# GROWTH INDUSTRY

To learn the chemical language of plants, Ian Baldwin has built up a German research empire that engineers seeds — and a field station in the Utah wilderness to grow them.

**BY ALISON ABBOTT**

In late spring 1988, Ian Baldwin was driving through the dessicating heat of the Utah desert in his rickety old VW microbus. The young researcher, from the State University of New York (SUNY), Buffalo, was searching for a native species of the tobacco plant as well as a place to sleep for the night. When he pulled up at the Desert Inn Ranch, he encountered a different form of wildlife. A posse of ferocious dogs flew out of the gate, puncturing his car tyres with their teeth. Behind them was rancher Herb Fletcher, cradling a submachine gun.

Baldwin was terrified. But when Fletcher called the dogs off, Baldwin slipped, very cautiously, out of the bus. Fletcher smiled — "He had a wonderful smile," recalls Baldwin — and invited him in. The scientist and the old rancher quickly bonded over their shared interest in natural history. It was the start of a firm friendship — and the opening of a new era in Baldwin's research life, one that has helped propel him into a dominant position in the burgeoning field of chemical ecology, the study of the chemical signals between plants and other organisms in the environment.

Rooted and unable to flee, plants have evolved many ingenious ways of repulsing their enemies, from generating noxious chemicals in their leaves to emitting complex, volatile bouquets to attract predators that will pick off the plant's attackers[1]. It is a highly sophisticated chemical language undetectable by the human nose and largely undeciphered by science. But if and when it can be understood, it might open the way to modifying plants' signals to give them stronger protection, or to developing environmentally friendly mimics of natural signals as alternatives to herbicides.

In his efforts to understand this language, Baldwin has embarked on a project unique in its ambition and scale, carried out along what he calls "the longest lab corridor in the world". Working in Jena, Germany, where he is a director of the Max Planck Institute for Chemical Ecology, he and his team develop powerful genetic tools to systematically knock out, or knock down, genes involved in making the chemical signals. Then they observe the effects by growing the modified plants in the wild — 8,844 kilometres away, next to the Utah ranch. The fastest journey from Jena to the field station takes 27 hours. The researchers have little choice, however. In Germany, with its populist aversion to anything genetically modified, such trials cannot proceed.

## COCKTAILS AND CRAZINESS

High-profile papers roll out of Baldwin's institute with regularity. One published in *Science* in August[2] showed that the plants, when nibbled by herbivorous insects, can change the ratio of isomers of some of their signalling molecules specifically to attract predators of the leaf-eaters. And although Baldwin deliberately keeps his distance from applications, the agricultural industry studies his results attentively. It wants to learn how plants, or mixtures of plants, might be persuaded to produce the best cocktails of volatile emissions for their own defences.

"Ian Baldwin is like a madman," says Ted Turlings, a plant scientist at the University of Neuchâtel in Switzerland, with some awe. "He doesn't stop working, day and night, and he lets nothing get in his way. He sets up a field station in an area where no one would think of going, builds himself a complete molecular tool set for his tobacco species, and sets out with purpose to get permission to use transgenic plants."

For Baldwin, though, the approach is the only way to learn how a particular plant has evolved to survive in the real, stressful world of harsh weather and hungry insects. "It seems to me it would be madder not to do it this way," he says.

With his humorous and low-key manner, and customary jeans, plaid shirt and baseball cap, Baldwin, 52, shows no sign of frenzy. The son of academic historians in Baltimore, Maryland, he decided early on that the ivory tower was not for him. "My parents are medievalists and live in the eleventh century," he says. "I wanted to know what the rest of the world did for a living." During high school and college he worked in his spare time as a fish cleaner, landscaper, truck driver, an auto and tractor mechanic, a logger and tree climber, and even a maple-sugar producer. And some of these skills became useful in unexpected ways.

As an undergraduate majoring in chemistry and biology at Dartmouth College in Hanover, New Hampshire, he became an informal assistant to Jack Schultz, one of the earliest pioneers of chemical ecology. Schultz, who was studying

S. DOERING/ARGENTUR FOCUS

**Ian Baldwin looks after *Nicotiana attenuata* plants at one end of the world's longest lab corridor, his greenhouse in Jena, Germany.**

forest canopies but couldn't stand heights himself, was as attracted to Baldwin's tree-climbing skills as to his precocious ability in the chemistry lab. In a joint experiment published in *Science* in 1983[3], the pair claimed that chemicals from leaves that had been ripped to mimic insect damage could travel through the air to neighbouring plants and change their biochemistry in a way that wards off further insect attack. Their 'talking trees' notion was dismissed by many plant scientists as a fanciful over-interpretation of results.

**BALDWIN'S TREE-CLIMBING SKILLS IMPRESSED AS MUCH AS HIS PRECOCIOUS ABILITY IN THE CHEMISTRY LAB.**

Burned by the reaction, Baldwin decided to play it safe for his PhD studies at Cornell University in Ithaca, New York, and instead researched the more mainstream internal signalling pathways within plants. The favoured plant model in the Cornell lab was *Nicotiana sylvestris*, a species of tobacco native to Peru. But when it came to extending this work into the field, Baldwin, by now on the tenure track at SUNY, decided to switch to a similar species native to the United States. His hunt for *Nicotiana attenuata* in Utah led to the fateful encounter with Fletcher.

Baldwin and his family spent the next seven summers with Fletcher, who regaled them with stories about the area's violent recent history. Fletcher had been brandishing a weapon at his first meeting with Baldwin because a neighbouring family of polygamists had been attacking him and his land. A mobster friend eventually put a stop to it.

If, during those summers, Baldwin learnt new things about how humans defend themselves, he learnt even more about plant defences. Fletcher would drive Baldwin around the 1,300-square-kilometre property to point out small clumps of *N. attenuata* he had spotted while out ranching, and Baldwin would use them in experiments to find out, for example, how the plants activated chemical defences against herbivores.

### THE HUNT FOR HOTSPOTS

After a brush fire in 1992, Baldwin discovered that the seeds of *N. attenuata* germinate only when activated by components of wood smoke penetrating the soil around seeds. Then they suddenly flourish in the temporarily nutrient-rich, herbivore-free, post-fire environment. He learnt to locate natural populations of *N. attenuata* more efficiently by chasing lightning strikes — "or simply phoning the fire department and asking them where they spent money". One of his earliest series of experiments was designed to understand the costs and benefits to the plant of one particular defence mechanism — producing nicotine in its roots and then pumping the toxin up into its leaves — in the field.

Plant biology had been transformed in 1990 with the discovery that the hormone jasmonic acid could induce volatile signalling. Baldwin immediately set out to see if it could also induce nicotine production, and found that it could. So he synthesized an artificial version of the hormone that he could inject into the soil around plant roots. His complex set of experiments involved four populations of *N. attenuata*, each with more than 1,000 plants, spread over a 100-kilometre loop. He found that among plants pretreated with jasmonate to artificially induce a level of nicotine defence, those that were not attacked produced less seed than those that subsequently were attacked, but not ravaged, by herbivores[4]. With this work, he proved a point about plant defence that had previously only been assumed — that using defences only when needed is an evolutionary advantage, because it maximizes benefits and minimizes cost.

More than a decade after his ill-received 'talking trees' *Science* paper, Baldwin was itching to return to the theme. The work had been vindicated by the early 1990s when several scientific groups working on crop plants had established that such plant volatiles not only exist, but stimulate responses from other species — pathogens, herbivores, herbivore-eating carnivores, and perhaps other plants as well. But most of the work had been done under laboratory conditions.

Baldwin wanted to understand plant biology in the real world. He particularly wanted to explore the volatile chemicals that plants exude, using genetic manipulation to take apart the machinery involved in making them. He was convinced that the desert-dwelling *N. attenuata* would make an ideal model because it has evolved such an array of mechanisms to survive severe environmental stresses including fire, herbivores and drought.

What wasn't yet available for *N. attenuata*, however, was the toolkit necessary for genetic engineering. One was already being assembled for *Arabidopsis* — the favoured study subject of lab-based plant biologists, but one that Baldwin regarded as "a boring weed of no use to ecological evolution research". He wanted to have the same for his *N. attenuata* — but he knew it would be expensive and take many years.

That didn't discourage the Max Planck Society in Munich, which recruited him in 1995. Following the reunification of Germany in 1990, the society was obliged to extend its network of research institutes into former East Germany, and it took the opportunity to add exciting areas of research and recruit more foreign directors. The society wholly bought into Baldwin's vision, and made him a founding director of the Max Planck Institute for Chemical Ecology in Jena. All Max Planck directors are given generous, guaranteed funding and time to develop long-term projects without having to apply for grants, making Baldwin's dream possible.

Baldwin now has a formidable institute employing more than 50 researchers, students and technicians to develop the chemical, as well as genetic tools to mimic or block signalling pathways.

Not even the might of the Max Planck Society could help him realize one part of his original vision — to stage field trials of genetically modified plants native to Germany. "Even if you do get approval, the German government now requires the GPS positioning of all field trials with transformed plants to be posted on the web — so every single trial is destroyed by activists," he says.

**SUNGLASSES AND iPODS ARE FORBIDDEN AT THE FIELD STATION TO ENSURE PEOPLE AVOID THE RATTLESNAKES.**

In the United States, the work is arduous but doable. The team in Jena engineers seeds and sends them to the US Animal and Plant Health Inspection Service in Rockville, Maryland, where they are inspected and sent on to the field station in Utah. This season, Baldwin's team planted out 4,000 seedlings for around 36 studies on topics ranging from plant–pollinator interactions to how plants allow their roots to be colonised by microbes. "This is really a lot of backbreaking work," says Baldwin.

M. KALLENBACH/MAX PLANCK INST. FOR CHEMICAL ECOLOGY

**In Utah, 8,844 kilometres from their German lab, Baldwin and his team study genetically modified plants.**

Life at the field station is tough in other ways. Brush fires spread "faster than you can run", says Baldwin. In 2005, a fire spotted on the horizon sent a dozen or so scientists running for their lives. Aware that their station has an explosive tank of propane fuel, they tore away in vans. (The fire shifted direction before reaching the station.) Baldwin admits to being "tyrannical" about safety. In a region shared with deadly animals such as the sidewinder rattlesnake, he forbids iPods and sunglasses — "people have to be able to hear and see snakes" — and no one is allowed to wander around the desert alone. It is an hour's rough drive to the nearest hospital. Everyone must learn how to change a tyre on the vans.

### LIFE IN THE WILD

Nature can add to their troubles in other ways. This year, for example, an elaborate series of experiments designed to study how the empoasca leaf hopper, a herbivore, recognizes and interacts with its host plant went to waste because the leaf hopper didn't show up.

But results continue to flow. One of Baldwin's most colourful papers, published in February this year[5], probes the dilemma of plants that need to attract pollinators while remaining inconspicuous to herbivores. *Nicotiana attenuata* normally flowers at night, emitting the volatile benzyl acetone to attract hawk-moths. Unfortunately, hawk-moth larvae are also herbivores, and the moths often leave their eggs on the leaves as they pollinate. When the plants become infested, the team found, they shut down production of benzyl acetone and open their flowers at dawn when the moths are gone. They are then pollinated by hummingbirds. Using a series of genetically modified strains, Baldwin's team showed how the oral secretions from the munching hawk-moth larvae trigger the dramatic switch in flowering time.

Baldwin's research has inspired attempts to develop new crop strains that could be practical for farmers in poorer countries who can't afford lots of pesticides and herbicides, says John Pickett, director of Rothamsted Research in Harpenden, UK, a historic agricultural research centre. The centre is working with some agricultural companies on field trials in the United States and United Kingdom of crops genetically modified to amplify chemical signals that plants make when they are under attack. Details are currently confidential, he says, but "we'll have big announcements in the next year or two".

Back in Jena, at the end of the 2010 season, Baldwin is planning next year's experiments with genetically altered strains designed to have elevated or suppressed emissions of volatile signals, which he labels as the 'screamers' or the 'mute'. He will investigate how single screamers planted among a colony of mutes, for example, might affect herbivore or predator behaviour.

Right now, Baldwin is 8,844 kilometres away from the next experiment at his barren, hostile field site. Human relations in the region are now a lot tamer. Relations between plants and insects, though, are as wild as ever. ■

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