Clockwork plants

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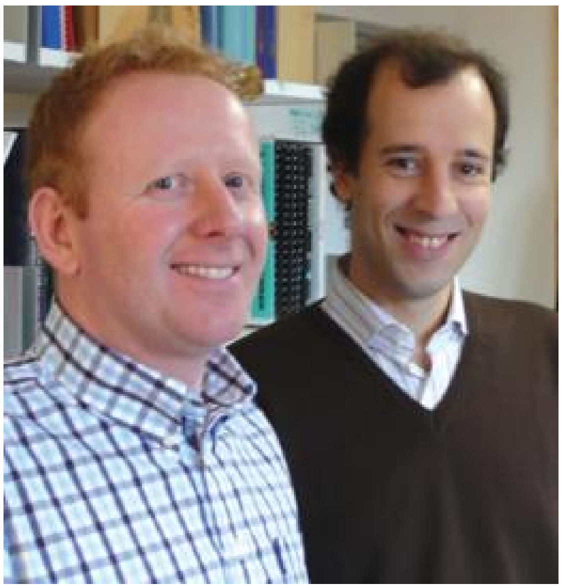

Dr Alex Webb (left) Dr Jorge Gonçalves

(PhysOrg.com) -- How do plants tell the time and the passing of the seasons? Plant scientists are enlisting the help of engineers in their quest to uncover the rhythms of circadian clocks.

Ever since the French scientist Jean-Jacques d'Ortous de Marian discovered in the 1700s that patterns of leaf movement follow a 24-hour clock, our understanding has been growing of the in-built clocks that plants and animals live by. 'Circadian' clocks are important for living organisms to maintain the rhythms of life and have evolved independently at least four times: in blue-green algae, fungi, animals and plants. Desynchronisation of the clock with the environment has adverse effects - all too familiar for those who have experienced the unpleasant feelings of disorientation during 'jet lag', where the crossing of time zones disrupts the functioning of the circadian system.

Plants, which are literally rooted to the spot, use their circadian clocks to help them adapt to the night/day cycles of light and temperature caused by the rotation of the Earth, whether it is preparing for day-time photosynthesis or preventing night-time water loss. Seasonal events like fruiting and leaf drop are also governed by the clock. Increasing our understanding of the molecular mechanisms at work therefore has wide implications: from the possibility of selective crop breeding, through increasing ecosystem productivity, to control of atmospheric CO_2.

Dr Alex Webb and colleagues Drs Antony Dodd and Michael Gardner in the Department of Plant Sciences have been working to understand the intricate processes of the daily clocks of plants. Recent findings have taken a surprising turn, one that is benefiting from the application of engineering principles through a collaborative project with Dr Jorge Gonçalves in the Department of Engineering. The research, funded principally by the Biotechnology and Biological Sciences Research Council (BBSRC) and the Engineering and Physical Sciences Research Council (EPSRC), is combining engineering control theory and plant cell biology, with the result that novel tools are being developed to understand oscillating biological systems.

Regulating rhythm

A circadian clock comprising 10-20 genes that form interconnecting feedback loops of gene expression is present in every cell of the plant. Initiated by changes in light and temperature, these linked loops of gene expression control a huge amount of plant biology; plants grow rhythmically, with rhythms of metabolism and even rhythms of photosynthesis, and a third of all plant genes are switched on and off within a 24-hour cycle.

How can the activity of so few genes have such a pervasive effect on the biology of plants? It seems that the level of calcium, a key regulator of cellular events in all organisms, is crucial. In plant cells, the concentration goes up and down with a 24-hour rhythm governed by the plant circadian clock.

Dr Webb and colleagues have discovered that what causes the rhythms of calcium to change is a molecule called cyclic ADP ribose (cADPR). By studying Thale Cress (Arabidopsis thaliana), the researchers found that the concentration of cADPR is regulated by the circadian clock genes and that fluctuations in calcium levels are caused by cADPR binding to protein channels in the internal membranes of plant cells, permitting calcium to enter the living part of the cell.

Loops within loops

The next discovery was a surprise: not only is cADPR regulated by the circadian genes but many circadian-regulated genes are themselves regulated by cADPR. This led to the intriguing hypothesis that the clock genes cause 24-hour oscillations of both cADPR and calcium, which in turn regulate the level of activity of the clock genes as part of a new loop in the plant circadian clock - a sort of loop within a loop. The problem was how to test this hypothesis.

This is where the skills of the engineers allowed an advance that could not be achieved using biological techniques alone. By creating mathematical simulations of how a plant's circadian system might behave, they were able to compare these simulations with the behaviours of genetically modified plants with altered cADPR levels. The results, published in December in Science magazine, demonstrate the existence of this feedback loop.

Running fast and slow

One intriguing feature of these findings is that by interfering with cADPR signalling the plant clock might be forced to run faster or slower. Dr Webb and Professor Andrew Millar at the University of Edinburgh found that mutant laboratory strains of plants with clocks that run fast or slow grow to half the size of neighbours with a correctly functioning clock. Remarkably, when put in artificial light/dark cycles that matched the 'expectations' of the mutant clocks, the mutant plants grew better than normal healthy plants. It seems therefore that matching a clock to the local day-length conditions could have beneficial effects on plant growth.

By making a plant clock run faster for short daylight hours or slower for long daylight hours, interesting opportunities might arise in crop development for bioenergy and agricultural output. This might in fact have been the accidental outcome of the selective breeding of barley by farmers thousands of years ago, when they began moving the crop further northwards, where summer day-length is longer. Working with colleagues at the National Institute of Agricultural Botany in Cambridge, Dr Webb is investigating the circadian clock of different barley varieties to see if this might be true.

New mathematical tools

Meanwhile, the collaboration between the engineers and plant biologists is continuing. One spin-off has been the development of new types of mathematical tools to understand complex systems.

The tools used by control theory engineers have been very successful at designing a large number of technological systems, from the simple cruise control required to maintain the speed of a car, to more complex controls that allowinherently unstable aeroplanes to fly. When looking at biology, however, it's clear that new mathematical tools are needed to analyse biological systems. These systems are highly complex, dynamic in space and time, have many components that are often used to perform multiple tasks, often involve feedback with clear non-linear behaviours, and, perhaps most challenging of all, biological data are typically expensive, lengthy to obtain and noisy. To deal with the complexities of biological systems, engineers Dr Gonçalves and Dr Guy-Bart Stan are developing new theoretic mathematical approaches to study such complex non-linear systems. As collaborations between biologists, engineers and mathematicians become more common, it seems that the world of biology is changing. And Engineering Departments too are changing: increasingly, engineers are turning their expertise towards biological systems such as plant growth, gene expression, cancer, cognition and the beating of the heart.

Provided by University of Cambridge (news : web)

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