Researchers find without microtubule guidance, cellulose causes changes in organ patterns during growth

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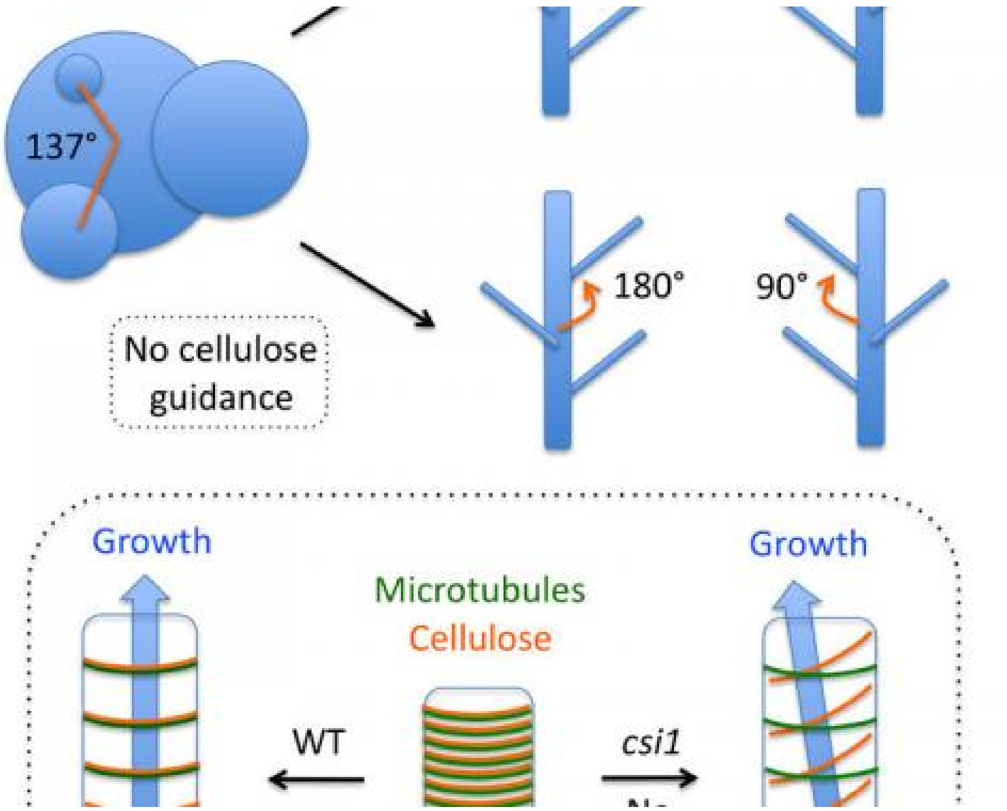
Arabidopsis wild type plants (left) grow successive organs at an angle of 137 degrees, while the pom2-4 mutant (right) exhibits a divergence angle of 184 degrees due to unguided cellulose growth. Credit: MPI of Molecular Plant

(Phys.org) —Mathematics is everywhere in nature, and this is illustrated by the spiral patterns in plants such as pine cones, sunflowers or the arrangement of leaves around a stem. Most plants produce a new bud at 137 degrees from its predecessor, and this mathematical precision leads to observable helices. Normally, the relative position of organs does not change during growth, because the stems grow straight. But if the connection between the cytoskeleton and cellulose is removed, the cellulose fibres are synthesized in a tilted fashion and the stems start to twist. As a result, the angle between successive flowers disappears, and is instead replaced by other mathematical patterns that prove to be equally robust. Incidentally, this work suggests that in the absence of regulation, all plant stems should twist rather than grow straight.

Already Leonardo da Vinci realized that organs on stems are far away from being randomly distributed, and one doesn't need to be a scientist to recognize such elaborate systems. The basic phyllotactic patterns are "opposite", with two organs growing on opposite sides of the stem on the same level, and "alternate", where the organs grow in a spiral around the stem. The spiral pattern has the advantage that plans can make the most of sunlight.

Many scientists have investigated how such patterns can emerge, notably highlighting the contribution of plant hormones. However, plants are also growing objects and despite constant changes in shape due to growth, patterns can still be recognized in adult plants. Does this mean that growth has no effect on plant architecture? What is the contribution of growth in the stability of plant patterns?



Normally the linker-protein CSI1 keeps the cellulose-synthesizing proteins on track and ensures straight stem growth. Without CSI1 the cellulose fibres tilt and cause stems twisting, which in turn changes organ pattern. Credit: Olivier Hamant

Staffan Persson and his team from the Max Planck Institute of Molecular Plant Physiology focus on plant cell walls. The main component of cell walls is cellulose, which is essentially a long chain of sugar molecules. The motile enzyme complex that makes cellulose from sugar is guided by the cytoskeleton. "While we were experimenting with plants in which the connection between the microtubuli and the cellulose synthesizing proteins is hindered, we noticed that the stems of the plants don't grow straight anymore," Persson explains. Instead, the stems started to twist and always showed a subtle right-hand torsion.

The scientists assumed that the cause for their observation might actually be the unoriented cellulose fibres. Without the guidance of the microtubuli the cellulose fibres become more and more tilted and, thereby, cause the torsion of the stem, which in turn dislocates the organs around the stem. The group of Olivier Hamant from the École normale supérieure (ENS) in Lyon, France, started taking exact measures on Persson's plants. "While wild type Arabidopsis plants show a constant divergence angle of 137.5 degrees between adjacent siliques, we observed angles of either 90 degrees or 184 degrees on our plants," first author Benoit Landrein describes their results. Plants which produced organs in a clockwise orientation showed a divergence angle of 90 degrees. If the organ formation was counter-clockwise scientists measured a constant 184 degrees. "The most surprising thing for us was that one mathematical pattern was replaced by another one," says Hamant and Persson. While the torsion of the stem does disrupt the spiral pattern, another, equally robust pattern is established.

To prove that it is really the cellulose fibres that are causing the torsion of the stem, the scientists conducted another experiment. This time they measured plants which, due to a mutation, produce significantly shorter cellulose fibres. The torsion of the stem was indeed not as pronounced, which was in accordance to their previous results.

Because the mechanisms behind patterning were largely unknown, developmental studies have largely neglected the impact of growth on morphogenesis, i.e. the development of organs and tissues. "Our findings thus shed a new light on plant development by including and understanding the contribution of growth in patterning," Hamant adds. It also highlights how a microscopic event, the disconnection between cellulose and cytoskeleton, can lead to major macroscopic consequences, a novel plant architecture. With these new results and the newly gained understanding about the interplay between growth and patterning, the time has now come to investigate morphogenesis in all its complexity.

More information: Landrein, B. et al. Impaired Cellulose Synthase Guidance Leads to Stem Torsion and Twists Phyllotactic Patterns in Arabidopsis
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