Interactions of plants with their environment

Plants influence everything from food chains to climate change. Yet we know little about the traits that allow plants to survive and adapt to their habitat or to a warming planet. We are a long way from being able to harness these adaptations for our own benefit. Our failure to understand these traits is in part due to the split of biology research into molecular–cellular and ecological–evolutionary disciplines. A new generation of plant scientists is needed to realize the full potential of plant genetics.

PLANTS AND THE ENVIRONMENT

Plants form the basis of most food chains on the planet. To pass on their genes, plants must find mates, avoid being eaten and compete for resources in an ever-changing environment — all while being rooted to the spot. They have evolved a myriad of strategies to deal with these environmental challenges.

Most adaptation strategies are chemical, many involving the production of secondary metabolites, such as alkaloids and steroids, which we, in turn, rely on as the basis of our pharmacological recipe book. Some 100,000 secondary metabolites have been discovered thus far, and technological advances will probably see this number double in the next decade.

The environment shapes plants, but plants also influence the environment. They store carbon, fix nitrogen and produce oxygen[1]. They shape weather patterns, provide flood defence, purify water, provide food, and offer solace and inspiration.

With nearly 7 billion humans affecting the environmental composition of the planet, however, plants are being forced to function under conditions outside their recent evolutionary experience, and it is unclear what the knock-on effects will be. Modelling studies are beginning to unravel the links between our changing environment and ecosystem health, but more research is needed to inform legislation.

A GENETIC LEGACY

Plant genetics will provide some of the answers. Plant genomes have been shaped by hundreds of millions of years of natural selection, and so carry a genetic record of how plants have adapted to previous environmental change. Our wanton destruction of plant species means that this biological legacy is disappearing, however, just as we are developing the tools to understand and use it.

The plant-genomics revolution began when thale cress (*Arabidopsis thalania*) became the first plant to have its genome sequenced. Since then, it has been found to contain more 'coarse-grained' genetic diversity than was thought, with individual plants sometimes differing by hundreds of genes[2]. Despite its approximately 500,000 single-nucleotide polymorphisms (SNPs), Arabidopsis contains just six major metabolic groupings, suggesting that only a few variable genetic regions result in metabolically distinct phenotypes[3]. Understanding these sources of genetic variation should shed light on how plants adapt to environmental change.

Although high-throughput methods and reduced sequencing costs have made such analyses more accessible, how the nucleotides interact to produce the cornucopia of substances found in plants is still unknown. Studies of these substances — proteomes and metabolomes — are still in their infancy, and a major challenge will be the knitting together of these studies to understand how the environment shapes the translation of genomes into adaptive phenotypes.

Plants share close links with other organisms, such as microbes, insects and herbivores, all of which generate signals that can alter plant function and phenotype. Signals from certain insects trigger the production of new plant structures (galls) and molecules from the saliva of plant-eating insect larvae can elicit the host plant to produce a new phenotype, including new defense traits, physiological properties and even a new type of flower.

Endophytic microbes, including bacteria and fungi, can promote plant growth and boost mineral availability. Although DNA fingerprinting has shown that most plants harbour vast microbial communities, the majority resist laboratory culture, and so their exact function remains a mystery and new techniques are needed for further investigation[4].

Studies of these plant interactions have already led to practical applications. The ability of the tumour-causing Agrobacterium to transfer genes to plants is regularly used to genetically engineer plants with new traits. The promise of plants engineered for pathogen resistance, and of harnessing the services of microbial mutualists in crop plants, has yet to be realized, however, largely because little is known of the full spectrum of microbes encountered by plants in their natural environment.

A QUESTION OF TIMING

Plants operate on different timescales to most organisms, with some living for thousands of years. Successful reproduction is often a matter of timing, with plants 'choosing' when to switch from a vegetative to a reproductive state. Although the

Key experiments exploring the solutions to environmental challenges hidden in plant genomes are underway at the Max Planck Institutes in Cologne, Marburg, Ploen, Tubingen and Jena. The training of field biologists in molecular science is underway at the Max Planck Institute for Chemical Ecology, where students have used transformed native plants to elucidate how a sophisticated mixture of floral chemicals helps plants to get what they need from their pollinators (Kessler, D. *et al.* *Science* **321**, 1200–1202, 2008).

- The laboratory-based study of plant genetics cannot fulfil its potential until it includes reference to the natural environment in which plants evolved.
- Genetically-equipped field laboratories and molecularly-trained field biologists are needed to explore the links between plants and their environment, and use them for practical application.
- Harnessing certain plant traits could help produce high-yield crops suitable for a warming world.

influence of climate change on these transitions is starting to be understood, how plants tell the time or become dormant to escape environmental stresses is less clear. Genetics and hormones are known to influence dormancy, but little is known about the precise nature of environmental cues used to break it.

Gene-expression data also indicate that plants can assess the genetic quality of a potential mate long before committing resources to reproduction. So improved understanding of the genetics of adaptive environmental responses will aid understanding of the qualities that influence mate selection[5].

GENETICS IN THE FIELD

Plant DNA studies are beginning to tease apart the links between genetics and the response to environmental change; however, to bear fruit, thousands of plant genomes require sequencing not only in constant well-defined laboratory conditions, but also in their natural habitat[6].

This will require additional expertise from engineers, chemists, bioinformaticians and mathematicians, to name but a few. The unhappy divorce that split biology departments also demands redress, with the training of a new generation of field biologists who can combine natural-history skills with genomic and molecular science. Alongside this, field stations are needed that can facilitate phenotyping of genetically defined and manipulated plants in the habitats in which they evolved. Researchers also need to produce man-made ecosystems that match their natural counterparts in terms of ecosystem services.

If the Earth is to support 9 billion people by 2050 — as is predicted — crop plants will need to tolerate climate change, be able to survive with less fertilizer and water, and become more efficient at fixing carbon and producing nutritious yields. Although native plants tick some of these boxes, plant genomics is still some way from being able to engineer species that tick them all.

above | Swamp, mountain and desert; plants have adapted to many diverse environments. However, deforestation, particularly in the Amazon, threatens this biological legacy (bottom right).

below | Plants use a sophisticated mixture of floral chemicals to entice pollinators.

Top right and bottom images: Danny Kessler

➟ For references see pages 38 and 39