Making crops cry for help

Plants attacked by hungry herbivores can release chemicals that attract their assailants' predators. Could these responses be exploited to develop environmentally friendly pest-control strategies? John Whitfield investigates.

JOHN PICKETT

Double act: maize can be protected from pests by planting 'intercrops' that attract predators.

Plants cannot run from trouble, but neither do they lie down and surrender. As well as producing a variety of noxious chemicals to deter herbivores, they can enlist help from higher up the food chain, releasing volatile chemicals that attract predators to eat the creatures that are eating them.

Some experts in crop protection believe it may be possible to tap into these lines of communication to provide non-toxic forms of pest control. But a great deal of research into the chemistry, genetics and ecology of these botanical cries for help will be needed to bring such strategies to the market. "It's definitely in the long-term category, but a very far-thinking company could put some effort into this," says Jonathan Gershenzon, who works on the genetics of plant defences at the Max Planck Institute for Chemical Ecology in Jena, Germany.

When plants are attacked by pests, they release volatile organic chemicals that attract predators and parasitoids — insects that lay their eggs inside other insect larvae, which are then devoured from within. The production of these volatiles was first noticed more than a dozen years ago[1]. Subsequent studies have revealed that predators and parasitoids learn to associate the volatile chemicals with the presence of their prey and hosts, and that plants usually produce the signals as a response to chemicals in the pest species' saliva, rather than to mechanical damage[2,3]. Their production can also be induced by a plant hormone called jasmonate[4].

The simplest approach would be to spray the volatile chemicals directly onto crops, or to induce their production using jasmonate. And in 1999, when Jennifer Thaler of the University of California, Davis, sprayed Californian tomato fields with jasmonate, she found that parasitism of *Spodoptera exigua* caterpillars by *Hyposoter exiguae* wasps increased twofold[5].

Crying wolf

Despite this success, many researchers remain sceptical of the value of such simple spraying regimes. "You don't want to make the mistake of attracting a parasitoid without a host being present," says Consuelo De Moraes of the US Department of Agriculture's Center for Medical, Agricultural, and Veterinary Entomology (CMAVE) in Gainesville, Florida. Farmers do not like to wait for an infestation to become established before applying pesticide sprays. But crying wolf by spraying preventatively would lead to the learned association between the plant volatiles and the availability of host species being broken — and the chemicals would soon lose their attractant power.

HOLT STUDIOS

Fatal attraction: spraying crops with the plant hormone jasmonate attracts wasps that parasitize *Spodoptera exigua* caterpillars.

Instead, many experts believe a better option will be to produce plant varieties that respond more strongly to attack by pests. "We are not there yet, but we shall be heading in that direction in the next few years," says James Tumlinson, a chemist at the CMAVE. Already, his team has identified a wild strain of cotton that produces up to ten times more parasitoid-attractants than domesticated varieties[6]. Over the past century, says Tumlinson, ignorance of this subtle chemistry seems to have resulted in plant breeders presiding over a decline in cotton's ability to call for help.

Such traits could be introduced into crops by conventional plant breeding. And in the Netherlands, that approach is being considered to protect the country's flower-growing industry. Marcel Dicke of Wageningen University is working with plant breeding companies and the Dutch Technology Foundation to develop varieties of the daisy *Gerbera* that are more resistant to herbivorous mites and more attractive to predatory mites. Dicke aims to gain a better molecular understanding of the volatiles involved, and how they are produced. Some of the enzymes involved in volatile manufacture are known[7,8], and it ought to be possible to speed up the process of selecting plants to be used for breeding by screening cultivars for enzymatic activity. This would bypass laborious tests involving exposure to pests.

Dicke also intends to use DNA microarrays to determine patterns of gene expression in plants responding to herbivore attack. His Wageningen team is just one of several groups turning their attention to the model plant *Arabidopsis thaliana*, in the hope that it will yield insights that can be applied to crops.

Volatile response

Such studies might suggest ways of genetically engineering plants to boost their production of volatiles in response to herbivore attack. "In principle, it shouldn't be difficult," says Gershenzon, who plans to study maize plants in which genes suspected to be involved have either been knocked out or engineered to produce larger quantities of their products. But although genetic engineering would probably be more efficient than conventional breeding, those gains would have to be balanced against public suspicion of plant genetic modification.

There is also much work to be done to understand how parasitoids and predators interpret the complex cocktails of volatiles produced by plants attacked by herbivores. Varieties of maize, for example, release blends with a dozen or more major and minor chemical components[9]. Which of these are key to the parasitoid response is unclear. Also unknown is how parasitoids learn to associate plant volatiles with their hosts. "It may not matter what the plant releases," suggests Gershenzon, "as long as it's distinctive, and released quickly in large amounts."

So far, industry has not come forward with large sums of money to invest in the necessary research. "If I were a plant breeder, I'd be saying 'show me that it works in the field'," says Ian Baldwin, who also works at the Max Planck Institute in Jena.

But Baldwin and his colleague André Kessler are working to address this scepticism. Last month, they reported on studies of wild tobacco, *Nicotiana attenuata*, in Utah[10]. This plant is attacked by caterpillars of the moth *Manduca quinquemaculata*, the eggs of which are eaten by the bug *Geocoris pallens*. By studying the volatiles released by the tobacco plants and applying them individually and in combination to the stems of plants growing in the field, Kessler and Baldwin identified three compounds that increased predation of *M. quinquemaculata* eggs by *G. pallens*. A blend of the three also reduced egg-laying by the moth. From these experiments, the researchers estimated that, by releasing volatiles, tobacco plants could reduce the number of herbivores attacking them by more than 90%.

If you're a farmer trying to use natural enemies, it's important to think about where they're coming from.

One especially hopeful sign is that *G. pallens* is not a fussy eater, and will prey on a wide range of herbivorous species. To Baldwin, this suggests that we may not need to understand the fine ecological details of every plant–herbivore–predator interaction to make use of plant volatiles in crop protection.

But Baldwin's studies fall short of showing that crops that produce more volatiles will attract enough extra predators to give effective and economically viable protection from pests. That would depend on there being a nearby reservoir of predators and parasitoids to rush to the plants' defence.

This is a real concern in intensive agricultural systems, where crops are grown in monocultures in enormous fields that may lack the necessary biodiversity. "If you're a farmer trying to use natural enemies, it's important to think about where they're coming from," says Thaler, who is now at the University of Toronto. "Stealing them from your neighbour's field isn't going to work." Indeed, some researchers suggest that the success of approaches to pest control that use plant–predator communication may depend upon the existence of 'set-aside' areas, hedgerows or unplanted field edges, to harbour populations of predators and parasitoids.

Mix and match

In the developing world, where agriculture does not function so much like an industrial process, this thinking can be extended to develop mixtures of crops that can be grown together to encourage predators and parasitoids. In East Africa, the staple crops of maize and sorghum are under constant attack from stem-borer caterpillars, slashing yields by up to 80%. African farmers have little or no access to chemical pesticides, but it is relatively easy for them to adapt their practices to plant and harvest mixtures of species.

SPL

Pest busters: herbivores such as this white spider mite can be curbed by their predatory relatives.

With this in mind, researchers from the International Centre of Insect Physiology and Ecology in Nairobi, Kenya, and Britain's Institute of Arable Crops Research (IACR) at Rothamsted in Hertfordshire, have designed a mix of plants dubbed 'push–pull'. Around fields of maize and sorghum they plant species that the stem-borers like to eat, pulling the pests from the crop. Among the crops, they grow species that repel stem-borers and attract parasitoids, including one species, *Melinis minutiflora* or molasses grass, that releases parasitoid-attractants even when untouched by pests. In such fields, the number of plants infested with stem-borers drops by more than 80%, and the number of parasitized larvae rises almost fourfold[11].

Following these successful Kenyan trials, says John Pickett of the IACR, push–pull planting is gaining popularity. The government in Uganda plans to promote it, Malawi is interested, and farmers in Ethiopia have taken it up of their own accord. There is also interest from China, India and countries in South America.

Such strategies may not yet be applicable in the developed world, but they show that plant–predator communication can be exploited in pest control. "There are a lot of unanswered questions, but there's a lot of potential," says Gershenzon. ■

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