

Plant defence and communication

Reaction times

Plants can respond slowly or quickly, depending on the stimulus

Tropisms make plants grow differently in response to environmental stimuli such as light, gravity or even a fence.

Plants can also change position and react to their surroundings quickly when they need to. For example, the stomatal openings in leaves that allow gas exchange and water loss can go from closed to fully open within ten minutes. This is controlled by the surrounding guard cells taking up water by osmosis, inflating and pushing the cells apart around the pores. According to some studies, the shape of the guard cells influences the speed of opening, with the dumbbell-shaped cells of grasses permitting faster opening than the kidney-shaped guard cells belonging to other plants. The stomata can be quickly closed as well; the hormone abscisic acid helps in this case.

A striking example of rapid-fire plant movements is the release of pollen from the anthers of the white mulberry tree. These catapult-like movements can be triggered by exposure to dry air. In 2006, scientists used high-speed cameras to capture bent stamens springing straight in less than 25 millionths of a second. The force required to generate the movement comes from build-up of turgor pressure (in which the plasma membrane is pushed against the cell wall) in cells in the stamens.

Keeping in contact

Plant cells can communicate chemically

Intercellular communication – signalling between cells of the same plant – involves plant hormones, among other chemicals.

The growth factors auxin and cytokinin, for example, send conflicting messages that control the balance between growth of the main shoot and that of the branches. Auxin inhibits side-branching, while cytokinin promotes it. Other chemicals involved in cell-to-cell signalling are being identified all the time, and we now know that some types of small RNA molecules, as well as factors that control DNA transcription, are transported between plant cells.

Perhaps more surprising is that there is growing evidence that plants can have a form of chemical conversation with their neighbours. This can be mutually beneficial, such as when trees share nutrients through mycorrhizae, a symbiotic network of fungal mycelium and the plant's roots, or when plants are alerted to the presence of danger. Studies of broad beans, for example, show that plants activate their anti-aphid defences when nearby plants are being attacked. The plants emit volatile organic compounds through the air and send underground messages through the mycorrhizal network.

Plant epigenetics

Plants pass along traits they acquire during their lifetime

Epigenetics is a branch of genetics that deals with how DNA is expressed in cells: which genes are switched on or off, and if they're on, the degree to which they are active. Expression is controlled by packaging and

chemical modifications to the DNA that don't affect the genetic code itself. In humans, scientists are exploring whether the epigenetic changes that we acquire in our lifetimes – for example, as a result of eating a certain diet – can be passed on to our children.

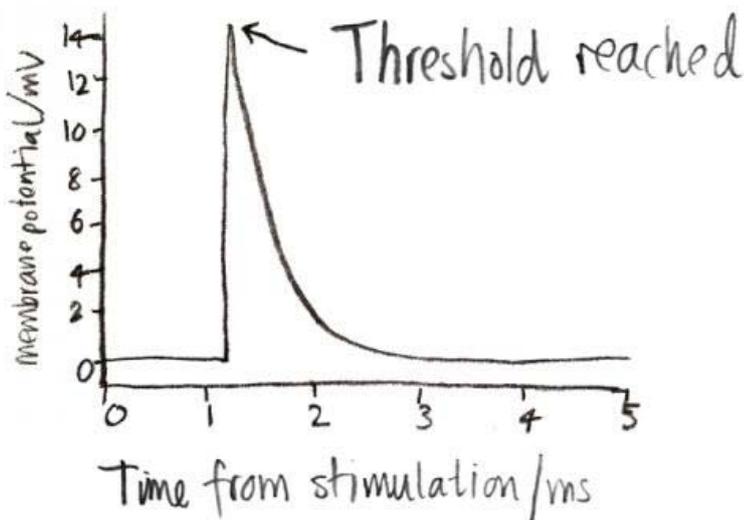
The same question can be asked of plants: do they inherit traits that their parents acquired in their lifetimes? In one 2010 study, plant biologists scrutinised the DNA of mangrove trees of the same species growing in different habitats. Near a riverside, these trees grew taller with larger leaves, while those near a salt marsh survived by staying squat and producing smaller leaves. The two groups' DNA codes were very similar, but what was different was the pattern of DNA methylation – a type of chemical modification to DNA. The scientists suggested that these epigenetic changes helped the trees to adapt to their environment more quickly than waiting many generations for evolution to occur via genome mutations and natural selection.

Other studies also have found plants that use epigenetic regulation of their traits. Genetic screenings of the cress plant *Arabidopsis* suggest it could have 130 different regulators.

Electrical signalling

Plants, like animals, use action potentials to respond to stimuli

An action potential in a venus flytrap



An action potential in a venus flytrap. The x-axis shows the time from stimulation in ms, while the y-axis shows the membrane potential in mV. CC BY NC ND Adapted from Volkov et al. (2007)

Venus flytraps are known for their ability to snap shut when an insect lands between their leaves. The mechanism behind this rapid response is not entirely clear, but scientists now know that it is controlled by electrical signals similar to those that form the nerve impulses of animals. The key to both types of electrical signal is something called an action potential – a difference in concentrations of ions between the two sides of a cell membrane.

Other plants use action potentials too – if not so dramatically. All plants produce electrical signals, which mediate functions such as recognising pollen and responding to pathogens.

A project led by Italian computer engineers is trying to categorise the electrical signals of plants and hook them up to electrical devices – creating biosensors or ‘cyborg plants’ – in order to use these signals to glean information about the environment. The idea is that because plants simultaneously process lots of different kinds of information about their surroundings, it might be a more efficient way to monitor the environment than by using different sensors for each kind.

Hardcore plants

Plants are incredibly resilient organisms, surviving fire, ice and even nuclear disasters.

Sixty-six million years ago a giant asteroid hit the Earth, killing off the dinosaurs in what’s known as the KT (Cretaceous–Tertiary) event. 80 per cent of all animal species became extinct, yet somehow plants fared much better. While the number of seed-producing plant species (gymnosperms) temporarily fell, this didn’t last long. What’s more, for flowering plants (angiosperms) there was actually an explosion of new species straight after the asteroid hit. By analysing fossils, scientists have shown that this wasn’t a one-off: plants have bounced back from extinction events faster than animals throughout our planet’s history.

Plants thrive in some of the world’s most hostile environments: from scorching deserts and high-altitude mountain ranges to the darkest depths of the ocean. They can even protect humans from destructive forces of nature. Mangrove forests, for example, act as natural buffers against tsunamis and tropical storms. Plants are incredibly resilient, and they do it all without being able to move. So how do they survive?

Burnt-out bombsites

In September 1666, the Great Fire swept through London, destroying one-third of the city and leaving behind a trail of destruction. But within days, *Sisymbrium irio*, a bright-yellow mustard plant, began to flower everywhere, thriving among the wreckage. It became known as London Rocket. The weed – and several of its cousins – would colonise London again during World War II, emerging from the ruins of burnt-out bombsites.

Fire is destructive to life, but some plants can use it to their advantage. In the USA, for example, forest fires devastate up to 2 million hectares of land every year. In the short term these fires wipe out much of what they touch, but over time they actually help plants thrive. By removing diseased plants and harmful insects, like beetles and moths, the flames ‘disinfect’ the forest ecosystem. They also remove dead or decaying matter, clearing the way for a new generation of plants and leaving behind nutrient-rich ash for them to grow in. By burning through thick canopies and undergrowth, wildfires also clear shade, providing light for new growth on the forest floor.

Some plants, like California’s giant redwood (*Sequoiadendron giganteum*), even rely on forest fires to help release their seeds. Their cones can hang on the tree for years without opening up, but when a forest fire sweeps through, the heat melts the resin that glues them shut, allowing them to open and scatter their seeds below. The trees themselves are covered with fibrous bark up to two feet thick, protecting their vital tissues from the flames.

Ice and rocks

Antarctica: the coldest, driest, and (for half the year) darkest continent on Earth. Not necessarily a place you’d expect to see much plant life, but this winter wonderland is home to a variety of ‘lower plants’ – mosses, lichens and liverworts. Even more surprisingly, certain foreign plant seeds, like chickweed (*Cerastium arcticum*) and annual bluegrass (*Poa annua*), have managed to hitch a lift to Antarctica on

visitors' clothes and boots, and establish themselves among the ice and rocks. So how do plants survive here?

Antarctica's native plants – and its successful foreign colonisers – are specially adapted to protect themselves from the continent's harsh conditions. For example, they tend to grow low near the ground and close together, maximising shelter and reducing damage from wind and ice particles. They can also photosynthesise in very cold weather, allowing them to store up energy to see them through the dark winter months. These plants are even adapted to deal with the dryness of the region, with small leaves to minimise water loss and shallow roots to avoid the permafrost – a layer of permanently frozen ground beneath the thin layer of soil. To cap it all, Antarctic plants are expert opportunists when it comes to reproduction – they are quick to produce seeds and can germinate in a small window of time if weather conditions allow.

While it's unlikely that Antarctica will suddenly become covered in rogue trees and flowers, certain intruders have already made a home there. And with climate change raising temperatures, it may be even easier for them to survive in the future.

Radioactive soil

On Monday 6 August 1945 at 8.15am, a US plane dropped an atomic bomb on the Japanese city of Hiroshima. 80,000 people were killed and the city was flattened instantly. Plants were incinerated, soils were charred, and radiation was everywhere. Experts said Hiroshima would be barren of life and nothing would grow for 70 years.

But they were wrong. Among the rubble of a city virtually wiped off the map, 170 'survivor trees' stood defiantly – broken, and badly burned, but alive. One, a weeping willow (*Salix babylonica*), was just 370 metres from the centre of the blast. Soon new buds were sprouting again, and today the trees stand under the care of the Hiroshima government. As well as the trees, bright red Canna flowers started springing up among the debris just a month after the bomb was dropped, bringing the survivors hope and courage.

Plants can withstand a great deal of radioactivity. In fact, the world's worst nuclear disaster – the explosion at the Chernobyl nuclear power plant in Ukraine in 1986 – holds a similar tale of plant resilience, despite far higher levels of radiation than in Hiroshima. Yet plants are thriving. Trees, bushes and vines have taken over the town's abandoned streets, despite the highly radioactive soil.

To understand how these plants have survived, scientists grew some soybean plants just 5 km away from the remains of the power station, and then analysed their beans. They turned out to be very different to beans collected from other plants further away, where radiation levels were much lower. The high-radiation beans weighed less, took up water more slowly, and contained much higher levels of a protective protein that binds to damaging heavy metals – like the radioactive caesium-137 in the ground near Chernobyl.

The plants have clearly protected themselves from Chernobyl's radioactive soil, but we don't yet understand how these changes help. Nor do we know why plants can seemingly shrug off deadly radiation while humans can't. One theory is that plants 'remember' prehistoric conditions on Earth, when the atmosphere was full of harmful radiation. More research is needed, but if we can understand how plants respond to radiation, scientists could start to modify crops to withstand – or even remove – nuclear contamination.