Secret of plant geometry revealed

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Researchers at the University of Leeds have discovered how plants set the angles of their branches.

While the other principle features governing the architecture of plants such as the control of the number of branches and positioning around the main shoot are now well understood, scientists have long puzzled over how plants set and maintain the angle of their lateral branches relative to gravity.

The mechanism is fundamental to understanding the shape of the plants around us: explaining how, for instance, a young Lombardy poplar sends its branches up close to the vertical while an oak sapling's spread is much flatter.

Dr Stefan Kepinski, senior lecturer in the University of Leeds' Faculty of Biological Sciences and lead author of a paper in the journal *Current Biology* that gets to the bottom of the mystery, said: "We began working on this after a train commute into Leeds. Looking out of the window, I was struck by the fact that the way we recognise tree and other plant species from a distance is largely informed by the angle at which their branches grow.

"These characteristic angles are all around us and the same thing is happening underground; different varieties within species often have very distinct root-system architectures that are determined mainly by the growth angle of lateral roots," Kepinski said.

The apparently simple puzzle of how a plant sets and maintains these angles in its architecture is complicated by the fact that the angle of root and shoot branches is not usually set relative to the main root or stem from which they grow but relative to gravity. If a plant is put on its side, these branches will begin a phase of bending growth, known as gravitropism, that reorientates them back toward their original angle of growth relative to gravity.

In the case of the main root or stem, which grows upright, the mechanism is well understood: gravity sensing cells called statocytes detect that the plant has been tilted, prompting an increase in the movement of a growth-regulating hormone called auxin to the lower side of the shoot or root and driving upward growth in the shoot and downward growth in the root. When growing vertically again, the statocytes stop sending more auxin to one side than the other and the bending growth stops.

The conundrum for the researchers was that many of the angles in branch and root architectures are at an angle to gravity, rather than being completely upright. Scientists did not understand how plants were able to set, relative to gravity, the particular non-vertical angle of growth for their branches—known as their "gravitropic set-point angle"—that determines their architecture.

Dr Kepinski said: "We have found that another growth component—the 'anti-gravitropic offset'—counteracts the normal gravitropic growth in these lateral branches. This offset mechanism sustains growth on the other side of a branch from the gravity-sensitive growth and prevents the branch from being moved beyond a set angle to the vertical. It turns out that this countervailing growth is also driven by auxin, the same hormone that causes gravity responsive growth on the lower side of the branch."

Branches that are growing close to the vertical have a weak anti-gravitropic offset, while in branches that are growing out at shallow angles away from the vertical the anti-gravitropic offset is relatively strong.

Dr Kepinski added: "You can compare it to the way a tank or paddle steamer is steered. If you want to go one direction, you speed up the track or paddle on the other side. If you want to straighten up, you balance the speeds—or in our case the 'speed' of growth on either side of the branch. In a given non-vertical branch, the anti-gravitropic offset is constant, while gravity responsive growth increases in magnitude according to how far the branch is away from the vertical, generating a robust system for maintaining a whole array of branch angles."

The Leeds team proved the presence of the offset by using a clinostat, which slowly rotates a plant growing on its side, thereby withdrawing a stable gravity reference and enabling the researchers to monitor the anti-gravitropic offset mechanism working unopposed by a coordinated gravitropic response. Under these conditions they observed that shoot and root branches displayed an outward bending growth, away from the main root and shoot that would normally be masked by the interaction with gravity-sensitive growth.

Dr Kepinski said: "The angle of growth of branches is an exceptionally important adaptation because it determines the plant's capacity to capture resource above and below ground. Depending on what sort of soil a plant is in, it might be beneficial to be foraging for nutrients in the top soil or to be going deeper. Similarly, in the shoot, a plant might gain an advantage from having more steeply pitched branches to avoid shading from neighbouring plants. Until now, nobody really knew how non-vertical growth angles, referenced to gravity like this, were set and maintained."

He added: "These insights are important for breeding and biotechnological approaches to crop improvement because breeders and seed companies want to be able to alter plant architecture to optimise the performance of crops. For example, lateral root growth angle has been shown to be critical for increasing nutrient uptake in both broadleaf and cereal crop species. Our findings provide tools and approaches to help meet these crop improvement challenges."

The team used the flowering plant *Arabidopsis thaliana* (thale cress), as well as pea, bean and rice plants in their experiments, observing the same results.

Kepinski expects the same mechanism to be observed in larger plants and young tree seedlings. In older trees, the mechanisms driving gravity sensitive growth in woody tissues are different to those in non-woody plants. Nevertheless, Kepinski says the same general principles may apply.

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