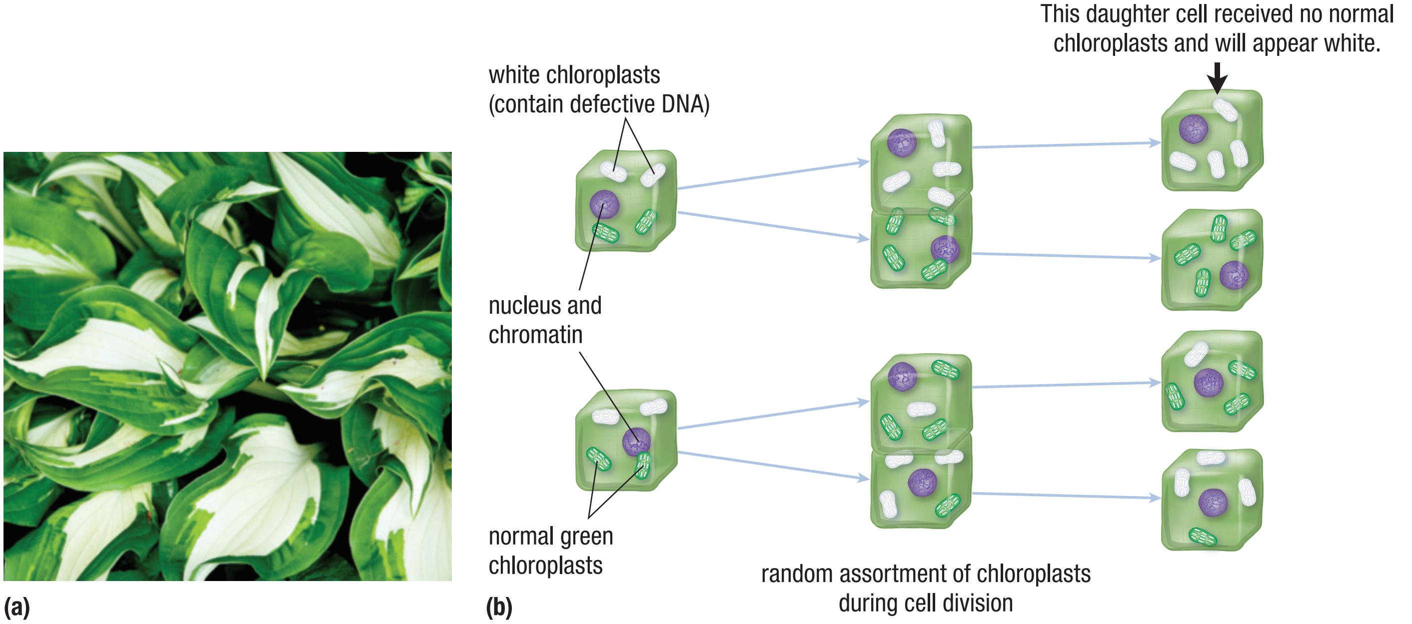

Figure 3 (a) Many varieties of hosta possess variegated leaves composed of patches of cells containing normal green chloroplasts and patches of cells containing mutant colourless chloroplasts. A gene controlling the ability to produce the green pigment is located on the DNA within the chloroplast. (b) Some plants contain both green and colourless chloroplasts. As the plant grows, it is possible for a cell to inherit only non-green chloroplasts. If this occurs, the cell will appear white. As this cell continues to grow and divide, it can give rise to large patches of white cells.

Plants with variegated leaves are valuable ornamental plants for use in horticulture. Interestingly, the random nature of chloroplast assortment means that no two plants will have identical patterns.

In humans, a number of rare genetic disorders are attributed to mitochondrial DNA. Since the genes in mitochondria often influence cellular respiration, these disorders are associated with energy metabolism. As with chloroplasts, cells may differ in the genetic content of mitochondria they contain, depending on the random assortment during cell division. Mitochondria containing defective genes may appear in some cells and not in others. The result is a complex pattern of inheritance, distribution, and disease-causing influences within the cells of the individual.

DNA Egg Swapping

British scientists recently developed a very controversial method that could be used to avoid the inheritance of mitochondrial diseases. If a mother is at risk of passing on a mitochondrial disease, the nucleus of her fertilized egg could be removed and transferred to an unfertilized and enucleated egg cell with normal mitochondria from a donor female. The resulting cell would then be transplanted into the mother. The result would be an embryo with nuclear DNA from both a father and a mother, and normal mitochondria from the donor.

Part Animal, Part Plant!

The green sea slug, *Elysia chlorotica*, is a very special organism. Shaped and coloured like a leaf, the slug is an animal with the ability to perform photosynthesis (**Figure 4**). *E. chlorotica* routinely feeds on algae when it is young. However, instead of consuming and digesting the algae cells entirely, the slugs ingest the algae but keep the chloroplasts intact. The chloroplasts are taken in by cells lining the highly branched digestive system of the slug, where they become resident within the cytoplasm. The intact chloroplasts continue to perform photosynthesis, thereby providing the cells of the slug with a steady supply of food. Having obtained a good initial supply of chloroplasts, the slugs can live out the rest of their lifetime of about a year, without feeding. They can simply bask in a sunny location—acting more like a leaf than an animal!

Figure 4 The green sea slug, *Elysia chlorotica*, feeds on algae cells when it is young and keeps the chloroplasts intact and within its body cells. For the remainder of its life, the slug relies on the products of photosynthesis.

This method of obtaining food is not entirely unique among animals. Other animals have "live-in" microbes that perform photosynthesis. In corals, for example, the microbes that perform photosynthesis are completely intact cells. In the case of the sea slug, only the chloroplasts remain.

What is even more surprising to scientists is the ability of these chloroplasts to continue to function for long periods of time. Chloroplasts do not normally contain all the genetic information they need to function. Some of the genetic information needed to maintain chloroplasts is found in the nucleus of the algae cells. Amazingly, the sea slug has acquired the necessary genetic information from the algae and has incorporated it into its own nuclear DNA. This passing of genetic information from one species to another is called horizontal gene transfer. There is growing evidence that horizontal gene transfer may be more common than was previously thought, and this is attracting scientists to this new area of genetic research.

4.5 Summary

- Mitochondria and chloroplasts are organelles within the cytoplasm that contain their own genetic material.
- The genes in mitochondria and chloroplasts provide information necessary for performing cellular respiration and photosynthesis.
- The genetic information in mitochondria and chloroplasts is usually inherited maternally.
- The combination of genetic variation within organelles and the random assortment of organelles into daughter cells can produce genetic variation within the cells of individuals.
- Some observable characteristics and genetic disorders are inherited through these cytoplasmic sources of DNA.
- Horizontal gene transfer can result in one organism exhibiting a characteristic of an entirely different organism.

UNIT TASK **BOOKMARK**

Is there a possibility that the genetic disorder you are investigating could be an example of cytoplasmic inheritance? Why or why not?

4.5 Questions

1. Describe the genetic material of eukaryotic cells that is found outside the nucleus. K/U
2. Scientists have discovered that the DNA in mitochondria and chloroplasts is more similar to the chromosomes in bacteria than it is to the chromosomes in the nuclei of eukaryotes. How might this be explained? K/U T/I
3. What is the role of genes in mitochondria and chloroplasts? Why are they extremely important to the survival of animals and plants? K/U T/I
4. The genetic information in the mitochondria of 10 men was compared to the mitochondrial DNA of each of their children. None were found to be a perfect match. How can this be explained? K/U T/I
5. Explain how genetic variation in chloroplast DNA can lead to variegation in plant leaves. How might leaf variegation be a disadvantage for plants? Can you think of any possible advantage? K/U A
6. The green sea slug is a very unusual organism. Describe how this animal has incorporated, and makes use of, genes from algae. K/U
7. Many insects are now known to have bacteria living within certain cells of their body. In some cases, both the insects and the bacteria cannot live without each other and the bacteria are passed on directly to the insect offspring. One fascinating example is that of the bacteria *Wigglesworthia glossinidia*, which lives in the tsetse fly—an insect that feeds on blood. Go online to find answers to the following questions: K/U T/I A
   (a) How do bacteria get passed from the adult tsetse flies to their offspring?
   (b) How does the tsetse fly benefit from the presence of the bacteria living within its body?
   (c) How do the bacteria benefit from living inside the tsetse fly?
   (d) Why is the tsetse fly of great significance to human health?
   (e) How would killing off the bacteria inside the tsetse fly help control the spread of disease?