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RESURRECTION PLANTS

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Imagine that you have a little potted plant at home. But you forgot to water it for a few weeks, and it looks dry and brown. Now imagine how great it would be if this little plant could become green again when you give it some water. This is not only an imagination game. It happens for real in nature. These plants are called resurrection plants. Some resurrection plants can stay dry for a few months and others for even longer periods. Resurrection plants protect themselves from the damage caused by the loss of too much water and come back to life when water is available again. We are learning from the mechanisms that resurrection plants use to stay alive while dry and applying what we learn in other areas of research.

What happens if the plants that you have at home do not get any water for 3 months? Do they become dry and brownish, lose their leaves, and die? If you said yes, you know that drying up and dying is what happens to most plants that do not get watered. But a few plants do not behave that way. If these special plants do not get any water for 3 months, they will become dry and brownish and look dead. However, if they get water again, they will recover their green color and flower. We call these plants **resurrection plants**. We know of 135 species of

RESURRECTION PLANTS

Plants that stay alive after being severely dehydrated.

Figure 1

World map showing the main areas (shaded) where resurrection plants grow. Adapted from Farrant et al. [2].

Figure 1

Figure 2

Resurrection plants in their natural habitats. The plants in the images are known as Vellozia and they can be found growing in rocky soils in Brazil (state of Minas Gerais). In Portuguese, they are called *canela-de-ema* (emu shin).

Figure 2

flowering plants that are resurrection plants (out of close to 295,400 species of known flowering plants)! [1].

Most resurrection plants grow in tropical regions on the top of rocks, in shallow soil (Figures 1, 2) [2]. Rain falls in these areas only a few months each year and water evaporates very quickly.

TOLERATE OR RESIST DEHYDRATION?

DROUGHT

Deficit of rainfall over a period of time, resulting in a water shortage. During a drought spell, there is not enough water available in the soil to be absorbed by the plants.

Resurrection plants stay alive because they tolerate the severe dehydration caused by **drought**. These plants are different from cacti. Cacti do not tolerate severe dehydration, they resist dehydration instead. This is an important difference to keep in mind.

In general, plants survive drought in three ways: avoiding, resisting or tolerating it. Plants that avoid drought have a short life (a few months).

SEED GERMINATION

Process in which a young plant sprouts and grows from inside a seed.

In the rainy season, after **seed germination** new plants grow. In a short time, these new plants flower and produce seeds. Then, the plants die before the dry season starts. Their seeds will stay alive in the soil, waiting for the next rainy season so they can germinate and continue the cycle. Many crops are examples of drought avoiders, such as corn, wheat, and rice.

Plants that resist drought, such as cacti and other succulents have several mechanisms to prevent dehydration. For example, they have structures inside their stems specialized for storing water. Also, their leaves look like spines and can absorb water from fog and dew. This way, drought-resistant plants minimize water loses and stay hydrated in the dry season. However, if the dry season is unusually long, they might not resist and could die.

Resurrection plants tolerate dehydration. They do not try to avoid or resist it. In the dry season, they lose water fast and put life on hold until the rainy season starts again. This means that they stay alive even while dry!

Losing water is part of life for all organisms. Humans, for example, lose water all the time through the skin (as sweat) and also via urine and tears. However, if we lose too much water, we will have a serious problem. If a person who weighs 30 kg loses 4.5 kg because of dehydration, that person's life will be in danger. Most plants are more tolerant to water loss than humans are. For example, a plant weighing 30 kg can lose 12 kg due to dehydration. Resurrection plants are even more extreme. If a resurrection plant could reach the weight of 30 kg (most of them are very small), losing 22.5 kg because of dehydration would not be dangerous at all. This extreme level of dehydration is called **desiccation**.

DESICCATION

Extreme level of water loss.

A LITTLE BIT OF HISTORY

Tolerating desiccation was important for the first organisms that left water to live on dry land. These organisms lived on the shores of muddy lakes, with limited water available and plenty of sunlight. Later in the history of life on Earth, plants acquired mechanisms to resist drought and became more sensitive to desiccation. This was an important step in the evolution of plants, because desiccation-tolerant organisms grow slowly. Plants that are drought-resistant instead of desiccation-tolerant grow much faster.

However, plants did not lose desiccation tolerance completely. Many plants still produce desiccation-tolerant seeds. Most seeds acquire desiccation tolerance while they are being formed inside the fruit, when still connected to the mother-plant. When the fruits are ripe, the seeds are dry and alive.

Resurrection plants can make desiccation-tolerant seeds and leaves. Their leaves are tolerant thanks to mechanisms like the ones that seeds use. It appears that resurrection plants borrowed the seed mechanisms for desiccation tolerance and adapted them to also work in leaves [3, 4].

HOW DO RESURRECTION PLANTS DEAL WITH DESICCATION?

The roots of plants send messages to the leaves when the roots sense that the soil is getting drier and drier. These messages tell the leaves to reduce water loss by closing tiny pores used for gas exchange. Air enters the plant through these pores and water exits the leaves through the pores. Keeping these pores closed can save a lot of water. However, the plants cannot keep the pores closed for too long. They need to exchange gas with the air, because this is how the plants get carbon dioxide. Plants convert carbon dioxide from the air and water from the soil into food, via a process called **photosynthesis**. After a few days with the pores closed, plants will starve because they cannot make food. Then, their leaves will turn yellow and wilted. If drought persists, their leaves will turn brow and drop off.

PHOTOSYNTHESIS

Process in which green plants convert carbon dioxide (got from the air) and water (got from the soil) into food (sugars) and oxygen (returned to the air).

Resurrection plants are better at responding to drought. At the beginning of a drought, they will react the same way as non-resurrection plants. Their roots will send messages to the leaves to close the pores. If the drought persists, they will let their leaves dry while carefully folding or curling them. Some leaves will lose their green color and turn brown. Others will accumulate a purple pigment called anthocyanin, which acts as sunscreen. These measures are important to reduce the damaging effects of sunlight.

Sunlight is essential for the life of plants, because plants need it for photosynthesis. Photosynthesis also produces a lot of small molecules called free radicals. Free radicals are necessary for life, but when there are too many of them they can damage the cells. When plants are hydrated, they can keep the amount of free radicals under control. But when they are dehydrated, things can get out of control. To avoid this problem, resurrection plants accumulate molecules that fight the buildup of free radicals. Also, resurrection plants stop photosynthesis. Some resurrection plants do this by breaking up their chloroplasts (where photosynthesis happens). These are the resurrection plants that turn brown when they are drying. When they rehydrate, they will quickly put the chloroplasts back together and start photosynthesis again. Other resurrection plants stop photosynthesis by accumulating anthocyanins (Figure 3). Anthocyanins act as sunscreens and shade the chloroplasts, stopping photosynthesis. When these plants rehydrate, the leaves unfold or uncurl and turn green again (for a resurrection plant coming back to life, see https://www.youtube.com/watch?v=IMsyFBcfo6g).

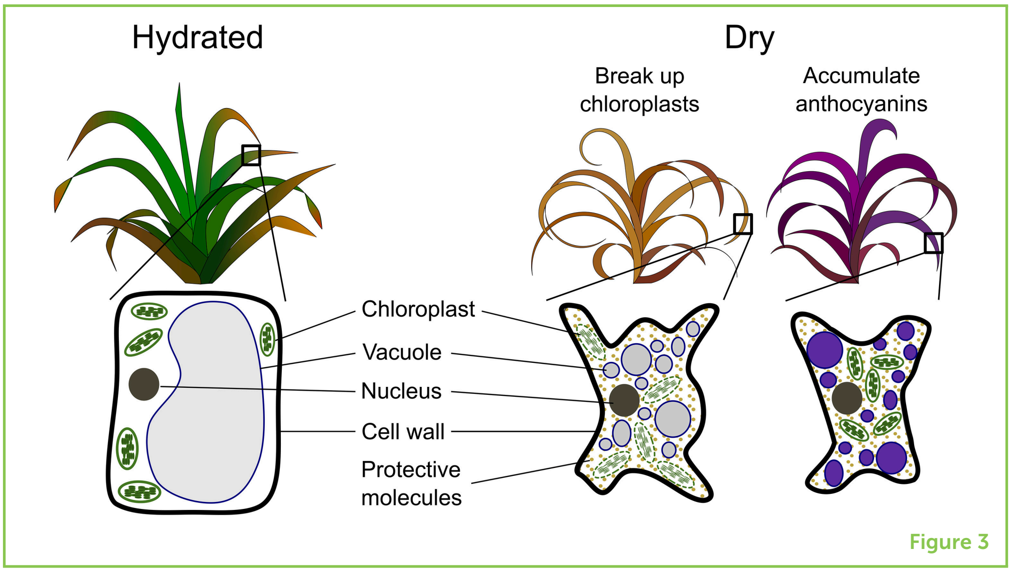

Figure 3

Mechanisms used by the cells of resurrection plants to tolerate extreme dehydration. Resurrection plants have cell walls that are flexible and fold without cracking. They accumulate protective molecules. These cells either break up their chloroplasts or accumulate anthocyanins to shade the chloroplasts so that photosynthesis does not occur. They split their big vacuole into small ones to help the cells retain their shape.

Drying damages the cells. In addition to the damage caused by excess free radicals, some cell components might lose their proper shape and cluster together. Once these clusters form, they do not split up and return to the right shape. To prevent the formation of these clusters, resurrection plants accumulate protective molecules, such as sugars and proteins that prevent formation of clusters. These protective molecules reduce the damage caused by dehydration and contribute to recovery when water is available again.

Cells are made up mainly of water. When this water is removed, the cells shrink. The cell wall is a thin layer that surrounds each cell and separates the inside from the outside. The cell wall is flexible, but it can crack if the cell shrinks too much. Resurrection plants have cell walls that are more flexible than the cell walls of other plants (Figure 3). This way, the cell wall can fold during dehydration without cracking. Another way for the cells of resurrection plants to avoid shrinking too much is to split a cell component called the vacuole into small vacuoles. Vacuoles are storage bubbles found in cells and they contain large amounts of water or food. Usually, plant cells have one large vacuole that can take up more than half of the space in the cell. The vacuole gains and loses water, depending on how much water is available to the plant. Splitting the vacuole helps to keep the cell's structure and reduce the shrinkage caused by the loss of water.

WHY DO WE STUDY RESURRECTION PLANTS?

Resurrection plants are intriguing plants. They tolerate dehydration to levels that are lethal to most other plants, and they can stay dry for long periods of time. We study resurrection plants to understand how life can continue under extreme conditions, including lack of water. The mechanisms that these plants use to tolerate desiccation are useful in many ways. For example, these mechanisms have been used in the development of vaccines that can be stored for longer periods of time and transported to places without refrigeration. They have inspired ways to extend the time that blood cells and organs can be used for transfusion or transplantation. The mechanisms used by resurrection plants have also been used to improve drought tolerance in crops, in order to minimize the crop losses farmers face during dry spells.

Desiccation tolerance in plants is extremely complex. In recent years, scientists have made substantial progress in understanding it. However, our understanding is still incomplete. We have a long way to go to fill the gaps in our knowledge, put together the main discoveries, and use them to improve the quality of life of millions of people.

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YOUNG REVIEWER

GABRIELA JAZMÍN, AGE: 12

Hi, my name is Gabriela Jazmín and I am 12 years old. I live in Mexico City and I love to read and play basketball with my friends. When I grow up I want to become a biologist, as I would like to help people learn about native species from my country.

AUTHOR

MARIA-CECÍLIA COSTA

Maria-Cecília Costa loves plants. During her studies to become a biologist, she stumbled upon seeds that could not be stored (unlike most seeds that we know). These seeds led her to the fascinating world of plants that survive and thrive in harsh environments. Her work focuses in understanding how certain plants survive extreme water losses. She aims at contributing to the development of crop plants that are more drought tolerant. These crops are necessary to improve the lives of small farmers living in drought prone areas. *maceciliadc@gmail.com