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Cryptobiosis in Nematodes: The Adaptive Phenomena to Survive Environmental Stress

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Introduction

Nematodes, also known as roundworms, are highly resilient organisms found in diverse environments worldwide, dominating both land and water ecosystems in terms of numbers per unit area. They also can thrive in a variety of living organisms, including insects, birds, animals, humans, and plants, highlighting their adaptability and capacity to endure harsh conditions such as extreme temperatures, water scarcity, and low oxygen levels. This resilience of the nematodes inspired Nathan Augustus Cobb to famously remark, “If you swept away the universe with all matter except the nematodes, you would still dimly see our globe, and all its mountains and valleys, as a film of nematodes.” His statement underscores their survival strategies in enduring extreme heat, cold, salinity, dryness, and low oxygen levels.

Many nematode species can withstand extended periods without food. Some produce antifreeze proteins to survive freezing temperatures, protecting their cells from ice damage. In hot and arid climates, they enter dormancy to conserve energy. Certain nematodes, such as Globodera and Heterodera species, form protective cysts that allow them to withstand harsh conditions until the environment becomes favourable again. In low-oxygen settings, some nematodes shift to anaerobic metabolism, generating energy through alternative pathways. Ultimately, their survival hinges on their remarkable adaptability and ability to find sustenance, often through a survival strategy known as cryptobiosis.

Cryptobiosis is a state of suspended animation in which an organism's metabolic activity is greatly reduced or completely halted. This allows the organism to survive extreme environmental conditions, such as lack of water, extreme temperatures, or low oxygen levels. There are three main types of cryptobiosis: anhydrobiosis, cryobiosis, and anoxybiosis.

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- **Anhydrobiosis** is the ability of an organism to survive without water. Many species of nematodes and other organisms are able to enter a state of anhydrobiosis by producing specialized sugars or other molecules that protect their cells from damage caused by desiccation e.g., Aphelenchoides fragariae, Aphelenchus avenae, Ditylenchus dipsaci
- **Cryobiosis** is the ability of an organism to survive extreme cold. Some species of nematodes and other organisms are able to survive freezing temperatures by producing antifreeze proteins or other cryoprotectants that prevent their cells from being damaged by ice crystals e.g., Panagrolaimus spp.
- **Anoxybiosis** is the ability of an organism to survive in the absence of oxygen. Some species of nematodes and other organisms are able to enter a state of anaerobic metabolism, in which they use alternative pathways to produce energy without the need for oxygen e.g., Plectus sp.

Mechanisms involved in cryptobiosis

During the initial stages of cryptobiosis, nematode's metabolic activity is significantly reduced, conserving energy and protecting cells from damage. This is achieved through mechanisms such as the suppression of energy-consuming processes and the synthesis of energy-storing molecules.

If extreme conditions persist, changes occur in cell signalling pathways that alter the expression of specific genes, influencing the production of protective proteins and other molecules. For instance, genes involved in energy metabolism may be suppressed, while others are upregulated to protect cells from damage. These changes also trigger modifications in cellular structures, helping to maintain cell integrity and safeguard against damage.

The substances produced by nematodes during cryptobiosis includes cryoprotective proteins, antifreeze compounds, and desiccation-tolerant molecules. These compounds play a vital role in shielding cells from extreme stress.

Cryoprotectants:

Some nematodes and other organisms are able to survive extreme cold by producing cryoprotectants, which are molecules that help to protect their cells from damage caused by ice crystals. Cryoprotectants can work by stabilizing the structure of cells or by inhibiting the formation of ice crystals.

Antifreeze proteins:

Some nematodes and other organisms are able to survive freezing temperatures by producing antifreeze proteins that prevent the formation of ice crystals in their cells. These proteins work by binding to the surface of ice crystals and inhibiting their growth, which helps to prevent damage to the cells.

Desiccation-tolerant molecules:

Some nematodes and other organisms are able to tolerate desiccation (drying out) by producing molecules that protect their cells from damage. For example, some nematodes produce high levels of sugars like trehalose, which help to stabilize the structure of their cells and prevent damage from occurring.

The role of Trehalose:

Trehalose is a prominent sugar compound produced by nematodes during cryptobiosis, plays a crucial role in their adaptation, survival, and recovery under extreme conditions. It helps protect cells from damage caused by desiccation, freezing, and other stressors, aiding nematodes in enduring and recovering from harsh environments. These includes the following:

- Stabilization of cell membrane: Trehalose helps to stabilize the structure of membranes and other cellular structures, which helps to prevent the loss of water and maintain the integrity of the cells during desiccation, a state where the organism is exposed to low humidity conditions
- Protection of proteins and enzymes: Trehalose also helps to protect proteins and enzymes from denaturation and aggregation. It does this by binding to them and stabilizing their structure which can help to maintain their function
- Maintenance of osmotic balance: Trehalose can provide an osmotic balance, preserving the integrity of membranes and proteins and protecting cells from damage during desiccation
- Resumption of growth: Trehalose is an important part of Anhydrobiosis, where the organism can survive and resume growth when water is re-established
- Freezing tolerance: Trehalose also plays a role in freezing tolerance, it can act as a cryoprotectant by reducing the freezing point of cellular contents, thus reducing the amount of ice crystal formation that can cause damage to the cell.

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`Besides trehalose, there are several specific biochemical components that are involved in the process of cryptobiosis in different organisms. Some examples include:

Biochemical component	Function
Spermidine	DNA repair, antioxidant defense, membrane stabilization
Proline	Stabilizes protein structure, prevents denaturation
Taurine	Osmoregulation, antioxidant defense, membrane stabilization
Glycine betaine	Osmoregulation, protection from dehydration
Superoxide dismutase (SOD)	Antioxidant enzyme that protects cells from damage caused by reactive oxygen species (ROS)

DNA repair pathways:

If the damage is happened in nematodes at DNA level during its adaptation or survival or recovery stage when exposed to high extreme conditions, the DNA repair pathway got activated. This DNA repair pathways in order to fix any damage that has occurred to their genetic material. This helps to ensure that the organisms are able to function normally when conditions become more favourable.

Conclusion:

Cryptobiosis is a survival strategy that allows some organisms, including nematodes, to survive extreme environmental conditions, such as desiccation, freezing, and anoxia. The organism's metabolic activity is greatly reduced or halted to conserve energy and protect cells from damage. Biochemical modifications are adapted to survive, including synthesis of protective molecules, stabilization of cellular structures, changes in gene expression, and DNA repair pathways. The specific mechanisms that are used may vary depending on the organism and environmental conditions and research in the field is ongoing to understand the complete picture.

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