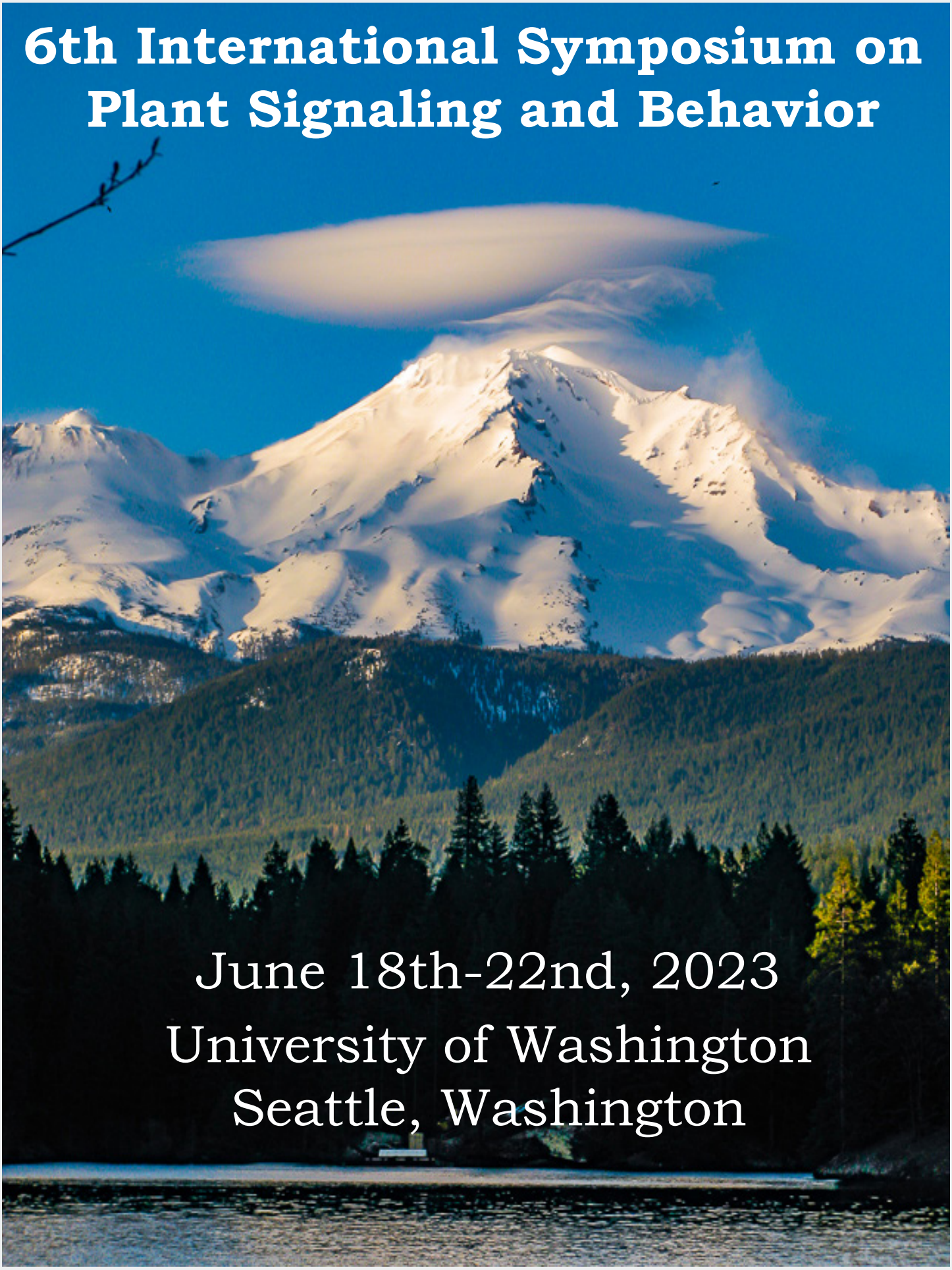
6th International Symposium on Plant Signaling and Behavior



June 18th-22nd, 2023

University of Washington

Seattle, Washington

Schedule At-a-Glance

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	Sunday, June 18, 2023
4:00-6:00 PM	Registration and Welcome Session (LSB Greenhouse Classroom)
	With refreshments.

	Monday, June 19, 2023
8:00 AM	Welcome Coffee and Snacks (Walker Ames)
9:00 AM	Opening Remarks (Kane 220)
9:15 AM	**Neuronal Molecules and Bioelectricity (Kane 220)**
SESSION 1	**Plants as Electromic Plastic Interfaces** *Gustavo Souza, Federal University of Pelotas*
	Melatonin as a Mediator of Plant Perception and Response to Changing Environments *Lauren Erland* **,** *University of the Fraser Valley*
10:45 AM	Refreshment Break
11:00 AM	**Neuronal Molecules and Bioelectricity (Kane 220)**
	Nitellopsis Obtusa Cells are Applicable Model System for the Investigation of the Participation of Ca2+ in Electrical Signalling of Plants *Vilma Kisnieriene, Vilnius University*
	The Effect of Glutamatergic Compounds On Action Potential Parameters and It's Propagation Velocities Along the Interdonal Cell of Nitellopsis Obtusa *Indre Lapeikaite, Vilnius University*
	Exploring Plant Electrophysiology Through Temporal Graphs *Yasmeen Hitti, McGill University*
	Response of The Plant Cell To Degradation of Its Wall *Ralf Oelmuller, Friedrich Schiller University Jena*
12:00 PM	Lunch
1:15 PM	**Calcium Signaling and Bioelectricity (Kane 220)**
SESSION 2	**The Venus Flytrap Dyscalculia Mutant Cannot Count Anymore** *Rainer Hedrich, University of Wuerzberg*
	Cytosolic Calcium Ion Dynamics by Mechanical Stimuli and Their Biological Roles In The Sensitive Plant, The Venus Flytrap and The Sundew *Mitsuyasu Hasebe, National Institute for Basic Biology*
	Systemic Calcium Signaling To Biotic and Abiotic Stresses *Simon Gilroy, University of Wisconsin-Madison*
	An Outward-Rectifying K+ Channel SPORK2 From Samanea Saman Exhibits Temperature-Sensitive Ion Transport Activity *Yuki Muraoka, Tohoku University*
3:45 PM	Refreshment Break Move to Life Science Building
4:15 PM	**Challenges for Plant Behavior Research (LSB 110)**
DISCUSSION	**Facilitated discussion in small groups coupled with group share out**
6:00 PM	Day 1 Adjourned

	Tuesday, June 20, 2023
8:00 AM	Welcome Refreshments | Poster Setup (Walker Ames)
9:00 AM	**Foraging, Cooperation, Competition (Kane 220)**
SESSION 3	**Plant Personalities: Consistent Individual Variation In Communication In Sagebrush** *Rick Karban, University of California-Davis*
	Plant Communication By VOC's In Natural Forest and Influence Toward Below-Ground *Kaori Shiojiri, Kyoto University*
10:30 AM	Refreshment Break
10:45 AM	**Foraging, Cooperation, Competition (Kane 220)**
SESSION 3	**Plant Communication and Ecological Dynamics: When Does It Pay For A Plant To Communication?** *Andre Kessler, Cornell University*
	Sounds Emitted By Plants Under Stress Are Airborne and Informative *Lilach Hadany, Tel Aviv University*
	Amplification of sucrose-stimulated growth increase by continuous 200 Hz sound in wild type Arabidopsis thaliana Col. *Emily Palm, University of Milan-Biacco*
12:00 PM	Lunch On Own
1:15 PM	**Evolutionary Ecology of Plant Behavior (Kane 220)**
SESSION 4	**Learning Root Learning** *Ariel Novoplansky, Ben Gurion University of the Negev*
	Beyond Foraging Precision: Understanding Root Foraging In A Complex Soil *Tara Rajaniemi, University of Massachusetts-Dartmouth*
2:45 PM	Refreshment Break
3:00 PM	**Evolutionary Ecology of Plant Behavior (Kane 220)**
SESSION 4	**Borrowing From Colleagues: Using Behavioral Theory To Understand The Ultimate Causal Drivers of Plant Root Growth** *James Cahill, University of Alberta*
	Woody Vine Boquila Trifoliolata Mimics Leaves of Artificial Host Plants *Felipe Yamashita, University of Bonn*
	Poster Lightning Round - 3 Minute Talks *Poster Presenters*

	Tuesday, June 20, 2023
4:45 PM	**Posters | Refreshments (Walker Ames)**
POSTERS	**How Do Grass Internode Patterns Emerge?** *Darshi Banan, University of Washington*
	Arabidopsis Retromer Subunit VPS29 Is Involved In SLY1-Mediated Gibberellin Signaling *Hak Soo Seo, Seoul National University*
	Can Increasing The Density of External Media Mimic Microgravity In Plant Roots? *Grace Miller, Grand Valley State University*
	Mechanosensing and Anesthesia of Single Internodal Cells of Chara *Mark Staves, Grand Valley State University*
	Plant-Plant Communication and The Plasticity of Plant Strategies *Daan Mertens, University of California-Davis*
	Effect of a Novel Trichoderma Strain On The Physiological Response of Arabidopsis Thaliana Under Salt Stress *Akanksha Gandhi, Friedrich Schiller University Jena*
	Inositol Hexakisphosphate (IP6) Modulates Parameters of Electrical Signaling in Characeaen Macroalgae Nitellopsis Obtusa *Vilmantas Pupkis, Vilnius University*
	Biosynthesis of Linalool Glycoside and It's Function In Cold Resistance of Tea Plant *Zhijie Bao*
	Classifying Circumnutation in Pea Plants Via Machine Learning *Qiuran Wang, University of Padova*
	A System For the Study of Roots 3D Kinematics in Hydroponic Culture *Valentina Simonetti , Ab.Acus s.r.l.*
	Linking Whole Plant Responses to Cell Physiology in Glycophates Exposed to NaCl Stress *Nathan Lauer, University of Victoria*
	Extracellular ADP Elicits Generation of Hydroxyl Radical in Plant Roots *Tomoko Kagenishi, Kitami University of Technology*
	Learning Physiology Through Plant Behavior *Liz Van Volkenburgh, University of Washington*
6:00 PM	Day 2 Adjourned

	Wednesday, June 21, 2023
8:00 AM	Welcome Coffee and Snacks (Walker Ames)
9:00 AM	**Plant Ecology and Interaction with Microbes and Insects (Kane 220)**
SESSION 5	**Volatile-Mediated Interactions In a Polluted Atmosphere: Modified Information Content** *James Blande, University of Eastern Finland*
	Species Interactions Shaped By Fungal Grass Endophytes *Benjamin Fuchs, University of Turku*
10:30 AM	Refreshment Break
10:45 AM	**Foraging, Cooperation, Competition (Kane 220)**
SESSION 5	**Selective Mechanisms Driving the Evolution Volatile-Mediated Plant-Plant Interactions** *Patrick Grof-Tisza, University of Eastern Finland*
	Plant Signaling and Behavior Under Anesthesia *Andrej Pavlovic, Palacky University*
	Eugenol Functions As A Signal Mediating Cold And Drought Tolerance Via UGT71A59-Mediated Glucosylation In Tea Plants *Mingyue Zhao*
12:00 PM	Lunch On Own
1:00 PM	**Plant Cognition and Intelligence (Kane 220)**
SESSION 6	**Cellular Sentience and Plant Cognition** *Frantisek Baluska, University of Bonn*
	The Coterminous Nature of Life and Sentience *Arthur Reber, University of British Columbia*
2:30 PM	Refreshment Break
2:45 PM	**Plant Cognition and Intelligence (Kane 220)**
SESSION 6	**Planta Sapiens and Human Impatience: Are We Patient Enough to Learn How Smart Plants Are?** *Paco Calvo, University of Murcia*
	The Grasping Side of Pea Plants: A Matter of Learning? | Evidence of motor intentions in plants *Silvia Guerra & Bianca Bonato, University of Padova*
	The Plant Neurobiology Revolution: a Metascientific Perspective *Peter Minorsky, Mercy College*
5:00 PM	Refreshment Break | Posters (Walker Ames)
6:30 PM	**Symposium Banquet (Ivar's Salmon House)**

	Thursday, June 22, 2023
8:00 AM	Welcome Coffee and Snacks (Walker Ames)
9:00 AM	**Communication of Our Science**
SESSION 7	**Using Plant Tracer To Create The Plant Movement Metaverse** *Eric Brenner, Pace University*
	Exploring Biological Agency in Art *Allison Kudla, Institute for Systems Biology*
10:30 AM	Refreshment Break
10:45 AM	**Communication of Our Science**
SESSION 7	**Making Use of The Broad Nature of Study Abroad Programs To Include Plant Behavior** *Emily Palm, University of Milan-Biacco*
	Plants Senses as a Versatile Tool To Teach Plant Biology *Jana Krtkova, Charles University*
	Concluding Session
1:00 PM	**Depart for Amazon Spheres Tour**

Oral Abstracts

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Poster Abstracts

pages 44–57

Stress Transmitting and Alleviating Biomolecules in Plants-Their Independent Roles and Crosstalk

Satish Chander Bhatla, Botany Department, University of Delhi

Plants and animals exhibit many similarities in their biochemical mechanisms of sensing stress and quenching of reactive oxygen species (ROS) produced as a consequence. Nitric oxide (NO), melatonin and hemoglobin (non-symbiotic 'phytoglobin') play independent roles and crosstalk in alleviating stress. Unequal distribution of electrons in the nitrogen atom of NO makes it a free radical and a suitable ligand to produce metal-nitrosyl (M-NO) complexes in various ROS scavenging enzymes. At high concentrations of NO, reactive nitrogen species (RNS) are generated which cause tyrosine nitration of proteins. The antioxidant and NO scavenging properties of hemoglobin are due to the donation of electrons to ROS and RNS, thereby facilitating their conversion into harmless counterparts. Melatonin, a neurotransmitter in human beings, is also produced in root and shoot tips, and serves as an antioxidant due to ROS quenching ability of 5-methoxy and 3-amide groups associated with its indole heterocyclic core. Phytoglobin is produced in root tips, shoot meristem and lateral branching points under a variety of stress conditions. It exhibits moderate to high affinity for oxygen. Heme oxygenase (HO-1) is an evolutionarily conserved enzyme in all forms of life. The products of heme oxygenation by HO action (CO, biliverdin and Fe2+) play important roles in cellular redox signaling, formation of antioxidants and iron recycling. CO, an established gasotransmitter in mammals, is now also known to modulate various developmental processes and alleviate oxidative stress in plants. Present work reports author's recent findings on the mechanisms of action of these biomolecules in plants.

Melatonin as a mediator of plant perception and response to changing environments

Lauren Erland, Berry Horticulture Research, Agriculture, University of the Fraser Valley

Melatonin was first discovered in plants in 199. Since its discovery, melatonin has been reported in at least 236 species of plants, and has been hypothesize to have evolved in the ancient ancestors to modern mitochondria and chloroplast, enabling them to survive in an increasingly oxygenated environment. While initial interest focused on discovery of a potential role for melatonin in mediating plant circadian rhythms, the roles of melatonin have been found to be much more diverse, mediating plant growth at every stage of the life cycle from seedling to seed and defending against biotic and abiotic stresses. This dual function of melatonin is mirrored both in concentration and location in tissues with dispersed and high concentrations of melatonin serving to defend plants against stress, while lower more localized levels are associated with mediation of growth and morphogenesis. I have developed methods to quantify melatonin both in isolation and in relation to other phytohormones in plants, to determine cellular localization of melatonin and to understand and predict signaling mechanisms in plants. My research is working to better understand the roles of melatonin in plants from its interaction within phytohormone networks to its role in mediating ecosystem level relationships. Through the use of interdisciplinary methods from plant tissue culture and metabolomics to quantum dot microscopy and ecological niche modelling I aim to understand the potential of melatonin as a mediator enabling plants to perceive and respond to changes in their environment, and to promote plant climate change resilience.

Plants As Electronic Plastic Interfaces

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Adrya V. L. Costa, Laboratory of Plant Cognition and Electrophysiology, Department of Botany, Federal University of Pelotas, Brazil
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Marc-Williams Debono, PSA Research Group, Palaiseau, France

The sessile lifestyle of plants exposes them to many challenges that must be overcome to ensure their survival. Despite their apparent lack of movement and behaviour, plants are very active and organisms that constantly respond to external cues and internal signals, making fine tunings at the metabolic, cellular and tissue levels. To accomplish this, plants largely rely on their relationship between phenotypic plasticity and cognitive abilities, which requires an information (or signalling) system. This information system is composed of many different signals, and among them are the electrical ones. Besides, in plants, there are many electrical activities that are not necessarily considered electrical signals. However, the sum of all electrical activity of a plant, considering all levels of organization, engenders an emergent electrical dimension of their life. This dimension of life that encompasses all the living beings has recently been named ‘‘electrome’’, in analogy with the other ‘omics’ from system biology approach. Herein, we will explore this concept to describe the plant electrical interface with its milieu. A typical electrome is a complex self-organized multi-colored ‘noisy’ signal, composed by a broad spectrum of frequencies often approaching a power-law distribution, indicating SOC behaviour. Most of main frequencies fall on a rage of very low band frequencies (0.1 – 0.5 Hz), but spikes of activity were found in higher band frequencies till aprox. 100 Hz, allowing an analogy with a typcal range of band waves distribution in humnan EEGs (e.g. Low, Delta (0.5–4 Hz), Theta (4–8 Hz), Mu (9–11 Hz), Alpha (8–13 Hz), and Gamma (20–100 Hz)). Moreover, the complexity of electrome signal, as evaluated by Aproximate Entropy and other complexity index, is quite related to physiological states of plants when facing different external stimuli. Such electrome changes, induced by external cues, are consistent enough to allow automatic classification by different statistical and AI methods, supporting a future plant-computer-interface device. Finally, Our research has shown that the electrome of plants is closely connected to their physiological states. Based on this finding, we have speculated that emergent global states of plant sensing, which could lead to cognitive states, may be supported by the bioelectrical continuum. This would involve approaching a putative electrome state of self-organized criticality (SOC) through shared sensory networks, ultimately allowing for the emergence of cognitive properties such as plant attention.

Nitellopsis obtusa cells are applicable model system for the investigation of the participation of Ca2+ in electrical signalling of plants

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The Characean peculiar long internodal cells and the presence of two membranes require a specific set of ion transport systems participating in excitation. Nitellopsis obtusa offers a robust experimental system to explore two-electrode current/ voltage clamp as well as droplet patch clamp techniques for excitability investigations. Separate and tandem internodal cells provide a model system for complex multi-parametrical investigation of instantaneous alterations in generation, propagation, and transmission of Action Potentials (AP) in vivo.
High temporal resolution recordings and analysis of real-time data indicated the effect of a variety of Ca2+ transport systems' modulators on AP parameters of Nitellopsis obtusa. Our experimental results on the alterations of AP parameters and the dynamics of ion channels' activity as well as fitted Thiel-Beilby model confirmed that the increased [Ca2+]cyt activates Cl− channels, leading to the depolarizing phase of the AP. The repolarization results from the Ca2+ being re-sequestered by the Ca2+ pumps, the closure of the Cl− channels, efflux of K+ through the depolarization-activated out channels and the re-activation of the proton pump after transient inhibition by the high [Ca2+]cyt. The tonoplast component of the AP is large and tonoplast excitability without plasma membrane excitation can be recorded. Putative Ca2+, Ca2+-modulated Cl− and K+ ion channels were shown to exist in the membrane of tonoplast droplets. Combined application of electrophysiological and molecular techniques in future studies should establish the molecular basis of electrical signalling in the absence of Ca2+-permeable glutamate receptors and Cl--permeable SLAC1 channel homologues in the Chara genome.

The effect of glutamatergic compounds on action potential parameters and its propagation velocities along the internodal cell of Nitellopsis obtusa

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Propagation of action potentials (APs) transmits information to distant parts of the plant body and leads to modulation of vital physiological functions. Reported GLR (glutamate receptor-like channels)-mediated electrophysiological responses are calcium-based and have specific functions in higher plants. Aquatic Characeaen macroalgae are a classical model organism allowing the exploration of electrical signals of a single cell. We employed intracellular two-electrode current clamp and voltage-clamp techniques to investigate glutamatergic compounds' effects on the parameters of APs and the excitation current transients. Results indicate that externally applied asparagine, glutamate and NMDA (a synthetic agonist of animal NMDA-like receptors) do alter the parameters of electrically induced APs: the increase of AP amplitude via hyperpolarization of excitation threshold potential (Eth) together with prolongation of AP repolarization phase was observed. These effects, together with alterations of excitation transient parameters, exhibit dose dependency (0.1-1 mM) and a specific effect pattern. Further, we employed two sets of previously described technique to impale two microelectrodes 3 cm apart in the intermodal cell. Thus, the glutamate effect on the AP propagation velocities in both directions was investigated. Results reveal that i) in standard conditions the AP propagation velocity to the apical direction is higher than to the basal direction; ii) exposure to glutamate increases the AP propagation velocity together with increased AP amplitude. Presented data indicate that the signalling function of glutamate combines both alteration of AP parameters and its propagation velocities.

Exploring Plant Electrophysiology Through Temporal Graphs

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Plant electrophysiology is an important field of research because it helps us understand how plants are responding to their environment. Plants use electrical signals to regulate how they adapt to different stimuli in their surroundings. Many have approached the interpretation of plant electrical signals with the help of machine learning and have successfully classified signals with respect to environmental conditions. Further work is needed to precisely understand what is happening at the physiological level of the plant and to go beyond treating plants as a blackbox. We propose to measure surface electrical potentials at 5 different locations on a growing plant and interpret the signals through the formulation of a temporal graph, where the connection between entities evolve over time. The graph nodes are the sensors and the edges are built based on similarity scores between time series collected at all sensor locations. The graph setup enables a different perspective on how the electrical signals are propagated throughout the plant and how the similarities between these signals are changing over time. To investigate the propagation of electrical signals in this fashion, we perform a case study with respect to a light stimulus. The plant is placed under a lighting system on relays where four narrow-band blue LEDs of 440 nm are activated separately every 20 mins. The signals are collected at a 10 Hz frequency for all sensors for a duration of 80 mins respectively. We expect to collect ~0.5 million data points to showcase the impact of light displacement on plant electrical signals.

The Venus flytrap Dyscalculia mutant cannot count anymore

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Funded by the ERC, my lab has been studying the roots of plant carnivory in general and the hunting skills of the Venus flytrap in particular for about a decade. What makes the Venus flytrap so special? As founders of modern (patch clamp) ion channel research in plants, we were impressed by the fact that the flytrap is electrically excitable. When a fly visits the trap and collides with the sensory hairs located at the inner trap surface, action potentials (APs) and Ca2+ signals are fired, similar to those known from excited nerve cells1. Our finding that the Venus flytrap can "count five" APs and makes decisions accordingly 2, sparked worldwide interest of scientists and the public 3.
But how can a plant "count"? To answer this question, we characterized a Dionaea mutant that lost the ability to count and thus cannot capture and process animals. We therefore named the mutant Dyscalculia (DYSC). Given that the mutant fires wildtype-like APs, grows normal traps and shows no developmental defects, DYSC obviously selectively lost its carnivorous syndrome - in other words, the capability to catch and process animals.
In search for the molecular grounds of this trap defect, we spotted the Ca2+ signaling pathway. In particular, we found elements known as decoders of Ca2+-electrical signals in plants strongly underrepresented or even lacking 4.
Our finding documents that proper decoding of touch-induced Ca2+-based action potentials is key for the Venus flytrap's count-dependent hunting cycle.
To find out about the genomic make-up required to count, to form a trap and to develop touch-sensitive sensory hairs, we recently sequenced the Venus flytrap genome 5 to chromosomal resolution. At the meeting, the molecular basis for the DYSC phenotype and mutants lacking sensory hairs or traps entirely will be presented.
References
1. Scherzer, S., Boehm, J., Huang, S., Iosip, A.L., Kreuzer, I., Becker, D., Heckmann, M., Al-Rasheid, K.A.S., Dreyer, I., and Hedrich, R. (2022). A unique inventory of ion transporters poises the Venus flytrap to fast-propagating action potentials and calcium waves. Curr Biol. 10.1016/j.cub.2022.08.051.
2. Böhm, J., Scherzer, S., Krol, E., Kreuzer, I., von Meyer, K., Lorey, C., Mueller, T.D., Shabala, L., Monte, I., Solano, R., et al. (2016). The Venus Flytrap Dionaea muscipula Counts Prey-Induced Action Potentials to Induce Sodium Uptake. Curr Biol 26, 286-295. 10.1016/j.cub.2015.11.057.
3. Plants count to five. (2016). Nature 529, 440-440. 10.1038/529440a.
4. Iosip, A., Scherzer, S., Bauer, S., Becker, D., Al-Rasheid, K.A.S., J., S., Kreuzer, I., and Hedrich, R. (2022). DYSCALCULIA, a Venus flytrap mutant that lost the ability of counting action potentials. Current Biology, submitted.
5. Palfalvi, G., Hackl, T., Terhoeven, N., Shibata, T.F., Nishiyama, T., Ankenbrand, M., Becker, D., Forster, F., Freund, M., Iosip, A., et al. (2020). Genomes of the Venus Flytrap and Close Relatives Unveil the Roots of Plant Carnivory. Curr Biol. 10.1016/j.cub.2020.04.051.

Cytosolic calcium ion dynamics by mechanical stimuli and their biological roles in the sensitive plant, the Venus flytrap, and the sundew

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Plants lack blood flow and nerves, but have evolved unique long-distance intercellular signaling mechanisms. Signals using plant hormones, peptides, proteins, and slow calcium waves have been well elucidated; however, the molecular mechanisms of long-range, rapid, intercellular signaling by action potentials with fast calcium waves, which evolved in parallel to similar signaling mechanism in animals, remains largely unknown. Rapid transmission of action potentials has been reported in specific tissues of the sensitive plant Mimosa pudica, the Venus flytrap Dionaea muscipula, and the sundew Drosera rotundifolia. To investigate the molecular mechanisms of generation and transmission of action potentials in relation to calcium waves, we have obtained genome sequences for three species and established techniques for transformation. We introduced a calcium ion sensor gene to monitor cytosolic calcium ion levels and found the speed of transmission is similar to that of action potentials. Furthermore, calcium ion dynamics could explain the memory system in the Venus flytrap, in which two mechanical stimuli within 30 seconds are necessary for movement. We are screening channels and transporters involved in the sensory organs and their disruption with CRISPR/Cas9 system resulted in the finding of genes involved in the regulation of the transmission of rapid calcium waves in Mimosa pudica.

Systemic calcium signaling to biotic and abiotic stresses

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Changes in cytoplasmic Ca2+ represent ubiquitous regulators across biology, with Ca2+-dependent signaling being linked to plant responses to a wide range of biotic and abiotic stresses. Thus, Ca2+ signals are generated at the sites of perception of stimuli as varied as wounding, pathogen invasion, cold stress and touch. However, we have found that in addition to these local reactions, all of these signals also elicit plant-wide responses. Imaging of the patterns of Ca2+ change using green-fluorescent protein-based biosensors has revealed the systemic molecular responses closely correlate with the plant-wide propagation of Ca2+ signals. The spatial and temporal patterns of Ca2+ change are different for each stimulus, consistent with a model where the dynamics of the variations in Ca2+ levels (its Ca2+ signature) may encode information that programs selective downstream responses. For touch and wounding, we have used Arabidopsis as a model to reveal roles for a subset of both the glutamate receptor-like channels (GLRs) and the cyclic nucleotide gated channels (CNGCs) in supporting the spread of these signals. These channels operate in both rapid organ-to-organ signaling, such as leaf-to-leaf, and within the subsequently responding systemic tissues. These responses propagate at speeds of up to mm/s, indicating an underlying molecular machinery capable of action in the range of seconds.

Response of the plant cell to degradation of its wall

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Yu-Heng Tseng, Pflanzenphysiologie, Dornburger Str. 159, Friedrich-Schiller-Universität Jena
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Cell wall integrity (CWI) maintenance is central for plant cells. Mechanical or chemical distortions, pH changes, or breakdown products of cell wall polysaccharides activate plasma membrane-localized receptors and induce appropriate downstream responses. Microbial interactions alter or destroy the structure of the plant cell wall, connecting CWI maintenance to immune responses. Cellulose is the major polysaccharide in the primary and secondary cell wall, and its breakdown generates short-chain cellooligomers. One of them, cellotriose, activates the malectin domain-containing CELLOOLIGOMER-RECEPTOR KINASE 1 (CORK1) in Arabidopsis. The activated CORK1 induces cytoplasmic Ca2+ elevation, reactive oxygen species (ROS) production, membrane depolarization, mitogen associated protein kinase (MAPK) activation, cellulose synthase phosphorylation, and the regulation of CWI-related genes. Phosphoproteome analyses identified early targets involved in signaling, cellulose synthesis, the endoplasmatic reticulum/Golgi secretory pathway, cell wall repair and immune responses. I will discuss the early phosphorylation events induced by the novel receptor kinase, compare its malectin domain with those of other malectin-receptor kinases, and propose that they might be crucial for balancing CWI/immune and growth responses.

An outward-rectifying K+ channel SPORK2 from Samanea saman exhibits temperature-sensitive ion transport activity

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Yoshiyuki Murata, Grad. Sch. Environ. and Life Sci., Okayama University
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Minoru Ueda, Grad. Sch. Sci. Tohoku University, Grad. Sch. Life Sci., Tohoku University

Temperature sensing is critical for the survival of living organisms. Thermosensitive transient receptor potential (TRP) cation channels function as thermosensors in mammals. In contrast to animals, land plants lack TRP genes. Previous patch-clamp studies in plant cells suggested the presence of ion channels whose activities are related to temperature, implying the presence of TRP-like channels. However, the molecular entities of such temperature-sensitive ion channels are still unknown in land plants. In this study, we observed that the unique rainfall-induced leaf folding movement of the legume Samanea saman was temperature-sensitive using a rainfall-mimicking assay. The chilling-induced leaf folding in S. saman was shown to be related to the swelling of the motor cells at the base of the leaflet. This swelling was suggested to involve temperature-sensitive deactivation of K+ currents, independent of fluctuations in ion channel gene expression in motor cells. These findings led us to examine the temperature sensitivity of an outward-rectifying K+ channel, SPORK2, which was reported as an ion channel responsible for the nyctinastic leaf movement of S. saman (Curr. Biol., 2018, 28, 2230-2238). And we discovered that SPORK2 exhibits temperature-sensitive K+ transport activity in the Xenopus oocyte expression system. In the same expression system, GORK, the well-known SPORK2 ortholog in Arabidopsis thaliana, was not temperature sensitive, while two legume orthologs showed similar temperature sensitivity to SPORK2. Therefore, SPORK2 is the ion channel in land plants with temperature-sensitive ion-transport activity that functions similarly to mammalian TRP channels (under review).

Plant personalities: consistent individual variation in communication in sagebrush

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Animals are said to have personalities when they exhibit consistent intraspecific differences in behaviors that are repeatable across different situations and stable over time. When animals sense danger, some individuals will alert neighbors with alarm calls and both calling and responding vary consistently among individuals. Plants, including sagebrush, emit volatile cues when they are attacked by herbivores and neighbors perceive these cues and reduce their own damage. We experimentally transferred volatiles between pairs of sagebrush plants to evaluate whether individuals showed consistent variation in their effectiveness as emitters and as receivers of cues, measured in terms of reduced herbivore damage. We found that 64% of the variance in chewing damage to branches over the growing season was attributable to the identity of the individual receiving the cues. This variation could have been caused by inherent differences in the plants as well as by differences in the environments where they grew or their histories. We found that 5% of the variance in chewing damage was attributable to the identity of the emitter that provided the cue. This fraction of variation was statistically significant and could not be attributed to the environmental conditions of the receiver. Effective receivers were also relatively effective emitters, indicating consistency across different situations. Pairs of receivers and emitters that were effective communicators in one year were again relatively effective in the next year, indicating consistency over time. These results suggest that plants have repeatable individual personalities with respect to alarm calls.

Plant communication by VOCs in natural forest and influence toward below-ground

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Studies of plant-plant communication via VOCs have been mainly reported on herbaceous plants and shrubs, indoors and semi-outdoors. In addition, most studies have focused on plant responses in the above-ground parts. Therefore, we focused our research on two questions: 1) Does VOCs-mediated communication among plants occur even in beech, a long-term dominant tree species in forest ecosystems, and 2) Does VOCs- mediated communication affect the below-ground?
Specifically, 1) was conducted in a natural beech forest. Immediately after leaf development, 90% of the leaves of one individual were cut in half as an emitter tree. 90 days later, leaf damage was counted on 126 beech. The results showed that leaf damage was less in individuals close to the emitter tree and more as the distance increased. In other words, it was demonstrated that communication via VOCs is taking place even in natural forests. For (2), we used a system of goldenrod and soybean. From the report that soybean that accepts the odor of goldenrod in the early stages of growth will have reduced leaf damage and more seeds, we hypothesized that aboveground plant communication reduces root nodule symbiosis via induction of bactericidal chemical defense substances, and it changes the soil-nutrient environment. Our experimental results showed that plants that received VOCs had higher saponin concentrations, and fewer root nodules than untreated plants. Moreover, soil C/N ratio was significantly lower in the soil of treated plants. Thus, plant communication aboveground led to reductions in root nodule symbiosis and soil nutrient concentrations.

Plant communication and ecological dynamics: When does it pay for a plant to communicate?

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Environmental stresses, such as herbivory, induce a complex reconfiguration of the plant metabolism, including changes in the production of resistance-mediating secondary metabolites. Some of these induced changes, most notably those of volatile secondary metabolites can function as chemical information that mediates diverse and complex interactions with herbivores. Those same compounds also mediate interactions with neighboring plants. Most of this plant-to-plant information transfer has been suggested to be eavesdropping on the plant's endogenous signal transduction or on chemically mediated interactions of plants with animals and microbes with a predicted fitness benefit for the receiver and significant costs for the emitter of the information. However, recent examples suggest that plant communication plays a far more important role in affecting ecological dynamics with potential beneficial effects for both the sender and the emitter of the information.
Here I use examples from our work on tall goldenrod, Solidago altissima, to illustrate how plant-to-plant communication can affect herbivore population dynamics and can affect the outcome of plant-herbivore interactions to affect emitter and receiver plants in a plant-to-plant information transfer. We demonstrate that induced resistance and the simultaneous transmission of information encoded in volatile organic compound emissions after herbivory significantly affect the movements of herbivores and so the distribution of herbivore damage within plant populations. The transmission of information is dependent on the community and population context and can be highly specific with respect to the attacking herbivores. Moreover, insect herbivores function as major agents of natural selection on the inducibility of chemical resistance as well as the plants' ability to transmit and receive chemical information in response to herbivore attacks.

Sounds emitted by plants under stress are airborne and informative

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Stressed plants show altered phenotypes, including changes in color, smell, and shape. Yet, airborne sounds emitted by stressed plants have not been investigated before. Here we show that stressed plants emit airborne sounds that can be recorded from a distance and classified. We recorded ultrasonic sounds emitted by tomato and tobacco plants inside an acoustic chamber, and in a greenhouse, while monitoring the plant's physiological parameters. We developed machine learning models that succeeded in identifying the condition of the plants, including dehydration level and injury, based solely on the emitted sounds. These informative sounds may also be detectable by other organisms. This work opens avenues for understanding plants and their interactions with the environment and may have significant impact on agriculture.

Amplification of sucrose-stimulated growth increase by continuous 200 Hz sound in wild type Arabidopsis thaliana Col.

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Vibrations are ubiquitous in nature, but we are only beginning to recognize their capacity to transmit information vital to plant survival. While the mechanisms through which vibrations are perceived and elicit physiological changes have yet to be fully elucidated, several factors are hypothesized as having a role as signal messengers and regulators of plant responses to sound, including sugars. Here, four-day-old WT A. thaliana Col. seedlings were grown on petri plates +/- supplemental 30 mM sucrose in insulated boxes for 12 days +/- continuous 200 Hz sound. With sucrose, the sound treatment had a significantly positive effect on the root elongation rate, lateral root number, true leaf area and the rate of emerging leaves; in the absence of sucrose, the effect of 200 Hz sound on these parameters was negative. Genomic and proteomic analyses showed rapid alteration in the expression levels of genes involved in hormone-regulated growth responses and leaf senescence within 24 hours of the start of the sound treatment with sucrose and increased content of proteins localized to the chloroplasts in sound + sucrose treated plants after seven days. Based on the present knowledge of the cellular mechanisms of sound perception in plants, our data provide support for the regulatory role of sucrose and suggest the need for further investigation into membrane properties at the intracellular and cellular level.

Learning root learning

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Despite their paramount role in plant life, the study of roots has been largely neglected until recently. Here, I shortly describe a few newly discovered abilities of plants to undergo adaptive changes and execute developmental decisions based on roots' perception and learning of information pertaining to imminent challenges and opportunities. Seemingly simple in their morphology and architecture, roots are able to perceive and integrate complex cues and signals that allow plants to perform elaborate behaviors analogous, some claim even homologous, to those of higher animals. Although our knowledge of root behavior is rapidly expanding, further understanding of its underlying mechanisms is largely preliminary, calling for detailed investigation of the involved cues, signals, and information processing controls, as well as their implications for plant morphogenesis, growth and reproduction under realistic ecological and agricultural settings.

Beyond foraging precision: understanding root foraging in a complex soil

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The soil environment is complex, and the strategic placement of roots is essential for successful establishment and growth of a plant. In addition to spatial variation in resource availability, root growth must respond to the roots of competing neighbors and well as potentially harmful or beneficial microbes, among other cues. Root responses to nutrient patches and neighbors are well documented, but also appear to be highly species- and context-dependent. The next challenge is to explain some of this complexity. I will describe some experiments that investigate pieces of the puzzle – how do plants integrate cues? what happens in multi-species communities? are there responses to microbial communities? – and discuss a possible framework for putting the pieces together.

Borrowing from colleagues: Using behavioural theory to understand the ultimate causal drivers of plant root growth

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Navigating heterogeneous landscapes is risky for all organisms, regardless of whether we are talking about a squirrel in grassland or grasses living next to the squirrel. Decisions about when and where to place's one's body impact an individual's immediate well-being and long-term fitness. Fortunately, complex landscapes provide diverse information that can lead to informed decision-making, such as literal road signs or in the plant-focused forms of nutrient and neighbour cues and signals. Decades of research by generations of animal behaviourists have identified many ultimate causations driving decision-making by organisms living in complex landscapes. However, the core evolutionary models which describe optimality in foraging decisions typically make no assumptions on the proximate mechanisms used to make decisions, and instead, they require natural selection to reward/sanction according to the consequences of decisions. Here I present a series of examples from my lab group testing specific and generalized hypotheses derived from animal behavioural theory, emphasizing root placement. Topics to be discussed include the well-documented issue of nutrient-patch use and suites of potential context dependence. A key goal of my research group is to integrate plant behavioural ecology into a larger-scale understanding, including implications for community assembly and conservation of biodiversity. Though animal behavioural models are often effective for understanding plant biology, at other times, they are not. Model failures appear to be a combination of challenges in translating to incorporate plant biology and recognizing that plants likely do not regularly exhibit many of the behaviours found among less vegetative organisms.

Woody Vine Boquila trifoliolata Mimics Leaves of Artificial Host Plants

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Boquila trifoliolata is a woody vine native to southern Chile capable of modifying the shape of its leaves according to the shape of the host plant's leaves. However, how these plants can perform this leaf mimicking is still unclear until now. Here we have performed three different experiments. The first one, already published, was based on leaves of artificial plastic plants and the result was that Boquila modified its leaves, trying to mimic the shape of artificial leaves. The second experiment was conducted with the Boquila plants separated into 3 groups. The first group placed into a wooden box was with a host plant, and the second group was without a host plant. The third group, as a control, was without a host plant and outside wooden boxes. The plant size was measured every week for 80 days. We can conclude with this experiment that Boquila plants growing with host plants within boxes grew faster than plants without host plants, as well as the control plants outside the boxes. The third experiment was placing Boquila plants into wooden boxes in which leaves of three different host plants are presented in form of color pictures. The results of this last experiment will be presented at the conference.

Volatile-mediated interactions in a polluted atmosphere: modified information content

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When plants are damaged by herbivores they release an assemblage of volatile organic compounds (VOCs) into the atmosphere. Those VOCs provide information on the physiological condition of the plant to the community. Neighbouring plants can detect the VOCs, which constitute a warning cue that herbivore's are in the locality, and respond by upscaling defence-related traits. Utilising Scots pine as a model plant species, we observed that VOCs induced by weevil-feeding on the bark, elicit a raft of changes in receiver plants, including increases in photosynthesis, stomatal conductance and emission (and priming) of VOCs. However, when plants were concurrently exposed to air pollution in the form of elevated ozone, the responses were largely altered. Interestingly, under both scenarios plants receiving weevil-induced VOCs gained greater resistance to weevils than plants exposed to undamaged neighbours. In a follow up study, we observed that weevil-feeding on emitter plants below the soil surface elicited similar responses in receivers. When mixing the VOCs induced by belowground feeding with ozone, there was a substantial increase in the formation of secondary organic aerosol (SOA) products. SOA are typically heavier than their parent VOCs and readily deposit on vegetation surfaces. Spraying formulations of SOA onto undamaged plants, we detected defence-related changes that were similar, but different, to those induced by VOCs. Here we will present and discuss novel findings related to plant-plant interactions and their functioning in a polluted atmosphere.

Species interactions shaped by fungal grass endophytes

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Plant-associated microbes are key players in shaping multi-trophic and species interactions in terrestrial ecosystems. Here, I present two types of plant interactions where endophytes shape the outcome: (1) interactions with herbivores and higher trophic levels and (2) interactions with pathogenic fungi and their joint effect on herbivores. Systemic and vertically transmitted fungal endophytes (Epichloë sp.) of cool-season grasses mediate plant defense via the production of alkaloids but the defensive mutualism with the plant host are context dependent. We show that the endophyte-conferred alkaloid biosynthesis is highly dynamic, shaped by plant age and season and is fine-tuned by multiple environmental factors including herbivore-specific induction. While locust herbivory induced the insect deterring alkaloid peramine, clipping induced the vertebrate toxic alkaloid lolitrem B in plant leaves. Under high defoliation however, alkaloid levels decreased in leaves and increased in seeds, which protected progeny seedlings from herbivory. Furthermore, indirect plant defense was improved by endophyte symbiosis, which lead to higher abundances of olfactory foraging predatory insects on endophyte-symbiotic and aphid-infested plants. Aphid predatory insects however, suffered lower performance caused by alkaloids, which cascaded-up in the food chain.
In co-occurrence with fungal pathogens from the same family (Clavicipitaceae), endophyte-symbiotic plants elicited a high infection frequency of seed pathogenic Claviceps purpurea. The co-occurrence of Epichloë and C. purpurea in plants elevated the ergot alkaloid levels, which reduced herbivore abundance, indicating a symbiotic co-existence of both fungi within the host.
Our results highlight the complexity and context-dependency of the mutualistic relationship between cool-season grasses and symbiotic Epichloë endophytes.

Selective mechanisms driving the evolution volatile-mediated plant-plant interactions

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When plants are damaged by herbivores, they emit a complex blend of volatile organic compounds into the surrounding environment. Neighboring plants can perceive and respond to these volatiles cues by inducing or priming a resistance response in preparation for an attack. While the selective mechanisms favoring the perception of volatile cues is clear, less clear are those favoring the sending of information that may benefit one's competitors. Using laboratory and field studies in both natural and agricultural systems, we explored the predictions of two non-exclusive hypotheses to explain why plants might emit cues, the kin selection hypothesis (KSH) and the mutual benefit hypotheses (MBH). The KSH has been invoked numerous times in the literature to explain the observation of stronger interactions between genetically related individuals. However, several alternative explanations exist, including volatile-mediated passively acquired resistance, which remain largely untested.

In sagebrush (Artemisia tridentata), we found evidence for both the KSH and MBH, depending on the relatedness between the interacting plants and the intensity of herbivory. However, we also found that the relatively stronger responses observed between related individuals could be in part explained by the adsorption of toxic or deterrent volatile organic compounds. In an intercropping system, we found evidence of the MBH; bean plants (Phaseolus vulgaris) could perceive and respond to maize plants (Zea mays) being fed on by fall armyworm caterpillars (Spodoptera frugiperda). This work sheds new light on the evolution of volatile-mediated plant-plant interactions and could lead to the development of novel integrated pest management strategies.

Plant signaling and behavior under anesthesia

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General volatile anesthetics are usually defined as compounds which induce reversible loss of consciousness in animals and humans. However they work also on plants. Using combination of different techniques, we investigated the effect of general volatile anesthetic diethyl ether on ability of plants to perceive different stimuli: wounding, touch and light. When Arabidopsis thaliana plants were wounded under diethyl ether anesthesia, systemic electrical signal propagation and calcium wave to neighboring leaves were blocked and systemic leaves were not able to activate defense response. On the other hand local damaged leaf was still able to sense wounding and even mild touch stimuli. Because the systemic electrical signal propagation is dependent on glutamate receptor-like (GLR) proteins GLR3.3 and GLR3.6, we investigated also the effect of intravenous anesthetic ketamine, a well-known inhibitor of animal ionotropic NMDA glutamate receptors. Ketamine was not able to inhibit systemic electrical and calcium wave signals propagation. Diethyl ether anesthesia inhibited also de-etiolation of dark-grown plants. Disruption of phytochrome and/or retrograde signaling attenuated nuclear gene expression encoding components of light-harvesting complexes in photosystem I and II. However application of diethyl ether itself caused a huge reprogramming of gene expression. This was caused by increased cytoplasmic calcium concentration resembling and mimicking a heat stress in plants. Our studies have shown that the effects of anesthesia go far beyond modern medicine having wider implications for a variety of organisms and deserve our further attention.

Eugenol functions as a signal mediating cold and drought tolerance via UGT71A59-mediated glucosylation in tea plants

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Cold and drought stress are the most critical stresses encountered by crops and occur simultaneously under field conditions. However, it is unclear whether volatiles contribute to both cold and drought tolerance, and if so, by what mechanisms they act. Here, we showed that airborne eugenol can be taken up by the tea plant and metabolized into glycosides, thus enhances cold and drought tolerance of tea plants. A UDP-glucosyltransferase UGT71A59, whose expression is strongly induced by multiple abiotic stresses, specifically catalyzes glucosylation of eugenol glucoside in vitro and in vivo was discovered. Suppression of UGT71A59 expression in tea reduced the accumulation of eugenol glucoside, lowered ROS-scavenging capacity, and ultimately impaired cold and drought stress tolerance. Exposure to airborne eugenol triggered a marked increase in UGT71A59 expression, eugenol glucoside accumulation, and cold tolerance by modulating ROS accumulation and CBF1 expression. It also promoted drought tolerance by altering ABA homeostasis and stomatal closure. CBF1 and CBF3 play positive role(s) in eugenol-induced cold tolerance and CBF2 may be a negative regulator of eugenol-induced cold tolerance in tea plants. These results provide evidence that eugenol functions as a signal in cold and drought tolerance regulation and shed new light on the biological functions of volatiles in response to multiple abiotic stresses in plants.

Cellular Sentience and Plant Cognition

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Because all life is based on cells, any evolutionary theory of the emergence of sentience and cognition must be grounded in mechanisms that take place in prokaryotes, the most ancient unicellular species. Cells emerged at the very beginning of life on Earth and are coterminous with life. Life on the Earth has evolved for an estimated 4 billion of years. For the first 2 billion of years of that evolutionary span, all life was unicellular, including at first archaea, bacteria and then eukaryotic protists. Unicellular organisms, such as diverse protists and algae, still live an unicellular life until present times. Plants evolved from algae and vascular plants are integrated into coherent bodies via plant-specific synaptic adhesion domains, action potentials (APs) and other means of long-distance signalling running throughout the plant bodies. Plant-specific synapses and APs are proposed to allow plants to generate their self identities having unique ways of sensing and acting as agents with their own goals. Plants move their organs with a purpose and with obvious awareness of their surroundings and require APs to perform and control these movements. Plants are sensitive to exogenous anaesthetics which inhibits APs and fast plant organ movements. Plants also produce endogenous substances, especially when stressed, that have anaesthetic and anelgesic properties when applied to humans and animals. Plants rely on neurotransmitters, including GABA and glutamate, and their receptors for cell-cell communication and integration. They use plant-specific sensory systems and neurotransmitter-based cell-cell communication to manage stress adaptation via plant-specific cognition and behavior.

The Coterminous Nature of Life and Sentience

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The core of what has been dubbed the Cellular Basis of Consciousness (CBC) theory is that a nonsentient organism could not have survived in the chaotic and dangerous environment into which the first life forms emerged some 4 billion years ago. Hence, the first prokaryotes were aware of themselves, sensitive to their environment, and had valenced perceptions -- in short, the features that are associated with consciousness. There is a rich empirical record showing that unicellular species, bacteria and archaea, respond appropriately to events by moving away from tissue damaging stimuli, learn(including learning simple ABAB patterns), form stable memories, and communicate both within and between colonies. Also, importantly, they respond to anesthetics.

It's reasonable to ask, given this is true, what is the message for those who study plants? The answer is found in one of biology's fundamental principles: "If it works, keep it." As one of the giants of evolutionary biology, Lynn Margulis, put it, "In evolution, nothing useful is ever lost." Since plants evolved from the same ur-species as all others, it follows that plants must be sentient, have valenced experiences, react appropriately to them, communicate and respond to anesthetics -- conclusions supported by many of the talks and posters in this conference.

Scientists are virtually all in agreement with the core proposition that all life began with prokaryotes and all species, extant and extinct, evolved from them. The CBC model's core principle is that sentience followed the same evolutionary path.

Planta sapiens and human impatience: Are we patient enough to learn how smart plants are?

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The investigation of plant intelligence is here to stay. And yet, despite the growing body of literature, we appear not to be making enough headway. Controversies over complex plant behaviors are part of a long botanical tradition. But things are only getting worse in today's academic 'publish or perish' culture (even worse, 'publish then perish' for young scholars). Fast science promotes quantity over quality. The result is lack of a common language and subsequent misunderstandings, misdiagnoses and construction of straw man arguments, and anthropomorphism of observations, among other perils. Many findings that have gripped the public's imagination are proving extremely difficult to replicate. This is a serious threat that undermines the credentials of the field. In this context, self-reflection is very much needed. Having taken root, after almost two decades since the first symposium on the Society took place, the time is ripe to take stock and to ensure that the field has the resources to increase its long-term impact. In this talk I offer some reflections on the risk of underdelivering and how to avoid biases that lead to overinterpreting results. Advancing the field of plant signaling and behavior calls for inclusion and adversarial collaboration; for the exploration of the guiding role that complementary, rather than competing, models and theoretical frameworks can play. Having a long-term impact calls for "slow science" and for the nourishment of social interactions in the plant and cognitive scientific communities. The goal is to grasp the challenges the community faces in the forthcoming years.

The grasping side of pea plants: a matter of learning?

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At first glance, plants seem relatively immobile, stuck to the ground in rigid structures, but movement pervades all aspects of plant behavior. Here, we address the main question of whether such movements are “goal-directed” and, if so, how such capacity is acquired. To this end, we shall present two kinematical studies on pea plants searching for and grasping a potential support in the environment. We characterized the growth movement of pea plant from the germination of the seed to the grasping of the support by means of three-dimensional (3D) kinematical analysis. In one study we demonstrate the ability of pea plants to process the intrinsic features of a support (e.g., thickness) and to modulate their approaching and grasping behaviour accordingly. In another study, we explore how this process is eventually ‘learned’ during growth. The results suggest that the information acquired by the plant at a certain growth stage is communicated to the following stage. A process that continues until the plant has acquired all the necessary information to successfully grasp the support. This mechanism is suggestive of a motor learning process based on the transmission of practice-related information across growth stages. Results are discussed in the light of available theories put forward to explain how plants sense the environment and adapt their growth to the task at hand.

Evidence of motor intentions in plants

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"How" an action is performed is not solely determined by biomechanical constraints, but it depends on the agent's intention, i.e., "why" the action is performed. Recent findings suggest that intentions can be specified at a tangible and quantifiable level in the kinematics of movements, that is different motor intentions translate into different kinematic patterns. In the present study we used 3D kinematical analysis to investigate whether the organization of climbing plants' approach-to grasp action is sensitive to the kind of intention driving their movement towards a potential support, namely individual or social. For the individual condition a plant in isolation acted upon the support. For the social condition two plants were located in the same pot opposite to each other with a support in the middle. Results indicate differences in kinematics depending on the context within which the plant is acting. In the presence of neighbours, climbing plants are able to modify their behaviours to maximize their long-term gains, including the grasping of a potential support. Overall these data suggest that the organization of climbing plants' kinematics is sensitive to the "intention" driving their movement towards a potential support. Among the physiological processes underlying this behavior we identify Strigolactones as playing a role to this endeavor. Data are discussed in the light of available theories concerned with social cognition and kin recognition in plants.

The Plant Neurobiology Revolution: a Metascientific Perspective

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The plant neurobiology movement is a coalition of plant biologists, including ethologists, biosemioticists, comparative psychologists and electrophysiologists, whose aim is to reform how plant biologists regard plants conceptually. Proponents stress that plants are exquisitely sensitive to environmental perturbations, and that seemingly innocuous experimental manipulations rapidly and profoundly alter plant sensitivity and function. Thus, much of what is purported to be 'known' about plants is unrelated to normal plant function. To understand the reality of plant life, Proponents believe that a more holistic, ecological, multi-disciplinary, synthetic, and pluralistic biology is needed to complement reductionist and determinist approaches. The thesis is presented that the differences between Proponents and Opponents lies less in the realm of day-to-day science than in the metasciences, i.e., the philosophy, history, sociology, and psychology of science. The plant neurobiology movement has its origins in the Age of Reflection, a rebellion against codification in every aspect of human endeavor: in contrast, Opponents embrace mechanistic thinking from the Age of Reason. Historically, plant neurobiology has been championed by free thinking polymaths often considered to be "outsiders" by the profession. Proponents, unlike Opponents, favor "lumping" over "splitting", a psychological proclivity that develops during early childhood. Sociologically, Opponents divide the world, including academia, into discrete, insular entities separated from one another by wide mental gulfs, while Proponents listen to, and learn from scholars from a broad range of disciplines, including those traditionally considered far removed from plant physiology (e.g., psychology, philosophy, and history).

Using Plant Tracer to create the plant movement metaverse

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Movement is a universal characteristic of all plants necessary to obtain optimal position for survival. Among plant movements circumnutation is the back and forth swaying common to most plant appendages, particularly young growing organs. The purpose of circumnutation is only partly understood despite the topic being a rich area of research among Darwin and his cohorts over a century and a half ago. In roots circumnutation functions as a boring motion to help the root apex dig into the soil. In the shoots of twining plants circumnutation functions a a seek and find motion grasping for growth supports. However, in most shoots the function of circumnutation has only been theorized. Gravitropism, movement in response to gravity, is a better studies process, but mostly in the roots of a few plants with little known about its function in shoots, particularly at the molecular level. In general, motion in the vast majority of plant species has not been documented leaving a large void in understanding a critical plant process. To help make characterization and measurement of plant movement a more routine process for research and education, we have developed the App, Plant Tracer (http://planttracer.com) to quantify plant movement from time lapse movies that are made with cell phones and other types of inexpensive cameras. Plant Tracer determines the speed and amplitude of circumnutating Arabidopsis flowering stems (inflorescences) as well as the speed, distance displaced, and angle of bending for Arabidopsis flowering stems undergoing gravitropic movement. Continued and expanded use of Plant Tracer will expand our knowledge of movement in the plant world.

Exploring Biological Agency in Art

Dr. Allison Kudla, Institute for Systems Biology, Seattle, USA

Art at the intersection of technology is commonly in dialogue with algorithms, systems, and generative processes. In my novel artistic work, I draw parallels between digital technologies and living systems — specifically plants. These works often focus finding and accentuating “algorithms” embedded in living biological systems and processes within an artistic framework. In doing this, I create time-based systems for experiencing biology working in hybrid with technology.

Making use of the broad nature of study abroad programs to include Plant Behavior

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'Plant Behavior' is both fortunate and unfortunate in that it can be interpreted to incorporate many different topics – making it fit everywhere and sometimes, nowhere. It has a conceptual flexibility that makes it ideal for a study abroad program where students are often taking courses outside of their normal program requirements. Study abroad programs in plant biology are rare due to home department course requirements and the financial and logistical challenges for many satellite campuses. However, it could be argued that plant behavior is an ideal upper-level course that stimulates creative discussions that are based in plant physiology concepts that can be extended to programs dedicated to philosophy, behavior, consciousness, and language: how do we define consciousness? What is the language that we use to describe the responses we see plants displaying due to environmental stimuli? How have local artists and agronomists interpreted plant behaviors? The benefits of this thought experiment extend beyond students with a background in plant biology: a plant behavior curriculum in this context, offered to a broad range of majors, would also provide students who have focused on the social sciences the opportunity to consider the ways that other living organisms may communicate, move, and respond to their world. The open, exploratory nature of study abroad programs provides a unique place where the topic of plant behavior might be more readily accepted and in some cases potentially lead to the integration of dedicated plant biology programs and opportunities for study abroad students in the hard sciences.

Plant Senses as a Versatile Tool to Teach Plant Biology

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In the last decades, we have witnessed tremendous progress in plant biology and deeper and more detailed understanding of plant processes. This may render teaching plant biology challenging. The approach from the perspective of plant senses turned out to be highly motivating for students and was considered as attractive. Different plant sensual inputs from its environment enable to explain general models of plant signaling – what a signaling pathway is, its molecular compounds, receptors and their structural parts, kinases, phosphatases, gene expression, developmental morphogenetic patterns etc. Plant senses can be further connected with the specific physiological response, for example photoperiodism, phototropism. Through plant responses to environmental cues the students can be introduced to stress biology, and therefore to the cutting edge applied research in international agricultural centers, to the role of genebanks, to four agricultural revolutions.
During my work with students, I unknowingly developed several types of their intelligence proposed by Howard Gardner, professor of education at Harvard University, in 1983. Linguistic intelligence – by forcing them read, ask questions, write a grant proposal, naturalist intelligence, logical-mathematical intelligence, musical intelligence – demonstration of basson music, since Darwin played on bassoon to plants –and possibly also spatial intelligence by showing maps and pictures of different landscapes.

Giving Nature a Voice: How to Design for Humans, Plants, and Animals

Helene Steiner, Open Cell

Humans have treated nature as an endless resource, including its co-habitants (plants and animals). On the one hand, this allowed us to move from hunter and gatherers to the agricultural and then industrial revolution, but it also made us victims of our own success. Our overconsumption reached nature's limits, making the systems we have built unsustainable. We must pivot from a human-centered design to an eco-centric approach to resolve this. This requires us to rediscover the links between nature and humanity and our intimate connection, which over-industrialization has made us forget. In recent years, we have witnessed the coupling of biological advancements with technology to generate an emerging trend toward hybrid technologies. Such examples include bio-fabrication, while other instances can be seen with more profound work into the genome with the rise of computational biology. This afforded us the ability to interface with different organisms. The opportunities to capture and analyze biological signals are on the rise and close the gap between natural and digital, ushering in the frontier of biological interfaces. These advancements offer new opportunities to design solutions in collaboration with other organisms and sync with the ecosystem through biological interfaces.This talk will discuss the framework of an eco-centric design approach and outline the development of a plant-human interface to achieve two-way communication between plants and humans. It will address the electronic set-up of the system to connect to a plant and capture various biological signals, including VP/AP and fluorescence emission changes. It will outline our use of natural language processing to translate between human and plant receivable signals. And discuss future applications for biological interfaces, including agriculture, wildlife conservation, and smart cities.

How do grass internode patterns emerge?

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Internodes provide the scaffolding for photosynthetic, storage, and reproductive organs in plants. Internode patterns – i.e. their size, number, proportion, and arrangement –reflect interactions between self, neighbor, and environment. This research uses the model grass, Setaria, to ask: What is the adaptive significance of internode patterns and how do internode patterns emerge? Internode patterns were measured by imaging mature culms harvested from a natural diversity panel of North American Setaria viridis accessions grown in a field common garden drought experiment. The timing of internode growth was tracked on a subset of taxa with contrasting phytomer counts in greenhouse experiments. These data were used to parameterize a mathematical model describing resource allocation between concurrently growing phytomers and reproductive investment. Internode patterns varied widely across the diversity panel. This internode pattern diversity clustered with the geographic distribution of accession collection sites and correlated significantly with reproductive investment and provenance climate. Vegetative internodes responded negatively to drought while peduncles responded positively. Field and greenhouse data both showed that the relationships between phytomer count, internode length distribution, and total plant height varied depending on taxa. Finally, modeling results indicated that internode patterns largely emerge from the duration of internode growth and the shift to reproductive development rather than the timing of internode emergence. These results suggest that internode pattern emergence is phenotypically plastic and genotypically diverse. Future work will assess how environmental perturbations modify internode patterns and use genomic approaches to explore the molecular basis for internode pattern emergence.

Arabidopsis retromer subunit VPS29 is involved in SLY1-mediated gibberellin signaling

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In plants, the large retromer complex is known to play roles in multiple development processes, including cell polarity, programmed cell death, and root hair growth in Arabidopsis. However, most of their roles in plant development remain known. Here, we show that Arabidopsis retromer protein VPS29 (vacuolar protein sorting protein 29) functions in gibberellin signaling. SLEEPY 1 (SLY1) protein was less abundant in vps29-3 mutants than in wild-type plants, but the DELLA protein RGA was more abundant in vps29-3 mutants than in wild-type plants. Expression of gibberellic acid (GA)-synthetic genes was down-regulated in vps29-3 mutants. But, transcript levels of GA receptor genes were not changed in vps29-3 mutants. Root growth of vps29-3 mutants was severely retarded and their cotyledons were abnormal in size and shape. Together, these data indicate that AtVPS29 positively regulates SLY1-mediated GA signaling and plant growth as a component of retromer complex.
This work was supported by National Research Foundation of Korea (NRF) grant funded by the Korea Government (MSIT) (Project No. 2021R1A2C1003446).

Can Increasing the Density of External Media Mimic Microgravity in Plant Roots?

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There are two leading models of plant gravity sensing: the statolith model, where statoliths sediment and sense gravity, and the gravitational pressure model, where the protoplast acts as the gravisensor. The statolith model is widely accepted, but plants without statoliths and plants with statoliths removed retain their ability to sense gravity. Thus, we tested between these models using Oryza sativa (rice) as it contains statoliths and grows well in liquid media. We grew the plants with the roots exposed to unilateral light in artificial pond water (APW) and OptiPrep solutions. The APW experiments gave a baseline for how roots respond to the light conditions. OptiPrep increased the density of the media and the root curvature increased, suggesting the gravity response was reduced. These results are consistent with the gravitational pressure model and inconsistent with the statolith model. We compared sections of rice roots to check statolith distribution, which was not affected by our experiments. These results lead us to conclude increasing the density of external media can mimic microgravity in plants. We are now testing this hypothesis by comparing the response of Arabidopsis to light and gravity stimulation in Optiprep solutions with their reported responses in microgravity on the ISS.

Mechanosensing and Anesthesia of Single Internodal Cells of Chara

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The giant (2-3 cm long) internodal cells of the aquatic plant, Chara, exhibit a rapid (>100um s-1) cyclic protoplasmic streaming which stops in response to mechanical stimuli. Since the streaming – and the stopping of streaming upon stimulation – is easily visible with a stereomicroscope, these single cells are ideal tools to investigate mechanosensing in plant cells, as well as the potential for these cells to be anesthetized. We found that dropping a steel ball (6mm in diameter) through a 4.6 cm long tube (delivering ca. 4 x 10-4J) reliably induced mechanically-stimulated excitation-cessation coupling, EC-coupling (i.e. the mechanical stimulation caused an excitation which resulted in the cessation of protoplasmic streaming). We found that the mechanically induced E-C coupling depends on external calcium concentration. In a buffered solution of pCa 5 (containing 10-5M free Ca2+), 100% of cells exhibited mechanically-induced E-C coupling, whereas at pCa7, E-C coupling was completely inhibited. To determine whether mechanically-induced E-C coupling in Chara was sensitive to anesthesia, we treated Chara internodal cells, resting upon filter paper saturated with a pCa 5 solution, to volatilized chloroform in a 9.8 L chamber. We found that low doses (0.5-0.75 ml) of chloroform did not always anesthetize cells, whereas large doses (1.5 ml and higher) proved lethal. However, 1ml of chloroform completely, and reversibly anesthetized these cells. To our knowledge, this is the first report of anesthesia in single plant cells and we believe this model may be useful for elucidating mechanisms of anesthesia in plant cells.

Plant-plant communication and the plasticity of plant strategies

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By producing information-rich blends of volatiles, plants can induce phenotypic responses in their neighbours with potential benefits for the receiving plant. Evidence suggests that this communication is more effective when plants are more closely related. However, many plants grow in genetically heterogeneous environments, where volatiles are much more diverse in their origin. Importantly, this diversity in information may also present opportunities for receiving plants to adjust their life history strategies, for example by anticipating competitive interactions. Yet little is known on how plants respond to more complex blends of volatile information.

To this end, we conducted a field experiment with Artemisia douglasiana, a plant species for which communication through volatiles has previously been established. Experimental plants were exposed to volatiles produced plants from the same population (kin), a mixture of volatiles produced by kin and one of two non-kin populations, or a diverse blend of volatiles produced by kin and both non-kin populations.

We did not find any significant differences between treatments in terms of plant development, damage, or reproductive strategy. We hypothesise that A. douglasiana either i) responds to kin-emitted volatiles independent of the presence of volatiles produced by non-kin, or ii) that the plants in our experiment did not distinguish between the different genetic sources of volatiles. Future research in more controlled environments is needed to confirm either hypothesis.

Effect of a novel Trichoderma strain on the physiological response of Arabidopsis thaliana under salt stress

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Salt stress is one of the major environmental factors that limits crop productivity. To mount an effective response to cope with salt stress, plants rely on the salt overly sensitive (SOS) pathway. This includes SOS1, SOS2 and SOS3 proteins that are crucial for the maintenance of ion homeostasis and the sos1 mutants are hypersensitive to salt stress. Symbiotic association of plants with beneficial microbes can increase the tolerance of plants to various abiotic stresses. One such versatile endophytic plant symbiont is Trichoderma spp. that can protect plants against salt stress. However, the molecular mechanism by which it mitigates the damage caused by salt stress remains elusive. In this study, we examined the effect of a novel Trichoderma strain on the growth of glabara1 (gl1) and salt overly sensitive (sos1) mutants in Arabidopsis thaliana under salt stress. Our results demonstrate that several plant growth parameters such as fresh weight, quantum efficiency of photosystem II and chlorophyll content were improved in Trichoderma inoculated sos1 plants under salt stress. Moreover, higher transcript levels of genes involved in ROS scavenging were observed in sos1 shoots colonized by Trichoderma. Also, Trichoderma enhanced the levels of osmolytes such as proline as a protective adaptation to salt stress. We found that the levels of phytohormones such as SA, ABA, JA was elevated under salt stress but were not influenced by fungal inoculation. Taken together, our results will unveil the beneficial role of Trichoderma spp. in improving the antioxidant and osmo-protective status of plants under salt stress.

Inositol hexakisphosphate (IP6) modulates parameters of electrical signaling in Characeaen macroalgae Nitellopsis obtusa

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In plants, the involvement of inositol 1,4,5 trisphosphate (IP3) as a second messenger in electrical signaling has been supported by several studies. However, the proposal remains controversial since no IP3 receptors have been identified in plants. Another molecule, inositol hexakisphosphate (IP6), has been reported to elicit an even more potent response than IP3. One of the putative targets of IP6 could be Ca2+ channels responsible for the release of intracellular calcium from the internal stores during the initiation of the action potential.
The intracellular two-electrode technique in current clamp and voltage clamp modes was used on the internodal cells of Characean macroalgae Nitellopsis obtusa. Parameters of membrane and electrically-evoked action potentials as well as excitation transients were registered after 30 min exposure to 75 µM and 150 µM IP6 solution.
The most significant observation is that IP6 hyperpolarises the action potential excitation threshold thus making the cells more excitable which implies altered voltage dependence of the Ca2+ channels responsible for the initial depolarization. Altered temporal characteristics of current transients presented in this study also indicate modulated dynamics of intracellular Ca2+ concentration. These results imply that IP6 plays a role as a bioactive compound involved in the electrogenesis of Characeaen algae.

Biosynthesis of Linalool glycoside and its function in cold resistance of tea plant

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Tea plant is an important leaf horticultural crop in China, and is also a perennial evergreen plant that likes temperature and humidity. Freezing stress has a great influence on the growth and development of tea plant and tea quality. Non-volatile glycoside aroma precursors are important secondary metabolites of tea plants, and are the main form of aroma substances stored in tea plants, which play an important role in the formation of tea plant quality and the response to stress. Our research group previously found that low temperature freezing injury can induce the release of aromatic substances such as linalool. Linalool is one of the important components of flower and fruit aroma of tea plant, but the molecular mechanism of its glycosylation and its role in cold resistance of tea plant are not clear up to now. This project intends to analyze the molecular mechanism of linalool glycosylation and discover its physiological function in cold resistance of tea by means of UGTs expression analysis, prokaryotic expression and gene silencing of tea plants under low temperature and freezing injury environment. Details are as follows:
The expression level of tea glycosyltransferase UGT1 was significantly induced by tea plant freezing stress, and also by volatiles released by tea plant freezing stress, suggesting that UGT1 may be involved in signal exchange under tea plant freezing stress. The prokaryotic expression and in vitro enzyme activity analysis of UGT1 showed that the optimal temperature of recombinant UGT1 protein was 30 ℃, the optimal pH was 6, the optimal sugar donor was UDP-rhamnose, and the optimal receptor substrate was linalool. LC-MS analysis showed that the enzyme activity product of UGT1 in vitro was linalool rhamnoside. Inhibition of UGT1 gene expression significantly reduced the accumulation of linalool rhamnoside in tea plants, while exogenous linalool spraying could induce the expression of this gene and the accumulation of corresponding glycosides, suggesting that UGT1 has the ability to catalyze linalool glycoside in tea plants.

Classifying Circumnutation in Pea Plants via Machine Learning

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Climbing plants that locate and attach to suitable support typically outperform those that remain prostrate. The search for support involves a unique movement pattern known as circumnutation, where the plant rotates around a central axis during growth. Although there have been numerous studies investigating the mechanics of circumnutation, how this process is controlled during support-searching remains unclear. Machine learning presents a potential solution for addressing this issue and enabling accurate phenotyping. Despite being in its infancy, machine learning has already demonstrated broad applicability in plant science. In this study, we tested whether simulation-based machine learning methods can capture differences in movement patterns nested in actual kinematical data. We compared machine learning classifiers with the aim of generating models that learn to discriminate between circumnutation patterns related to the presence/absence of a support in the environment. Results indicate that there is a difference in the pattern of circumnutation, depending on the presence of a support, that can be learned and classified rather accurately. We also identified distinctive kinematic features at the level of the junction underneath the tendrils that seems to be a superior indicator for discerning the presence/absence of the support by the plant. Overall, our findings suggest that machine learning approaches are powerful tools for understanding plant movement.

A system for the study of roots 3D kinematics in hydroponic culture

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Recent studies support the hypothesis that the root apex exhibits computational features related to sensory integration. To date, it is difficult to test this idea from a behavioural perspective given that available technologies for root imaging focus mostly on static characterizations, lacking time- and 3D spatial information. Investigating roots' growth as a mean of their interaction with the environment might be of key importance to unveil how sensorial processing serves the roots to code for elements in the environment and behave accordingly.
We developed a system enabling effective dynamic 3D imaging of the maize root tip in hydroponic culture. The system is based on infrared stereo-cameras acquiring time-lapse images of the roots for 3D reconstruction compensating for water distortion. The acquisition protocol guarantees the root growth in complete dark while the upper part of the plant grows in normal light conditions. The system extracts the 3D trajectory of the root tip and a set of descriptive kinematic features.
The system was tested individually on several maize seedlings during the first 7 days of growth. The system shows good intra-operator reliability and good measurement accuracy. Values obtained are in line with expected values when considering maize growing in hydroponic culture.
The system and protocol proposed enables accurate 3D analysis of root growth. The approach is fairly easy to adopt and has the potential to become a standard for dynamic root imaging. The system is now in use to investigate roots interaction with the environment in the presence of different stimuli/obstacles.

Linking whole plant responses to cell physiology in glycophytes exposed to NaCl stress

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The responses of glycophyte plants to NaCl stress have been well documented and include rapid decreases in root water flux, transpiration, photosynthesis, and growth. Once acclimated, plants exhibit a more conservative growth form characterized by decreased chlorophyll concentration but increased compatible solute concentrations, senescence of older leaves, and lateral root formation. The most widely accepted explanation for this phenomenon states that the observed trend is caused by a plant's inability to obtain water followed by foliar Na+ toxicity. However, emerging evidence suggests this response is governed by the plant via systemic electrical signals initiated at the root tips and sent through the vascular tissue. The systemic signals stunt plant growth and initiates a cell signaling cascade at different cell types to fundamentally alter cell physiology leading to the aforementioned phenotypic response. The secondary cell signaling responses include elevated cytosolic Ca+2, the enzymatic production of reactive oxygen species and nitric oxide, the induction of autophagy, the proliferation of peroxisomes, changes in gene expression, and changes to organelle activity. The cell signaling processes in root cortex, guard cells, and other cell types are well studied whereas the signaling processes governing mesophyll cells and photophysiology are mostly unexplored. This work will discuss this emerging paradigm and will provide a conceptual framework for studying the cell signaling events that may govern photophysiology under NaCl stress conditions.

Extracellular ADP elicits generation of hydroxyl radical in plant roots

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Plant tissues release extracellular purine molecules such as adenosine triphosphate (ATP) in response to stress conditions. In roots, it has been shown that eATP is extracellularly released by touch stress and attenuates gravitropic response. Extracellular ATP (eATP) is a signaling molecule activating several intracellular cascades across the plasma membrane by generating reactive oxygen species (ROS) and calcium influx. Extracellular adenosine diphosphate (eADP) causing cellular responses in roots was also reported. However, the effect of eADP on ROS response in plant tissues is not well known yet. Hydroxyl radical is essential for modulating cell wall properties, root growth, and tropisms. However, due to its highest activity among ROS, and a short life span, it is difficult to monitor with conventional histochemical staining methods. To explore extracellularly-generated hydroxyl radicals in roots by eADP, we observed intact Arabidopsis thaliana, maize and Brassica rapa roots by the electron paramagnetic resonance (EPR) method. Our results showed that the exogenously applied ADP promoted a stable generation and abundant hydroxyl radicals than the ATP treatment. eADP might be a signaling molecule in plants and play a different function from eATP.

Understanding and Broadening the Scope of Plant Physiology

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Plant behavior, how a plant adapts and functions in its habitat, is determined by physiological processes most of which are still obscure. When complex behaviors arise, such as responses to herbivores or developmental events leading to flowering, responses too are complex, based on interactions between resting and induced states. When learning how plants work, students often are stymied by their unfamiliarity with plants, the lingo we use to describe plants and their bodies, and the novel plant traits of being rooted, of making their own food and nutrients, and of dispersed sensory systems. It is unusual for a human being to 'identify' with a plant. Hence, learning and understanding how they work requires creative and active strategies. We have found that opening classroom discussion to invite: prior knowledge especially from animal physiology, full expression of student experiences with plants, active formation of hypotheses for how things work (guesses, speculations, ideas) to be tested by data available in the scientific literature, mixed with plenty of discussion and white-board work – these activities contribute to an inclusive group setting where lots of learning happens. Whether students go on to further academic work in plant biology and ecology, or pursue other professions including medicine, it is certain that they hold knowledge about plants as living organisms more dearly and for longer. Hopefully this contributes to better information and decision-making in our human communities.

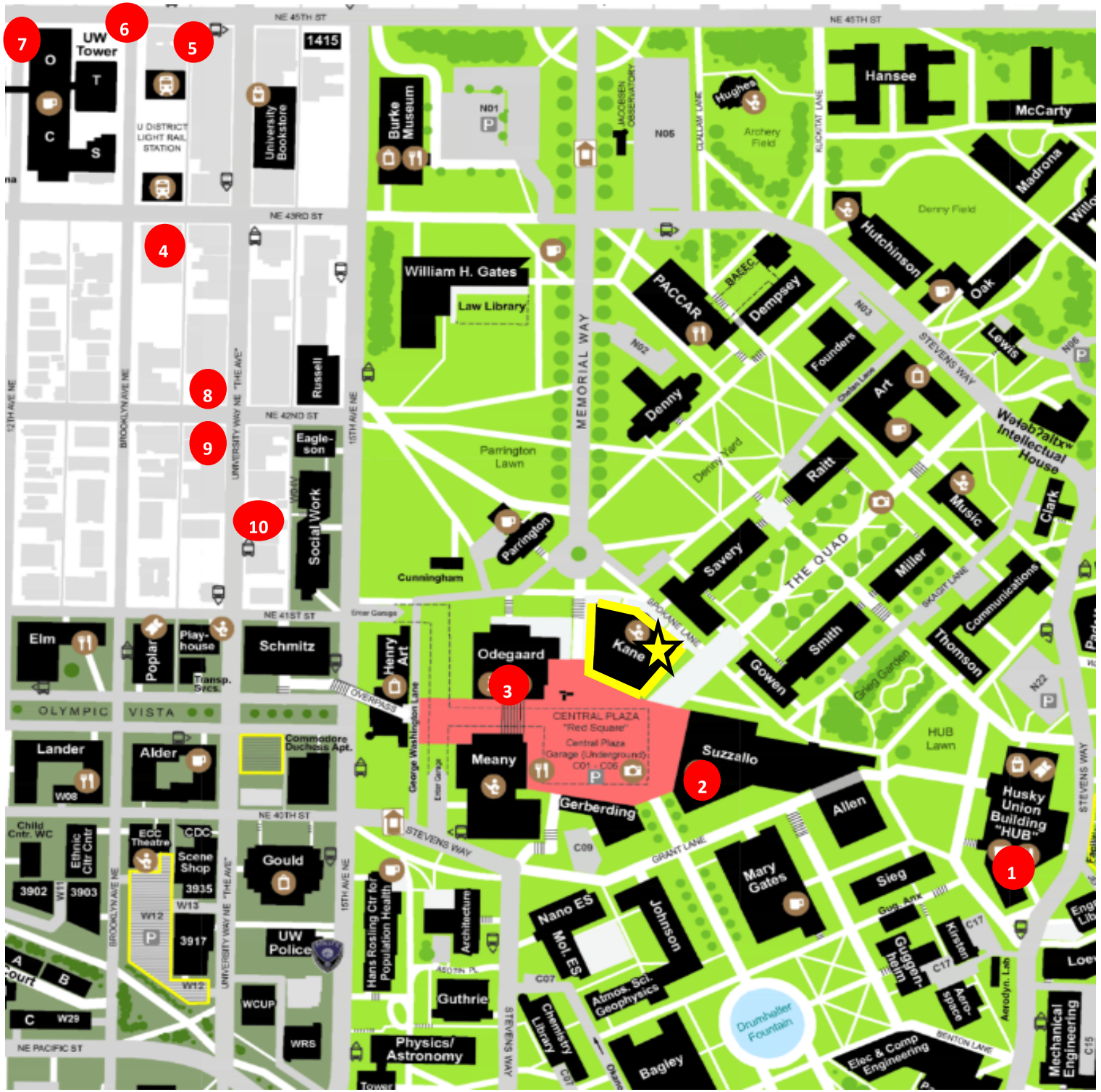
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Staves, Mark	stavesm@gvsu.edu	Mechanosensing and Anesthesia of Single Internodal Cells of Chara	Posters	47
Steiner, Helene	helene.steiner@network.rca.ac.uk	Giving Nature a Voice: How to Design for Humans, Plants, and Animals	7	43
Volkenburgh, E Van	lizvanv@uw.edu	Understanding and Broadening the Scope of Plant Physiology	Posters	56
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Yamashita, Felipe	felipeyamashita@uni-bonn.de	Woody Vine Boquila Trifoliolata Mimics Leaves of Artificial Host Plants	4	27
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LEGEND

Conference Venue

1. **Starbucks, The HUB**
2. **Starbucks, Suzzallo Library**
3. **By George Café, Odegaard Library**
4. **Ugly Mug Café — NE 43rd ST**

   M-F: 8am-2pm

   Sat/Sun: 9am-3pm

5. **Leon Coffee House — NE 45th ST & Brooklyn Ave NE**

   M-F: 7:30am-6pm

   Sat/Sun: 8:30am-6pm

6. **Poindexter Coffee, The Graduate Hotel**

   M-Sun: 6:30am-5pm

7. **Kitanda Espresso & Acai — NE 45th ST & 12th Ave NE**

   M-F: 8am-5:30pm

   Sat: 8am-5pm

   Sun: 8am-4pm

8. **Café on the Ave — NE 42nd ST & University Way NE**

   M-Thurs/Sun: 7am-11pm

   Fri/Sat: 7am-2am

9. **Starbucks on the Ave — NE 42nd ST & University Way NE**

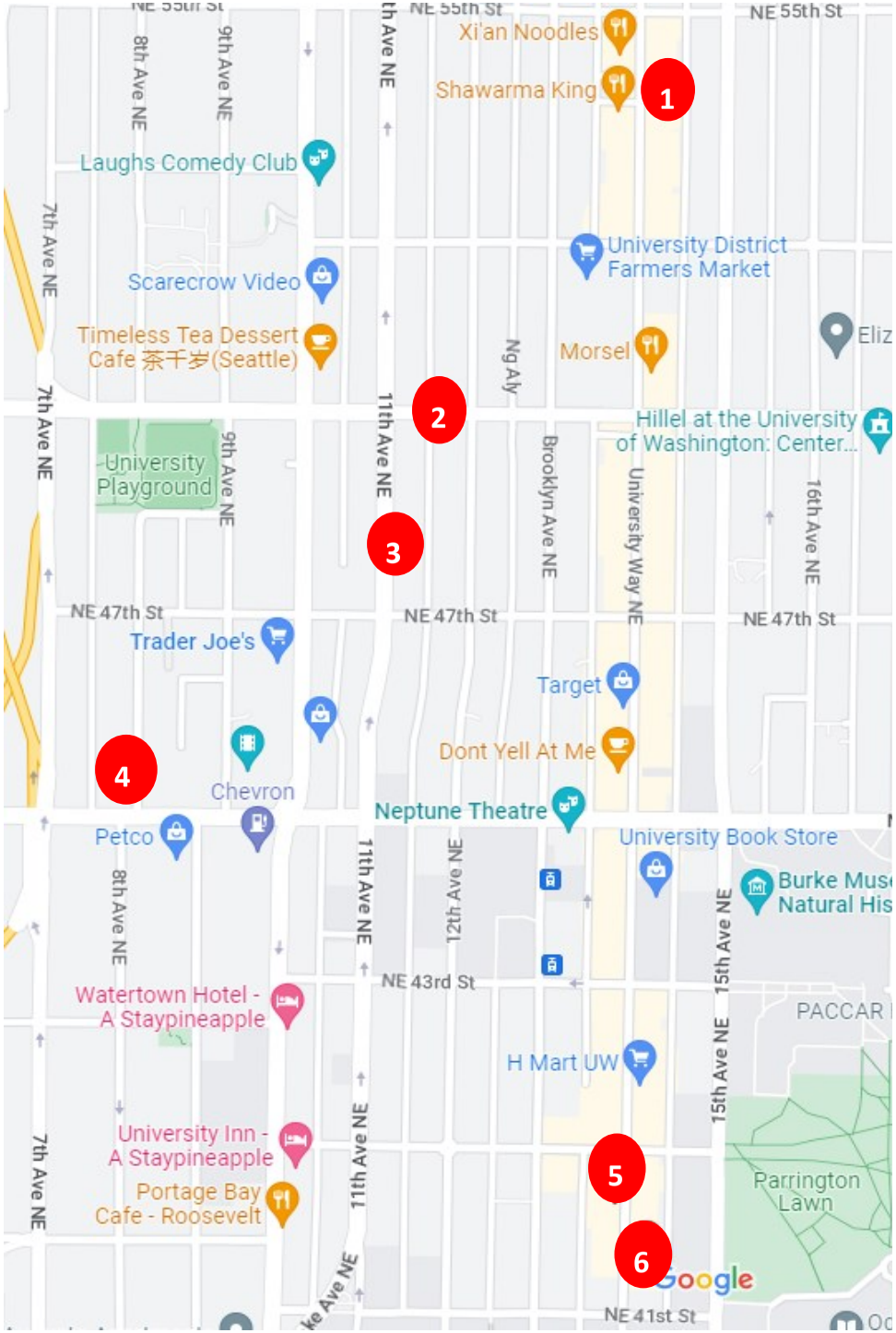
   M-F: 6am-7pm

   Sat/Sun: 7am-7pm

10. **Café Solstice — University Way NE**

    M-F: 6:30am-5pm

    Sat/Sun: 7am-5pm



U-DISTRICT EATS

1. Araya's Place

Mon-Thurs/Sun: 11:30am-3pm & 4:30-9pm

Fri/Sat: 11:30am-3pm & 4:30-9:30pm

5240 University Ave NE Vegan Thai restaurant and bar. A favorite in the U-District!

2. Broadfork Café

Mon: CLOSED

Tue-Sun: 11am-8pm

4757 12th Ave NE Vegan restaurant with wide selection of sandwiches, bowls, salads, smoothies, juices, and baked goods. Try the mushroom melt sandwich!

3. Hiroshi's Poke

Mon-Sat: 11am-8pm

Sun: CLOSED

4712 11th Ave NE Great poke bowls for take-out!

4. Ladd & Lass Brewing

45th Street close to I-5 and an easy walk from both hotels but they are closed Monday and Tuesday; Wed-Sun: 2-10pm

5. Big Time Brewery & Alehouse

Mon-Thurs: 12pm-12am

Friday/Sat: 12pm-1am

Sun: 12-11pm

4133 University Ave NE Burgers, pizzas, salads, soups, and beer Vegetarian friendly

6. Schultzy's Bar & Grill

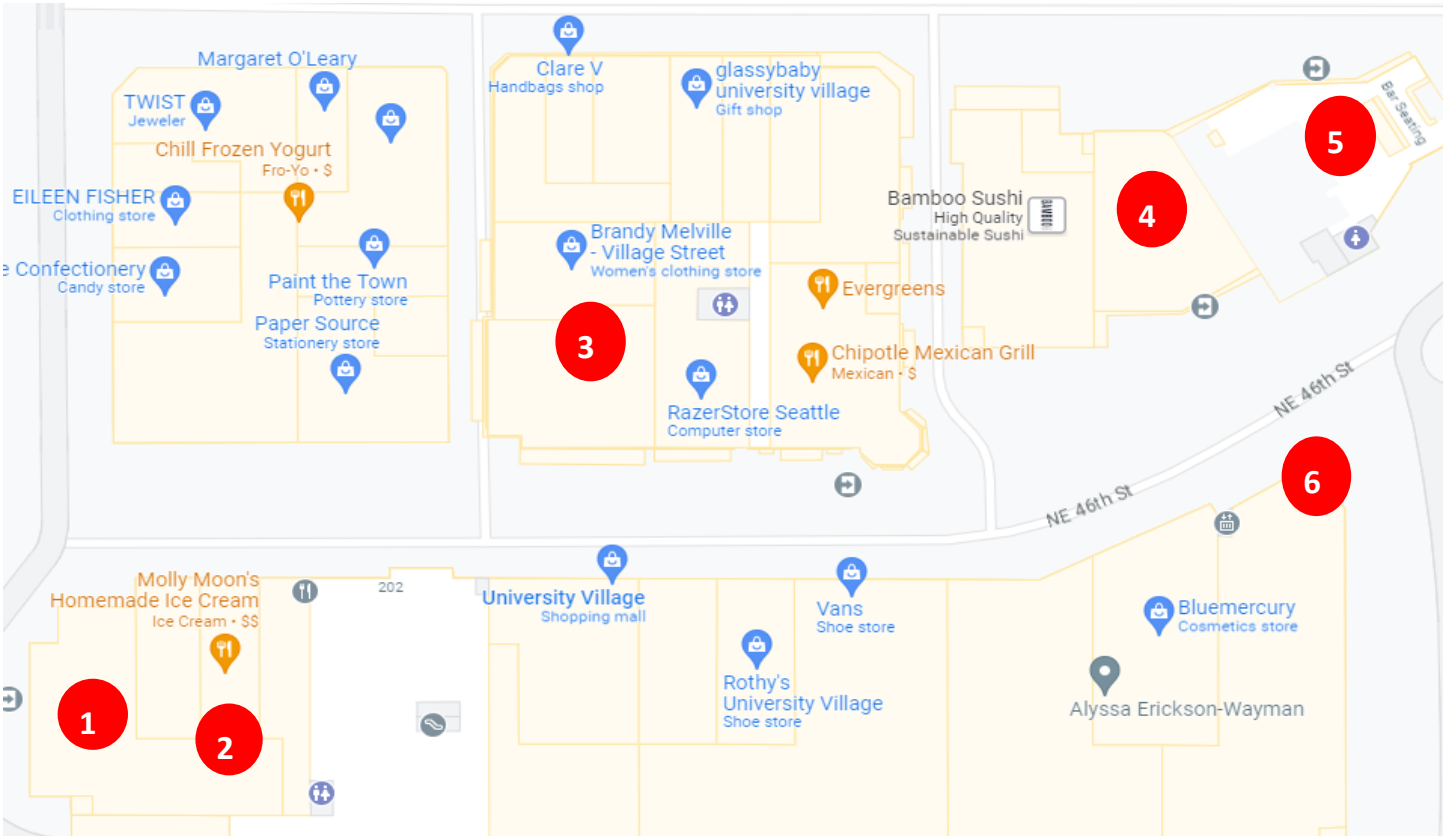
Sun/Mon: CLOSED

Tues/Thurs: 11am-12am

Fri: 11am-1am

Sat: 12pm-1am

4114 University Ave NE Sausage dishes, salads, sandwiches, beer Non really vege-



U-VILLAGE EATS

1. JOEY

MON-SUN: 11AM-12AM

Relaxed, contemporary dining with a broad menu featuring international and regional dishes. Sliders, Japanese gyoza, crab cakes, steak, Korean fried cauliflower, sushi, salads

2. DIN TAI FUNG

MON-SUN: 11AM-9:30PM

The BEST dumplings around. Modern Seattle outpost of a Taiwan chain famed for its Shanghai dumplings and noodles.

3. EUREKA!

MON-SUN: 11AM-11PM

Hip dining spot serving “elevated” burgers, great beer selection, and whiskey drinks Crispy brussels sprouts, ahi poke stack, mac n’ cheese balls, wings, burgers, fish and chips

4. Mr. West Café Bar

MON-SUN: 8AM-8PM

All day breakfast menu, sandwiches, salads, and a toast menu. Vegetarian and vegan friendly

5. PIATTI

MON-SUN: 11:30AM-9PM

Italian trattoria with great selection of house made pastas, soups, and pizzas. Vegetarian friendly and they will sub gluten free pastas.

6. BA BAR

MON-SUN: 11AM to 9PM ; Vietnamese food, great cocktails


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