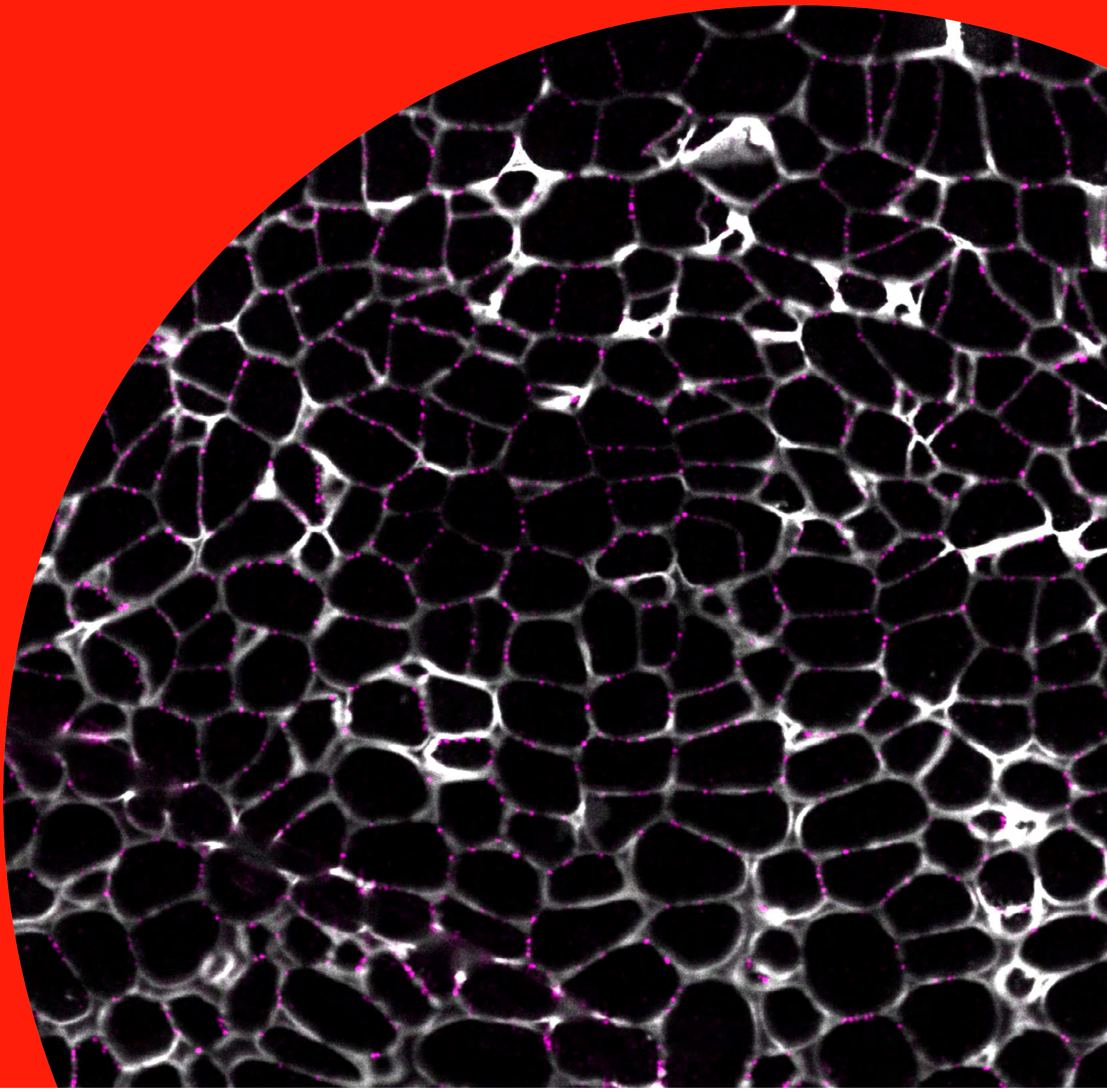
UK Plant Biomechanics Conference 2025

28 March 2025
The Studio, Leeds, UK



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Conference Programme

10:00 AM - 10:20 AM	**Registration and Arrival Refreshments**
10:20 AM - 10:30 AM	**Welcome**
10:30 AM - 11:15 AM	**Invited Speaker** **Yoel Forterre**: Physics of rapid motion in plants: lessons from the Venus flytrap and Mimosa pudica
11:15 AM - 12:15 PM	**Short Talks 1** **11:15 AM - 11:35 AM Jodie Armand**: Live 3D imaging sheds new light on the mechanics of stomatal movement in Arabidopsis thaliana **11:35 AM - 11:55 AM Elise Muller**: Dual role of the FERONIA sensor in regulation of plant mechanical properties and growth **11:55 AM - 12:15 PM Zoe Nemec Venza**: Cells at the root surface use mechanical cues to activate edge-based growth control in Arabidopsis
12:15 PM - 1:30 PM	**Lunch**
1:30 PM - 2:00 PM	**Invited Speaker** **Suruchi Roychoudhry:** Integrating angle-dependence into root gravitropism
2:00 PM - 2:30 PM	**Flash Talks** **2:00 PM - 2:06 PM Dražen Zanchi:** Plant tendril writhing under external load : where Kirchhoff meets Lockhart **2:06 PM - 2:12 PM** Amir Ohad: Twining Plants Capitalize on Circumnutations to Assess Mechanical Properties of a Candidate Support, and Initiate a Thigmotropic Twining Response **2:12 PM - 2:18 PM** M Bastien Dauphin: From Nano to Macro: An Optogenetic Approach to Studying Plant Cell Wall Integrity **2:18 PM - 2:24 PM** Sabrina Gennis: The Efficiency of the Phloem Sugar Transport and Its Geometrical Dependency **2:24 PM - 2:30 PM** Adele Coppel: How wind-associated mechanical signals regulate plant immune response?
2:30 PM - 4:00 PM	**Afternoon Break and Poster Session**
4:00 PM - 5:00 PM	**Short Talks 2** **4:00 PM - 4:20 PM Marilena Ronzan**: Investigation of the structural and mechanical properties of Geraniaceae awns and their role in dispersal **4:20 PM - 4:40 PM Euan Smithers**: Understanding the Biomechanics of Plant Tissues: Where to Place a New Cell Wall **4:40 PM - 5:00 PM Laurence Wilson:** The carnivorous plant Genlisea harnesses active particle dynamics to prey on microfauna
5:00 PM - 5:15 PM	**Closing Remarks**
5:30 PM - 6:30 PM	**Meet for Drinks** Hoist House, 5 Wellington Pl, Whitehall Rd, Leeds, LS1 4AP

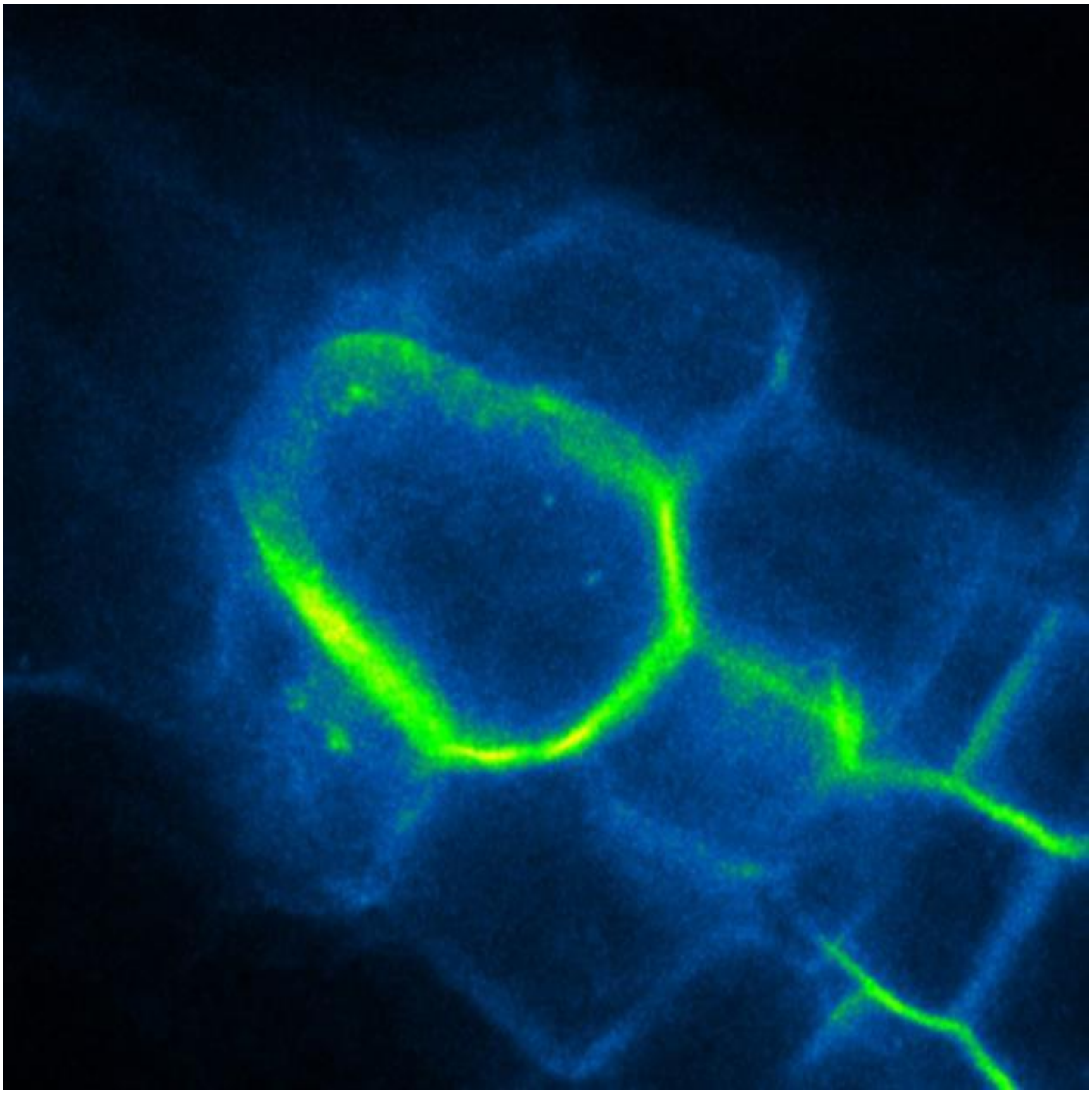
Invited Talks

Integrating angle-dependence into root gravitropism

Dr Suruchi Roychoudhry[1], Marta Del Bianco[1], Harry Taylor[1], Chris Wolverton, Stefan Kepinski[1]
[1]University Of Leeds, United Kingdom

Invited Speaker: Suruchi Roychoudhry, March 28, 2025, 13:30 - 14:00

Research on plant gravitropism has been dominated by two main ideas: that gravity is perceived through the sedimentation of starch-rich plastids within specialised gravity-sensing cells (Starch-statolith hypothesis), and that tropic growth is driven by auxin asymmetry across the graviresponding organ (Cholodny-Went hypothesis). Our recent work on gravity-dependent, non-vertical growth in lateral organs in Arabidopsis, has highlighted the importance of a third, even older concept in gravitropism: angle-dependence. However, the mechanistic basis of how statolith sedimentation, and eventually Cholodny-Went driven auxin asymmetry, translates into angle-dependent gravitropic behaviour remains unexplored. Here, using a combination of live cell vertical confocal imaging with time lapse tracking software, we characterise for the first time the dynamics of gravisensing in the columella of the Arabidopsis primary roots. We observed that statolith sedimentation across individual tiers of columella cells occurs according to the angle of displacement from the vertical axis. We also demonstrate how statolith sedimentation leads to angle-dependent PIN3/7 polarisation in specific columella domains. We show that different PINs/columella tiers play distinct and non-redundant roles in establishing the asymmetric auxin gradient at different angles. Our findings provide a fundamental framework to further explore the mechanisms that regulate angle dependent gravitropic responses in both primary and lateral organs, with major implications for engineering crop architecture.



Physics of rapid motion in plants: lessons from the Venus flytrap and Mimosa pudica

Yoel Forterre[1]
[1]Aix-Marseille Université, France

Invited Speaker: Yoel Forterre, March 28, 2025, 10:30 - 11:15

Plants have evolved unique mechanisms to generate fast movements in the absence of muscles. Understanding these mechanisms is important not only in biology, but also in engineering for biomimetic applications. In this talk, I will discuss the physics of these "green machines" using two emblematic fast plant movements: the trap closure of the carnivorous plant Venus flytrap and the rapid bending of the pulvinus of Mimosa pudica. I will show that both plants have found original ways to upscale conventional osmotic mechanisms based on water transport across cell membranes.

Short Talks

Investigation of the structural and mechanical properties of Geraniaceae awns and their role in dispersal

Marilena Ronzan[1], Stefano Mariani[1], Luca Cecchini[1], Carlo Filippeschi[1], Silvia Dante[1], Nicola Pugno[2,3], Barbara Mazzolai[1]

[1]Bioinspired Soft Robotics Laboratory, Italian Institute of Technology, Italy, [2]Laboratory for Bioinspired, University of Trento, Italy, [3]School of Engineering and Materials Science, Queen Mary University of London, United Kingdom

Short Talks 2, March 28, 2025, 16:00 - 17:00

The Geraniaceae family has attracted considerable attention due to the hygroscopic properties of its seed dispersal units, known as awns. These structures, which vary in form across the family, are sterile extensions of the mericarp and can absorb and release atmospheric moisture. This moisture absorption causes the awns to coil and uncoil, a movement that aids in seed dispersal. While much research has focused on the mechanisms behind this coiling, there is limited understanding of how the anatomical features of the awns contribute to their function as dispersal units. To address this gap, this study compares the awns of two species from the Geraniaceae family, Pelargonium appendiculatum (L.f.) Willd. and Erodium gruinum (L.) L'Her., which exhibit similar coiling behaviors but differ in structural characteristics. A multidisciplinary approach, incorporating both structural and biomechanical analyses, was used to explore these differences and their potential impact on dispersal. From our investigation we observed that the dispersal potential is strictly related to structure and biomechanical properties of the awns, given the different results per species. The results of this analysis have important implications in understanding plant dispersal, particularly in identifying the parameters involved in the process, and its evolution in the Geraniaceae family.

Dual role of the FERONIA sensor in regulation of plant mechanical properties and growth

Elise Muller[1], Stéphanie Drevensek[1], Arezki Boudaoud[1]
[1]Ecole Polytechnique, France

Short Talks 1, March 28, 2025, 11:15 - 12:15

Response to mechanical stress exerted on the plant cell wall is actively mediated by wall integrity sensors. If impaired sensing was associated to wide-spread defects, mechanisms transducing mechanical stresses to growth control are poorly understood. We thus focus on the role of the integrity sensor FERONIA, as well as of the downstream kinase MARIS, in plant morphogenesis.

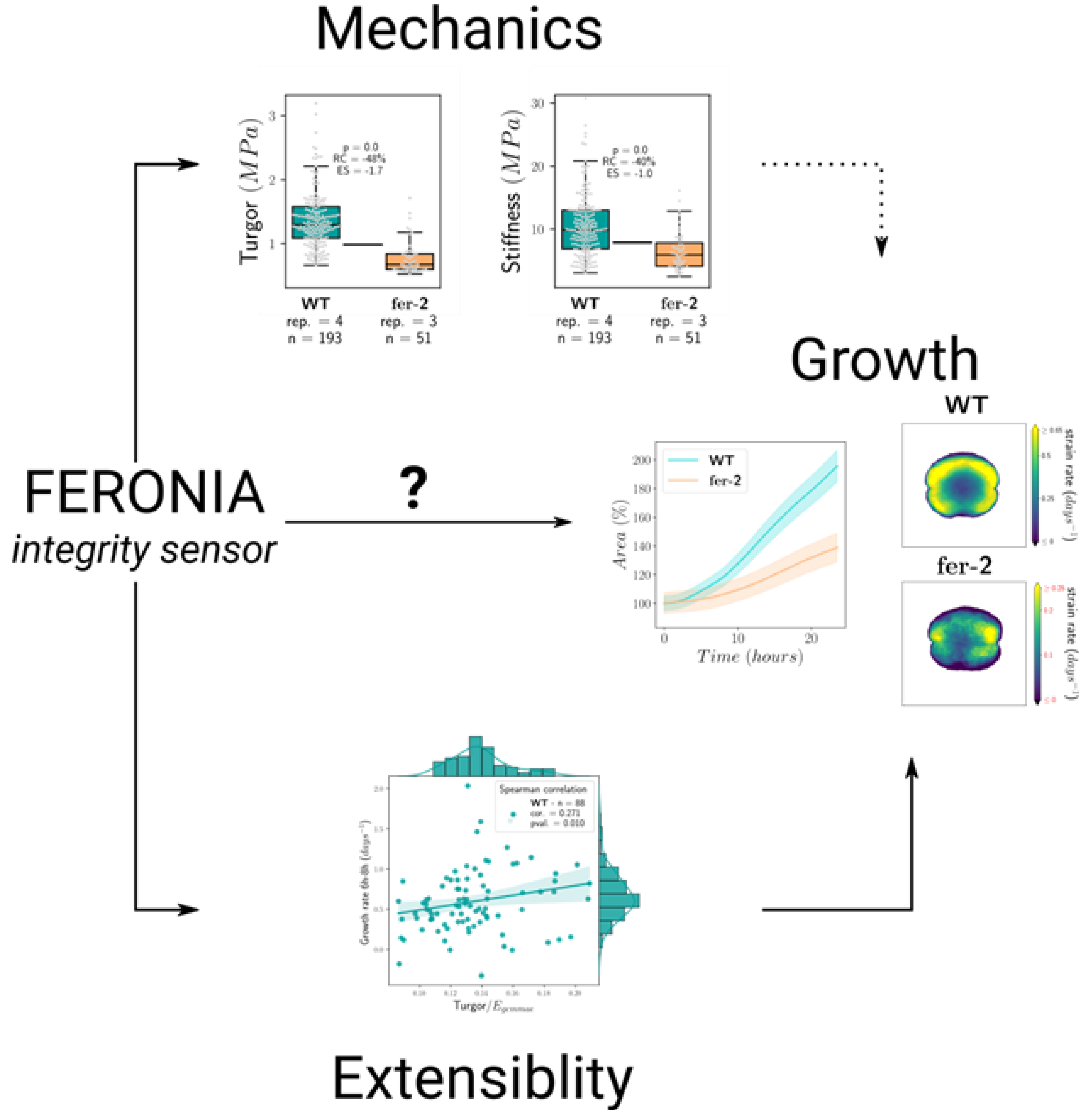
We use Marchantia polymorpha as a model system and take advantage of its low genetic redundancy and its simple organization to analyse its early morphogenesis in a high-throughput way thanks to a microfluidic device (Laplaud et al., 2024).

FERONIA is known to be a versatile growth regulator. In the context of Marchantia early morphogenesis, we demonstrated FERONIA to promote growth and to be crucial for growth spatial patterning. Indeed, compared to wild-type, feronia loss-of-function mutant early growth is delayed and more localized to the stem cell regions.

Additionally, we probed plant mechanical properties thanks to osmotic steps, giving evidence that FERONIA promotes a high turgor and a high cell wall stiffness. FERONIA is as well part of mechanical properties spatial patterning regulation. However, thanks to correlations with growth data, we concluded that mechanical regulation cannot fully explain the growth regulation by FERONIA.

Therefore, thanks to mechanical perturbations of the system by osmolytes treatments, coupled to modelling, we postulate that FERONIA regulates growth through extensibility modification, in response to the plant mechanical state.

Altogether, our work deciphers the contribution of integrity sensing as a mechanical properties regulation and an extensibility regulation.


Mechanics
Turgor (MPa)
3
2
1
p = 0.0
RC = -48%
ES = -1.7
WT
rep. = 4
n = 193
fer-2
rep. = 3
n = 51
Stiffness (MPa)
30
20
10
p = 0.0
RC = -40%
ES = -1.0
WT
rep. = 4
n = 193
fer-2
rep. = 3
n = 51
Growth
WT
fer-2
$Area$ $(\%)$
200
180
160
140
120
100
0
10
20
$Time$ $(hours)$
strain rate $(days^{-1})$
≥ 0.65
0.5
0.25
≤ 0
≥ 0.25
0.2
0.1
≤ 0
FERONIA
integrity sensor
?
Spearman correlation
WT - n = 88
cor. = 0.271
pval. = 0.010
Growth rate 6h-8h $(days^{-1})$
2.0
1.5
1.0
0.5
0.0
0.10
0.12
0.14
0.16
0.18
0.20
Turgor$/E_{gemmae}$
Extensiblity

Cells at the root surface use mechanical cues to activate edge-based growth control in Arabidopsis

Dr Zoe Nemec Venza[1], Nathan German[1], Annamaria Kiss[1], Simone Bovio[1], Charlotte Kirchhelle[1]
[1]Laboratoire Reproduction et Développement des Plantes, École Normale Supérieure de Lyon, France

Short Talks 1, March 28, 2025, 11:15 - 12:15

For the development of multilayered organs, plants need to coordinate cell growth between layers. To do so, internal cells and cells at the organ surface need to acquire different properties by integrating positional and lineage-based information. Can mechanical cues act as positional signals to differentially regulate gene expression and cell growth? To address this question, we are using Arabidopsis lateral roots, where the epidermal layer is initially covered by the root cap, but becomes exposed to the organ surface after root cap death. RabA5c is a RabGTPase needed for directional growth of root cells (Kirchhelle et al. 2016, 2019) and is only activated in epidermal cells following root cap death. Using a combination of root cap mutants and time-lapse imaging, we show that RabA5c activation follows root cap cover. However, ablations experiments show that root cap presence is not sufficient to repress RabA5c, suggesting that this effect is mediated by the mechanical action of the root cap. Our model, based on the mechanical characterization of covered and uncovered cells, predicts higher cell wall tension in the epidermis after root cap death, and we showed experimentally that increasing cell wall tension with osmotic treatments or medium stiffness results in an increase in RabA5c levels.
Overall, our data illustrates how cells at the organ surface use mechanical signals to regulate their growth by activating RabA5c, thus enabling growth directionality.

Understanding the Biomechanics of Plant Tissues: Where to Place a New Cell Wall

Dr Euan Smithers[1], Mahwish Ejaz[1], Leo Serra[1], Sarah Robinson[1]
[1]Sainsbury Laboratory, University Of Cambridge, United Kingdom

Short Talks 2, March 28, 2025, 16:00 - 17:00

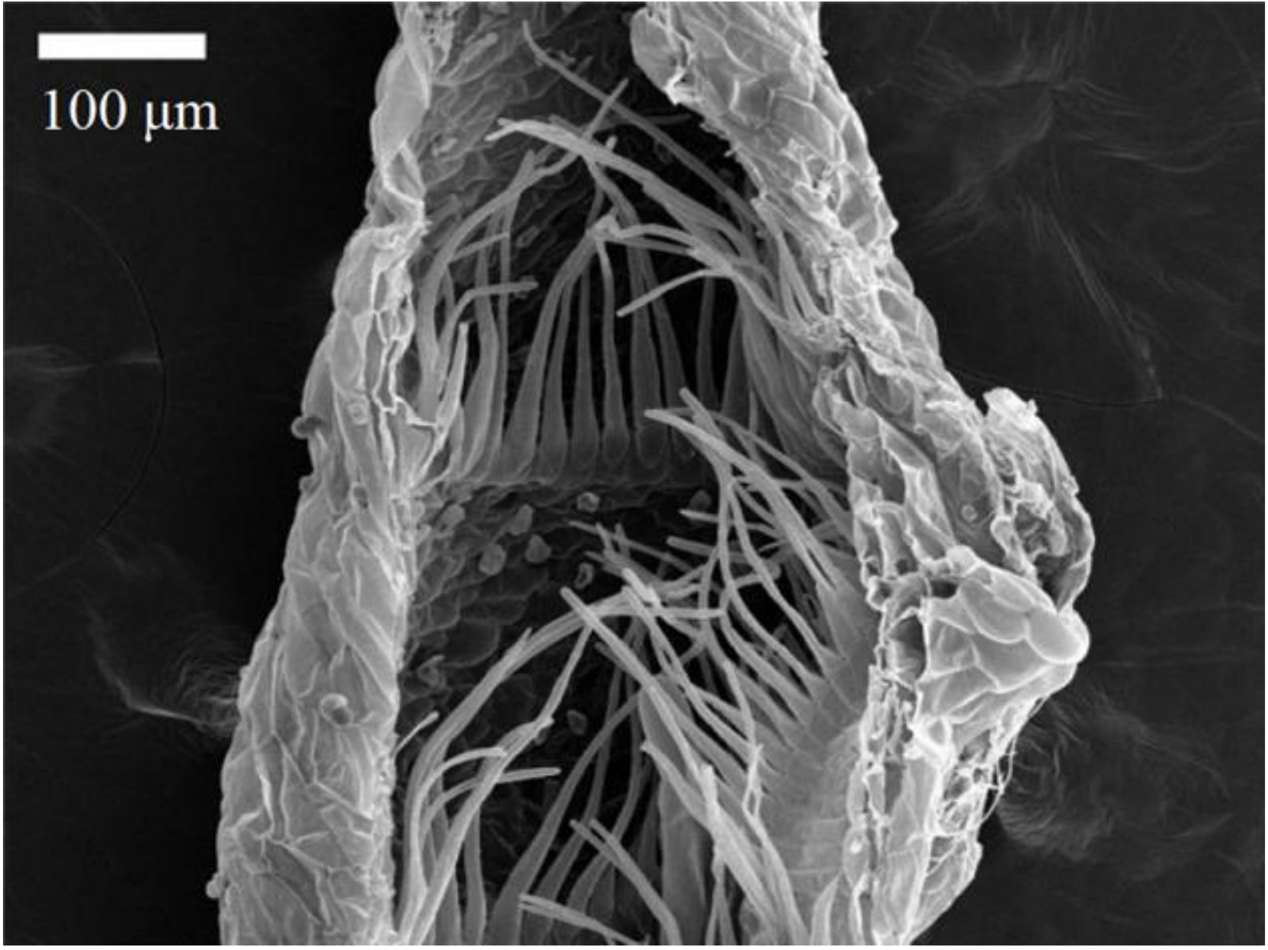
How would you build a plant? Where to place the cell walls? Does this even matter? Due to turgor pressure, plant cell walls must resist substantial tensile stresses, and if not managed properly, they can lead to structural damage or an ineffective use of resources. Since plant cells are rigidly connected to one another, to resist this mechanical stress, precise control over the placement of new cell walls is vital for developing effective and efficient tissues. To explore how plants manage these stresses, we use interdisciplinary methods, such as mechanical perturbations on live tissues using an extensometer and performing finite element inflation simulations of different deformations. For this purpose, we have built up and improved existing modelling software to simulate plant tissues in 3D efficiently and with multiple layers. Through such methods, we have investigated the consequences of cell shapes and tissue structure across multiple scales. Our findings offer new insights into the role of cell division patterns, the prevalence of 3-way junctions (staggered like bricks in a wall), and why plant cells take certain shapes like rectangles. This research advances our understanding of how plants sense and respond to mechanical forces in their environment.

The carnivorous plant Genlisea harnesses active particle dynamics to prey on microfauna

Dr. Laurence Wilson[1], José Martín-Roca[2], C. Miguel Barriuso G.[2], Raúl Martínez Fernández[2], Camila Betterelli Giuliano[3], Ronjing Zhang[4], Chantal Valeriani[2]
[1]University of York, United Kingdom, [2]Universidad Complutense de Madrid, Spain, [3]Elvesys—Microfluidics Innovation Centre, France, [4]University of Science and Technology of China, China

Short Talks 2, March 28, 2025, 16:00 - 17:00

Carnivory in plants is an unusual trait that has arisen multiple times, independently, throughout evolutionary history. Plants in the genus Genlisea are carnivorous and feed on microorganisms that live in soil using modified subterranean leaf structures (rhizophylls). A surprisingly broad array of microfauna has been observed in the plants' digestive chambers, including ciliates, amoebae, and soil mites. I will discuss what physics can tell us about carnivory in Genlisea. It functions as a 'bacterial ratchet'; human-made versions of these structures have been studied in the soft/active matter community for nearly 20 years, but this is (to our knowledge) the first known naturally-occurring example. We show, through experiments and simulations, that Genlisea exploit active matter physics to 'rectify' bacterial swimming and establish a local flux of bacteria through the structured environment of the rhizophyll toward the plant's digestion vesicle. In contrast, macromolecular digestion products are free to diffuse away from the digestion vesicle and establish a concentration gradient of carbon sources to draw larger microorganisms further inside the plant. Our experiments and simulations show that this mechanism is likely to be a localized one and that no large-scale efflux of digested matter is present.

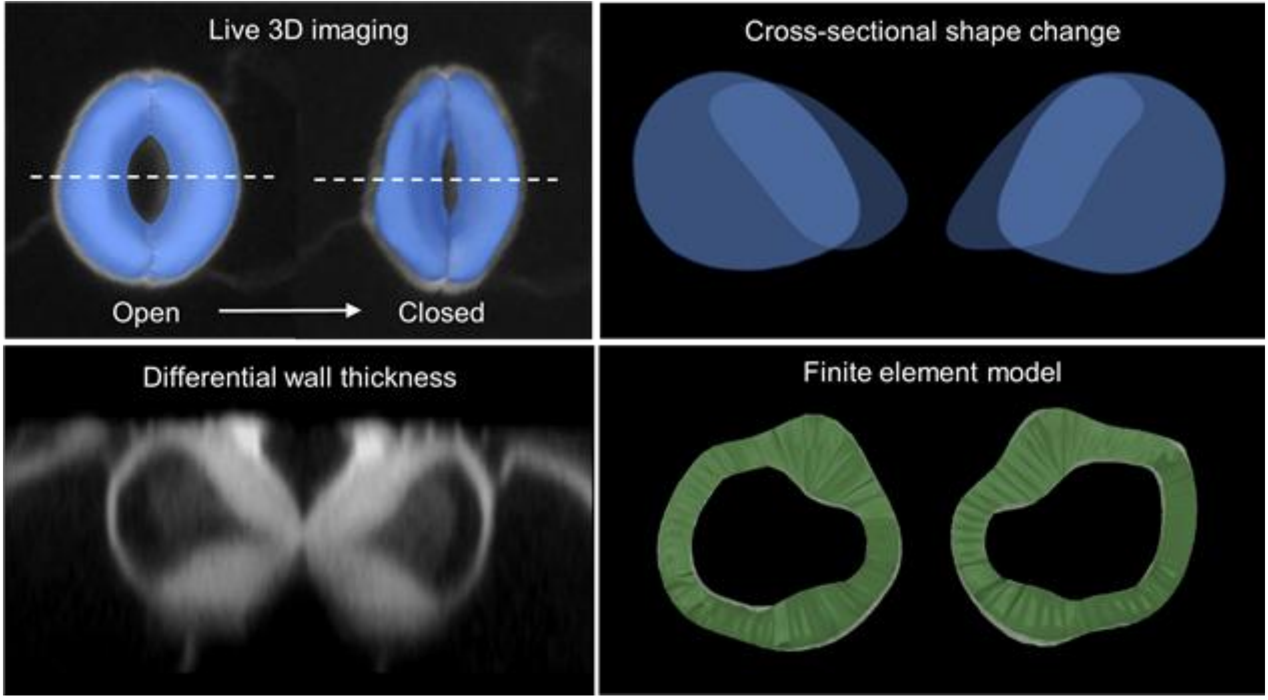


Live 3D imaging sheds new light on the mechanics of stomatal movement in Arabidopsis thaliana

Jodie Armand[1], Andrew Fleming, Julie Gray, Matthew Wilson, Melissa Tomkins, Richard Morris, Richard Smith
[1]University Of Sheffield, United Kingdom

Short Talks 1, March 28, 2025, 11:15 - 12:15

Stomatal movements are enacted by reversible, turgor-driven shape changes in the pair of guard cells (GCs) that surround each pore. Understanding how the structure of the GC wall gives rise to the mechanical properties required for GC shape change is an area of continued interest and computational modelling is proving to be a useful tool for testing hypotheses in silico. However, most of our computational models have only been built from 2D observations of stomatal movement. To address this we have combined 3D confocal time-lapse imaging and advanced image segmentation to capture and quantify the 3D changes in GC shape that take place during stomatal movement in Arabidopsis thaliana. This has revealed previously unseen changes to the cross-sectional shape of the GCs during stomatal dynamics which we believe may be facilitated by the differential thickness of the GC wall. To help test this we are now developing a more accurate computational model of stomatal mechanics – one that's guided directly by our 3D data on GC morphodynamics and that incorporates a more accurate GC wall thickness profile - which we are using to elucidate more precise structure-function relationships within the GC wall and advance our understanding of stomatal function.



The Efficiency of the Phloem Sugar Transport and Its Geometrical Dependency

Sabrina Gennis[1], Kaare Jensen[1]
[1]Technical University Of Denmark (DTU), Denmark

Flash Talks, March 28, 2025, 14:00 - 14:30

Plants account for about 80% of all biomass on Earth, making them an essential part of the ecosystem. For plants to survive and thrive, they must not only produce but also transport sugars and other assimilates from source to sink. The phloem is used for this transport, consisting of cylindrical sieve elements connected by porous sieve plates. Good transport efficiency is necessary to achieve the delivery of photoassimilates to the sink tissue. However, a phloem efficiency and its dependence on geometry has yet to be established. Additionally, a question of optimality arises: Are plants optimized?

We developed a mathematical expression for phloem efficiency and compared different plants while varying geometrical values. Our results reveal that the radius of the phloem sieve element is a significant geometrical factor, and fractional changes in this value can greatly impact phloem performance. Overall, we found that plants optimize their phloem geometry, although some outliers exhibit poor phloem efficiency. This raises further questions about plant evolution, while the value of phloem efficiency could be beneficial in agricultural breeding to enhance phloem transport.

How wind-associated mechanical signals regulate plant immune response?

Adele Coppel[1], Frédéric Garcia[2], Adelin Barbacci[1]
[1]Université de Toulouse, INRAE, CNRS, Laboratoire des Interactions Plantes Micro-organismes Environnement (LIPME), France, [2]Université de Toulouse, INRAE, Mathematiques et Informatique Appliquées de Toulouse (MIAT), France

Flash Talks, March 28, 2025, 14:00 - 14:30

Mechanoperception is a central function in plant adaptation to biotic and abiotic environments. It plays a key role in regulating growth processes such as morphogenesis, gravitropism, proprioception, and thigmomorphogenesis. Our research has demonstrated that the perception of mechanical cues associated with pathogens is essential for triggering plant immune response.

Among the mechanical stimuli encountered by plants, wind represents a major source of mechanical stress and strain. These fluctuations, often associated with windy episodes, sometimes precede rainfall events that facilitate the development of fungal diseases. The ability of plants to detect and respond to wind-generated mechanical signals may act as an anticipatory mechanism against biotic threats.

Preliminary results reveal that wind-generated dynamical stresses and strains in plant structure modulate plant immunity. However, this modulation appears complex, as the immune response varies depending on the intensity of the mechanical signals and the plant's genotype. In some cases, the response is enhanced, while in others, it may collapse entirely.

These initial findings suggest a dominant effect of somatic memory related to the repeated wind-induced bending. To uncover the molecular basis of this memory and how it influences the immune response, further biomechanical studies are required. These studies will clarify how mechanical signals are perceived by plant structures and integrated at the cellular level to modulate defense mechanisms.

A deeper understanding of the biomechanics underlying the modulation of immune responses by wind-generated mechanical signals could lead to developing plants that leverage wind to boost their immune responses.

Twining Plants Capitalize on Circumnutations to Assess Mechanical Properties of a Candidate Support, and Initiate a Thigmotropic Twining Response.

Amir Ohad[1], Amir Porat[1], Yasmine Meroz[1]
[1]Tel Aviv University, Israel

Flash Talks, March 28, 2025, 14:00 - 14:30

Climbing plants prioritize longitudinal to radial growth, resulting in loss of mechanical stability, compensated by attaching to supporting structures. While much is known about the twining process itself, little is understood about what signals underpin the onset of twining. We measure the force exerted by stem twining beans while encountering an obstacle during circumnutations – periodic movements of shoots, commonly identified with facilitating search for supports. Forces are and force trajectories are characterized by a sine-like form, with different amplitude and period. We find twining occurs after a minimal contact time of half a circumnutation period.

Experimental observations are outfitted with a minimal model for circumnutating shoots pushing against a rod, informed by mechanical properties of bean shoots. Simulations, based on a previously developed numerical framework for morpho-elastic rods, recover force trajectories with the observed sine form, where the amplitude is set by mechanical properties, and the period is set by the circumnutation period, directly relating observed forces to circumnutations. We find consistent differences in the period of simulated and experimental force trajectories, in line with an internal response to accumulated internal stresses. Analysis of shoot position right after slip events reveals smaller than expected jump angles, based on the measured circumnutations period before contact. This discrepancy increases with contact time, pointing at decreasing rotation rates during contact.

This study suggests climbing plants capitalize on circumnutations to push against encountered supports, enabling assessment of mechanical stability, and initiating twining according to accumulated stresses or strains.

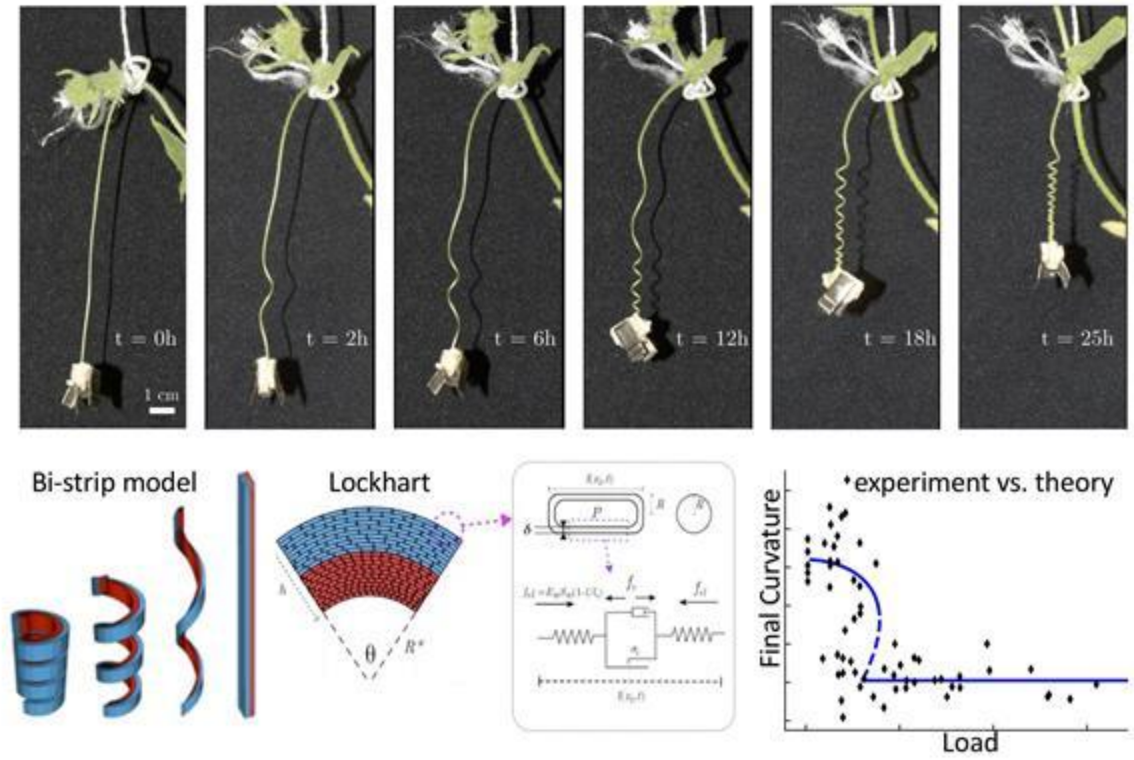
Plant tendril writhing under external load : where Kirchhoff meets Lockhart

Dražen Zanchi[1], Julien Derr[2], Émilien Dilly[1,2,3]
[1]Université Paris Cité, France, [2]École Normale Supérieure de Lyon, France, [3]LIPhy, Université Grenoble Alpes, CNRS, France

Flash Talks, March 28, 2025, 14:00 - 14:30

Plant tendrils, rod-like organs by which plants (such as cucumbers, vines, and passionflowers) attach to supports, exhibit a spectacular example of writhing transition. Experiments were conducted on approximately 100 living cucumber tendrils. The time evolution of tendril curvature was monitored over three days under controlled traction T. Once a straight tendril finds a support and attaches to it, it undergoes differential growth associated with heterogeneous stresses. Whether these stresses cause writhing and subsequent coiling depends on the external load T. The heterogeneous stress arises from the physiological evolution (growth) of the tendril. Conversely, tendril growth itself is stress-dependent. A standard approach for describing this relationship is implemented in Lockhart-like models. By combining insights from the Kirchhoff model of writhing and the Lockhart model of growth, we propose a simple morphoelastic model to describe the evolution of plant tendrils under axial constraints. The results align well with the experimental data, reproducing a well-identified jump associated with the writhing instability.

[1] Traveling Perversion as Constant Torque Actuator, Emilien Dilly, Sébastien Neukirch, Julien Derr, D. Zanchi, Phys. Rev. Lett. 131, 177201 (2023)
[2] Critical Phenomena in Helical Rods with Perversion, Emilien Dilly, Sébastien Neukirch, Julien Derr, D. Zanchi, hal-04838602v1 (2024).
[3] James A. Lockhart. An analysis of irreversible plant cell elongation. Journal of Theoretical Biology, 8(2):264–275 (1965).
[4] T. McMillen and A. Goriely. Tendril Perversion in Intrinsically Curved Rods. Journal of Nonlinear Science, 12(3):241–281 (2002).


t = 0h
1 cm
t = 2h
t = 6h
t = 12h
t = 18h
t = 25h
Bi-strip model
Lockhart
h
θ
R*
δ
P
R
f_v
f_el
experiment vs. theory
Final Curvature
Load

From Nano to Macro: An Optogenetic Approach to Studying Plant Cell Wall Integrity

M Bastien Dauphin[1], Yaowen Wu[2], Laura Bacete Cano[1]
[1]Umeå Plant Science Centre, Umeå, Sweden, [2]Umeå Centre for Microbial Research, Sweden

Flash Talks, March 28, 2025, 14:00 - 14:30

Adaptation to varying stimuli can significantly differ across species and is critically dependent on an organism's ability to perceive these stimuli. Plants are no exception and are capable of deciphering diverse signals, whether of chemical or mechanical nature.

As the first layer of contact, the cell wall (CW) is a highly dynamic structure whose composition can be adjusted based on these signals with significant implications for its mechanical properties and thus cell function. Such adjustments are done through the cell wall integrity monitoring system which perceives various cues, though the nature of the mechanical ones remains particularly unclear due to their subtle and dynamic characteristics.

To decode these mechanical signals, we have developed an optogenetic system that induces perturbations in the CW structure by expressing inactive halves of CW-modifying enzymes and utilizing light to reassemble functional proteins in vivo (Fig1). Early-stage progress on in vitro protein production and activity in this system will be presented, and future optimization and aims in Arabidopsis thaliana will be discussed. Leveraging the spatiotemporal control offered by this optogenetic approach, we can precisely regulate the activity of different cell wall-modifying enzymes to achieve subtle mechanical perturbations (Fig1). Utilizing recent advancements in microscopy we will measure the real-time effects of these perturbations on CW properties. This integrated approach of combining mechanical measurements with chemical CW modifications and high-resolution microscopy will be presented to provide insights into how mechanical signals are locally perceived and subsequently transmitted to neighboring cells.

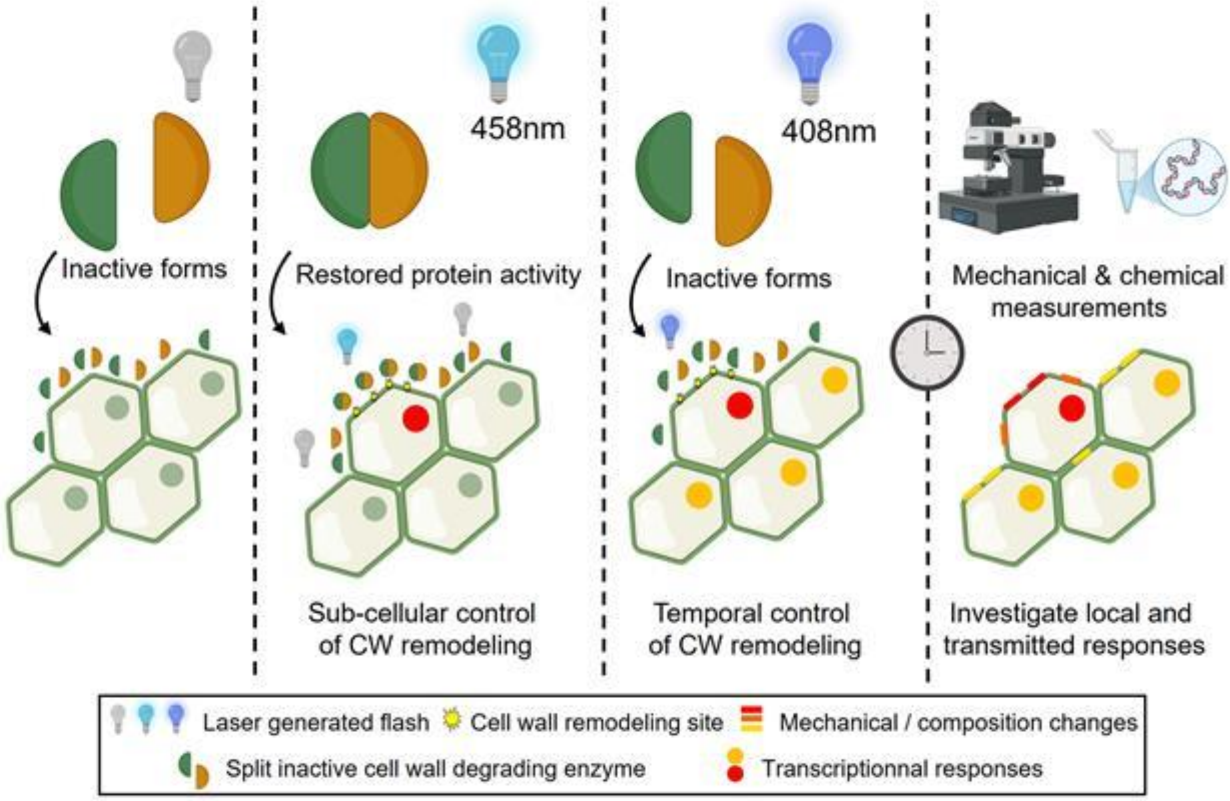


Fig1: Achieving spatiotemporally controlled CW remodeling through optogenetic tools: Cell wall modifying enzymes targeting diverse substrates are expressed as split and inactive forms and reconstituted through specific light wavelengths and a chemical dimerizer (not represented). The mechanical and chemical consequences of their local activity on neighboring cells can be measured in real-time to study the perception and transmission of mechanical signals.

Poster Presentations

Cell Division as a Mechanical Regulator of Arabidopsis Growth

Emily Oren[1], Sarah Robinson[1]
[1]Sainsbury Laboratory, University of Cambridge, United Kingdom

Afternoon Break and Poster Session, March 28, 2025, 14:30 - 16:00

Plants grow and develop throughout their lives, creating complex morphology through cell expansion and cell division. How plants control these processes is a pressing and unanswered question in the field of developmental biology. This project seeks to investigate the regulatory relationships between three factors known to impact plant growth: hormonal signalling, mechanical feedback, and cell division. While all three factors are known to contribute to growth regulation, how each feeds back on the others is currently unclear. To begin to unravel this complex process, cell division was studied in Arabidopsis hypocotyls, an organ with very little endogenous division, and manipulated using inducible lines that increase cell division frequency. Hormonal activity was manipulated directly through exogenous hormone and inhibitor treatments, and indirectly through environmental conditions such as far-red light. Mechanical properties were quantified using Atomic Force Microscopy (AFM) and Automated Confocal Micro Extensometer (ACME). AFM allows for cell wall scale measurement of stiffness, while ACME operates at the whole organ scale. Inducing excess cell divisions in the Arabidopsis hypocotyl results in altered growth behaviors: increased growth after treatment with BR, and decreased growth in shade mimicking conditions. These differences appear to be due to changes in wall modification responses to the stimuli, not due to mechanical constraints caused by the presence of extra walls. Future work will focus on whether this is due to changes in hormone movement or some other factor.

A method for estimating Young's modulus of maize stalks using torsional vibration mode

Haruka Tomobe[1], Taiken Nakashima[2], Yoichiro Kato[3]
[1]Institute of Science Tokyo, Japan, [2]Hokkaido University, Japan, [3]The University of Tokyo, Japan

Afternoon Break and Poster Session, March 28, 2025, 14:30 - 16:00

Lodging in crops has been a limiting factor for crop yields as well as causing yield loss and reduced operational efficiency. Accurate and high-throughput measurement of Young's modulus of stalks is necessary to produce varieties with high resistance to lodging in cereal crops. Recently, high-throughput techniques have been developed to measure Young's modulus of stalks. Among these methods, the method for estimating Young's modulus of a stem from the wave velocity of ultrasonic waves propagating in the longitudinal direction of the stalk is faster than existing methods. Still, the obtained Young's modulus is inconsistent with that obtained by destructive testing. This paper first shows that it is considerably challenging to obtain an accurate Young's modulus using existing methods of transmission and reception with the aid of theoretical solutions of ultrasonic propagation and numerical simulations using the finite element method. Since the dispersion characteristic of the elastic wave should be accurately simulated, the semi-analytical time integrator is utilized for the time integration. Second, after finding a theoretical solution and numerical simulations for the transmission-reception method that can obtain an accurate and robust Young's modulus, field tests were conducted on maize plants in the field.

Integrating Growth, Mechanics, and Genetic Control in Plant Morphogenesis

Amir Porat[1], Henrik Jönsson[1]
[1]Sainsbury Laboratory Cambridge University, United Kingdom

Afternoon Break and Poster Session, March 28, 2025, 14:30 - 16:00

Plant morphogenesis emerges from an intricate feedback loop between growth, mechanics, and genetic regulation. A key question in plant development is understanding how morphogens such as auxin, WUS, CLV3, and cytokinin influence growth. This project aims to analyse the morphoelastic effects of these biochemical morphogens using a multiscale, physics-based modelling approach.

We focus on two organs with distinct symmetries: the apical hook, a slender, rod-like structure with pronounced macroscopic curvature, and the shoot apical meristem (SAM), a dome-shaped stem cell niche from which organs form periodically. By leveraging the self-similar growth kinematics of these organs, which maintain stable geometry and morphogen patterns despite cell proliferation, we address an "inverse morphoelastic problem"—determining the elastic profiles and growth laws that drive the observed kinematics, and how these are modulated by spatiotemporal morphogen patterns.

In the SAM, we combine theory and simulations to explore feedback loops coupling morphogens to cell wall properties, such as elastic strain and stiffness, to explain size regulation, phyllotaxis, mutant phenotypes, and responses to biochemical treatments. For the apical hook, we apply macroscopic morphoelastic rod models to demonstrate that the shape dynamics can be fully captured by a one-way wave equation describing the curvature of the centreline. Using this framework, we further investigate how residual stresses influence the growth-driven movement.

Thigmomorphogenic responses: crops phenotypic and structural responses to mechanical stimulation

Annalene Hansen[1], Agnieszka Gladala-Kostarz[2], Rebecca Hindhaugh[1], John Doonan[1], Maurice Bosch[1]
[1]Aberystwyth University, United Kingdom, [2]Durham University, United Kingdom

Afternoon Break and Poster Session, March 28, 2025, 14:30 - 16:00

Mechanical stimulation, such as rain or wind, induces responses in plants collectively known as thigmomorphogenesis, including dwarfing, changes in cell wall composition and stem anatomical features. Japanese farmers have utilised mechanical stimulation for centuries, a process called mugifúmi – treading on wheat and barley seedlings to increase crop yield and resilience, but improper application can lead to adverse effects. While most thigmomorphogenic studies focus on dicots, monocot grasses like cereals are vital for global food security. Grasses exhibit some unique responses, such as increased tiller number in wheat, in an age- and dose- responsive way, and monocot-unique transcriptional regulation is beginning to be illuminated. Similarities to dicots include increased stem structural rigidity, which may be in part due to increases in cell wall thickness and lignin content. In winter wheat, higher chlorophyll content has been observed following mechanical treatment, similar to dicots, while in spring wheat, grain colour changes were noted in one of the two varieties tested. Grain number and weight decreased in Brachypodium and winter wheat varieties, but not in spring varieties. These findings suggest species and varietal differences in thigmomorphogenic responses, though further research is needed to establish general patterns. Mechanical stimulation may offer an underexplored strategy to increase crop resilience to environmental stresses by activating broad, non-specific defense pathways, as reported in dicots. However, the underlying mechanisms in monocot grasses remain poorly understood. Can mechanical stimulation be harnessed to improve agricultural practices for sustainable crop production?

Survival in the desert - how cacti harvest fog droplets

Jessica Huss[1]
[1]Boku University Vienna, Austria

Afternoon Break and Poster Session, March 28, 2025, 14:30 - 16:00

Water is essential for life on earth. In arid and semi-arid regions, rainfall is typically low and occurs irregularly throughout the year, posing a substantial challenge for plants. However, some desert plants have developed fascinating structural adaptations that allow them to collect fog and dew droplets as an alternative source of water for growth. In this poster, I will illustrate how cactus spines effectively collect fog droplets via shape-morphing. While cactus spines are widely known as mechanical defence structures against herbivores, species in fog-rich habitats with porous and flexible spines suggest a fundamentally different function: fog harvesting. We investigated the tissue properties that enable shape-morphing and fog harvesting using confocal Raman microscopy and x-ray tomography. Additionally, we traced the path of fog water using stable isotopes and mass spectrometry. These powerful tools revealed how cactus spines increase the plant's water supply through shape-morphing and fog harvesting.

Rethinking stomatal mechanics: Insights from a new model of onion stomata

Melissa Tomkins[1], Matthew Wilson[2], Clinton Durney[1], Jodie Armand[2], Julie Gray[2], Richard Morris[1], Richard Smith[1], Andrew Fleming[2]
[1]John Innes Centre, United Kingdom, [2]University of Sheffield, United Kingdom

Afternoon Break and Poster Session, March 28, 2025, 14:30 - 16:00

Plant stomata are essential for regulating gas exchange between plants and their environment, influencing both photosynthesis and water balance. Despite their seemingly simple structure—a pore formed by two guard cells—stomata display remarkable morphological diversity across plant species. Previous studies on non-grass stomatal systems consisting of two kidney-shaped guard cells, have highlighted the importance of mechanical properties such as radial stiffening and pectin-based pinning of polar ends in facilitating stomatal opening.

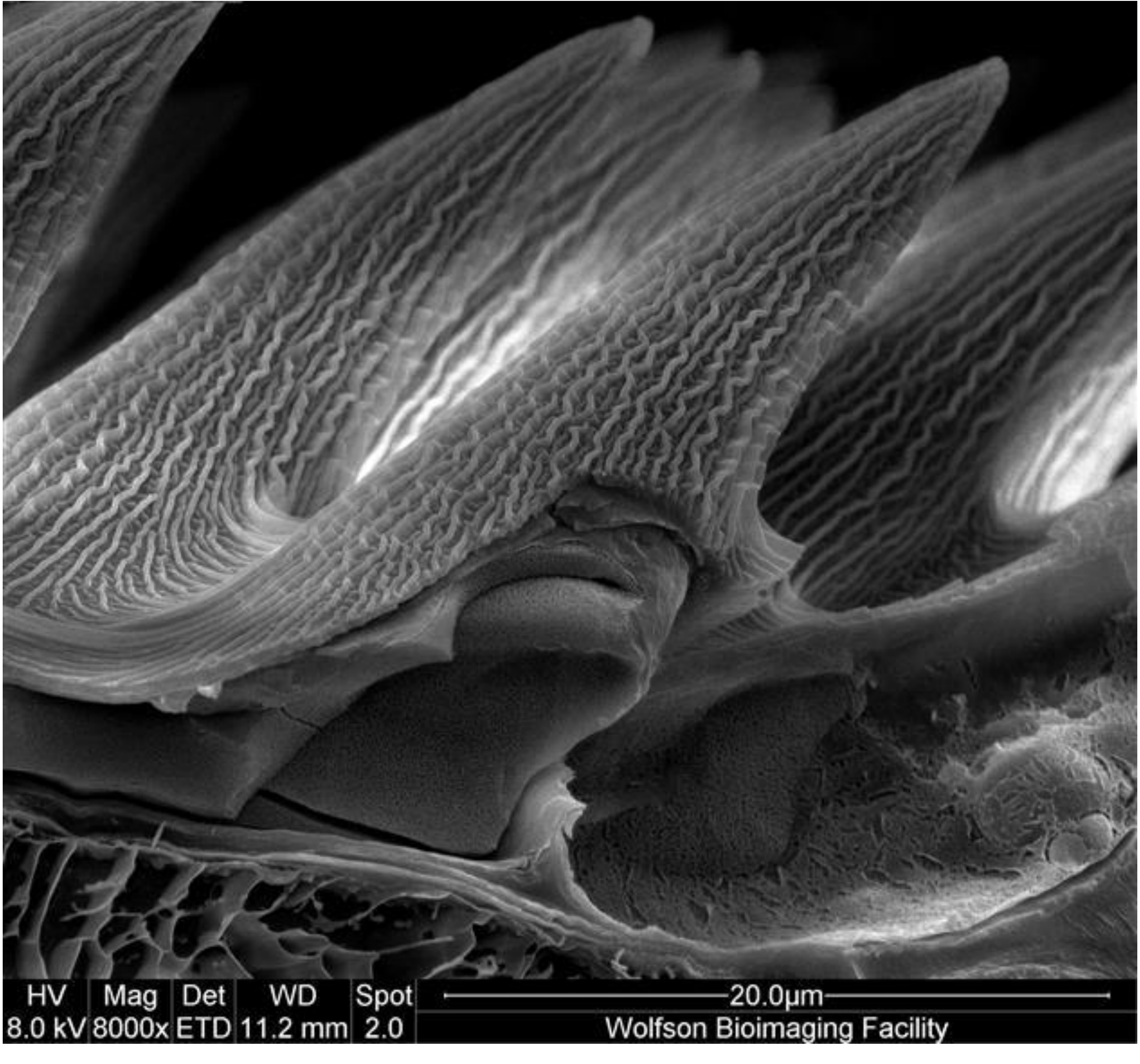
In this talk, we present a novel finite element method (FEM) model of onion stomata, offering fresh insights into the relationship between guard cell morphology and function. We demonstrate how the flattened geometry of onion guard cells enhances the efficiency of turgor pressure in opening and closing their pores. Using the 3D modelling software MorphoDynamX, we inflate and deflate both 2.5D and fully 3D mesh representations of stomatal guard cells derived from confocal microscopy images. This approach allows for a comprehensive examination of how realistic cell geometries influence stomatal function and behaviour. Understanding the interplay between morphology and function holds the key for unravelling the mysteries of the evolutionary diversification of stomatal shapes across plant species.

From Grip to Slip: How Pitcher Plants Disrupt Insect Adhesion

Igor Ceran[1], Sienna Read[1]
[1]University of Exeter, United Kingdom

Afternoon Break and Poster Session, March 28, 2025, 14:30 - 16:00

The prey capture mechanism of Cephalotus pitcher plants has been poorly characterized in comparison with other carnivorous plant genera such as the Nepenthes. This study provides first insights into the prey-capturing adaptations of Cephalotus follicularis, focusing on the interplay between its surface topography, wettability, and slipperiness. Using CryoSEM imaging, friction force measurements, and contact angle analysis, we characterized the plant's surface microstructures and their functional roles in trapping insects. The peristome was found to possess hydrophilic properties, in contrast to the superhydrophobic collar and moderately hydrophobic underside of the lid. Friction force experiments revealed that ant adhesion was significantly reduced on the peristome compared to other regions, with the collar being the most slippery. These findings suggest that C. follicularis effectively counters insect climbing adaptations, such as claws and suction pads found in ants, through an optimized combination of microstructural diversity and surface chemistry. The results provide valuable insights into the evolutionary biomechanics of pitcher plants and present opportunities for designing biomimetic surfaces inspired by these natural mechanisms.



Bending and buckling of plant root hair

Shohreh Askari[1], Anagha Sanjay Datar[1], Joonas Ryssy[1], Matilda Backholm[1], Juan Alonso-Serra[2]
[1]Department Of Applied Physics, Aalto University, Finland, [2]Viikki Plant Science Center, University of Helsinki, Finland

Afternoon Break and Poster Session, March 28, 2025, 14:30 - 16:00

Plant roots are essential for nutrient absorption and anchorage, with their biomechanical properties playing a pivotal role in plant health, growth, and resilience to environmental challenges. Among root components, root hairs—slender, unicellular extensions integral to water and nutrient uptake—exhibit unique mechanical dynamics that remain challenging to study at a mesoscale level. Understanding these dynamics is crucial for uncovering how roots adapt to mechanical stresses in soil environments.

In this study, we employed the micropipette force sensor (MFS) technique to characterize the mechanical properties of radish root hair. The MFS method, which enables nanonewton-scale force measurements through the deflection of a slender glass cantilever, allowed us to analyze how root hair bend, buckle, and respond to external forces. These measurements provide insights into the elastic properties and structural behavior of root hair, which are closely linked to their roles in nutrient absorption and anchoring.

By integrating the principles of biomechanics with plant physiology, our research advances the understanding of root hair mechanics and their contributions to root system function. These findings have implications for improving crop resilience and optimizing agricultural productivity by leveraging the biomechanical properties of roots to enhance growth and stress adaptability.

Pathogen-derived mechanical cues potentiate the spatio-temporal implementation of plant defense

Adelin Barbacci[1]
[1]Université de Toulouse, INRAE, CNRS, Laboratoire des Interactions Plantes Micro-organismes Environnement (LIPME), France

Afternoon Break and Poster Session, March 28, 2025, 14:30 - 16:00

Mechanoperception is a fundamental process in plant life that regulates various complex mechanisms throughout the organism's existence, including morphogenesis, growth and tropic movements. However, abiotic environmental factors are not the only sources of mechanical signals. Interactions between plants and microorganisms also involve physical forces beyond the molecular communication between their genomes.

To decipher whether mechanoperception is also involved in regulating plant immunity, we focus on the interactions between plants and necrotrophic fungi in Arabidopsis thaliana leaves. We show that the mechanoperception of pathogen-derived mechanical cues triggers the formation of an immune layer we term Mechano-signalling Triggered Immunity (MTI). During disease progression, the pathogen induces tissue hydrolysis, which alters mechanical stresses within the apoplast. The internal stress reorganization forms an over-tension ring surrounding the necrotic lesion actively perceived through the reorganization of microtubules. In healthy cells forming the ring, we observe the overexpression of hundreds of resistance genes several hours before the fungal colony arrives. The establishment of MTI in the ring depends on the microtubules' ability to reorganize in response to mechanical signals. MTI works synergistically with other layers of resistance and contributes to 40% of the overall defense response. This introductory work highlights the importance of mechanoperception in plant adaptation to both abiotic and biotic environments. Since mechanical signals can be artificially generated, these results may open avenues for controlling plant immunity using exogenous mechanical signals.

Characterisation of the cuticle striation patterns in Hibiscus trionum petals

Humberto Herrera-Ubaldo[1], Chiara Airoldi[1], Bhavani Natarajan[1], Lijun Zhou[1], Carlos A. Lugo[1,2], Beverley J. Glover[1]
[1]Department of Plant Sciences, University of Cambridge, United Kingdom, [2]Sainsbury Laboratory, University of Cambridge, United Kingdom

Afternoon Break and Poster Session, March 28, 2025, 14:30 - 16:00

The colours in flowers are produced by the presence and distribution of cells containing pigments; additionally, modifications on the epidermal cells' surface can interfere with light, creating additional optical effects. For example, the petals in the Hibiscus trionum flower develop a purple region characterised by the presence of nano ridges in the cuticle of the adaxial cells, which affects light diffraction and produces iridescence. The latest model for striation patterning in the petal epidermal cell cuticles predicts the contribution of cuticle layers stiffness, cell wall curvature, cell in-plane expansion, and cell growth rates in the formation of the observed patterns at the single cell level.

This work aims to identify the specific mechanisms underlying the fine-tuning modification of the striation patterns in the petal cuticles. We are studying the formation of ridges at the macroscale level. At the whole petal level, we have observed differences in the striation patterns (ridge density, direction), which are probably related to whole-organ features such as curvature and cell size and shape across the petal. Additionally, we are studying how the dynamics of cell growth (2D and 3D) before flower opening affect the initiation and features of the striation patterns.

Ethylene mediated cell wall mechanics regulate root responses in hard soils.

Dr Bipin Pandey[1]
[1]University Of Nottingham, United Kingdom

Afternoon Break and Poster Session, March 28, 2025, 14:30 - 16:00

Soil stress significantly impacts crop yields, posing a critical global agricultural challenge. Soil compaction reduces root length while promoting radial expansion, a process regulated by the plant hormone ethylene. We demonstrate that ethylene orchestrates changes in cell wall properties to drive root radial expansion. Specifically, soil compaction induces ethylene-mediated upregulation of Auxin Response Factor in the root cortex, which represses Cellulose Synthase gene expression. This repression alters the thickness and mechanical properties of cortical cell walls, creating a "stiff epidermis-soft cortex" mechanical contrast. Our research establishes a crucial link between ethylene signaling and root mechanics through the regulation of cell wall synthesis and strength, highlighting the dynamic role of cellulose synthesis in root penetration of soil.

Biophysical study of plant’s morphogenic movement

Lucie Poupardin[1], Julien Derr[1], Mohammed Bendahmane[1], Judit Szecsi[1]
[1]RDP, France

Afternoon Break and Poster Session, March 28, 2025, 14:30 - 16:00

Peculiar movements have been observed in growing leaves such as Persea americana (avocados tree), citrus, or oak, which can only be explained by a synchronisation of the growth of the midribs and the blades. Our working hypothesis is that this growth synchronisation is due to mechano-sensitivity: the shape taken by the leaf at each time point is the result of the elastic equilibrium state of the local growth. However, while the elastic equilibrium state minimises the global elastic energy, some residual stresses are still present locally and can affect the growth process in a mechanical feedback loop.

For this, we choose a kinematic approach to studying growing leaves using time-lapse photography to record the position in 3D space of the surface of a leaf. The goal is to quantify the leaf motions and global growth and characterise their correlation. We manage to measure dynamical growth variation related to geometry, coherent with elastic contractions, and the presence of residual stresses affecting the growth. Using blade-cutting experiments, where we release the tension in the leaf lamina, we can show evidence of the importance of secondary veins in the motions.

Iridescent Petals: understanding the mechanics of nanoridge formation

Dr. Bhavani Natarajan[1], Xiao Wang[1], Beverley Glover[1]
[1]Department of Plant Sciences, University of Cambridge, United Kingdom

Afternoon Break and Poster Session, March 28, 2025, 14:30 - 16:00

Iridescence is a form of structural colour found in various organisms. In Hibiscus trionum, iridescence is produced due to interference of light by nanoridges present on the petal epidermal cells. Nanoridges are formed by buckling of the cuticle, and mechanics plays an important role in this. A mechanical model from previous work in the lab had identified five parameters crucial for nanoridge formation, namely cuticle thickness, cuticle stiffness, extracellular matrix stiffness, cell elongation, and turgor-induced deformation.
In this study, we aim to experimentally test this model using three distinct approaches: (1) We will modify nanoridges—and thus iridescence—by generating transgenic H. trionum plants with defects in cuticle biosynthesis, and identify the affected parameters; (2) We will investigate various Hibiscus species, both with and without nanoridges, to determine if variations in these five parameters account for their phenotypic differences; and (3) We will examine Grielum grandiflorum, which produces nanoridges with a higher aspect ratio (amplitude/wavelength) compared to H. trionum. This phenomenon cannot be explained by our current model or other existing wrinkling models, presenting a valuable opportunity to identify new parameters and enhance our understanding of wrinkling and buckling theory. Overall, these approaches would be the first to test the mechanical model of nanoridge formation in any organism.

Symplastic guard cell connections buffer pressure fluctuations to promote stomatal function in grasses

Matthew Wilson[1], Shauni McGregor[1], Clinton Durney[2], Melissa Tomkins[2], Jodie Armand[1], Richard Smith[2], Julie Gray[1], Richard Morris[2], Andrew Fleming[1]
[1]University Of Sheffield, United Kingdom, [2]John Innes Centre, United Kingdom

Afternoon Break and Poster Session, March 28, 2025, 14:30 - 16:00

Stomata regulate plant gas exchange via repeated turgor-driven changes of guard cell shape, thereby adjusting pore apertures. Grasses, which are amongst the most widespread plant families on the planet, are distinguished by their unique stomatal morphology which is proposed to have significantly contributed to their evolutionary and agricultural success. One component of grass stomatal structure which has received little attention is the presence of a discontinuous adjoining cell wall of the guard cell pair. Here we demonstrate the presence of these symplastic connections in a range of grass species and use finite element method simulations to assess hypotheses for their functional significance. Our results show that opening of the stomatal pore is maximal when the turgor pressure in dumbbell-shaped grass guard cells is equal, especially under the low pressure conditions that occur during the early phase of stomatal opening. Asynchronous pressure scenarios were predicted to result in both sub-optimal opening of the stomatal pore and increased mechanical stress. In contrast, we demonstrate that turgor pressure differences have less effect on the opening of kidney-shaped guard cells, characteristic of the majority of land plants, where guard cell connections are rarely or not observed. Our data describe a functional mechanism based on cellular mechanics which plausibly facilitated a major transition in plant evolution and crop development.

Biomechanics of Prey Capture in Carnivorous Sarracenia flava Pitcher Plants

Prafulla Sujatha Nagesh[1], Michal R. Golos[1], Ulrike Bauer[1]
[1]University Of Exeter, United Kingdom

Afternoon Break and Poster Session, March 28, 2025, 14:30 - 16:00

North American pitcher plants of the genus Sarracenia have evolved specialised leaves to attract, capture, and retain insect prey. Despite extensive interest in these carnivorous plants, the detailed biomechanics underlying their predatory success remain poorly understood. This study focused on Sarracenia flava, investigating how its specialised surface properties mediate prey capture and retention. Cryo-SEM images of the pitcher’s lid, neck, upper inner surface, and downward-pointing hairs revealed distinct microstructures that facilitate prey capture and retention. Contact angle measurements confirmed that the upper inner surface is superhydrophobic, with wax deposits layered over cuticles, effectively reducing insect adhesion. Frictional force experiments with ants, conducted across the pitcher surfaces in wet and dry conditions, as well as in inward and outward direction, quantified how these structures diminish grip and impede climbing. Running tests with ants attempting to climb out of the pitcher confirmed the effectiveness of the pitcher surfaces to impair traction and prevent escape. Once prey fell into the pitcher, long downward-pointing hairs in the lower section ensured retention by physically obstructing escape. By combining surface characterisation, experimental biomechanics, and behavioural observations, this research provides new insight into Sarracenia flava's prey capture mechanism. Our findings contribute to the broader understanding of carnivorous plant ecology and evolution and may inspire biomimetic designs of water-repellent and friction-modulating surfaces.

Elucidating relationship between pit-field callose depositions and nanomechanical and structural cell wall properties in tomato fruits.

Dr Lazar Novakovic[1], Richa Yeshvekar[1], Simon Connell[2], Yoselin Benitez-Alfonso[1]
[1]Center for Plant Science, School of Biology, University of Leeds, United Kingdom, [2]Molecular and Nano-scale Physics Group, School of Physics and Astronomy, United Kingdom

Afternoon Break and Poster Session, March 28, 2025, 14:30 - 16:00

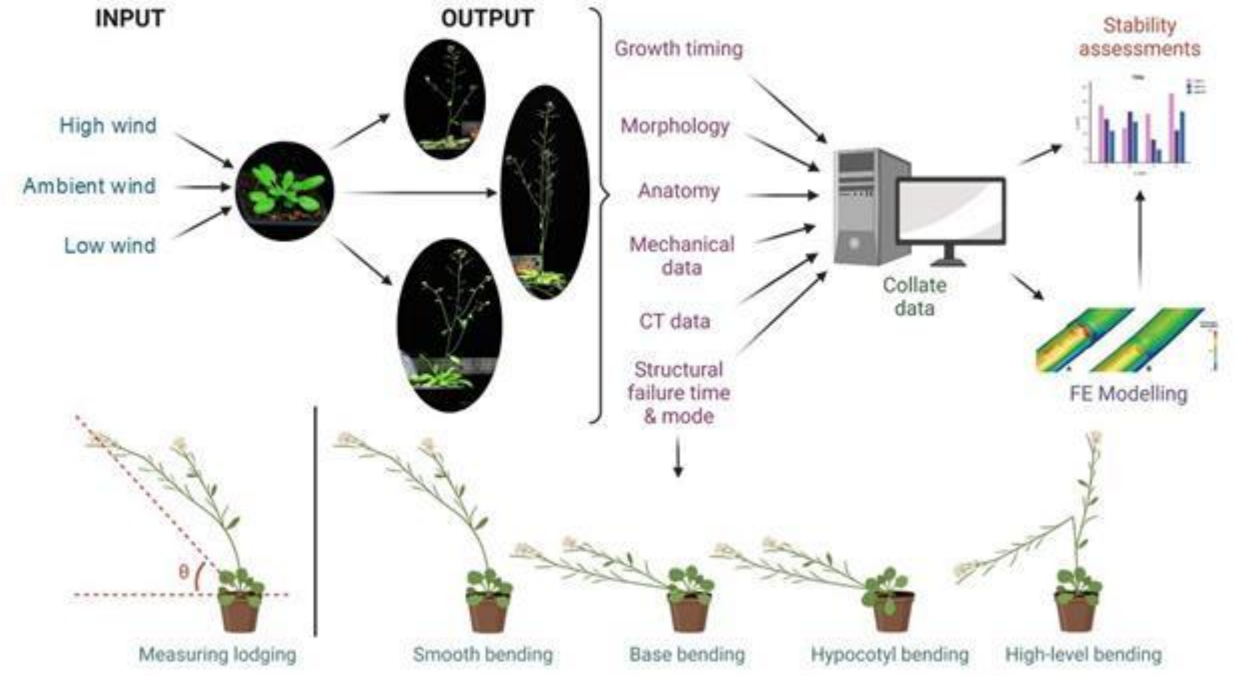
Cell wall is polysaccharide exoskeleton deposited above plasma membrane, covering all plant cells. Plant cells are connected by plasmodesmata, nano-channels traversing cell walls, enabling communication of neighbouring cells and directly connecting their cytoplasm. Diameter of plasmodesmata opening is regulated by polysaccharide callose. Fine tuning of callose determines size of molecules which can travel through plasmodesmata. Plasmodesmata diameter changes considerably during the growth and development of plants, affecting morphogenesis of tissues and organs. We transiently overexpressed two candidate genes for callose degrading enzymes in tomato fruits and measured elastic modulus using atomic force microscopy inside pit-fields (cell wall regions of dozens and hundreds closely clustered plasmodesmata) and far away from pit fields. Transient transgenic lines, where overexpression of callose degrading enzymes was increased, showed increase in cell wall stiffness in both pit-field and contiguous cell wall regions compared with wild type and empty-vector controls. It seems that removal of callose, although it is one of the scarcest cell wall components could be altering interactions between major cell wall components such as cellulose, pectins and hemicellulose affecting global cell wall mechanical properties such as elastic modulus. In addition to this, transgenic lines showed significant increase in cellulose microfibrils diameter, compared to wt, as shown by high resolution AFM imaging. This study could act as a stepping stone in better understanding complex role of cell wall in fruit growth and ripening potentially opening new avenues to improve and extend shelf-life of various fruits.

Mapping Mechanical Input to Structural Remodelling Output in Arabidopsis Stems

Samuel Mason[1], Tom Masselter[2], Evie Quinlan[1], Daniel Khosravinia[1], Angela Kedgley[1], Olga Speck[2], Thomas Speck[2], Naomi Nakayama[1]
[1]Imperial College London, United Kingdom, [2]Universität Freiburg, Germany

Afternoon Break and Poster Session, March 28, 2025, 14:30 - 16:00

The climate crisis is increasing likelihood of plant shoot failure due to mechanical overload, which is often presented as lodging. Currently 16-50% of UK oilseed rape yield can be lost when plant stems fail due to environmental conditions such as wind and rain (Kendall et al., 2017). This crop failure rate will likely increase as extreme weather becomes more frequent, with disproportionate impact on the Global South (IPCC, 2022). In this study, the model plant Arabidopsis thaliana, a relative of many common crops, is used to understand stem remodelling in response to controlled magnitudes of wind load. Wind load inputs are quantified using hot wire anemometry. Plant remodelling outputs are measured using techniques such as uniaxial bending tests, histology and 3D laser scanning. We found that the force exerted by Arabidopsis stems during bending falls within a gap in the sensitivity range of commercially available uniaxial mechanical testing devices; thus, we have designed and built a custom rig. The rig is designed to be open-source, affordable, user-friendly and easily manufacturable using 3D-printed parts. Using this, Arabidopsis stem bending tests have been completed and methods were developed to systematically link the mechanical inputs to plant remodelling outputs. Experimental data informs on failure loads/modes, plant strength and stability. The data will be built into computational models to understand internal stress and strain, to simulate environmental conditions that cannot be tested experimentally, and to predict remodelling response.



Influences of a microtubule mediated mechanical feedback during early stages of flower development

Dr Argyris Zardilis[1], Arun Sampathkumar[2], Henrik Jönsson[1]
[1]Sainsbury Laboratory, University Of Cambridge, United Kingdom, [2]Max Planck Institute of Molecular Plant Physiology Potsdam, Germany

Afternoon Break and Poster Session, March 28, 2025, 14:30 - 16:00

The main morphological event that happens after the initial development of the flower primordium is the outgrowth of sepal primordia in the four poles and their subsequent folding to partially come on top of the central meristem region. The genetic basis of these events and the contribution of differential growth has been studied before but here we are interested in the role of mechanical signals, mediated through the microtubule (MT) network or molecular components, to this process.

We firstly show, through computational and experimental evidence, that the MT network correlates with mechanical stress directions and growth directions in a way that is consistent with the hypothesis that the MT network drives cellulose deposition and therefore with the mechanical properties of the cells. Perturbing the MT network severely perturbs the shape of the organs. Secondly, we show that mechanical stress is associated with the expression of the important developmental gene CUC (important for boundary formation) showing another pathway for the effect of mechanics.

This work provides a good example of the importance of mechanical signals in the most morphologically complex organ in plants and could give insights into other processes that share similar growth characteristics (e.g., folding).

Unravelling the structure of the guard cell wall

Nathanael Tan[1], Andrew Fleming[1], Julie Gray[1], Jamie Hobbs[1]
[1]University of Sheffield, United Kingdom

Afternoon Break and Poster Session, March 28, 2025, 14:30 - 16:00

Stomata leverage large changes in turgor pressure to reversibly alter their shape, modulating gas exchange to and from the leaf. The de facto explanation for how this occurs centres around their unique arrangement of cellulose microfibrils, thought to wrap around the guard cell, which endow their walls with anisotropic stiffness and thus promote elongation under turgor. While intuitive, this mechanism has had limited success in explaining or predicting observed changes to stomatal function when cell wall polymers are altered e.g., by molecular genetics or enzymatic attack.

I propose that this failure originates from its idealised representation of the structure and arrangement of the microfibril network, which results in a limited conception of the cell wall's function. In this project, I seek to remedy this by obtaining a more complete picture of both the cell-scale microfibril arrangement and the cell wall's nanostructure. I have uncovered a previously unreported variation in cellulose optical anisotropy around the guard cell's cross-section, suggesting differences in cellulose density and/or alignment.

Such variations carry deep implications for the role of cellulose microfibrils in guard cell function. When combined with emerging data showing the shape changes underlying stomatal function to be more complex than initially presumed, these observations converge upon a potential supplementary mechanism to the current stomatal model.

Exploring the variability of plant cell wall mechanical properties

Elise Laruelle[1], Kumud Saini[1], Martin Lenz[1,2], Sarah Robinson[1]
[1]Sainsbury Laboratory Cambridge University, United Kingdom, [2]Cambridge Advanced Imaging Centre, University of Cambridge, United Kingdom

Afternoon Break and Poster Session, March 28, 2025, 14:30 - 16:00

The mechanical properties of the plant cell wall play an important role in growth and defense. The existing tools enable characterisation of mechanical properties at different resolutions. Atomic Force Microscopy (AFM) or Brillouin microscopy provide high sub-cellular resolution, while extensometers typically provide organ resolution. In both cases there are advantages to combining the measurements with microscopy images of the cells being measured. The combination of methods enables correlations to be made between mechanical properties and cell geometry or gene expression. It also helps with extracting mechanical properties at the most meaningful resolution, often the resolution of the cell wall. To reach this intermediate resolution, it is necessary to process the mechanical data. Currently there are no standardized tool or protocols for this aim. In this study, we combine the extracted mechanical information with microscopy images, to obtain cell wall resolution measurements from extensometer and AFM data. This enables us to look at the order underlying the variability of the wall mechanical properties in the tissue layers of Arabidopsis thaliana.

Iridescence in Flowers - How and Why? Insights from lisa mutant

Miss Lijun Zhou[1,2], Humberto Herrera-Ubaldo[1], Bhavani Natarajan[1], Hamish Symington[1], Beverley J. Glover[1]
[1]Department of Plant Sciences, University of Cambridge, United Kingdom, [2]School of Landscape Architecture, Beijing Forestry University, China

Afternoon Break and Poster Session, March 28, 2025, 14:30 - 16:00

Colouration in nature arises not only from pigments but also from physical phenomena, which are known as structural colours. Iridescence, a change in colour due to changes in viewer position, results from light interference and scattering caused by the periodic arrangement of nanoscale structures (diffraction gratings). Iridescence in Hibiscus trionum is generated in the epidermis from a cuticle that buckles, creating arrays of regularly spaced ridges on the petals. However, the process remains poorly understood and its ecological significance is still unclear. We identified a mutant line, lisa, derived from an EMS-mutagenized H. trionum population, which exhibits a significant reduction in iridescence, with the proximal part of the petals being purple-gray instead of purple-blue. We found that the nanoscale ridges on the petal surface fail to develop normally, they do not cross cell boundaries and exhibit disrupted directionality. These changes prevent the ridges from functioning as an effective diffraction grating. To better understand this mutant, we plan to 1) check the mechanical reason underlying the defects in ridge formation by analysing the cuticle layers features; 2) check chemical differences in cuticle composition and pigments; 3) explore molecular mechanism by identifying the mutated gene. Finally, to study how iridescence affects plant-pollinator interactions, we are using the iridescent artificial flowers and lisa mutant flowers to test bee preferences. We hope to offer new insights about the formation of nanoridges in the petals, which, in the future can help the generation of biologically-inspired, structurally-colored materials for diverse applications.

Phonon Microscopy Reveals Sub-Cellular Mechanical Adaptations in Rice Roots

Dr Salvatore La Cavera[1], Lucas Peralta Ogorek[2], Fernando Perez-Cota[1], Malcolm Bennett[2], Bipin Pandey[2]
[1]Optics and Photonics Group, University Of Nottingham, United Kingdom, [2]Plant and Crop Science Department, University of Nottingham, United Kingdom

Afternoon Break and Poster Session, March 28, 2025, 14:30 - 16:00

The mechanical properties of plant cell walls play a critical role in supporting growth and responding to environmental stresses. Using phonon microscopy, an optical elastography technique that leverages Brillouin scattering, we explored the impact of soil compaction on the biomechanics of rice root endodermal cell walls. By mapping the relative Brillouin frequency shift (Δf_B) and acoustic attenuation (α_B) with sub-cellular resolution, we investigated how mechanical properties differ under compacted and non-compacted growth conditions.

Our analysis uncovered notable variations in elasticity and viscosity between compacted and non-compacted samples, particularly within the endodermal region. Control measurements from cytoplasmic areas confirmed the specificity of these observations to cell walls. These results suggest that soil compaction elicits distinct mechanical adaptations in the root architecture, which may reflect broader physiological strategies to cope with challenging growth environments.

This study highlights the power of phonon microscopy for uncovering fine-scale biomechanical changes in plants, offering new perspectives on how environmental conditions shape cellular properties.

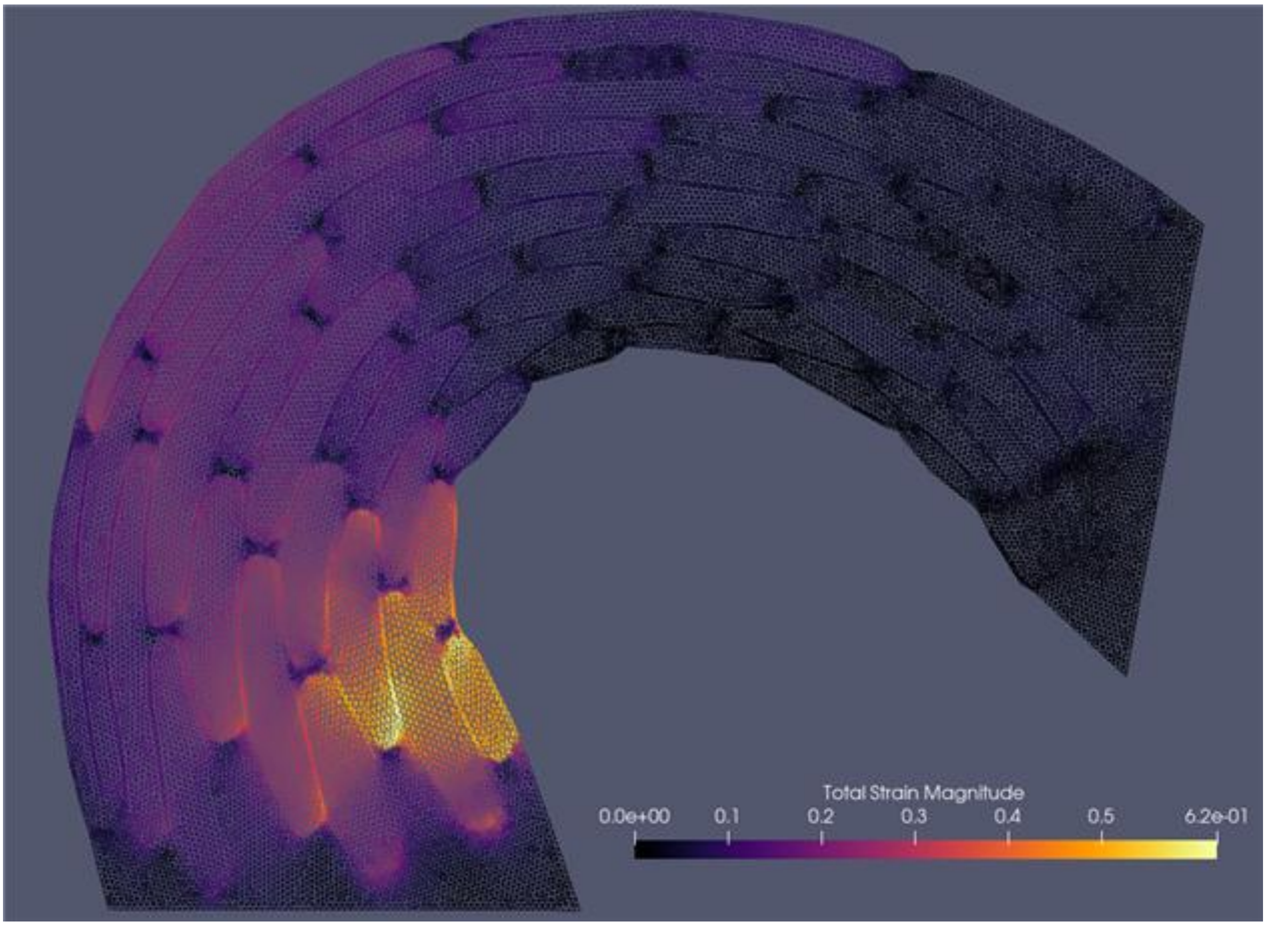
Exploring growth mechanics of apical hook morphogenesis in Arabidopsis using finite element modelling.

Sara Raggi[1], Hemamshu Ratnakaram[1], Özer Erguvan[1,2], Asal Atakhani[2], **Adrien Heymans**[1], Siamsa Doyle[1], Krzystof Wabnik[3,4], Stéphane Verger[1,2], Stéphanie Robert[1]
[1]Umeå Plant Science Centre, Department of Forest Genetics and Plant Physiology, SLU, Sweden, [2]Umeå plant Science Centre, Department of Plant Physiology, Umeå University, Sweden, [3]Centro De Biotecnología Y Genómica De Plantas, Instituto Nacional De Investigación Y Tecnología Agraria Y Alimentaria, Spain, [4]Departamento de Biotecnología-Biología Vegetal, Escuela Técnica Superior de Ingeniería Agronómica, Alimentaria y de Biosistemas, UPM, Spain

Afternoon Break and Poster Session, March 28, 2025, 14:30 - 16:00

The apical hook, a transient U-shaped structure at the tip of dicotyledonous plant hypocotyls, serves as a critical mechanical shield for the cotyledons during early development. This dynamic structure progresses through three distinct phases: formation, maintenance, and opening. These phases are driven by differential cell elongation and tissue mechanics, which collectively shape the apical hook's development. The precise regulation of differential growth rates during these phases offers a compelling model for studying dynamic morphogenesis. Using finite element modeling (FEM), we investigated the biomechanics underlying apical hook morphogenesis by simulating growth patterns based on wild-type and aberrant Arabidopsis mutants. Our control configuration started with a pre-formed apical hook mesh replicating the anatomical traits of the wild type, characterized by distinct gradients in cell length, such as longer cells on the outer curvature and shorter ones on the inner side. The mechanical properties of this baseline scenario featured high anisotropy and a high strain rate. Subsequently, we simulated three aberrant scenarios, systematically altering the strain rate, the mechanical anisotropy, or both simultaneously.

The simulations revealed that anisotropy in mechanical properties and strain rates significantly impact the dynamic maintenance of the apical hook. Aberrant patterns, mimicking mutant growth profiles, displayed deviations in hook geometry and reduced structural stability. These findings provide mechanistic insights into how variations in cell elongation and mechanical constraints regulate the formation, maintenance, and eventual opening of the apical hook. This work advances our understanding of plant biomechanics, particularly in the context of growth regulation and tissue mechanics during morphogenesis.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0.2
0.3
0.4
0.5
6.2e-01

The energy absorbing behaviour of seed bearing structures

Luke Malone[1], Darshil Shah[1]
[1]Department of Architecture, Centre for Natural Material Innovation (CNMI), University of Cambridge, United Kingdom

Afternoon Break and Poster Session, March 28, 2025, 14:30 - 16:00

Background

Nature has evolved carefully engineered structures designed to release seeds under optimal conditions. If the structures open too easily the seeds will likely die, either being eaten, or released into unfavourable environments. Conversely, if the structure is too difficult to open, the seeds may never be released. Studying these seed bearing structures could lead to the creation of new complex systems that can dynamically respond to their external environment.

Materials and Methods

The seed bearing structures of the Cupressus Pendula tree were studied. The structures were imaged using Bruker Ultima 2Pplus Two-Photon Microscope, the Skyscan 1172 Bruker micro-CT, as well as at the European Synchrotron Radiation Facility (ESRF) BM18. The static and cyclic compressive mechanical properties were studied using Tinius Olsen 1ST universal tensile testing machine, under a $0.1\ s^{-1}$ strain rate.

Conclusion

The seed bearing structures could be divided into smaller domains or plates, with the seeds located at the boundary between different plates (Figure 1b). Two-photon microscopy revealed that the interface between neighbouring plates was complex, with a carefully constructed interlocking ‘zip-like’ structure (Figure 1c). During compression testing, cracks spread along the low energy ‘valleys’ between plates, protecting the seeds. Cyclic testing revealed a remarkable recovery between subsequent cycles, allowing the seed structures to absorb and dissipate high levels of mechanical stress prior to release. These observations could inspire future shock absorbers that mimic the ‘zip-like’ structure. Cracks could be designed to preferentially spread along the low energy ‘valleys’, dissipating energy, whilst protecting the material inside.

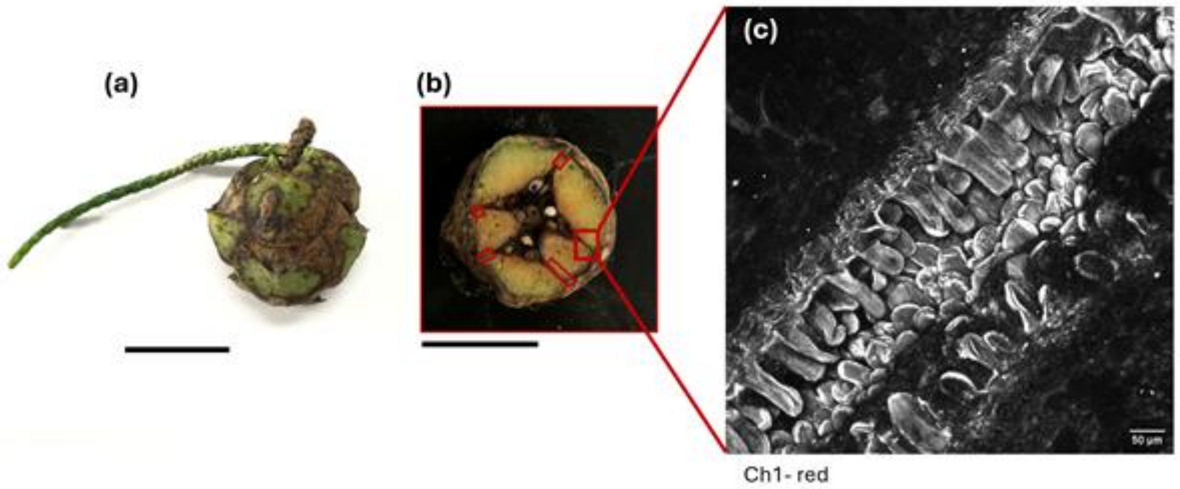

Figure 1. Seed bearing structure of the Cupressus Pendula tree. ***(a)*** *External view of the structure.* ***(b)*** *Micro-Vibratome slice of the seed bearing structure. The low energy ‘valleys’ between neighbouring plates are marked by red rectangles. In images (a) and (b) a 1 cm scale bar has been marked.* ***(c)*** *Two-photon microscopy image, (Ch1 red) of the interface region. The interface region contains a highly complex ‘zip-like’ interlocking structure, that helps protect the seed prior to its release but can open under the right conditions.*

Coordination Between Mesophyll Cells and Pavement Cell Shape Acquisition in Arabidopsis Leaves

Dr. Vinod Kumar[1], Stéphanie Robert[1]
[1]Umeå Plant Science Centre, Department of Forest Genetics and Plant Physiology, Swedish University of Agricultural Sciences, Sweden

Afternoon Break and Poster Session, March 28, 2025, 14:30 - 16:00

The leaf outermost epidermis cell layer of the leaf sense and responds to environmental threat, protecting the plants against various stresses such as wind, rain drought and pests. The epidermis cell layers sandwiches the porous, low-density mesophyll cells layers specifically, palisade and spongy mesophylls, which maintain tissue integrity and contribute to the mechanical stiffness to the leaf. Epidermis cells in the leaf exhibit diverse shapes and include specialized structures such as trichomes, stomatal complexes, and pavement cells, specialized for different functions and developmentally coordinated. During the expansion of epidermal pavement cell, the elongation of one cell inevitably leads to the indentation of the neighboring one(s). Thus, pavement cells display an interlocking jigsaw-puzzle pattern with multiple protrusion and indentation that interdigitate among their neighboring pavement cells. The diverse physical and mechanochemical nature of pavement cell wall is crucial for epidermal cell-shape acquisition to maintain the leaf tissue integrity. However, the contribution of mesophyll sublayers in regulating the shape and tissue integrity of epidermal pavement cells remain poorly understood. To address this knowledge gap, we screened several mesophyll cell mutants with defects in cell shape and density in Arabidopsis leaves and analysed the resulting shapes of epidermal pavement cells. Additionally, we mechanically ablate the single palisade mesophyll cells and followed the pavement cells shape at different time points (0, 24, 48 and 72h) using live cell imaging. Our analysis indicates that mesophyll sublayer certainly participates to the shape of epidermal pavement cells through mechanical and/or molecular signaling mechanisms.

Damage-Resistant Plant Actuators: The Role of Cell Wall Composition and Tissue Structure in Hygroscopic Movements of Fir Cone Scales

Łukasz Wiczołek[1], Dorota Borowska-Wykręt[2], Aleksandra Liszka[1], Anna Nowak[2], Jan Łyczakowski[1], Dorota Kwiatkowska[2]
[1]Department of Plant Biotechnology, Faculty of Biochemistry, Biophysics and Biotechnology, Jagiellonian University in Krakow, Poland, [2]Institute of Biology, Biotechnology and Environmental Protection, Faculty of Natural Sciences, University of Silesia in Katowice, Poland

Afternoon Break and Poster Session, March 28, 2025, 14:30 - 16:00

Cell walls are key contributors to the mechanical properties of plant organs. Secondary cell walls, formed after cell growth cessation, play a crucial role in ensuring the functionality of plant structures long after the death of protoplasts. In this study, we explore the complex relationship between cell wall composition, tissue structural traits, and the mechanical properties of Abies concolor cone scales as a model system of a plant organ composed of dead cells.

Our investigation combines biochemical and structural analyses, mechanical measurements, and deformation analysis to examine the hygroscopic movements of Abies cone scales. Through deformation analysis using artificial landmarks applied to the scale surfaces, we demonstrate the contrasting behaviours of the two surfaces during hydration. Additionally, we identify the role of vascular bundles as mechanical scaffolds within the scales. Selective tissue removal from one of the scale sides reveals the active and resistance sides responsible for its movements. Biochemical and structural differences between these sides are further analysed to elucidate their specific contributions. Notably, these natural actuators exhibit remarkable damage resistance, underscoring their potential for applications in biomimetic device design. This study provides new insights into the mechanics of plant organs and highlights the relevance of cell wall composition and structural traits in driving complex, moisture-responsive movements.

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Multiscale modelling and analysis of biomechanics of plant tissues

Mariya Ptashnyk[1], Arezki Boudaoud[2], Annamaria Kiss[3]
[1]Heriot-Watt University, United Kingdom, [2]LadHyX, CNRS, Ecole Polytechnique, France, [3]RDP, ENS de Lyon, Claude Bernard University Lyon France

Afternoon Break and Poster Session, March 28, 2025, 14:30 - 16:00

Many biological tissues must be structured in such a way as to be able to adapt to two extreme biomechanical scenarios: they have to be strong to resist high pressure and mechanical forces and yet be flexible to allow large expansions and growth. A part of nature's solution to this intriguing problem are the complex microstructures and microscopic (cellular) processes, that modify tissue's elastic properties. To analyse the interplay between the mechanics, microstructure, and growth we derive microscopic models for plant tissue biomechanics. Multiplicative decomposition of the deformation gradient into elastic and growth parts is used to model the stress or strain based growth. The macroscopic tissue-level model is derived using homogenization techniques. Numerical solutions for the macroscopic model demonstrate the impact of the microstructure on tissue deformations and growth.

Investigating the role of mechanical signals in plant cell fate decisions

Ioannis Theodorou[1], Léa Bogdziewiez[2], Stéphane Verger[1,2]
[1]Umea Plant Science Centre (UPSC), Department of Plant Physiology, Umea University, Sweden,
[2]Umea Plant Science Centre (UPSC), Department of Forest Genetics and Plant Physiology, Swedish University of Agricultural Sciences, Sweden

Afternoon Break and Poster Session, March 28, 2025, 14:30 - 16:00

Mechanical signals play important role in plant development. Differential growth and environmental factors generate mechanical stress anisotropies. The responses of plant cells and tissues to these anisotropies through changes in the cortical microtubules and cell wall properties are the essence of plant morphogenesis. However, what is the role of mechanical signals in plant cell fate decisions? We try to answer that question through responses of xylem precursors to mechanical stress. Xylem precursors can differentiate either to tracheary elements or xylary fibers. The mechanism behind that decision is currently unknown. We utilize two mechanically distinct systems to look into the contribution of mechanical signals to promote xylary fibers differentiation. In the first system, we look into the cell fate dynamics of hybrid Aspen tree stems under compression or tension release. This is a mechanically preset system with pre patterned topology and mechanical constraints on vascular cambium. The second system utilizes cell suspension cultures, where the previous properties are uncoupled. Specifically, in plant cell cultures, the cells arrange in seemingly random cell clusters under no constrain. Notably, the induction of tracheary elements is possible through hormonal or transcriptional factors. However, not all the cells differentiate, while differentiation of wood fibers in cell cultures is not yet documented. In both systems, we use fluorescent and confocal microscopy in combination to cell wall dyes and different induction methods/treatments to identify the necessary set of mechanical conditions to promote xylary fiber differentiation, investigating changes to cell organisation, structure and morphology. Our approach will allow us to understand the influence of mechanical signals on xylem cell differentiation and gain valuable insights into plant development and cell fate decisions.

Biofluidic Microscope: An Integrated Atomic and Fluidic Force – High-Resolution Confocal Microscopy Imaging Platform

Gleb Yakubov[1]
[1]University of Leeds, United Kingdom

Afternoon Break and Poster Session, March 28, 2025, 14:30 - 16:00

BioFluidic microscope ('BFM') is a new integrated imaging platform that combines ultra-fast confocal imaging with the atomic force and nano-fluidic functionality. BFM enables characterisation of localised biochemical and physiological processes in three dimensions of space, time and force, thus offering a step-change capability for exploration of biological and bioinsipred systems in 5 dimensions of 3D Space, Time and Force ('5D microscopy'). The BFM unlocks new avenues for applications in plant science and biomechanics. The unique design of the BFM enables accommodating an array of complex biological samples to perform quantitative and predictive characterisation of single molecules, plant cell walls, single cells and tissues, as well as whole plants. The BFM's applications cut across several domains, delivering benefits to a broad range of research topics in the areas of cell wall mechanics, plant development and and cell physiology.

The practical implementation of this system is based on integrating an open architecture Fluidic Force Microscope (FluidFM) based on Bruker JPK NanoWizard V and CytoSurge FLuidFM module with a Confocal Laser Scanning System (CLSM) based on LSM 980 Ayriscan 2 with Multiplex imaging. The microscope is equipped with an ultra-fast scanning unit (UFSU) and automated multi-scale (from nano to sub-millimetre) positioning system with uncustomary large Z-range. Underpinned by advances in nano-positioning, low-noise ultra-fast imaging and high-resolution capabilities (120 nm), coordination between high-speed 3D-imaging and fluidic analysis and manipulation of macro-to-micro-scale objects ensures information can be correlated down to < 100 nm resolution, on a single platform.

Poster Presentations

Poster No.	First Name	Last Name	Organisation	Paper Title
1	Shohreh	Askari	Aalto University	Bending and buckling of plant root hair
2	Adelin	Barbacci	Université de Toulouse	Pathogen-derived mechanical cues potentiate the spatio-temporal implementation of plant defense
3	Igor	Ceran		From Grip to Slip: How Pitcher Plants Disrupt Insect Adhesion
4	Annalene	Hansen	Aberystwyth University	Thigmomorphogenic responses: crops phenotypic and structural responses to mechanical stimulation
5	Humberto	Herrera-Ubaldo		Characterisation of the cuticle striation patterns in Hibiscus trionum petals
6	Adrien	Heymans	Umeå Plant Science Centre, Slu	Exploring growth mechanics of apical hook morphogenesis in Arabidopsis using finite element modelling.
7	Jessica	Huss	BOKU University Vienna	Survival in the desert - how cacti harvest fog droplets
8	Vinod	Kumar	Umea Plant Science Centre, Swedish University Of Agricultural Sciences	Coordination Between Mesophyll Cells and Pavement Cell Shape Acquisition in Arabidopsis Leaves
9	Salvatore	La Cavera	University of Nottingham	Phonon Microscopy Reveals Sub-Cellular Mechanical Adaptations in Rice Roots
10	Elise	Laruelle		Exploring the variability of plant cell wall mechanical properties
11	Luke	Malone	Department of Architecture	The energy absorbing behaviour of seed bearing structures
12	Sam	Mason	Imperial College London	Mapping Mechanical Input to Structural Remodelling Output in Arabidopsis Stems
13	Bhavani	Natarajan		Iridescent Petals: understanding the mechanics of nanoridge formation
14	Lazar	Novakovic	University of Leeds	Elucidating relationship between pit-field callose depositions and nanomechanical and structural cell wall properties in tomato fruits.
15	Emily	Oren	SLCU	Cell Division as a Mechanical Regulator of Arabidopsis Growth
16	Bipin	Pandey	University of Nottingham	Ethylene mediated cell wall mechanics regulate root responses in hard soils.
17	Amir	Porat		Integrating Growth, Mechanics, and Genetic Control in Plant Morphogenesis
18	Lucie	Poupardin		Biophysical study of plant’s morphogenic movement

19	Mariya	Ptashnyk		Multiscale modelling and analysis of biomechanics of plant tissues
20	Prafulla	Sujatha Nagesh	University of Exeter	Biomechanics of Prey Capture in Carnivorous Sarracenia flava Pitcher Plants
21	Nathanael	Tan	University of Sheffield	Unravelling the structure of the guard cell wall
22	Ioannis	Theodorou	Umeå Plant Science Centre (UPSC), Department Of Plant Physiology, Umea University	Investigating the role of mechanical signals in plant cell fate decisions
23	Melissa	Tomkins		Rethinking stomatal mechanics: Insights from a new model of onion stomata
24	Haruka	Tomobe	Institute of Science Tokyo	A method for estimating Young's modulus of maize stalks using torsional vibration mode
25	Łukasz	Wiczołek	Uniwersytet Jagielloński	Damage-Resistant Plant Actuators: The Role of Cell Wall Composition and Tissue Structure in Hygroscopic Movements of Fir Cone Scales
26	Matthew	Wilson	University of Sheffield	Symplastic guard cell connections buffer pressure fluctuations to promote stomatal function in grasses
27	Gleb	Yakubov	University of Leeds	Biofluidic Microscope: An Integrated Atomic and Fluidic Force – High-Resolution Confocal Microscopy Imaging Platform
28	Argyris	Zardilis	Sainsbury Laboratory, University Of Cambridge	Influences of a microtubule mediated mechanical feedback during early stages of flower development
29	Lijun	Zhou		Iridescence in Flowers - How and Why? Insights from lisa mutant

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