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TREE MEMORIES: HOW CAN TREES REMEMBER WITHOUT A BRAIN?

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YOUNG REVIEWERS:

LAURI
AGE: 15

THE SPROUTS
AGES: 8–11

Conifer trees are good at adapting to environmental challenges. Epigenetic memory, unlike the slow process of natural selection, allows trees to quickly adjust to challenges in their surroundings. Epigenetic memories are formed when trees experience stress such as temperature fluctuations, radiation exposure, and insect attacks. These memories can influence future responses and may even be passed on to subsequent generations. Studying epigenetic stress memory in long-lived species like conifers, which experiences many challenges over their lifetimes, is important. By understanding how these trees use epigenetic memory to survive, researchers can develop strategies to create forests that are more ready to face climate change and pest attacks.

TOUGH PLANTS

Plants come in all shapes and sizes. Some plants live in tropical rainforests, others live in parched deserts. Some are tiny and some

NATURAL SELECTION

The process by which individuals who are best able to survive in their surroundings produce the most offspring and pass on their instructions (DNA) for how to survive.

ADAPTED

Refers to an individual changing how it looks, acts, grows, or senses to better live in its surroundings.

DNA

The molecule that makes up the genetic instructions for how a living thing looks, acts, grows, and senses its surroundings. This genetic code is passed from parents to kids.

Figure 1

Instructions for how to deal with environmental challenges are written in a plant's DNA code (genetics). Plants may be challenged by attacking insects or diseases (living environmental challenges), as well as cold weather, drought, or radiation (non-living environmental challenges). These challenges do not change the plant's DNA directly but may cause epigenetic changes, which change how the plant uses the genetic instructions in its DNA. For example, certain genes can be turned off (red epigenetic marks) or on (orange epigenetic marks) by epigenetic changes. Epigenetic changes change how the plant functions and deals with its environment.

are taller than a 30-story building and larger than 25 school buses. Some plants live for a few months, others live for hundreds of years—or even 1,000's of years. During their lifetimes, plants face many challenges. Maybe it is too hot or too cold. Maybe the plant becomes lunch for a very hungry caterpillar or food for a plant-killing fungus. Unlike animals, plants cannot hide during a storm or move away from an insect attack. Instead, they must stand still and deal with every challenge that comes their way. This has made plants masters of self-defense and experts at adjusting themselves to changes in their environments.

HOW DO PLANTS SURVIVE ALL THE CHALLENGES THEY FACE?

One way plants can change to deal with challenges is through a process called **natural selection**. This is usually a very slow process in which those individuals that are best **adapted** to their environments produce the most offspring, or seeds. Being "best adapted" means that a plant has physical characteristics or behaviors that help it survive and make seeds. Adaptations could be sharp thorns that protect a plant from being eaten by a giraffe, or poisonous leaves that protect it from caterpillars. If these characteristics are "written" in the plant's **DNA** (the instruction manual for how a living thing grows and functions) they are passed on to the seeds (Figure 1). Since successful individuals make more seeds than unsuccessful ones, useful characteristics become more common in the next generation of plants. Through natural selection, a species can gradually change over time and fine-tune itself to the environment where it lives.

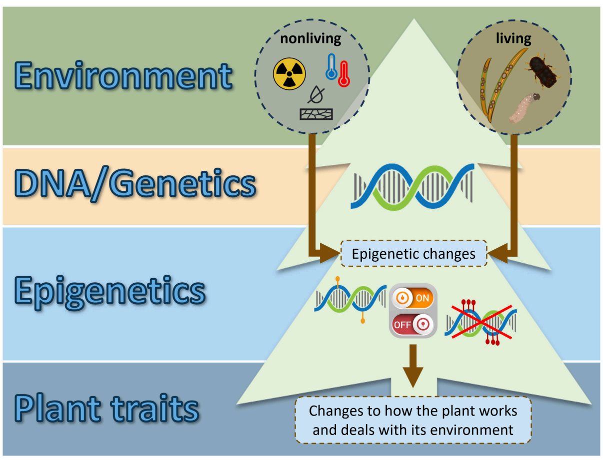

Figure 1

As we mentioned, change through natural selection usually happens very slowly. In long-lived plants like trees, it can take many generations and hundreds of years for helpful changes in the DNA to spread and become common in the species. Luckily, there is another, much quicker way for plants to adapt to their environments. They can change when and how instructions in their DNA are carried out. This type of change is controlled by something called **epigenetics**—"epi" means that changes take place on top of, or in addition to, the genetic instructions written in the DNA. Epigenetic marks on the DNA control how compacted ("turned off") or loose ("turned on") the DNA is (Figure 1). Changes in the location of epigenetic marks allow for rapid changes in how a plant responds to its environment. These changes can also provide the plant with a "memory" of past stressful events and may be passed on to their seeds, making the next generation better prepared to face the challenges around them.

Studying epigenetic change is important to understand how plants adapt to their environments. This type of adaptation is especially important in long-lived trees, like **conifers**, as they may face a wide range of environmental conditions in their lifetimes. Conifers are part of an ancient group of plants called **gymnosperms**, which dominated the world around the time dinosaurs appeared and have adapted to live and thrive in extreme environments—from the dry deserts of Namibia (southwestern Africa) to the cold **taiga** of Siberia (Figure 2). Today, some of the most important timber species in the world (and almost all Christmas trees!) are conifers. Epigenetic changes allow conifer trees to remember the past and be better prepared for the future. Conifers can form epigenetic "memories" in response to many kinds of environmental cues, such as temperature conditions, insect attacks, and radioactivity.

EPIGENETICS

Changing the way the genetic instructions written in the DNA are carried out, without changing how the instructions are written.

CONIFERS

Trees that make cones that hold their seeds and have needle-like leaves.

GYMNOSPERM

An ancient group of plants that produce seeds in cones or similar structures.

TAIGA

A forest of the cold, subarctic region just south of the Arctic Circle.

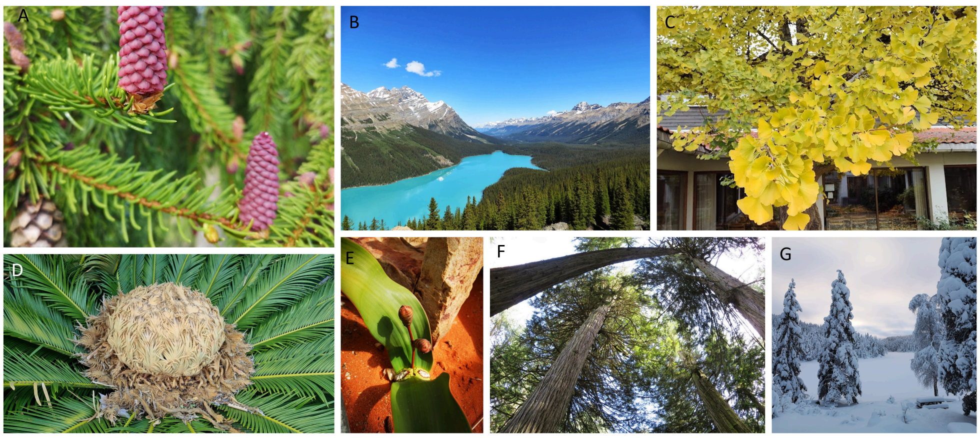

Figure 2

Figure 2

Gymnosperms around the world. **(A)** Young cones on a Norway spruce tree. **(B)** Engelmann spruce surrounding Peyto Lake near Banff, Canada. **(C)** A ginkgo, native to China, in golden fall color. **(D)** Palm-like cycads are found in the subtropics and tropics. **(E)** The unique, two-leafed *Welwitschia mirabillis* lives in the warm deserts of Namibia. **(F)** Western red cedars tower over tourists in Vancouver's Pacific Spirit Park. **(G)** Norway spruce enduring the cold and snow of Nordic winter (photos by Paal Krokene, Melissa Mageroy, and Marco Viejo).

TREES USE EPIGENETIC CHANGES TO REMEMBER THE PAST

One environmental signal that can trigger conifer memories is the temperature the baby trees experienced when the seeds were developing. Trees growing from seeds that developed at different temperatures show different timing in terms of when new needles appear in the spring (Figure 3). New needles appear earlier on trees from seeds that developed at lower temperatures, and trees from seeds that developed at warmer temperatures grow new needles later in the season. This temperature memory has been observed to last for at least 20 years, and researchers think it may last for the tree's whole lifetime [1].

Figure 3

Figure 3

Temperature is one type of signal that can cause epigenetic changes and trigger conifer memory. These two Norway spruce trees are identical twins that have exactly the same DNA code. The tree to the right (blue outline) developed at lower temperatures (18°C) and begins to grow much earlier in the spring (see the new light green shoots). The twin on the left (red outline), which developed at warmer temperatures (28°C), is just about to start growing its shoots. So, thanks to epigenetic changes, these 12-year-old trees still remember the conditions they experienced when they were babies.

GAMMA RADIATION

High-energy rays emitted from radioactive particles that causes burns and damage to DNA.

Another environmental cue that can create a memory in conifers is **gamma radiation**. The Chernobyl nuclear power plant disaster in April 1986 gave scientists a unique opportunity to understand how radiation can trigger conifer memories. Trees that grew up in an area that received high radiation from the accident look like bushes, while trees that received low to medium radiation look like normal trees. One reason for this difference could be that the varying radiation levels triggered unique epigenetic changes, by damaging the trees' DNA [2]. So far, researchers do not know the nature of these epigenetic changes.

Conifers can also make memories when an insect lays her eggs on the needles. Researchers have noticed that needles with sawfly eggs on them are eaten less by the caterpillars that emerge from the eggs. Sawflies are a kind of wasp that feeds on plants and has larvae that are very similar to the caterpillars of butterflies. When the mother sawfly lays her eggs, she cuts the needles and releases special egg proteins into the needle. The wounding and contact with these proteins signal the needles to change the way they use their DNA instructions, helping them to defend themselves [3].

Treating conifers with plant-made defense chemicals can also trigger memories. When small spruce trees are treated with plant-made defense chemicals in the fall, they are better able to defend themselves against insect attack when they are planted out in the forest in the spring [4]. (To learn more about how plant-made chemicals help conifers better protect themselves, see our previous FYM article). Like with egg laying, defense chemicals tell a conifer to change how, and how rapidly, the DNA instructions for defense are carried out in response to insect attack.

CONCLUSIONS—WHY IS IT IMPORTANT TO STUDY EPIGENETICS?

Trees remember the past—not with brains, like us, but through epigenetic changes that alter how the genetic instructions written in their DNA are carried out. There are still a lot of things we do not know about how and how long trees can remember the past. We know that various environmental cues cause different epigenetic changes and form unique types of memories. The kind of signal a tree receives, and whether it is received early or later in life, seems to affect how strong the memory is and how long a tree remembers. However, we do not yet understand how this works. For example, we still know very little about how memories created by one signal affect a tree's ability to respond to a different signal. For example, will a memory of drought affect how a tree responds to an insect attack? Does root colonization by "good" microbes, such as fungi that supply the tree with water and minerals, make a tree better (or perhaps worse) at fighting an insect attack on the needles? Because trees experience many kinds of environmental cues during their long lives, it is important to understand how different memories work together. When we have learned more about tree epigenetics, we can perhaps grow new forests that are better at dealing with climate change or recovering from insect attacks or diseases.

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ORIGINAL SOURCE ARTICLE

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REFERENCES

1. Viejo M, Tengs T, Yakovlev I, Cross H, Krokene P, Olsen JE, et al. 2023. Epitype-inducing temperatures drive DNA methylation changes during somatic embryogenesis in the long-lived gymnosperm Norway spruce. *Front. Plant Sci.* 20:1196806. doi: 10.3389/fpls.2023.1196806

2. Nybakken L, Lee Y, Brede DA, Mageroy MH, Lind OC, Salbu B, et al. 2023. Long term effects of ionising radiation in the Chernobyl Exclusion zone on DNA integrity and chemical defence systems of Scots pine (*Pinus sylvestris*). *Sci. Tot. Environ.* 15:166844. doi: 10.1016/j.scitotenv.2023.166844
3. Hundacker J, Linda T, Hilker M, Lortzing V, Bittner N. 2024. The impact of insect egg deposition on *Pinus sylvestris* transcriptomic and phytohormonal responses to larval herbivory. *Tree Physiol*. 11:tpae008. doi: 10.1093/treephys/tpae008
4. Chen Y, Puentes A, Björkman C, Brosset A, Bylund H. 2021. Comparing exogenous methods to induce plant-resistance against a bark-feeding insect. *Front. Plant Sci*. 20:695867. doi: 10.3389/fpls.2021.695867

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CONFLICT OF INTEREST: The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

YOUNG REVIEWERS

LAURI, AGE: 15

Hello, my name is Lauri and I live in southern Germany. I am 15 years old and I like climbing and playing the piano. I also like being in nature and often go cycling or hiking.

THE SPROUTS, AGES: 8–11

The Sprouts group of Young Reviewers is composed by Giosuè, Edoardo, Yuri, Flavio, Ernesto, Lorenzo, and Mattia. They attend their 3rd-5th year at the primary outdoor parental school GermogliAmo in Colonna (nearby Rome, Italy).

AUTHORS

PAAL KROKENE

I am a forest entomologist at the Norwegian Institute of Bioeconomy Research. I study conifer trees and how they defend themselves against bark beetles and pathogens. One reason I find bark beetles fascinating is that they can kill huge numbers of trees that are 100 million times larger than themselves. The beetles do not operate alone, but team up with tiny fungi called blue-stain fungi. The beetle is like a bus carrying its fungal passengers from one tree to another. In return, the fungi help the beetles break down tree defenses. When I am not working, I renovate my old house and run in the forests in Ås, where I live.

MELISSA HAMNER MAGEROY

I am a molecular plant biologist at the Norwegian Institute of Bioeconomy Research. From an early age, I have been curious about how and why things work the way they do. I also found plants fascinating, as they contribute so much to our lives: food, oxygen, shelter, medicines, etc. In my current work, I study how spruce trees defend themselves against pests by making defensive chemicals and forming memories of previous pest attacks. Not only do I find spruce trees fascinating to study, but I also enjoy walking in the spruce forest by my house and seeing, hearing, and smelling the life that abounds there. *melissa.mageroy@nibio.no