Volatiles may help calm farming stresses

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Unlike most animals, plants can't get up and move away when there's something unpleasant in their immediate environment. As a result, they are subjected to a barrage of stressful conditions. They must therefore have the capacity to cope with relatively large changes in their environmental conditions.

The source of the stress might be:

- Biotic – such as insect pests, bacteria, viruses and so on; or,
- Abiotic which includes extremes of temperature, drought, flooding, high light, soil salinity and air pollution, to name a few.

In Australia, we have perhaps more than our fair share of abiotic stresses, and it is predicted that the conditions which promote these stresses will get worse in the coming years. Abiotic stress results in decreased growth rates, poor yield, reduced reproduction and even death.

Natural defense mechanisms

Fortunately, plants have developed a complex network of defense mechanisms to protect themselves against stresses. One of these mechanisms is production of compounds called reactive oxygen species (ROS).

As the name suggests, these compounds are highly reactive; they contain oxygen

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and include compounds such as hydrogen peroxide, superoxide, singlet oxygen and hydroxyl radicals. These compounds are always present in plants and play an important role in plant biochemistry and physiology, particularly in photosynthesis.

Under stress conditions, they act as signaling molecules, initiating signal cascades to warn the plant that it is in danger. These signal cascades elicit a variety of responses, including activating genes which produce defense compounds. But ROS production is a double-edged sword – ROS can also cause a lot of damage if accumulation is not tightly controlled.

When the delicate balance is upset, runaway ROS accumulation causes large scale cell death and tissue necrosis. This is clearly exemplified by responses to some biotic attacks – for example, fungal and bacterial leaf sport diseases.

In these cases, the pathogens prefer to feed on dead tissues, so the accumulation of ROS is encouraged by the pathogen. In some other cases, the ROS buildup and resulting cell death is a strategy by the plant to kill infected cells and stop the spread of pathogens which require living cells to survive, such as viruses.

This is called a hypersensitive response, and is a specialised defense mechanism used by a resistant cultivar.

Unintended hypersensitive response can also be initiated by some abiotic stresses, for example, air pollution from ozone.

When plants suffer high light stress, they accumulate lots of ROS at photosynthetic membranes; in extreme cases, this causes photobleaching of the chlorophyll and tissue death. Under temperature stress, plant membranes undergo oxidation, which also results in production of reactive oxygen species (lipid peroxides and hyperoxides).

Tobacco plants don't normally produce the volatile isoprenoid compound isoprene. By genetic engineering, a gene can be inserted that allows them to produce isoprene. Here, the genetically modified plant bearing the isoprene synthase gene is growing in tissue culture. (Photo Claudia Vickers)

When tobacco plants are genetically modified so that they can produce isoprene, they are protected from damage when they are fumigated with ozone. The plant on the left, which is emitting isoprene, shows very little tissue necrosis. But the plant on the right, which is not emitting isoprene, shows extensive tissue necrosis which is typical of ozone-mediated damage. (Photo Violeta Velikova)

In fact, many (and possibly all) abiotic stress conditions result in the accumulation or reactive oxygen species. When stresses are combined, for example, high light + high temperature, very large amounts of ROS can accumulate.

Volatile compounds

It has been known for many years that plants produce volatile compounds. Some of these are very well known as scents. Examples are the monoterpenes limonene and pinene, which are made by lemons and pines trees, respectively. Many of these compounds are produced via the isoprenoid pathways, and are known as 'volatile isoprenoids'.

Of all the volatiles, one – isoprene – is produced in by far the largest proportion (about 50 per cent of total volatiles). There is a huge variety of other volatile isoprenoids, and new ones are constantly being identified.

The roles of volatiles in biotic interactions, for example, as insect attractants and repellents, have been well-documented.

But recent research has suggested that volatile isoprenoids are also involved in abiotic stress responses. For example, isoprene has been shown to provide protection from high light and temperature stress and ozone pollution, and monoterpenes also protect against heat and high light.

Leaf from *Populus tremula*, a poplar species which emits isoprene. (Photo Claudia Vickers

How plants are protected

We have developed a theory to describe how these volatile isoprenoids protect plants.

It appears that the volatile compounds affect the buildup of ROS, and supply an extra control level to stop runaway accumulation. Since most abiotic stress conditions result in production of ROS, this mechanism allows for the varied collection of protective effects afforded by volatile isoprenoids.

In Australia, our native plant species produce a huge variety of volatiles – think of the smells of eucalyptus and maleleuca. Eucalyptus species can also produce very large amounts of isoprene. These volatiles react with other gases in the atmosphere in many complex ways.

Particles called 'secondary organic aerosols' are commonly produced from these

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reactions – Fritz Wendt originally identified these particles as the source of the famous ‘blue hazes’ that hover over many forests in the world.

These hazes have lent their names to many places, including the Blue Mountains in NSW and the Smoky Mountains in southeastern US.

It is possible that the relatively high production of volatile isoprenoid compounds in Australian species contributes to the relative ability to withstand stressful conditions.

Volatiles and crops

What does this mean for agricultural crops?

For a start, a better understanding of how plants react to abiotic stresses will help us to predict the effect of climate change on different plant species. Some plants produce these volatile compounds others don’t, and it is reasonable to assume that various species of plants will respond differently to climate change depending on whether or not they produce these volatiles.

This also applies to non-crop species. Knowing which species produce volatiles, which volatiles they produce, and how those volatiles protect the plant will be important for these predictions.

Secondly, we can also use this knowledge to help us to produce better stress-resistant crop species in the future. This may be by classical breeding or by targeted genetic modification.

This article is based on research conducted and published by a team of scientists working at Essex and Lancaster Universities in England. Dr Claudia Vickers has returned to Australian and is continuing this area of research at the Australian Institute for Bioengineering and Nanotechnology at The University of Queensland. ■

Under normal growth conditions, tobacco plants that have been genetically modified to produce isoprene (on the left) look the same as the control plants which do not emit isoprene conditions (on the right). (Photo Claudia Vickers)

Many temperate forest species, such as these poplar trees, produce large amounts of isoprene from leaves. Isoprene emission is temperature-sensitive, and is highest in the warm summer months. (Photo Claudia Vickers)