Adaptation: responding to environmental challenges

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Since Jean-Baptiste de Lamarck and Charles Darwin, we know that living beings were not created once and for all by a divine force to constitute a harmonious nature. The harmony of nature is only a matter of the imagination and every living species must constantly respond to the challenges imposed by the environment, both biotic and abiotic. Life has only been able to proliferate and diversify on Earth by developing adaptive capacities. They allow it to adapt to an often hostile environment, in any case always changing, either seasonally or over the long term. These adaptations cover all their biological characteristics, from physiology to morphology and ethology. They concern all levels of life organization, from the individual level to the population level.

1. Adaptations at the individual level

Physiological adaptation commonly refers to changes at the individual level. An individual's metabolism changes temporarily, by regulating gene expression, in response to external conditions. Such coping mechanisms are essential for life and reproduction. The selection pressure for their development has certainly been very strong. There are many examples of this in all types of living organisms.

In the animal kingdom, let us mention two of the most famous. In humans, exposure to sunlight, especially ultraviolet rays, leads to the synthesis of a black pigment, melanin, which stops these rays and protects the skin from their mutagenic effects (see Cellular impact of solar UV). In all terrestrial mammals, the coat varies in density according to the seasons, and allows adaptation to seasonal temperature differences.

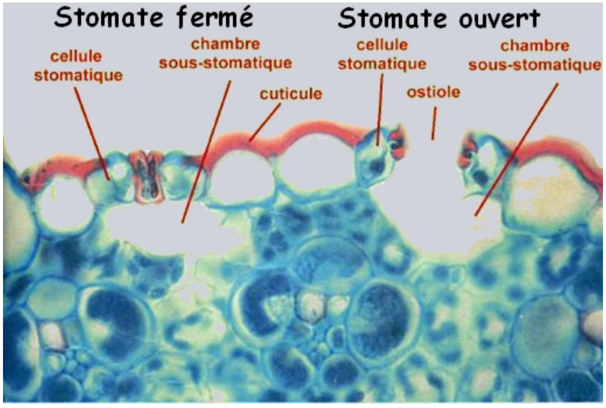

Figure 1. Section of a leaf showing open or closed stomata. [Source: svtmontacourbevoie.wordpress.com]

In plants, fixed to the ground and therefore unable to protect themselves from adverse external situations, these physiological adaptation mechanisms are even more essential (see The fixed life of plants and its constraints). Among the most important environmental factors for plants, there is of course the sun and water. Sunlight allows photosynthesis to proceed smoothly. It is easy to observe, in nature or even in house plants, the phototropism that directs the branches towards sunlight. They grow faster on the bright side than on the shaded side. But in the presence of high temperatures, it is also vital to avoid water loss. This is the role of foliar stomata that control the gas exchanges associated with photosynthesis. Through these openings in the leaf surface, plants absorb carbon dioxide and emit oxygen. But stomata then promote the evaporation of water or evapotranspiration. When the water loss is too high, they close and evaporation is stopped.

For plants living in arid regions, even more drastic adaptations of their own morphology were required (see the example of cactoid plants in the text Inheritance or convergence?) or the example presented at the beginning of this article by *Welwitschia mirabilis*, an endemic plant in the Namib Desert in southern Africa. But this is a second level of adaptation: that of the populations.

2. Population-level adaptations

Hereditary changes promote the adaptation of a population to a constantly changing environment and lead, in the long term, to the evolution of species. The living world has thus acquired mechanisms that allow it to be more and more autonomous from the environment: for example, homeothermic{ind-text}The characteristic of animal species (birds, mammals) whose internal environment (blood and lymph) maintains a constant temperature, regardless of the temperature of the external environment, within very wide limits.{end-tooltip} animals or the ability to store water. Our species has even acquired the ability to modify the environment itself. It was on the mechanism of these evolutionary adaptations that Lamarck and Darwin's theories radically diverged. The first explained biological evolution - "*transformationism*" at the time - by a direct and inheritable effect of the environment on individuals (see Theory of Evolution: misunderstanding and resistance and Lamarck and Darwin: two divergent visions of the living world). Darwin explained it by selecting, from random genetic variation - the "*descent with modifications*" - individuals capable of leaving the most descendants in a given environment. His theory has been verified by more than a century of research. This "Darwinian process" promotes genotypes{ind-text}Information carried by the genome of an organism, contained in each cell in the form of deoxyribonucleic acid (DNA). In the DNA molecule, it is the sequence of nucleotides that constitutes the genetic information.{end-tooltip} that are most adapted to the environment and results, over generations, in the modification of species.

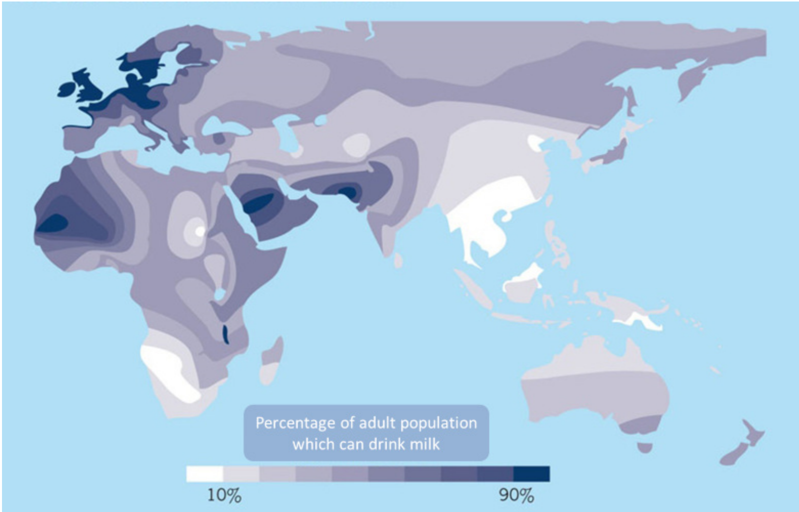

Figure 2. Lactose tolerance is widespread in Northern Europe, some parts of Africa and the Middle East. This can be linked to the abundant consumption of fresh milk. The mutations that caused this tolerance in adults would have appeared independently depending on the region. The persistence of different mutations in geographically separated human populations is an example of a convergent evolution in humans. [Source: Adapted from ref. [1]]

In the text "Genetic polymorphism and selection", Michel Veuille cites the case of mutations that have become advantageous in the environmental context created by agricultural and medical techniques. Mutations that have rapidly established themselves in populations: insecticide resistance genes in insects, antibiotics in bacteria, etc. He also gives the example of lactase in the human species. The gene encoding this enzyme, which digests lactose, is active in infants and inactive in adults. Since the practice of Neolithic breeding - about 10,000 years ago - variants of this gene (alleles) that allow the synthesis of lactase even in the adult state have become advantageous. They are found in most peoples at variable frequencies, but all the more so as livestock farming is more important (Figure 2) [1]. This example also illustrates the fact that, contrary to a widespread idea, evolution is still ongoing in our species. Moreover, we do not see why and how it could be otherwise. As for the mechanism of natural selection, which can be viewed as the "engine" of adaptation and evolution, it is often misunderstood. The text "Inheritance or convergence? The winding paths of species evolution" talks about it at some length and presents it in a simple and precise way.

3. Epigenetic memory

A third level of adaptation falls between the two previous levels. Like the first level, it is individual and plays only on the regulation of gene expression, without intervention on their structure. But this third level involves a transient hereditary transmission of these regulations. This allows descendants, over a few generations, to benefit from the adaptive response of their parents. This is referred to as epigenetic memory or transgenerational effect (see Epigenetics, the genome and its environment). This type of phenomenon has been known for a long time, but it has remained relatively exceptional. The first known cases mainly concerned paramecia, unicellular eukaryotes{ind-text}Unicellular or multicellular organisms whose cells have a nucleus and organelles (endoplasmic reticulum, Golgi apparatus, various plasters, mitochondria, etc.) delimited by membranes. Eukaryotes are, along with bacteria and archaea, one of the three groups of the living organism.{end-tooltip} . Since 2000, examples have multiplied and cover a wide range of characters. They have often been observed in response to environmental stresses, but also in the case of maternal behaviours in rats [2].

Figure 3. Experimentation on Arabidopsis thaliana seedlings. [Source: photo © CEA-Grenoble]

We will cite two very similar examples that link to the text "The genome between stability and variability". These are experiments showing the existence of mechanisms for stimulating this variability by external agents. The first example concerns the drosophila{ind-text}Small fly also called the vinegar fly or fruit fly. Because of its ease of breeding, the fruit fly is a model species in genetic research.{end-tooltip} [3] ; the second, the simplest to describe, a plant: the thale cress (*Arabidopsis thaliana*) [4]. In the latter example, UV irradiations or the action of flagellin (a trigger for plant defence systems) stimulate homologous recombination{ind-text}Type of genetic recombination where nucleotide sequences are exchanged between identical or similar DNA molecules.{end-tooltip}. This stimulation is transmitted to the descendants over at least four generations. In this way, the repair of possible DNA damage created by stressors will be facilitated. But at the same time, genomic variations will also be increased. This phenomenon of increased genetic variability due to environmental stresses, already well known in bacteria since the 1980s, therefore seems generalizable to plants and animals, with transgenerational effect. More and more research confirms this [5].

About this epigenetic memory, some popularization authors and even some scientists speak of a return to lamarckism{ind-text}Movement related to Lamarck's ideas. Often reduced to the idea of the transmission of acquired traits, although Jean-Baptiste Lamarck's transformist theory is much broader than that.{end-tooltip} (or even to lyssenkoism!). This is inappropriate because epigenetic changes are reversible, they can only allow temporary adaptation to stress. Not based on DNA sequences changes, they do not modify the genetic structure of the lineage concerned and a process of speciation{ind-text}Evolutionary process leading to the emergence of new living species that individualize from populations belonging to an original species.{end-tooltip} is therefore excluded. However, although there are only few studies on this subject, we may imagine that this type of transgenerational memory is complementary to the Darwinian process. It will allow individuals under environmental stress to survive and reproduce by transmitting protection to their descendants. If the stress disappears, the response fades and the population returns to its previous life; if it persists, this response allows the population to maintain itself and gives it time to adapt through the Darwinian process. The fact that genome variation mechanisms are stimulated for a few generations will facilitate this adaptation by increasing genetic variability.

References and notes

Cover image. *Welwitschia mirabilis,* a unique plant of the Namib Desert tSource: Petr Kosina via Visual hunt (CC BY-NC 2.0)]

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