Life without Water

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Introduction

Life on earth without water is difficult to imagine. We may survive without food for two months but we cannot survive without water for more than a week. Water makes up nearly 65% of the constituents of the body. Our metabolism is crucially dependent on water. We may die if we lose even 14 % of the water content from our body.

Anhydrobiosis

Interestingly some organisms can afford to lose 95% to 99% of their body water but can still remain alive for hours to decades. They enter into a state called 'anhydrobiosis' or life without water. This ability to withstand extreme desiccation is evidenced in all the three branches of life. It is found in nematodes, rotifers and tardigrades among animals, barophytes among plants and a number of bacteria, terrestrial microalgae, lichens and yeast among microorganisms. This ability to lose water and yet survive varies from one organism to another. The loss of the same amount of water can cause severe adverse effects on metabolism in higher organisms but have very little effect on lower organisms. In fact, a wide variety of animals, plants and microbes can withstand complete desiccation, defined as water content below 0.1 gram per gram of dry mass.

Despite the fact that some organisms can survive desiccation, it is not a very common phenomenon. No animal longer than 5 mm can tolerate desiccation. No crop used as food by humans can enter the state of anhydrobiosis. The mystery behind this rarity remains unsolved though a number of hypotheses have been offered so far.

Keywords
Anhydrobiosis, desiccation, stress tolerance.

Effect on Metabolism

In a strict sense, anhydrobiosis should be defined as the ability of the organism to survive the cessation of metabolism caused by the water loss and enter a state of suspended animation. The metabolic activities in them come to a halt. In hibernating animals metabolism continues albeit at a very slow rate, but it cannot continue in the anhydrobiotic state and is comparable to a dead organism. The only difference lies in the fact that a dead organism never revives whereas an anhydrobiotic organism starts growing and reproducing once a favorable condition appears (i.e., water is available again in the environment).

Effect on Ageing

Anhydrobiosis also interferes with ageing. Following hatching of eggs, many nematodes die within weeks while they can sustain their life for a couple of years by entering the anhydrobiotic state. Thus anhydrobiosis draws a mark of differentiation between chronological age and physiological age of an organism. However the processes involved in damage repair are also inhibited during anhydrobiosis. Hence any damage that occurs during the dried state cannot be repaired and may hasten the death of the organism.

Protective Substances

Water is essential not only for the chemical reactions involved in metabolism but also for maintaining the structure of the biomolecules that constitute the cellular machinery. When the water content of the cells of an organism decreases beyond a certain level, cellular proteins are denatured and membranes get disorganized. Desiccation-tolerant organisms synthesize some stress-combatants, which impart into them the ability to enter into an anhydrobiotic state. The most extensively studied molecule in this context is the disaccharide trehalose.[1]

[1] A disaccharide containing two glucose units, and is called alpha-D-gluco-pyranosyl alpha-D-glucopyranoside.

Baker's yeast (*Saccahromyces cerevisiae*) is one of the most common examples of desiccation-tolerant organism. It can be obtained as dried powder and revived simply by adding water. It has been found that the yeast cells accumulate a high amount of trehalose (a polyhydroxy compound) during anhydrobiosis. It is believed that polyhydroxy compounds are able to replace water in stabilizing the macromolecules by physically interacting with polar residues and thereby protect cellular proteins from getting denatured during anhydrobiosis. This postulation, known as "water replacement hypothesis", has been substantiated by several investigations. In the dry state, trehalose and many other sugars form a highly viscous liquid, called a glass. Due to high viscosity of cytoplasm in the glassy state, chemical reactions are slowed down and thus degenerative processes that are likely to occur during desiccation (e.g., crystallization of solutes, alteration of pH) are prevented. Trehalose maintains the glassy state at very high temperature and at extreme levels of desiccation. It is also postulated that trehalose causes lowering of phase transition temperature of the membranes so that they maintain their liquid-crystal state in the dry condition. In general, during anhydrobiosis, animals (like nematodes) and yeasts accumulate trehalose within the cells, whereas seeds and pollen grains of higher plants accumulate sucrose. Some resurrection plants accumulate both sucrose and trehalose.

Disaccharides alone are not sufficient to confer protection against desiccation-induced damages. A group of proteins, discovered during the eighties, were found to accumulate in water-deficient plants. They were called LEA (Late Embryogenesis Abundant) proteins. Subsequent discovery of some genes that encode a category of LEA proteins in nematodes revealed that LEA proteins are desiccation combatants present both in plants and animals.

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Association between Anhydrobiosis and Other Types of Stress Tolerance

Production of reactive oxygen species (ROS) is enhanced both during irradiation and desiccation.

Desiccation tolerance in some bacteria is known to be associated with radiation tolerance. The ability of some bacteria (e.g., *Deinococcus radiodurans*) to survive high doses of ionizing radiation is attributed to the presence of an efficient intracellular repair system, which patches up damage in the cellular DNA caused by radiation. Shearing of DNA is a major factor involved in desiccation-induced mortality. Hence a repair system, which takes care of radiation-induced DNA damage, assumes a protective role also during desiccation. Since high doses of ionizing radiation occur nowhere on earth, it is believed that radiation tolerance in bacteria was evolved as an offshoot of desiccation tolerance.

Production of reactive oxygen species (ROS) is enhanced both during irradiation and desiccation. Loss of control of the respiratory electron transport chains and dissipation of the aqueous barriers to gaseous diffusion leading to the elevated exposure to atmospheric oxygen are some of the factors that might be responsible for the increased generation of ROS inside the cell during dehydration. ROS are deleterious to the cellular constituents. Besides damaging DNA they also inflict irreparable and irreversible damage on cellular proteins by the mechanism of iron-dependent carbonylation. Protection from ROS-induced damage is a pre-requisite for desiccation tolerance and prolonged longevity in the desiccated state depends on the ability of the organism to scavenge ROS. When cellular proteins are protected from oxidative damage, the repair systems of the cell survive and function efficiently during recovery. Therefore, it is not surprising that cellular antioxidants (e.g., glutathione, manganese) appear to play an important role in desiccation tolerance and also in linking desiccation tolerance to radiation tolerance.

Biotechnological Aspects

Attempts have been made from time to time to preserve cells and organs, which can be used for therapeutic purpose. Taking a cue from the desiccation-tolerant organisms, researchers are making an effort to mimic the strategy evolved by them. Trehalose is a potential candidate molecule for this purpose. G M Beattie and his colleagues from Whittier Institute, Department of Pediatrics, University of California at San Diego School of Medicine, developed a method for preserving insulin-producing mammalian cells using trehalose along with dimethyl sulfoxide (DMSO), which is conventionally used for this purpose. The rate of recovery of adult islet cells improved substantially after cryopreservation with trehalose compared to the cells preserved with DMSO alone. In order to overcome the problem of impermeability of mammalian cell membranes to trehalose, the investigators took advantage of the leakiness of membranes during transition of membrane lipids from fluid to solid phases above the freezing point. Subsequently a team of investigators used a recombinant pore-forming hemolytic protein, alpha-hemolysin, for delivering trehalose. This protein was so engineered that the pore remained closed in the presence of zinc and opened in the absence of zinc. They incubated the mammalian cells with the recombinant protein. Trehalose was delivered into the cells by withdrawing zinc from the medium. Very high rate of survival of two mammalian cell lines was obtained in the frozen state using this technique. The potential of trehalose for cryopreservation of hematopoietic stem cells has also been demonstrated. Thus it might be a useful replacement for the conventional cryoprotectant DMSO, which is known to be considerably toxic. Encouraging results have been obtained from investigations on the role of trehalose in the cryopreservation of human adipose tissue. Further, trehalose has been found to be useful in the cryopresrva-

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tion of RNA that can be subsequently used for vaccine development. Thus trehalose has catapulted as a molecule of immense biotechnological importance.

Anhydrobiosis is also associated with some potential problems. Tardigrades, rotifers and nematodes are found to be highly resistant to ionizing radiation, ultraviolet radiation, high and low temperature and high hydrostatic pressure during anhydrobiosis. They also show tolerance to biocides in the anhydrobiotic state. Hence insects can escape the effect of pesticides by entering a state of anhydrobiosis.

Conclusion

It is evident from the foregoing discussion that anhydrobiosis is a phenomenon which has attracted the attention of scientists working in the area of pure and applied research alike. It is revealing as to how natural events, simulated in the laboratory, might offer benefit to mankind. Future investigations on the interlink between anhydrobiosis and tolerance of organisms to other stress conditions are likely to offer insight into the intricacies of the cellular machinery.

Suggested Reading

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