All 2017 PRL Stories

How cyanobacteria define their middle point

1/11/17

Joshua MacCready, Danny Ducat, Igor Houwat

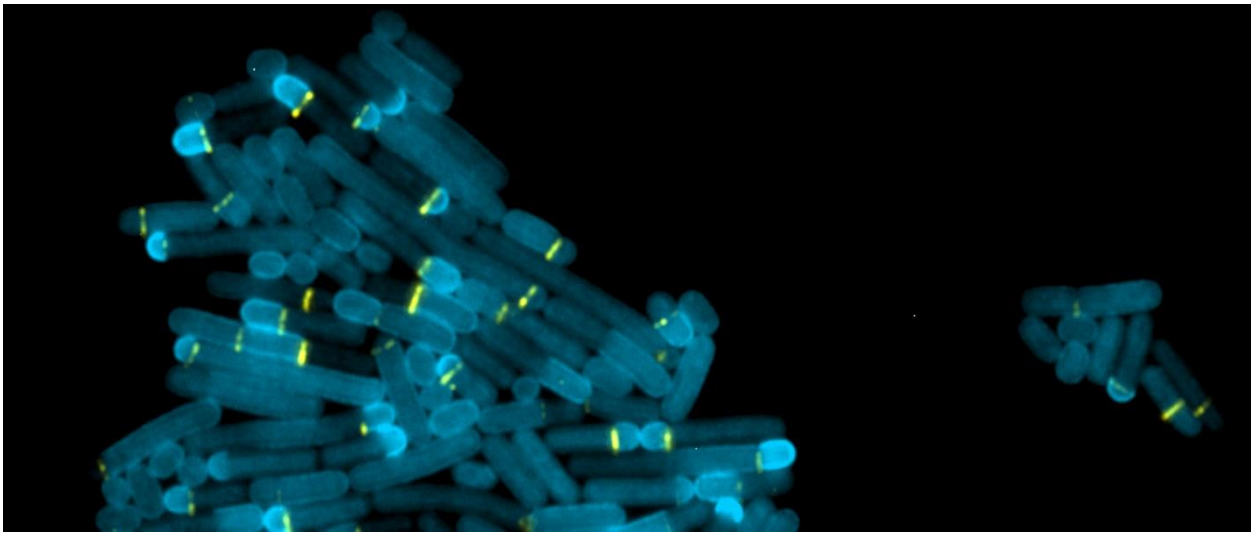


Figure 1 Banner image by Ducat lab

The **Ducat lab** in direct collaboration with the **Osteryoung lab** has shown, for the first time, how cyanobacterial cells define their middle point, in order to promote cell division that ensures the daughter cells are of equal size. The results have been **published as the cover article in the journal, *Molecular Microbiology***.

Josh MacCready, the first author on the study, is a PhD student in the **Department of Microbiology and Molecular Genetics**, and is co-advised by Drs. Katherine Osteryoung and Danny Ducat. Josh says, “Cell division in most bacteria occurs at the middle of the cell. If division deviates away from this plane, daughter cells might not inherit important cellular material, compromising their ability to survive and reproduce.”

The first mechanism found to allow bacteria to “identify” their middle was first discovered in the bacterium Escherichia coli. Known as the Min system, the mechanism involves three proteins that oscillate across the cell from pole-to-pole, and by doing so help to define a zone at the middle of the cell.

“Basically, because these Min proteins concentrate onto one pole then the other, when you consider them over time, they reside the least in the center of the cell. This helps to designate a zone at the center where conditions are right to assemble the division machinery. A variety of factors, including another protein called FtsZ, are then able to assemble into a ring-like structure that gradually constrict, leading to the pinching of the cell in two equal halves.”

Yet, when the Min mechanism was first discovered, it solved one problem while generating a whole slew of other mysteries. For example: how do Min proteins “know” to go to the poles? What “directs” them

to move back and forth? In the past 30 years, many researchers have tackled these problems, determining that this behavior is an example of a complex pattern that emerges out of properties of self-organization from the Min proteins.

“The behavior of Min proteins isn’t very intuitive and can be difficult to grasp. But we see emergence of complex behaviors from very simple components all over nature,” says Dr, Danny Ducat, Assistant Professor at the PRL.

“A good example is an ant colony: no individual ant “knows” the master plan, but through a set of simple rules and repeated interactions between ants, a complicated behavior emerges that allows ants to appear much more “directed” at the level of the colony. The emergence of complicated oscillations of Min proteins within the cell is a similar phenomenon: rigid rules of interaction between Min proteins within the cell creates a surprisingly complicated pattern, seemingly spontaneously!”

Studying cell division in cyanobacteria

Despite many years of study, most direct research on the Min system has been focused on in *E. coli* and a small handful of similar bacteria. “From this research, we know that Min protein oscillation is highly dependent upon them attaching to accessible membranes inside the bacteria,” according to Josh.

“Yet, this is a problem when you think of some other forms of bacteria that possess additional internal membranes: Would Min proteins still “know” how to navigate these more complicated cells?"

The Ducat and Osteryoung labs wanted to look at this problem directly in cyanobacteria, given that their internal makeup is more complex than that of *E. coli*. Josh adds, “Cyanobacteria contain a network of thylakoid membranes not found in *E. coli*. These membranes are found throughout the entire cell and are used to generate energy from sunlight. We thought the presence of these additional membranes might “confuse” the Min system or even just present a physical barrier for Min proteins seeking to find the cell pole.”

But despite these spatial constraints in cyanobacteria, the lab observed beautiful pole-to-pole oscillation of Min system proteins.

To examine how the Min proteins navigated the more complicated innards of cyanobacteria, the Ducat and Osteryoung labs used computational models – with help from Jory Schossau from Chris Adami’s lab here at MSU – to simulate Min proteins interacting within an artificial cell.

The simulations showed that it is likely that Min proteins in cyanobacteria have an additional talent (*Video 2*). “Cyanobacterial Min proteins must somehow be able to identify and avoid the thylakoid membranes. Instead they likely squeeze through small gaps in the stacks of thylakoids in order to reach the cell membrane – our model tells us it’s less likely they bind to the thylakoids at all.”

Another mystery emerges

“We still don’t know how Min proteins can “identify” one membrane from another," Josh says. "But regardless, the fact this system works at all in cyanobacteria is incredible! If oscillations can occur in such a geometrically-complex organism, chances are Min oscillations might be widespread across other bacteria, even those with unusual cell shapes. One of the most tantalizing implications is that this may

even be true in some organelles, like the chloroplast of plants or the mitochondria of animals. We'll have to do more work to verify this idea."

Indeed, the Osteryoung laboratory has expertise in cell division within the plant chloroplast, and believes that it is likely that the methods cyanobacteria use to define their division plane are likely conserved in higher plants.

Moving forward, Josh is interested in the behavior of this system in the context of circadian rhythms. But the work also has implications for controlling the size of cyanobacterial cells – a useful trick for improving the **biotechnological potential for cyanobacteria**.

Scratching the genetic surface of poisonous mushrooms

1/17/17

Igor Houwat, Jonathan Walton

The Walton lab has sequenced the genomes of two species of Amanita mushrooms which are responsible for the majority of fatal mushroom poisonings. The results have extended previous observations about how the mushrooms produce their deadly poisons, while surprising the researchers with the versatility displayed in their DNA.

The results are published in the journal *BMC Genomics*.

The "Death Cap" and the "Destroying Angel"

Dr. Jonathan Walton, Professor at the PRL, is fascinated by how poisonous mushrooms produce toxins. "These poisons that hurt or kill us are cyclic peptides, basically smaller, simpler proteins. Because they are ring-shaped and do not have any free ends, it is hard for our bodies to latch on to them in order to break them down or to repel them."

"So the toxins get into our blood streams and cells very easily."

Figure 1 The "Death Cap" A. phalloides. © Diana Gerba, 2016

Walton's genetic study focused on two Amanita species, the "Death Cap," which grows all over Europe and the US west coast, and the "Destroying Angel," native to Michigan. "We actually did a partial DNA sequence of the two mushrooms 10 years ago, and as sequencing has gotten faster and cheaper, we were able to complete the project recently."

As Walton and his colleagues expected, the data revealed the genes responsible for several of the known harmful cyclic peptides. But, to their surprise, they discovered that the mushrooms have the potential to synthesize many more cyclic peptides than previously known, potentially billions, through one production platform – the equivalent of producing an unlimited number of car models on a single assembly line.

"Imagine you have 10 different lego bricks," Walton says. "There are so many ways you can put them together. Cyclic peptides are assembled just like legos, each one made of 8-10 out of a total of 20 possible amino acids. If you scramble these components, you can make thousands, millions, even billions of these molecules through that one molecular platform."

And so far, Walton and his colleagues have already discovered three previously unknown cyclic peptides. "We found a new gene family closely related to the known toxic cyclic peptides. So we predicted, correctly it turns out, that some of those genes produce similar molecules."

Figure 2 The "Destroying Angel" A. bisporigera. By Dan Molter, Mushroom Observer, CC BY-SA 3.0

Many cyclic peptides are not poisonous, however. And even though the researchers are still beginning to understand the power of this flexible production platform, they can already picture future adaptations for human use.

“Various cyclic peptides are already known to be important drugs against tuberculosis, drug-resistant Staphylococcus, and cancer. Up till now, the only studies done with this type of mushroom extracts have been looking for things that kill mammals.”

“By harnessing the Amanita system, we can imagine a less crude and potentially more effective way to synthesize a large pool of new nontoxic cyclic peptides in the lab, with potential pharmaceutical uses.”

Into taxonomy

The genetic data also revealed how scientists are just scratching the surface of how complex the mushroom kingdom is.

Species are usually identified through universally accepted locations in DNA that function like barcodes. Different species have unique barcodes.

One of the mushrooms analyzed, Amanita bisporigera (“Destroying Angel”), is native to the midwest and East coast of North America, including Michigan. The genetic barcode in this case was 92% identical to another specimen of A. bisporigera mushroom sequenced in an earlier study.

“In comparison, human and chimpanzee genomes are 95% identical,” Walton adds, “yet they are not considered the same species at all. So, by any measure we currently have, these two mushrooms are different species, even though they look identical and we currently call them by the same name.”

Furthermore, the two specimens of A. bisporigera were found to have the genetic capacity to make almost entirely different cyclic peptides. Walton thinks this indicates that the cyclic peptide repertoire of these mushrooms is evolving very quickly, probably because they grant a strong adaptive advantage to the mushrooms in their environment.

“In a sense, this study tells us how little we know about classifying organisms and how advances in DNA sequencing are changing our ideas about how we label things. It is going to require many years of work to fully identify the differences between these two mushrooms.”

Investing in cell wall growth for improved photosynthesis

1/24/17

Igor Houwat, Sarathi Weraduwage

The **Brandizzi** and **Sharkey** labs have found that changes in methylated pectin content, a type of cell wall carbohydrate, affect how malleable plant cell walls are, which in turn highly influence plant growth and photosynthetic performance.

The study is published in the journal **Plant Physiology**.

Leaves, the powerhouses of photosynthesis in the plant world, come in various shapes and sizes – large and thin, small and thick, or with cells densely or loosely packed – depending on how their cells expand and grow.

“Specifically, the plant cell wall – which is rigid in order to protect the cell – controls how big each cell grows, and by extension, how the totality of cells are distributed within a leaf,” says Sarathi Weraduwage, a post-doc in the Sharkey lab and lead co-author. “Ultimately, how well a plant develops is very sensitive to the makeup of the leaf cell wall and the resulting leaf size.”

A critical carb for flexibility

Cell walls are built mainly with carbohydrates, and the study examined one, methylated pectin, which controls the cell wall’s flexibility and ability to expand. Working with Arabidopsis plants – the lab guinea pig of plants – the researchers altered the level of enzymes that synthesize the methylated pectin to examine the effect on cell walls.

“Suppressing the gene responsible for producing that enzyme drastically reduced the amount of methylated pectin. The result was rigid cell walls, leading to small, dense, and tightly packed leaf cells, with a significant reduction in air spaces between the cells. Ultimately, plant leaves were smaller than their genetically unaltered counterparts.”

Figure 1 Packed crops tend to compete for sunlight. By Bs0u10e0, CC BY-SA 2.0

On the other hand, inducing the plant to produce more enzymes led to more malleable cell walls, larger and loosely packed leaf cells with more airspaces between them. The leaves ended up bigger.

A wise carbon investor

The next step was to determine how the changes affected photosynthetic performance.

“We saw that the smaller leaves had a difficult time absorbing carbon dioxide – the source of carbon for photosynthesis – from the atmosphere, because their cells were tightly packed,” Sarathi says. “Interestingly, we found this prominent in older leaves, as the younger ones fully rivaled their larger counterparts in photosynthetic performance rates.”

“So that ruled out the idea smaller leaves were either the cause or result of poor photosynthetic performance.”

It turned out that the changes in leaf area were a result of how much carbon – plants’ energy currency – was invested in expanding the leaf. **Plants, like any system with limited resources, have to allocate the available carbon to their best advantage, whether for growth, defense, or other activities**.

“Cells with more methylated pectin can expand, which creates a demand for more and more carbon for cell growth, resulting in leaf area increase. On the other hand, cells with low methylated pectin cannot grow, so the plant does not invest carbon in leaf expansion, resulting in smaller leaves.”

Looking to improve plant performance

Here is the twist. Although photosynthetic performance didn’t directly affect leaf size, leaf size did determine how big the plant could grow.

“We did see that larger leaf area, due to more methylated pectin in cell walls, allowed for more sunlight to be captured for photosynthesis, which in turn increased the supply of carbon available to the plant.”

The result: bigger plants.

“This is a pretty dramatic discovery,” Sarathi adds. “The relationship between one carbohydrate at the cell level and the final size and shape of an entire plant is very strong.”

And Sarathi is excited in the potential for this discovery to someday unlock additional plant horsepower. Photosynthesis is, after all, the source of energy for most life on our planet. And in the effort to help feed billions more people, or even to power our cars and planes with biofuels, **scientists are looking at different ways to make the process work better**.

“Look at crop plants. Farmers tend to pack them close together to save space, so the crops end up competing for sunlight. Maybe someday we can fine-tune crops to have thin and large leaves that can better capture light and atmospheric carbon dioxide, leading to greater photosynthetic efficiency and ultimately, more energy produced.”

Fellow MSU scientists Federica Brandizzi, Thomas D. Sharkey, Sang-Jin Kim, Luciana Renna, and Fransisca C. Anozie contributed to the discovery and publication. Banner image by Samuel Zeller on **Unsplash**, unsplash.com/photos/hWUiawiCO_Y?utm_source=unsplash&utm_medium=referral&utm_content=creditCopyText

Growth-defense gene pulls many strings in plant cell factories

2/7/17

Igor Houwat, Cristina Ruberti

Figure 1 Banner image of droplets on a maple leaf by Sander Meekes, ***Public Domain***

The Brandizzi lab has demonstrated how one master gene fine-tunes how massive protein factories in plant cells allocate resources to growth and defense functions.

The results have been published in ***The Plant Journal***.

Grow or defend?

One of the biggest decisions plants constantly make is whether to grow or defend, because they cannot do both optimally and at the same time. So they have evolved strategies that allocate resources toward one or the other function depending on their needs.

“These types of balancing acts happen at many levels in a plant, including one my lab is interested in: the bookmark iconendoplasmic reticulum, a massive factory found in any eukaryotic cell, producing one third of that cell’s bookmark iconproteins.” says Cristina Ruberti, a post-doc in the **Brandizzi lab** and co-author of the published paper.

The published study focused on a master gene called CPR5 (*constitutive expressor of pathogenesis-related genes-5*) that has been previously observed to affect both growth and defense functions in the endoplasmic reticulum.

For example, when under attack from bacteria or pathogens, plants rely on the bookmark iconhormone salicylic acid for protection, which is a common defense strategy. (*fun fact: salicylic acid is used to treat*

acne, dandruff, and other skin conditions). During these threatening times, CPR5 fine tunes the hormonal system in order to ensure growth functions don't fully shut down.

On the other side of the growth-defense spectrum, previous research had shown CPR5 helps the endoplasmic reticulum control plant cell development, including how big cells can grow or how the protective bookmark iconcell wall is built.

"In that sense, the CPR5 gene is a master controller of crucial growth and defense processes, but we did not know how it worked in such balance."

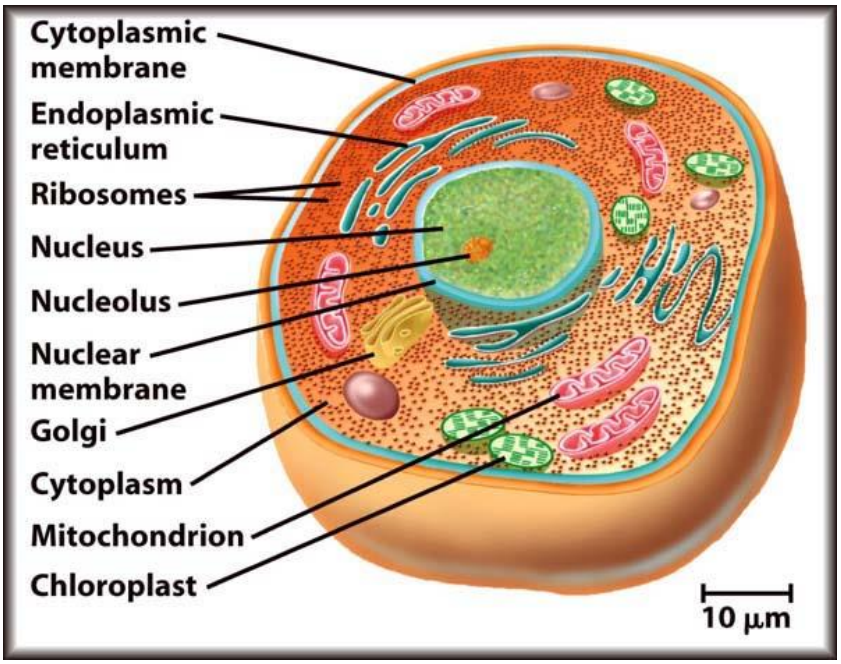


Figure 2 The endoplasmic reticulum connects the nucleus, the mastermind, to the cell's extremities. By AJC1, CC BY-SA 2.0

Protecting the endoplasmic reticulum

The intersection of CPR5 with the other processes was found in the endoplamic reticulum's quality control mechanism for protein production. **Known as the unfolded protein response, this quality control kicks in during stressful times – such as extreme heat or growth – when the endoplasmic reticulum is prone to produce defective proteins.**

Specifically, the unfolded protein response mechanism is activated through two "arms", or light switches, that turn the quality control function on. And the connections between CPR5, the defense hormone, and the unfolded protein response play out at the site of these two light switches.

The researchers observed that when the plant is under pathogen attack, the salicylic acid defense hormone operates in the endoplasmic reticulum through the unfolded protein response's light switches, simultaneously inhibiting growth. On its end, the CPR5 gene tempers the growth inhibition triggered by the hormone so that growth functions do not shut down.

In addition to controlling the defense hormone's interactions with the quality control mechanism, Cristina found that CPR5 directly monitors the quality control itself in times of extreme stress.

“Under severe environmental conditions, CPR5 directly represses both light switches, allowing some of the plant’s energy to go towards growth instead of exclusively prioritizing defense. In that role, CPR5 ensures the endoplasmic reticulum doesn’t overdose on its own quality control, which if extreme, causes a preemptive programmed cell death.”

Cristina adds that the study further demonstrates how CPR5 is truly a master gene with its hands on a number of unrelated processes.

“On a larger scale, it is becoming clear that plant components talk to each other in more complex ways than previously observed. In this case, one gene is helping to control two seemingly distinct protection mechanisms – the defense hormone and the quality control system – to ensure that the endoplasmic reticulum, one of the plant’s most important components, remains healthy.”

Power Plants: Kramer lab featured in MSU President's 2016 Report

3/16/17

Igor Houwat

https://youtu.be/ebNkHPZond4

The video features **PhotosynQ**, a sophisticated scientific platform that measures plant health and productivity parameters in real time and in dynamic environmental conditions, outside of the lab. The technology is easy to use and inexpensive, **making it possible for researchers, farmers, and plant experts around the world to connect** and maximize big data for big solutions.

You can access the **rest of the MSU President's 2016 Report**, which includes videos and 360-degree, interactive environments that provide a closer look at the work the selected participants - including Mona Hanna-Attisha and Tom Izzo - are doing.

From the lab to the world: solving big problems in agriculture and energy

3/22/17

Igor Houwat, David Kramer

SUMMARY

- The Kramer lab has unveiled a sophisticated, user-friendly, and cheap scientific instrument to measure plant health and photosynthesis parameters.
- It solves the problem that scientists still lack the ability to measure plant performance in the real world. Current technology with that ability is expensive and difficult to use.
- Collected data is uploaded to an online platform and is available for anyone who joins: plant scientists, citizen scientists, farmers, and breeders.
- The Kramer lab is using the collected data (over 425,000 data sets from over 28 countries, to date) to understand how to improve plant yields.

"We are in trouble," says **David Kramer**, Hannah Distinguished Professor in Photosynthesis and Bioenergetics at the PRL. "Our crops are not keeping up with our population. In fact, in some cases we are falling behind. And we need plants for all our food and much of our fuels. The problem is that arable land is not increasing, but our population and our lifestyles are demanding more from our farms. Even more urgently, the climate is changing."

Although there have been recent leaps in understanding plants' chemical and genetic make ups, what really holds us back to improving plants is the ability to accurately measure how they perform in the real world, where they face stress, disease and other factors that cannot be replicated in laboratories.

"We need to peer inside the living plant and see how things work, which components are working better, and why they fail. Once we can do this, we can figure out what genes are controlling performance so we combine them to make crop varieties that perform better."

Although some technologies currently can do all that, they are prohibitively expensive and difficult to use, placing them out of reach to all but the richest companies, institutions, and governments.

Figure 1 The MultispeQ, a tool to measure plants in their natural environments. Source: photosynq.org

MultispeQ: a game changer

A team of researchers led by Kramer – including scientist and first co-author Sebastian Kuhlgert, engineer Robert Zegarac, software expert Prabade Weebadde, and open-source science leader Greg Austic – held a series of brainstorming sessions to imagine a new technology to reach a wider user base, like plant scientists wanting to breed superior plants or farmers needing to better manage their land.

“We mapped out the reasons why current technology wasn’t widely available, from high instrument cost, to the complexities of gathering and understanding complex data generated by such instruments, to the ability to compare the data to crop genetics and field conditions.”

“We also wanted the data to be publicly available, meaning we had to teach users around the globe how to use the technology.”

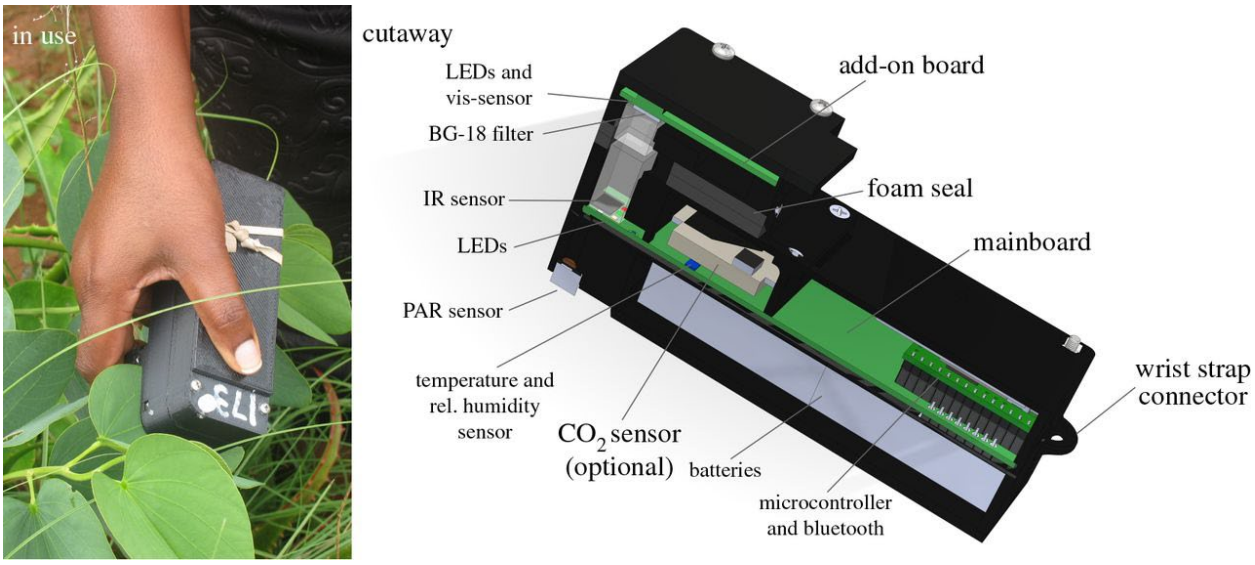


Figure 2 A MultispeQ beta in the field (left); Cutaway schematic diagram (right). By Kramer lab, as found in Royal Society Open Science, CC-BY 4.0

The result, published in the journal ***Royal Society Open Science***, is the newly unveiled MultispeQ, a sophisticated, portable, and user-friendly scientific instrument that overcomes many of the major limitations of currently available instruments. It comes at less than 10% of the cost of available technologies.

The MultispeQ makes non-invasive measurements of parameters related to plant productivity and health, including a range of environmental factors (light intensity and quality, temperature, relative humidity), leaf pigmentation (chlorophyll, anthocyanin) and various photosynthetic parameters based on static or light-driven fluorescence yield and absorbance changes.

Open-source platform

The tech shines with its user interface. The device automatically guides users to make the right measurements and then wirelessly transmits the results to a cloud-based data sharing platform, called **PhotosynQ**.

To date, beta users have captured over 425,000 data sets, in over 1,500 projects, and in around 28 countries. And similarly to social media platforms, **data is accessible to anyone who joins the open-source platform, opening up synergistic opportunities for collaboration**.

Take the project between Marty Chilvers, a field crops pathologist, and the **Kramer lab**, interested in photosynthesis: Marty researches soilborne root rot diseases that rob yield but that often have no obvious symptoms above the ground, making early disease detection crucial.

In one project, Marty's team set the trial up, and the Kramer lab came in to take the measurements.

"The platform allowed multiple people from different fields to look at the numbers in ways that we may not have had thought of, adding value to the data," Marty says. "And while we were interested in how the parameters predicted plant health and soybean sudden death syndrome caused by root rot, the Kramer team used the same data set to analyze photosynthetic performance."

Figure 3 Making the journal cover: MultispeQ researchers in Zambia. By Kramer lab, as found in Royal Society Open Science, CC-BY 4.0

A gateway to improving plant yields

The Kramer lab's particular interest in these massive data sets is to understand plant performance in their natural environements in order to improve plant yield.

And insights are flowing in.

“There are strong indicators that these data can predict crop yield at early stages of plant growth,” David says. “We can also catch disease at very early stages, when it is still not apparent to the eye. We can measure plant stress levels.”

But, ultimately, David thinks the secret lies in improving photosynthesis, an area plant breeders have yet to address. And his team believes that, to their knowledge, the technology is giving them an unprecedented look at how photosynthesis works in the wild, at such a large scale.

“Research is showing that photosynthesis is rather inefficient – plants lose energy during the process. If we understand where those losses happen, we could potentially breed more efficient plants or create artificial photosynthetic systems that do the job better. Already, we have worked with Zambian research collaborators to identify stretches of DNA that improve bean photosynthesis performance under their local conditions.”

The team is looking to expand its user base to include researchers, growers, and citizen scientists for community-driven plant research, removing barriers that have prevented these stakeholders from *collectively* understanding the basic biology needed to improve plants on the ground.

*The MultispeQ is now out of beta. For more information, visit **www.photosynq.org**. This work is made possible by funding from the Department of Energy Office of Science, Basic Energy Sciences, the McKnight Foundation, and USAID.*

Unpacking a new bacterial mini-factory

3/30/17

Igor Houwat, Jan Zarzycki

Many bacteria contain microcompartments that function like mini-factories, efficiently processing compounds for diverse purposes. For example, they sequester toxic intermediates in organisms like the notorious Salmonella and *Escherichia;* or in cyanobacteria, they enhance the efficiency of photosynthesis.

The PRL's **Kerfeld lab** is at the forefront of understanding different kinds of these bacterial microcompartments - how they work and are built - with the goal of bioengineering them someday to produce sustainable energy sources and other "green" or medical products, without using fossil fuels.

And in a recent publication in ***Scientific Reports***, Dr. Jan Zarzycki, a former post-doc in the Kerfeld lab, describes a new microcompartment widely spread among different kinds of bacteria, increasing our understanding of the enzymes packed within it.

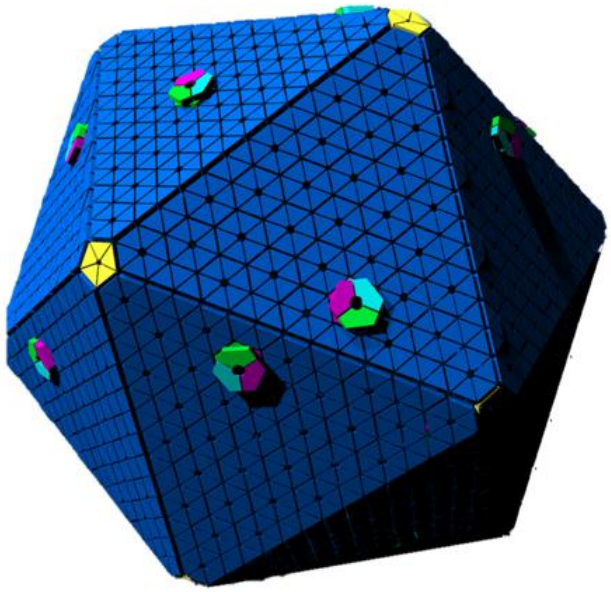


Figure 1 This microcompartment, and others like it, live inside many bacteria. Someday, they might help create useful materials for us. By Clement Aussignargues, Kerfeld Lab

Bacterial starter kits

Although many bacterial microcompartments share a common way of processing compounds into useful products, they differ in what compounds they employ as raw materials.

"These compartments' functions are defined by what enzymes they package," says Jan, currently **a post-doc with Dr. Tobias Erb at the Max Planck Institute for Terrestrial Microbiology**. "Specifically, the enzyme that catalyzes the very first step of the reaction sequence determines the overall function."

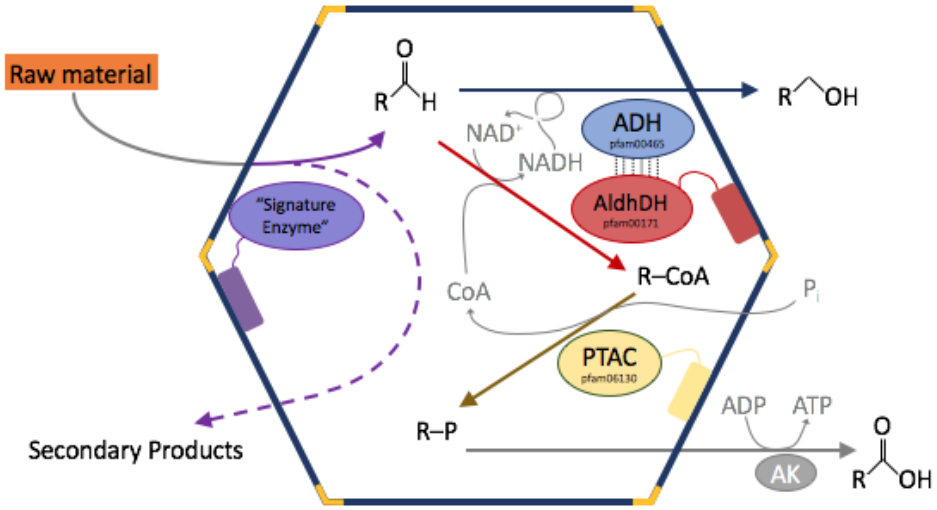


Figure 2 The raw material enters the mini-factory. It is processed first by a "signature enzyme," in this case, the GRE. By Clement Aussignargues, Kerfeld lab

The defining enzyme in Jan's newly described microcompartment is a so-called glycyl radical enzyme (**GRE**).

"GREs that are not associated with microcompartments have been widely studied. However, now, in the era of genome sequencing, tons of GRE encoding genes are popping up in databases, many accompanied by bacterial microcompartment genes. These GREs appear to have novel functions inside the mini-factories, and some functions have been recently described."

Jan adds that although these functions can sometimes be predicted with bioinformatics methods, the challenge is to demonstrate them in the lab.

"Unfortunately, GREs are hard to directly examine, because they are destroyed after the slightest contact with oxygen. It took us a lot of effort to work with a GRE under strictly oxygen-free conditions, but we were able to determine and prove its function, and thus the function of the microcompartment it is involved with."

From biology to engineering applications

Synthetic biologists are very interested in the versatility of the GREs and their microcompartments, as they could become a platform for **designing molecular pathways that sustainably produce "green" chemicals**, medicines, renewable materials like rubber, even renewable energy.

"In the big picture, in order to transform biology to become a real engineering science, we first need to understand how nature, and in this case, microcompartments work. This knowledge would enable us to potentially reassemble those mini-factories to perform these new functions in both bacteria and plants."

"Biologists can already engineer single enzymes that work as well, if not better, than natural ones. But building complex systems with multiple enzymes is still a great challenge, because we often don't understand the natural systems well enough."

Howe receives 2017 MSU Innovation Center Award

4/13/17

Igor Houwat

Dr. Gregg Howe, an MSU Foundation Professor at the MSU-DOE Plant Research Laboratory and the Department of Biochemistry and Molecular Biology, has been awarded the **2017 Innovation of the Year** for his pioneering work **challenging a long-held assumption that plants cannot both grow and defend optimally at the same time**.

Dr. Howe was among the honorees recognized by the **MSU Innovation Center** at the 7th annual Michigan State University Innovation Celebration on April 12. The MSU Innovation Celebration is an annual showcase of innovative technologies and startups developed in campus labs, classrooms, and beyond. The event honors MSU researchers and students who have reported an invention, licensed a technology, or were awarded patents during the academic year.

Figure 1 Gregg Howe at the award ceremony. Photo courtesy Moonsail North.

“The award recognizes a new technology that stems from our lab’s research showing that certain genetic modifications can effectively uncouple the antagonistic relationship between plant growth and defense,” Howe said. “If the approach can be successfully replicated in crop plants grown under natural field conditions, it may open up exciting avenues for improving agricultural yield.”

After filing a patent application describing how this technology may be used to boost the production of food and other plant-derived products, Howe was pleasantly surprised to learn that this idea was selected as the “Innovation of the Year” by the MSU Innovation Center.

https://youtu.be/yymA7EjVXKE?list=PLTFBM5GFsoZkMvx0Ui89ohIuRE6wIgDx6

“I have really enjoyed working with the MSU Technologies office over the years on various projects, and I’m grateful to all the students and collaborators who made this possible.”

Christoph Benning, Director of the PRL, says, “We at the PRL congratulate Gregg Howe on receiving this well-deserved recognition. Gregg has led a team of PRL scientists, supported by the US Department of Energy-Basic Energy Sciences collaborative grant. The discoveries that led to this invention disclosure are an example of how successful collaborative basic science lays the foundation for potentially practical applications that can benefit agriculture in the near future.”

Gregg Howe awarded Fellow of ASPB Award

4/18/17

Igor Houwat

Gregg Howe is the recipient of a Fellow of ASPB Award by the American Society of Plant Biologists.

Established in 2007, the **Fellow of ASPB Award** recognizes distinguished and long-term contributions to plant biology and service to the society by current members in areas that include research, education, mentoring, outreach and professional and public service.

“I am honored to receive a Fellow of ASPB Award,” said Howe. “More than anything, the award reflects the hard work and dedication of the many students and postdoctoral fellows I have had the privilege to work with over the past 20 years at Michigan State.”

Christoph Benning, PRL Director, said that Howe has played a key role in elucidating the perception mechanism of jasmonic acid in plants.

“Gregg and his coworkers have also established how plant trichomes [leaf hairs] provide chemical defenses against insects,” Benning explained. “Currently, he studies how jasmonic acid affects carbon partitioning for growth and defense functions. In addition to his scientific accomplishments, Gregg has been a great citizen as editor and reviewer, and a great mentor to his students and postdocs. This recognition is well-deserved, and we congratulate Gregg on becoming a Fellow of ASPB.”

A formal awards ceremony to honor this year’s recipients will be held on June 24 during ASPB’s Plant Biology 2017 meeting in Honolulu, Hawaii.

A thousand tales of plant defense

4/25/17

Igor Houwat, Andre Velasquez

André Velásquez and Matt Oney wanted to find out how many types of defenses a plant could muster against harmful bacteria. No other study had ever done that on a large-scale; at most, a few tackled 20, 40, maybe 80 plant varieties at any one time.

So, André, Matt, and their mentor, **Sheng Yang He**, examined over 1000 natural variations of one plant – found in places ranging from Europe to Western Asia – and dipped them into pots full of harmful bacteria to see who would make it through unscathed.

Disease is one of the major issues holding back crop yield, **with studies reporting annual productivity drops costing in the billions of dollars**, which is why scientists like André are conducting large-scale studies in the attempt to reduce crop losses worldwide.

And only a fraction of Andre's and Matt's plants actually fought off the bacteria. "We found that these plants employed at least four types of previously reported defense mechanisms," says André, a post-doc in the He lab. "They ranged from surface defenses that prevent an invasion to molecular defenses that are activated once the bacteria breach through. In some cases, we didn't know how the defenses were working, which shows the limits of our current knowledge."

The study is published in ***The New Phytologist***.

Plants under siege

Plant immune systems don't work like ours. When bacteria attack us, we produce antibodies tailored to fend them off, and we store the information in our systems. So, the next time the same bacteria attack, our immune systems retrieve that information, produce more of these antibodies, and we don't get sick.

"Plants, generally, don't have an adaptive immune system like ours. If a strain of bacteria successfully infiltrates a plant once, the next time it attacks, chances are the plant will get sick again," André says. "Unfortunately for plants, they are stuck with the defenses they are born with, be it thorns, an almost impenetrable bark, antimicrobial compounds, or anything else."

"So, we wanted to know how a plant would fare against a bacterium it might have never encountered before and see what types of resistance strategies it would deploy."

André and Matt got their hands on 1,041 natural varieties of Arabidopsis – basically the lab guinea pig of plants – and pit them against the bacterium *Pseudomonas syringae*, a major foe of tomatoes.

Figure 1 An Arabidopsis plant. By Harley J Seeley

"We subjected the plants to a severe test, more extreme then they probably face in the wild," André says. "Matt dipped each plant in a solution full of very high levels of bacteria, and the pots were placed in **humid environments that made the plants susceptible to disease**."

Only 14 plant varieties out of over 1,000 resisted the bacterium, and the researchers observed four previously known defense strategies at work, in addition to another strategy they had not encountered before.

"One of the known mechanisms was a surface-mediated resistance mechanism designed to prevent bacteria from invading. But if the bacteria made it through to the inside of the leaves, the plant was doomed."

The other defenses were activated once the bacterium made it in. They ranged from producing high levels of a defense hormone, a derivative of which is found in aspirin, to making reactive oxygen species, the same molecules that, in humans, might cause aging (and that we combat with antioxidants).

There was even a peculiar strategy that activates a programmed cell death that wipes out infected plant cells, to prevent the bacteria from invading the rest of the plant.

"We also observed three plants that showed some enhanced resistance, but we don't know how that worked. We are currently stuck with the knowledge that we have."

Taking it to the world

Figure 2 André

André notes that research such as his will lay the groundwork for studying disease in major food crops.

“Arabidopsis is easy to work with. You can hold tens of thousands of seeds in one handful, and they grow fast, which makes it simple to do experiments quickly. But Arabidopsis has no economic value.”

“Still, we have to start somewhere. It’s tough to study diseases in agricultural crops. They grow much slower. And, we can’t get our hands on as many variants as Arabidopsis, because, over time, plant breeders have selected only a small subset from each species to be consumed as food.”

Take potatoes, André says. Some wild varieties have no tubers, others would send you to the hospital for poisoning, and others are too small to harvest and make a profit on.

“Yet, they’re all distinct from the limited number of potato varieties that we know well and that we farm. But what if some wild potatoes have natural defenses that are absent in crop potatoes? We’d miss out on discovering those if we only studied the crops that we know.”

Ultimately, André muses, understanding the basic mechanisms of how plants resist disease is a way forward to reduce crop sickness.

“As our knowledge base increases, we can perhaps identify wild potatoes or tomatoes, or any other plant of interest, with specific defenses and cross them with their cultivated relatives. We could even make plants that are more resistant to specific diseases.”

“We are still scratching the surface of what is possible,” André adds. “The number of plants, bacteria, viruses, and the interplay between them… there is a stunning variety of things going on in nature.”

Banner image: **The Siege and Destruction of Jerusalem** by **David Roberts (1850)**

Looking deeper into peroxisome proliferation

5/2/17

Igor Houwat, Jianping Hu

The **Hu lab** has identified a new protein that helps with the division and proliferation of little cellular factories, called peroxisomes. The study is published in the ***Journal of Integrative Plant Biology***.

"Peroxisomes are found in plants and animals, and they perform a variety of functions," says Dr. Jianping Hu, Professor at the PRL. "They are like food processors that break down fatty acids (fats) into smaller pieces so they can be used by their hosts to produce energy. They also help protect their hosts from environmental stresses."

Over time, researchers have identified a family of proteins that helps these important organelles develop, but they are still trying to understand how they properly divide and proliferate.

"In this study, we specifically identified a protein, called Forkhead-Associated Domain Protein 3 (FHA3), that is found in the cell's nucleus. We suspected that it plays a role in controlling the genes responsible for dividing the peroxisomes."

The team found that FHA3 directly represses the expression of a peroxisome division gene, called *PEX11b*, preventing it from dividing the peroxisome.

In other words, if DNA is like a book, and genes the words, expressing a gene is like speaking the words aloud, bringing their magic to life. FHA3's work prevents the genes responsible for division from being spoken at the wrong time.

Figure 1 Jianping Hu. Photo by Harley J Seeley Photography

"Indeed, when we identified a mutant plant without FHA3, the level of PEX11b gene expression was higher. We also created a plant with an overabundance of the FHA3 protein, and we found that plant to

display deficiencies in peroxisomal division, further suggesting FHA3 is a repressor of peroxisome division."

A complex web

Hu also found that it is possible that the FHA3 protein interacts with another nuclear protein that controls peroxisome division.

"We previously found that another nuclear protein, HYH, induces peroxisome proliferation by directly promoting the expression of *PEX11b*. In this study, we discovered that HYH may directly repress the expression of *FHA3*, thus promoting PEX11b activity indirectly. Therefore, HYH can induce peroxisome proliferation through at least two pathways."

"Our results lead us to suspect that FHA3 may affect other division factors and physiological processes that remain unknown."

Research into peroxisomes is particularly of interest in the agricultural and medical fields, as these organelles play a large role in metabolism and defense against diseases.

Future pie-in-the-sky applications could include engineering crops with better metabolism or improved defenses, or **cures for devastating human peroxisomal disorders** that lead to poor growth, neurological dysfunctions, hearing/visual problems, and liver disease, among other symptoms.

Sheng Yang He reappointed as a Howard Hughes HHMI Investigator

5/9/17

Igor Houwat

Sheng Yang He, a University Distinguished Professor of plant biology and a Howard Hughes Medical Institute (HHMI) – Gordon Betty Moore Foundation (GBMF) Investigator since 2011, has been re-appointed as an HHMI Investigator, which extends his appointment to 2024.

The reappointment is a reflection of **He's exceptional work**, which is opening up new frontiers in the study of fundamental mechanisms underlying plant diseases.

"I am delighted about Sheng Yang He's reappointment as HHMI investigator, which recognizes his outstanding personal research accomplishments in the past and affirms his promise for further breakthrough discoveries in the future," said Christoph Benning, PRL director. "In addition, Sheng Yang is a great colleague respected by all for his insights into all matters related to plant sciences at MSU, and I congratulate him on his reappointment as HHMI investigator, the first and only one at MSU."

Figure 1 Sheng Yang He. By Harley J Seeley

He's research over the past five years has unlocked mysteries of how bacteria hijack plant hormone signaling or plant defense machinery in order to cause disease. His research also began to clarify long-standing questions about the profound effects of climate conditions (humidity and temperature) on plant disease progression.

"Five-year reviews at HHMI are legendary; I've been told of many scary stories," He said. "Indeed, it was truly a unique experience to report, on behalf of my group, before some of the best minds in the fields of medical and plant sciences. I would like to take this opportunity to thank my lab members for all the

wonderful work they do and MSU for being a supportive host institution. There are so many outstanding questions to explore and new phenomena to discover in biology. We are excited to carry on."

HHMI is a science philanthropy whose mission is to advance biomedical research and science education for the benefit of humanity. HHMI empowers exceptional scientists and students to pursue fundamental questions about living systems.

Growing pains and how that might affect seed quality

5/16/17

Igor Houwat, Sang-Jin Kim

How healthy a plant matures depends on how well it grows during its early life stages, which is not a surprise to anyone who has raised children.

And in the face of mounting pressures, like inconsistent temperature patterns or the burden to produce more for us due to the lack of new arable land, plant health might be taking a beating.

Sang-Jin Kim and the **Brandizzi lab** are interested in making plants more productive and resilient in the face of these challenges so we can meet our own, like feeding a burgeoning global population or powering our cars and airplanes with sustainable biofuels.

In a **study published in the journal *Planta***, Sang-Jin and his colleagues show how early stages of plant development, when seeds develop, are a turbulent time for a plant.

How well it can manage internal and environmental pressures is crucial to yield quality later on, and exposure to extreme heat at such a young age could be bad.

Protecting biofuel plants

Many of the nutrients that we get or the stuff that ends up in biofuels are created by proteins, which, in plant cells, are produced at massive secretory production centers called the endoplasmic reticulum.

“We were interested in the proteins that produce carbs that go into new seeds, specifically in plants targeted for producing biofuels, like sorghum or switch grass. The more you can pack those carbs in a seed, the more the yield later on.”

Like any manufacturing center, the endoplasmic reticulum has a control mechanism, known as the unfolded protein response (UPR) when things go wrong.

“The endoplasmic reticulum might produce defective proteins, and that happens for many reasons, like high environmental heat or a heavy load of protein synthesis during early plant development.” In those cases, the UPR kicks in to lower the burden of protein production and tells the plant to produce more of the good ones.

With climate change causing temperatures to rise globally, plants will struggle to keep up with hotter temperatures, and Sang-Jin wanted to see how heat affected seed development in sorghum and switch grass.

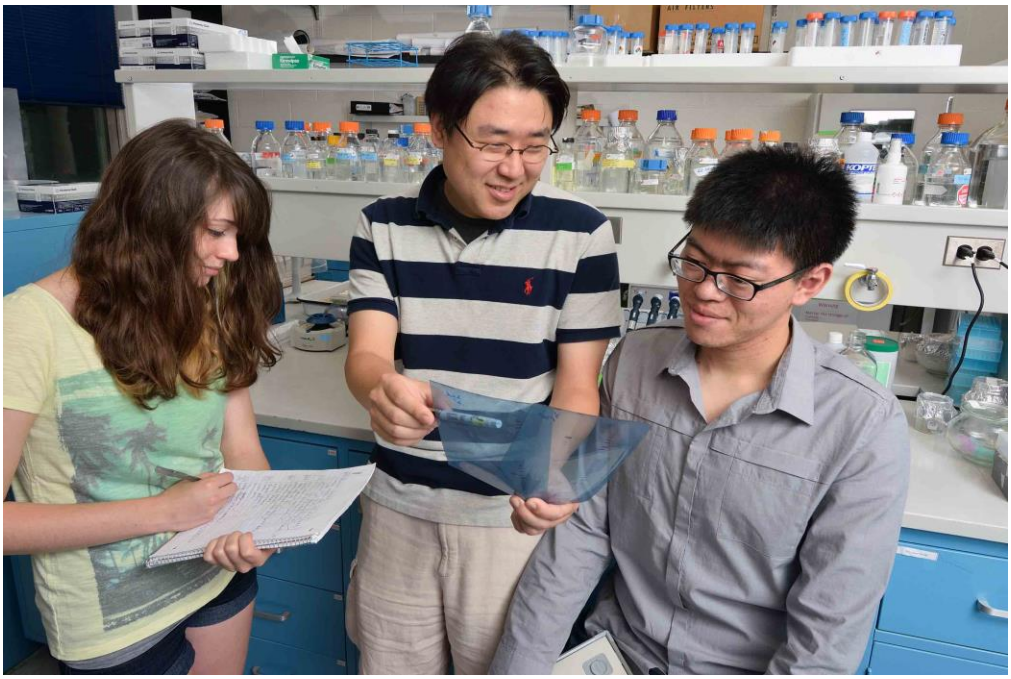


Figure 1 Dr. Sang-Jin Kim (center). By Harley J Seeley

“But the UPR had been studied in other plants, not these two. We worked with a close relative of these plants, Brachypodium, which is easier to study in the lab. And we indeed confirmed the existence of the UPR.”

Sang-Jin then subjected Brachypodium plants to various stresses to gauge their responses. “We treated them with artificial chemicals and also exposed them to hot temperatures they might face in nature, well over 100 degrees Fahrenheit. Both situations caused plants to feel the stress and activate the protective mechanism, possibly because they started cranking out defective proteins.”

Seed quality suffers under extreme heat

Crucially, Sang-Jin also found that extreme heat affected how well seeds developed.

“Early on during seed development, the UPR is turned on at all times, *even without any of the environmental stresses* that usually trigger it.”

“Perhaps, since filling the seeds with sugars and other nutrients requires massive amounts of new proteins, more than the usual, production is working at a higher rate. In that case, the UPR control is developmentally turned on as a precaution, or, more likely, because the rate of defects is higher.”

When young seeds were exposed to hot temperatures, the already active UPR didn’t ramp up much more. “Maybe the UPR is at full capacity at this stage, unable to take any more load.”

In a separate observation, heat exposure at early developmental stages led to seed quality taking a hit. The team noted that a crucial carbohydrate for human and livestock consumption, called MLG, was less present in heat-stressed seeds. "The seeds weighed less, and the genes responsible for making the carb were less abundant."

Sang-Jin is not sure yet whether the high activity rate of the UPR and seed nutritional quality are interrelated during seed development, but he suspects it’s the case.

"What we do know is that seed quality decreases with exposure to extreme heat, which affects crop yield later." And as the climate continues to change, plants might need our help in order to stay vigorous. We’ll need theirs too.

Banner image: Sorghum harvest by **Claire Benjamin/Carl R. Woese Institute for Genomic Biology, CC BY 2.0**

Getting first prize at the UURAF: Our 3 winners tell us how

5/24/17

Igor Houwat

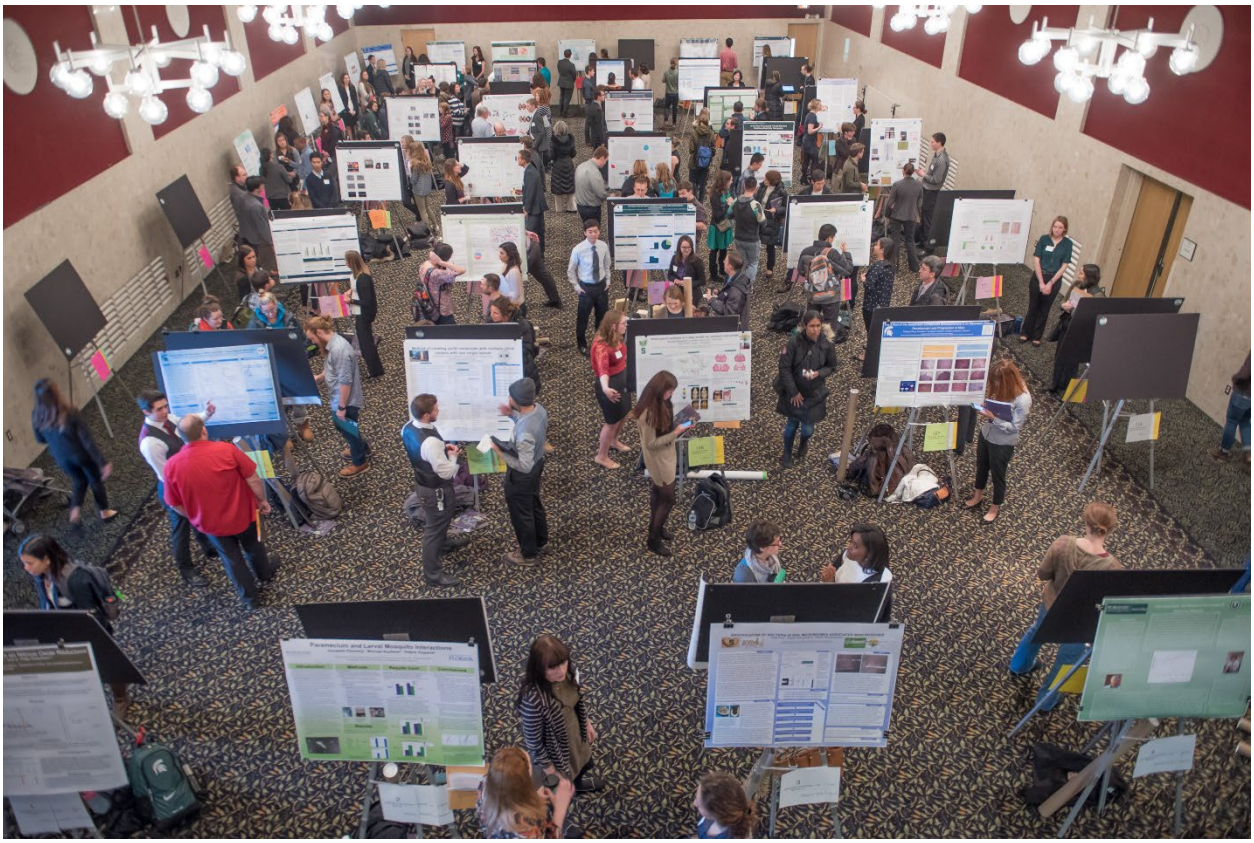


Figure 1 Banner image of UURAF 2017 at the MSU Union, by Trumpie Photography

Three MSU-DOE Plant Research Laboratory (PRL) undergrads won first prize at this year's University Undergraduate Research and Arts Forum (UURAF).

The **UURAF gives MSU undergrads the chance to present their work in a public setting**, which allows them to gain presentation experience, interact and answer questions from audience members, and receive feedback from judges. The best presenter in each category was awarded $100.

Here are our three winners, followed by excerpts from an interview following the event:

- **Hope Hersh**, with the **Benning lab**, has a degree in Biochemistry and just added another in Plant Biology. She has worked with cutting edge gene editing technology (called CRISPR) to help us understand more about how plant seeds make oil.
- **Cassie Dutcher**, a Biochemistry and Biotechnology sophomore, is helping the **Kerfeld lab** to reengineer a protein structure found in bacteria so it could be used to produce useful materials, such as rubber (the only way to create it right now is by using trees and or petroleum.) from carbon dioxide and sunlight.

- **Michael Das**, a Biochemistry and Biotechnology senior, is in the **Howe lab**, researching how plants defend against insects. His research found out that plant defenses against herbivores improves at higher temperatures.

What got you interested in science?

MICHAEL: I got first interested in science in middle school. I had a really good science teacher who let us do all our own experiments. Up to that point, science was about knowing and memorize stuff. She let us explore, which got me interested in science, and I stuck with it.

CASSIE: I wanted to a doctor, at first. During high school, I went to the Battle Creek Area Math + Science Center and took a biotechnology class. We got to run gels and see science applications, and I thought that was something I want to do.

HOPE: It is really cool that you got to do that in high school! I have always been interested in science and math. I wanted to go to medical school. Part of that ambition was to work in a lab to get the experience on my resume. But as time went on, I thought I might not be cut out for med school, and that's ok. I actually forgot about it and fell in love with working in the Benning lab. Now I can't stay out of there!

Figure 2 Cassie Dutcher. By Trumpie Photography

What do you think gave you the edge at the UURAF?

HOPE: I sat through a few presentations. Without sounding too confident, I think I was on a next level of understanding my science. I went into complex biochemistry behind what was going on, at a level the

other presentations didn't reach. I also spent a lot of time and effort making my presentation, practicing by myself and at a lab meeting. I went in with the mindset that I wanted to win first place!

MICHAEL: Yeah, I agree that having a good understanding of all the science helps, not just what happened in your experiments. Being able to explain what the experiments mean and why you were doing them, why they are significant in the big picture, that really helped.

Figure 3 Hope Hersh with another champ. By Ryan Holland

HOPE: If you have a better understanding, you can answer audience questions better. That was important for the judges.

CASSIE: I actually didn't think my presentation went terribly, but I didn't think that I would win either! I could have been more prepared. But then, one of the positive comments was about how well I could talk about the applications of what we're doing, and that showed the importance of what we are doing.

On the flipside, what would you do better next time?

CASSIE: I could have presented it better. I went over my poster ahead of time, but I never presented it fully. I was able to explain everything well, but tended to forget to address something or the other. And it varied from presentation to presentation. It got better as I went along.

So, here is what I would do next time: I would practice, walk through the poster with others, including people who have an understanding of the topic, like people in the lab, because if they have questions, they will probably be things that other people will ask.

I think even if you don't come in prepared to win, it's a good learning experience that you should do anyway. It's great to get feedback and learn what you can do better and what you've been doing well, and also just get the experience speaking.

MICHAEL: I would add: preparing the presentation to people who are not familiar with the topic. My discussions were with other people in the lab who are familiar with it. That's really good in a lot of aspects, but when you get to the poster presentation, you are talking to people who aren't necessarily scientists. So you have to adjust how you are presenting everything on the fly.

Figure 4 Michael Das. By Trumpie Photography

(INTERVIEWER) *Do you feel that, what you are talking about right now, the ability to talk to people, is that something you learned with experience presenting, or is it just because you've become more familiar with the science?*

MICHAEL: I think, this time last year, the work I presented at the UURAF was stuff I had done with a postdoc, so I wasn't as familiar with all the research. Whereas a lot of the work I've done this time was independent work, and that made it easier for me to understand everything.

CASSIE: I think that would help, because I mean I'm not independent right now. I feel if I had been I would be better prepared. Eventually, I'll be more independent.

HOPE: I compared CRISPR to Photoshop. Every slide tried to not make it such complex science and relate it to something that's easily understood, and I think that I would add more of that. A lot of people liked it. I always make a point to present to my boyfriend, who doesn't know anything about science. He is always so confused by what I'm doing, so I make sure he can understand it before I go present.

Ultimately our science affects the world. You need to be able to relate your work in layman's terms.

What do you want to be when you grow up?

CASSIE: I'm not really sure. I want to go to grad school, and I am considering a career in academic research. But I'm not decided 100%. I think research is nice, because you have a lot of freedom with it. You could do research in so many different fields.

MICHAEL: I'm in the same boat. I'm really into research, and I'm planning to go to grad school, but I'm not entirely sure if I'm going to industry, eventually, or where else. I just really like research, so I want to be involved in that. Research is like doing puzzles. It's a really complex puzzle where you're trying to figure out what's happening and why. And nobody knows the answer, which I think is cool.

HOPE: I'm applying to grad school in the fall. And I definitely want to get my PhD. And go into industry and be head scientist at, like, Monsanto or Dow Agro, something like that. I want to be the one doing the research that matters, not just pipetting volumes all day, doing repetitive stuff. I want to be designing research and doing things that actually change the world.

2017 Anton Lang Memorial Award Winners Announced

5/26/17

Igor Houwat

Clement Aussignargues and Joshua MacCready were awarded the Anton Lang Memorial Award during a ceremony which took place on Monday, May 8, 2017 at the Molecular Plant Sciences building.

The Anton Lang Memorial Fund was established in honor of the founding director of the Plant Research Laboratory, who passed away in 1996. Proceeds from the fund go towards annually supporting the Anton Lang Memorial Lecture – given this year by Dr. Richard Vierstra from Washington University in St. Louis – and recognizing a graduate student and a postdoctoral research associate who exemplify the research excellence, ideas, dedication, and vision of Anton Lang.

Figure 1 Clement Aussignargues. By Igor Houwat

Clement, from the Kerfeld lab, won the post-doc award. The Kerfeld lab wants to repurpose microcompartments, found in a wide range of bacteria, as tailored nano-factories to produce chemicals and renewable energy (like biofuels or medicine).

Clement was able to engineer a building block of the microcompartment's outer shell to bind a metal cofactor, which allows electrons to move to and from these microcompartments. The finding is a major step towards controlling desired chemical reactions within those microcompartments.

"Receiving this Memorial Award and being part of the PRL's history is a tremendous honor for which I am extremely grateful," Clement said. "The collaborative aspect in this project (inside and outside of the PRL) was very important, and without it, it would have been extremely difficult to complete this work."

Figure 2 Josh MacCready. By Igor Houwat

Josh, from the Ducat lab, won the graduate student award. “I’m pleased to have been selected for such an honor,” Josh said, “I owe many thanks to the PRL and the entire plant biology community at MSU for helping me succeed.”

Josh studies how **protein-self organization controls the positioning of cellular division in cyanobacteria**.

The awardees received an engraved rosewood piano finish clock, a cash reward, and their names have been added to a permanent award plaque located in the Plant Biology Laboratories.

MSU hosts first ever Fascination of Plants Day

5/30/17

Igor Houwat

Michigan State University plant biologists hosted the first ever Fascination of Plants Day on Saturday, May 20th at the **Molecular Plant Sciences Building** on main campus.

The event, called **"*From Seed to Fruit*",** invited the general public to explore the world of plants and algae, including fun hands-on activities for kids and adults.

The idea first came from **Dr. Bjoern Hamberger**, who had participated in a previous edition at his former lab in Copenhagen. Anne-Sophie Bohrer-Cognon, a post-doc in BMB, quickly joined as the event coordinator, alongside Aparajita Banerjee, also a BMB post-doc, who was the volunteer coordinator.

"We rapidly came up with the general themes to present, from the germination of seeds to the production of specialized metabolites and their uses," Anne-Sophie said.

"After that, 30 volunteers – grad students, post-docs and faculty – from the **MSU-DOE Plant Research Laboratory**, **Biochemistry and Molecular Biology**, **Plant Biology**, **Horticulture**, and **Plant, Soil and Microbial Sciences** units joined us. The activities and the plant-related science they presented at the event were incredible!"

Figure 1 Around 100 visitors attended, from various ages and backgrounds. By Bjoern Hamberger

"The kids had a lot of fun extracting DNA from fruits and simulating the dispersion of fungal spores while the adults could really take time to discuss and learn more about the plant-related research we have here at MSU."

Figure 2 At the terpene station. By Bjoern Hamberger

“As a post-doc, I really enjoy the opportunities to do public outreach. I believe that it is our responsibility as researchers to communicate with the public about what we do, how we do it, and, most importantly, the importance and the diversity of plant research.”

“Seeing how successful the event was this year, I really hope that the Fascination of Plants Day will become a recurring event at MSU.”

“From Seed to Fruit” took place alongside hundreds of events in over 50 countries, under the umbrella of the **European Plant Science Organisation (EPSO)**.

The goal of “Fascination of Plants Day” is to get as many people as possible around the world enthused about the importance of plant sciences for agriculture, forestry, non-food products (paper, timber, chemicals, and energy) and pharmaceuticals. The role of plants in environmental conservation is also a key message.

Check out some more images from the event:

Figure 3 Presenters, gearing up in the MPS Building. By Anne-Sophie Bohrer

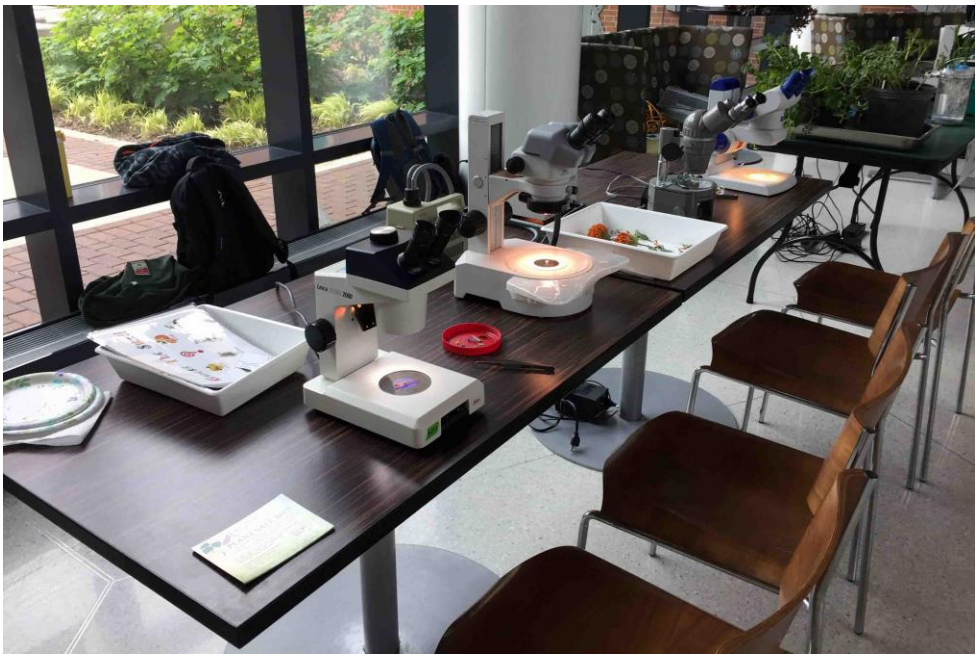


Figure 4 By Peiyen Kuo

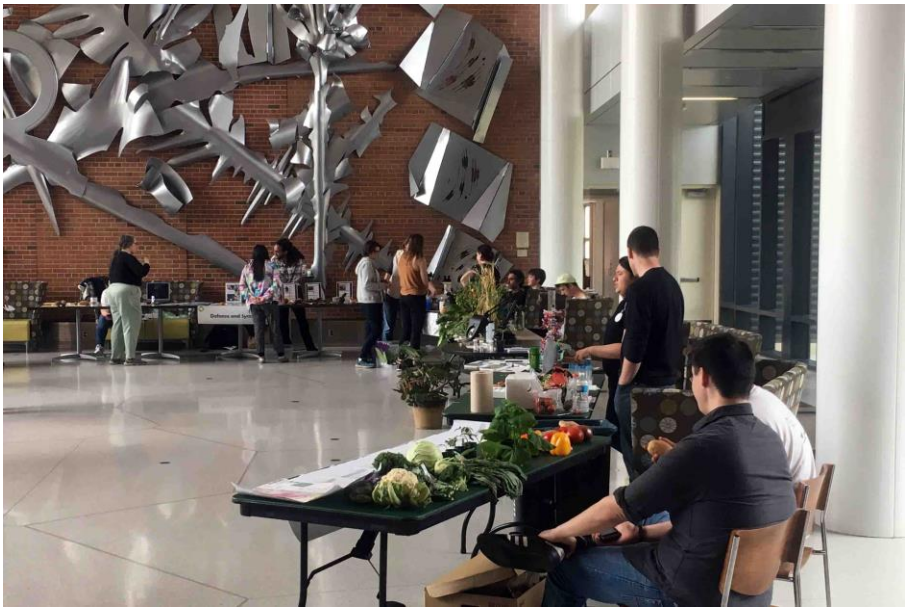


Figure 5 By Aparajita Banarjee

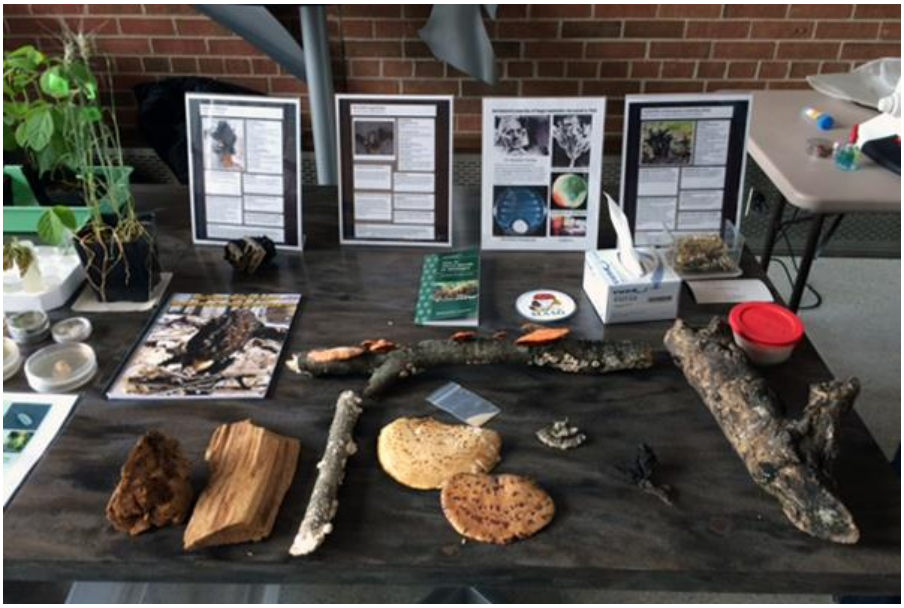


Figure 6 By Aparajita Banarjee

The organizers want to thank the Office of the Vice President for Research and Graduate Studies, the College of Natural Sciences, the MSU-DOE Plant Research Lab, the Biochemistry and Molecular Biology Program and the Department of Plant Biology for their financial support.

Bowling scores only a mom could love, records shattered at PRL bowling tourney

5/31/17

Igor Houwat

If you thought Mother's Day weekend would keep the PRL away from the bowling lanes, think again:

Instead, mothers were treated to one of the most epic Gutter Balls in recent memory.

Over 105 bowlers from the plant community came together for the 23rd edition, which took place at City Limits East. That number was the highest it has been for a while, according to event co-producer John Froehlich.

"We filled the place up, all 24 lanes!" John said. "A very special mention goes out to all of the young bowlers who came this year. By their enthusiastic participation, the future of Gutter Ball looks very bright!!"

Good times were had...

... and things got a bit competitive. The Kerfeld lab even had team t-shirts made!

Figure 1 By the Kerfeld lab

But history was yet to be made later that night. Eric Young, a grad student in the Ducat lab, won bigly to take home his first Gutter ball trophy.

His score of 267 set a new all-time high score for a Gutter Ball champion!

Figure 2 Eric Young

Here are some stats for the fans:

Notable Scores:

- Eric Young: 200, 267
- Erik Durfee: 176, 204
- Tony Schilmiller: 167, 155, 190
- Bryan Ferlez: 170
- Joe Reidy: 169
- John Froehlich: 167
- Eric Poliner: 167
- Giovanni Stefano: 152
- Sam Vaitkevicius: 151

Women's Division:

- Linda Danhof: 132, 127
- Starla Zemelis-Durfee: 132
- Ashley Horn: 132
- Sarynna Lopez: 130
- Barb Sears: 121

Previous Gutter Ball Champs:

- John Froehlich (2003, 2006)

- Ken Keegstra (2004, 2007)
- Jon Glynn (2005)
- Jackson Gehan (2008)
- Robin Harris (2009)
- Katie Cabot (2010)
- Andy Scollon (2011)
- Erik Durfee (2012)
- Matt Oney (2013)
- Henrik Tjellstrom (2014)
- Tony Schilmiller (2015, 2016)
- **Eric Young (2017)**

Will Eric hold on to his trophy in 2018? Will the record hold?

We will find out soon enough.

In the meantime, congrats Eric!

How to build an artificial nano-factory to power our futures

6/14/17

Igor Houwat, Manuel Sommer

Many bacteria contain little factories for different purposes. They can make sugars from carbon dioxide to fuel life, or digest certain compounds that would be toxic for the cell, if the digestion took place outside of these factories.

Manuel Sommer is studying how the factories building sugar from carbon dioxide through photosynthesis, called carboxysomes, are built and work.

This is a step toward **designing new kinds of factories, based on their natural cousins, that could produce synthetic materials**, like fragrances, or the building blocks for green fuels or products used to diagnose diseases.

The thing is, **bacteria are incredibly diverse, found in every environment, from polar ice to hot springs**, and carboxysome-based structures can be just as diverse in what they can do.

Part of the problem in building synthetic carboxysomes has been identifying the essential building blocks. And, for the first time, Manuel and the **Kerfeld lab** have analyzed over 200 sets of genes from different cyanobacteria, also known as blue-green algae that contain carboxysomes, taking us closer to understanding these essentials.

The study is **published in the *Journal of Experimental Botany***.

An inventory of miniature factories

Recent studies have made hundreds of new cyanobacteria genomes (a complete blueprint of organisms' DNA) available for study.

Figure 1 The Grand Prismatic Spring of Yellowstone National Park showing steam rising from hot water, which is surrounded by huge mats of brilliant orange algae and bacteria. By Brocken Inaglory (Own work) [CC BY-SA 3.0 or GFDL], via Wikimedia Commons

“Only five years ago, there were under 50 cyanobacterial genomes available. With the latest analysis we’ve done, we have over 350, with many species we haven’t looked at yet," Manuel says.

Why cyanobacteria?

“Carboxysomes, which are found in cyanobacteria, specialize in photosynthesis. And there is so much research on cyanobacteria already, which makes them easy to study."

"This flood of information makes such carboxysomes a good target for producing a complete inventory of factory parts. Then we can devise strategies to re-engineer them into synthetic factories.”

The idea is to use the synthetic carboxysome copies to create renewable materials, stuff they don’t usually make (see below), inside of bacteria that have been tamed for biotech use.

Building blocks, like legos

Carboxysomes are made of shells, each made up of about 7 different types of proteins that fit together like legos.

“The shells are both filters and barriers, controlling what raw materials come in and what finished product – like sugar precursors – comes out. **The chemical reactions happen inside that protected shell.** That is why understanding the shell structure is an important step towards building our own systems.”

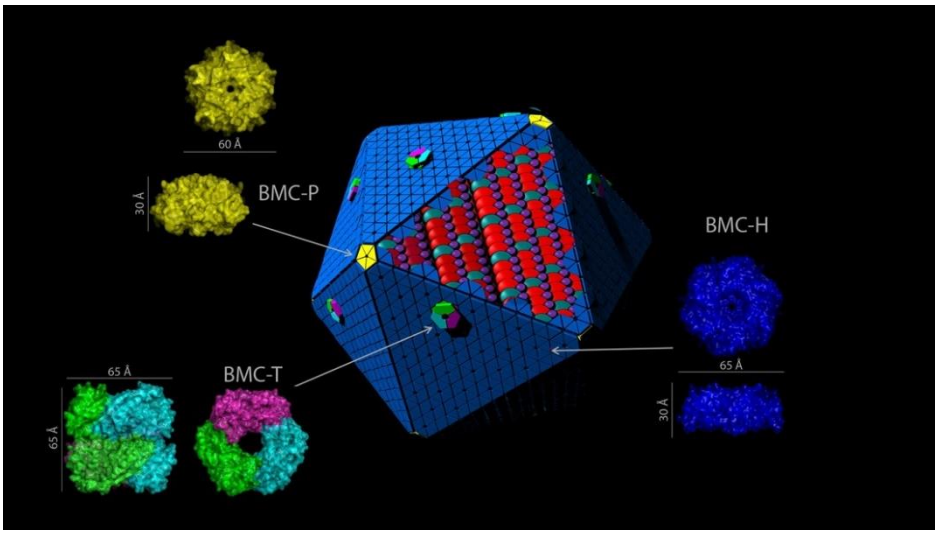


Figure 2 Different types of proteins, such as the three pictured here (BMC-T, BMC-P, and BMC-H), fit together like legos to build the shell structure, located in the center of the image. By Seth Axen, Markus Sutter, Sarah Newnham, Clement Aussignargues, and Cheryl Kerfeld [Creative Commons Attribution-ShareAlike 4.0 International License], via Kerfeld lab.

The first major finding was to discover two new variations on these shell proteins that had never been seen before.

“We’re thinking that the whole reason why the carboxysome needs a handful of proteins in the first place is that it gives the organism a lot of flexibility to grow under different conditions.”

For example, Manuel adds, some viruses need one protein for creating a shell encasing their damaging DNA, but cyanobacteria included in the study have 4 to 9 of these shell proteins.

“It is possible that each protein lets specific substances in. The more proteins available, the more the shell can fine tune what comes in and out.”

The idea is to use the synthetic carboxysome copies to create renewable materials, stuff they don’t usually make.

Evolution of the factories: “Calling ground control”

If DNA is like a book, genes are the words. And speaking the words aloud – or ‘expressing’ the gene – brings their meaning to life.

Manuel found that the genes for the carboxysome shell proteins were expressed differently, depending on how close or far they were located from each other.

“One type of carboxysome (alpha carboxysome) clusters all the genes in one location. The advantages are many. Being closer makes it easier to build the shell, or easier for the genetic code to transfer from one organism to the other, which is one way evolution happens. That probably explains why these types of compartments are found in evolutionarily diverse bacteria.”

But while alpha carboxysomes have one control unit, the type of carboxysomes analyzed in the study (beta carboxysome) makes use of extra genes on other locations in the DNA.

“We think that makes those carboxysomes more sophisticated. As long as a gene is found in the main unit, it is expressed at the same time with its neighboring genes.”

“But as soon as it moves to a satellite location, it becomes completely independent.”

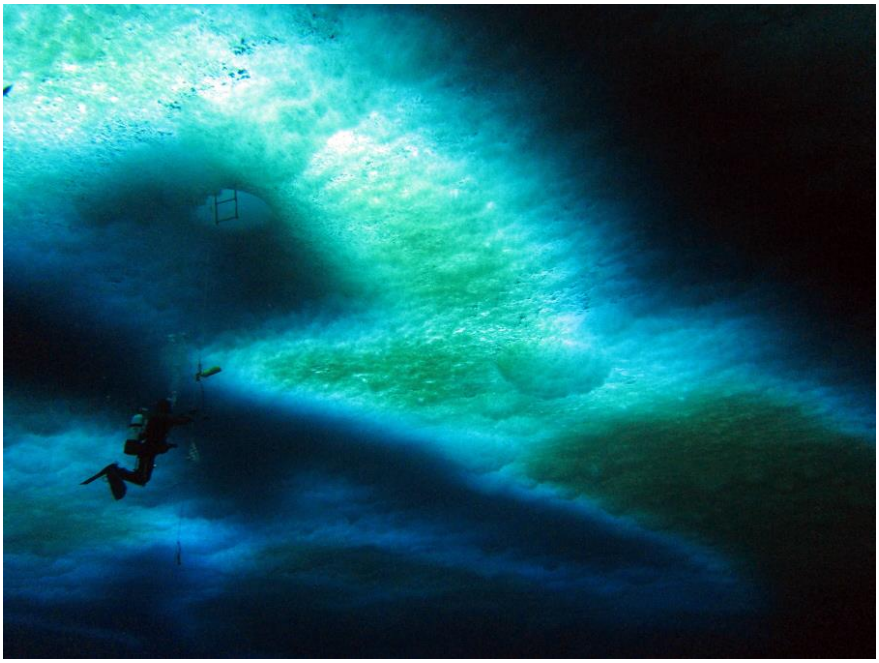


Figure 3 Cyanobacteria have evolved to be hardy. They can survive under extreme conditions, such as this polar sea area. By Andrew Thurber [CC BY-SA 4.0], via Wikimedia Commons

And, the thought goes, this diversity helps cyanobacteria navigate different environments.

“These types of cyanobacteria are quite sophisticated. Each has at least one satellite locus away from the main genes. It makes sense, since they live in dramatically different environments, like alpine lakes, hot springs, salt water, Antarctic waters. They are global citizens.”

If light or water quality change, or if the current takes them to different environments, the satellite genes would provide backup or alternative options, without messing with the main shell genes.

“That is the whole reason we believe **the evolutionary solution has been to disperse the genes so they are expressed separately**, as needed.”

Synthetic cousins that could do a lot

Tapping into **that natural factory might unlock some amazing technology someday,** Manuel says.

The Kerfeld lab wants to **build artificial carboxysomes** that can be custom fit with enzymes. That would allow them to create renewable materials that could eventually replace industrial products, such as petroleum for example.

Manuel suggests another angle: importing carboxysomes into crop plants.

“One of the biggest problems for crop plants is that they are very inefficient with how they process carbon dioxide to form organic molecules. The result is lower yield.”

“Carboxysomes are much better at processing carbon dioxide because the process takes place inside an isolated shell, impermeable to undesirable molecules.”

The potential is promising, but scientists have struggled to make cyanobacterial carboxysomes work in land plants.

Manuel thinks that, perhaps, tapping into the recently discovered wealth of the cyanobacteria genome will clear the way.

“Essentially, we’re learning how cyanobacteria have survived and evolved over time. And that knowledge is getting us much closer to understanding the basic building blocks needed to build our own artificial nano-factories.”

Banner image of futuristic city by Mysticsartdesign, **Public Domain**

Squeezing oil out of plants and into your gas tank: it's hard.

6/20/17

Igor Houwat, Yang Yang

Sometimes, when a science experiment doesn't work out, **unexpected opportunities open up**.

That's what Yang Yang and the **Benning lab** have found in their latest work on sustainable biofuels.

When they tried to transfer a method that increases energy content in a lab plant to another plant that is targeted to make biofuels, the technique did not lead to the expected result.

But in looking into why, they found out a lot about subtle differences between two different types of plants. This basic research, conducted at the **Great Lakes Bioenergy Research Center**, is crucial to furthering biofuels explorations.

The study is published in ***The Plant Cell***.

Firing up your car with lipids

Meet lipids: small molecules found in fats, oils, and waxes. It's lipids that provide the boundaries for all living cells.

But they do much more than surround cells. For the Benning lab, one of the more attractive characteristics is that **lipids store energy**. That's why we grow chubby when we don't exercise, or how birds can migrate long distances without eating.

"**One of the ways to create biofuel is to have specific crops make extra lipids** that we can harvest as raw material for those biofuels," says Yang, who is a post-doc with the Benning lab and first author of the paper.

Here is one way to do it. Yang works with an Arabidopsis plant (basically the guinea pig of lab plants).

"Arabidopsis can make lipids through two sources in plant cells. Half of the precursors come from the chloroplasts (the solar power plant for the plant's survival) and half from the endoplasmic reticulum, a massive cellular factory."

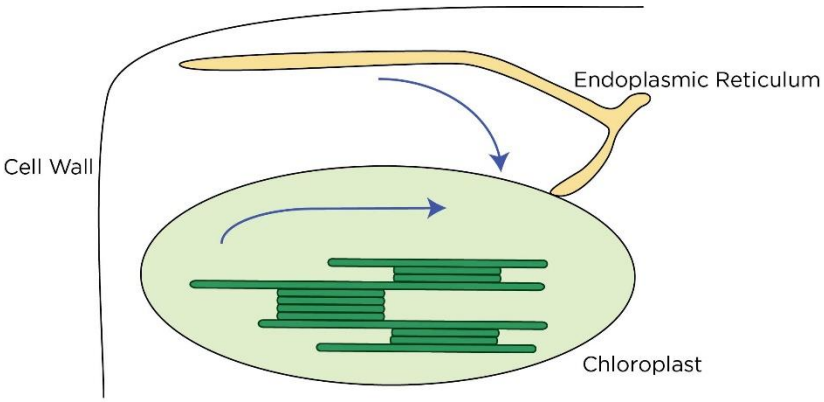


Figure 1 Source: Christoph Benning

She lets the leaves develop properly. Then she blocks the transfer from the endoplasmic reticulum, which causes extra lipid droplets to accumulate in the leaves and stems.

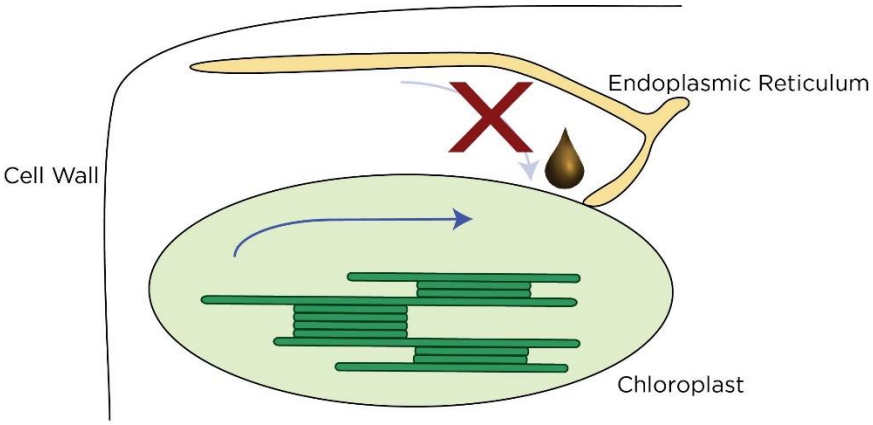


Figure 2 Oil drop by User:Slashme (Own work) [Public domain], via Wikimedia Commons

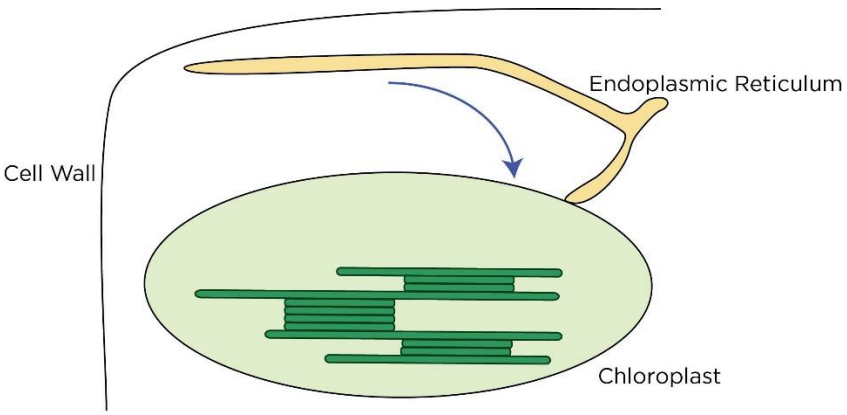
The idea would be to retrieve those lipids for industrial biofuels. “But Arabidopsis is not a suitable plant. We just use it for preliminary experiments since it is well-studied.”

“We are interested in plants like switchgrass or sorghum. But when we tried applying this lipid approach to a relative of such plants, Brachypodium (nicknamed Brachy), it unexpectedly did not work. It was a surprise!”

Digging in, they found some very cool stuff about the biology of grasses.

The building of centaurs

It turns out that the **biofuel grasses, like Brachypodium, get their lipids only from the endoplasmic reticulum.**



“That is the common feature between Brachy and Arabidopsis - that movement of lipids from the endoplasmic reticulum to the chloroplast. But somehow, blocking that pathway didn't lead to extra oils in Brachy.”

Yang narrowed the difference down to three proteins originally discovered in the Benning lab – TGD1, TGD2, TGD3 – found in that common transport machinery in both plants.

And in a process, a bit like building a centaur (half-man/half-horse), she systematically took pieces of the Brachy protein TGD1 and placed them, piece by piece, back into the Arabidopsis counterpart.

The idea was that once the distinct part of the Brachy protein made it into Arabidopsis, the biofuel technique would stop working Arabidopsis, as it originally did.

“We nailed the difference between the two plants to just 27 amino acids from TGD1. In the big picture, that is an extremely small difference.”

Yang thinks the reason is that the three proteins, although similar in both plants, evolved differently over time. “They probably had to co-evolve in each plant. That means that, if one protein changed, the others had to adapt to preserve the overall transport fun.”

“One of the ways to create biofuel is to have specific crops make extra lipids that we can harvest as raw material for those biofuels.”

So, **why does the idea work in the one plant only**?

Yang thinks that, since Arabidopsis has two ways to make lipids, blocking one might encourage the other to pick up the slack. Somehow, we end up with extra useful lipids in the leaves.

Brachy has the one way only, so it doesn’t have any backup plan when that is blocked.

“One takeaway is that, although plant biologists have studied Arabidopsis extensively over decades, our knowledge doesn't necessarily transfer elsewhere. Still, we have discovered some great biology about how plants work in subtle different ways.”

Yang and Benning are back to the drawing board. They are now looking at different strategies to get lipids made inside the plant stem.

The search continues.

Banner image by Martin Vorel, **Public Domain**. Study acknowledgements: This research was funded by the DOE Great Lakes Bioenergy Research Center (DOE Office of Science BER DE-FC02-07ER64494). This research was partially supported by a fellowship to AL from Michigan State University under the Training Program in Plant Biotechnology for Health and Sustainability (T32-GM110523). Linda Danhof and Susan Myers from the GLBRC MSU Brachypodium Service Center both made the Brachypodium plants that had reduced activity of TGD1 (knock-down plants). The authors also thank Dr. Shin-Han Shiu and Dr. Danny J. Schnell for valuable discussions and members of the Benning lab for further experiments and research insights.

[VIDEO] Our first ever look at bacterial organelle shells

6/23/17

Igor Houwat, Layne Cameron, Markus Sutter

https://youtu.be/YYx6iUGt3mk

Remember when, in biology class, we were taught that animal and plant cells had little organelles in them – like chloroplasts or mitochondria – and bacteria lacked those? And how that fact made bacteria feel a bit less special?

It turns out bacteria have their own **counterparts, called bacterial microcompartments** (or **BMCs** for short).

And, in a feat that took about two years to accomplish, **Cheryl Kerfeld and her lab** have seen the fine details of the shells that make up these bacterial organelles, which function as the organisms' nano-factories.

The results, led by Michigan State University are featured in the **current issue of *Science***.

"We've produced a detailed snapshot – at atomic-level resolution – of the membrane of bacterial organelles," says Cheryl Kerfeld the Hannah Distinguished Professor of Structural Bioengineering at the MSU-DOE Plant Research Lab. "By seeing the intact bacterial organelle shell, we now understand how the basic building blocks are put together to construct the organelle membrane."

Markus Sutter, co-author says, "It is like you see something kind of blurry. You put glasses on, and then you see it all clear. This is really exciting. This is what we have been looking to do for years."

The structure described is likely to become the textbook model of the membrane of primitive bacterial organelles, Kerfeld says.

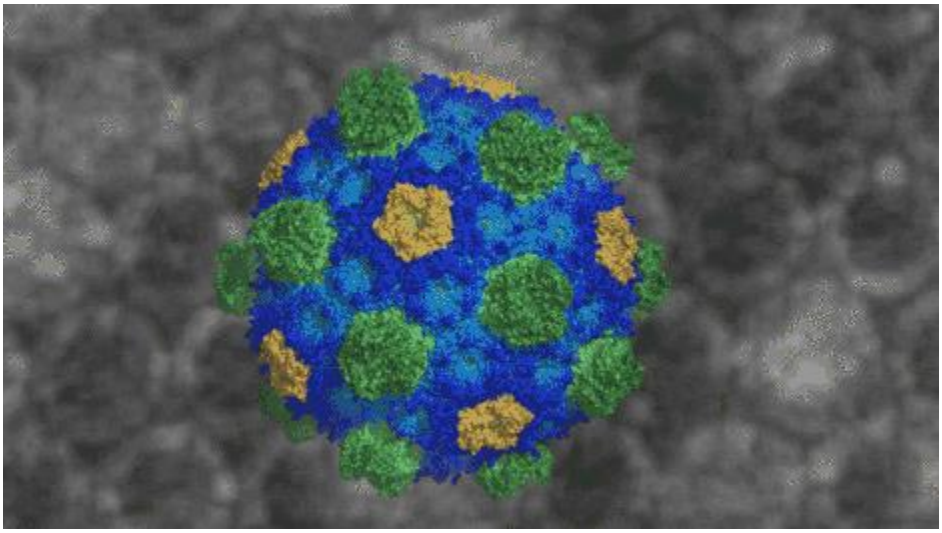


Figure 1 A GIF of the bacterial microcompartment. Source: Markus Sutter

Why this is important: BMCs for nanotechnologies

While plant and animal cell organelles are made of lipids (small molecules found in fats, oils, and waxes), BMCs are made of different types of proteins.

BMCs are used differently across a diverse range of bacteria. Some pathogenic bacteria use them to outcompete "good" bacteria, while others use BMCs to create energy compounds through photosynthesis.

But the protein shells that make up BMCs are fundamentally the same. And now that Kerfeld and her team can **see** a BMC structure, it makes it easier to understand how BMCs work and target them for medical or renewable energy applications.

The structure described is likely to become the textbook model of the membrane of primitive bacterial organelles.

"Our results provide the structural basis to design experiments to explain how molecules cross the organelle shell, how specific enzymes are targeted to the inside and how the shells self-assemble," said Kerfeld, who's also an affiliate of Lawrence Berkeley National Laboratory.

"This work also provides the **foundation to develop therapeutics** to disrupt the assembly and function of the BMCs found in pathogens or enhance those that play a role in photosynthesis in order to make fuel molecules, rubber, or plastic."

For more, **check out the original story on MSU Today by Layne Cameron**.

Thomas Sharkey joins the PRL

7/3/17

Igor Houwat

Figure 1 Banner image by Harley J Seeley

Thomas D. Sharkey, Michigan State University Distinguished Professor and former chair of the **MSU Department of Biochemistry and Molecular Biology (BMB)** in the **College of Natural Science**, has become a faculty member of the **MSU-DOE Plant Research Laboratory (PRL)**.

“It is an honor to join the PRL,” said Sharkey, who will hold a joint appointment in BMB. “The opportunities to pursue my individual research projects and to participate in multi-investigator projects makes the PRL an ideal environment for my work.”

The Sharkey lab studies the biochemistry and biophysics that determine the exchange of gases between the biosphere and the atmosphere. Current research concentrates on three projects: carbon metabolism of photosynthesis – from carbon dioxide uptake to carbon export from the Calvin-Benson Cycle; isoprene emission from plants; and abiotic stress tolerance.

An MSU alumnus, Sharkey was recruited back to MSU as BMB chair, a position he held from 2008 through April 2017.

“Tom returned to the PRL 30 years after he studied gas exchange in plants under the guidance of Klaus Raschke,” said Christoph Benning, PRL director. “For some time, Tom has been a key PRL external contributor to the Department of Energy–Basic Energy Sciences grant that supports work on photosynthesis conducted at the PRL. Inviting him to join the PRL faculty after stepping down as the

BMB chair felt like a natural step. We welcome him back and wish him many more successful years in photosynthesis research."

Sharkey received his B.S. from Lyman Briggs College and his Ph.D. in botany and plant pathology via the PRL from Michigan State University. He was recently named a Highly Cited Researcher by the Institute of Scientific Information and is a fellow of the American Society of Plant Biologists and the American Association for the Advancement of Science. Sharkey is also a founding member of the newly established Plant Resilience Institute at MSU.

The ref and the fighter: two sides of plant defense

7/5/17

Igor Houwat, Ian Major

A year ago, the Howe lab developed a plant that upended a common misconception that plants can defend or grow, but not both. **Theirs could**.

As part of this work, they designed a plant with higher defense capabilities against pests. Ian Major, a post-doc in the **Howe lab**, wanted to understand what made it special.

Because, knowing how plants defend against caterpillars and other herbivores could help us develop tougher crops.

The USDA estimates (*www.ers.usda.gov/topics/farm-practices-management/chemical-inputs/pesticide-use-markets/*) that annual US crop losses to pests are significant, with some estimates showing up to 79 percent in lost harvest. And annual pesticide use is in the hundreds of millions of pounds (*www.ers.usda.gov/webdocs/archived/publications/43854/46736_eib124_summary.pdf?v=41830*), a financial drain with potential harmful effects to the environment.

And in a new study, published in the journal ***New Phytologist***, Ian shows us that the genes involved with plant growth and defense are more tangled than previously thought.

Plant defense: restraint and release

Genes make things work in living beings. But there are also genes whose job is to prevent things from working.

Plant defenses use both types - and for good reason. They work a bit like a ref and a fighter.

“Plants normally have a set of genes that prevent defenses from turning on when they are not in danger,” Ian says. **“That saves energy**.”

But when a plant detects a caterpillar munching on a leaf, the defense restraint is removed.

Figure 1 Plant defenses have a ref side and a fighter side (MYC genes). The ref holds the fighter back, which saves energy. But once the ref is out the way, all bets are off. By Manuel/CC BY-SA 2.0

With the restraint gone, genes, called MYCs, are unleashed and turn on the defenses, producing molecules that give caterpillars the equivalent of indigestion. That is enough to stop most from finishing their meal.

In previous work, **the Howe lab removed the restraints to see what it was like to have a plant constantly on guard**.

"This constantly defended plant grows almost as large as its wild cousins, which might seem encouraging, especially if we think about agricultural uses," Ian says. "But removing the restraint also upset many aspects of the plant's growth and development."

Many defense molecules that are harmful to caterpillars turn out to be useful for us.

Fighters do more than just fight

"Observing the unleashed MYCs firing off defenses at all times showed us that they control seemingly unrelated plant developmental processes," Ian says.

And the way to examine that was to remove the MYCs and see how the plant reacted.

The result, produced by former lab member Yuki Yoshida, was a plant with eight genes knocked out. "It is a special person that would see that through. You need determination and patience to do it. It is rather impressive."

Without MYCs, plant defenses went offline, which was expected (the tell: the insects that fed on it grew fatter).

But other things showed up. Without MYCs, the plant's leaves and roots grew faster than normal, and the rates of photosynthesis were a bit higher.

"**I think that these MYCs are bona fide growth controllers themselves** – they seem to slow it down. We are still not sure how the MYCs do it all."

Figure 2 Plant defense molecules can benefit human health. By stevepb/Public Domain

Into evolution and biotech apps

Taking out plant genes that are responsible for both repressing and activating defenses is a unique way to study how the genes work, Ian says.

“This approach has revealed things we wouldn’t otherwise see. Typically, you wound a plant and study its response over time, which is an indirect approach.”

But using genetic approaches to remove the genes cuts to the heart of the matter, because they reveal extreme responses, almost immediately.

These methods could help us understand defense strategies in a wider range of plants. **Because, how plants control their defenses against insects tends to be similar across all terrestrial plants.**

“When plants emerged from the ocean, this type of defense starts appearing in mosses and then evolves further. You can imagine that, once on land, plants had to adapt to new enemies.”

In itself, this is **encouraging to scientists who want to create or breed more resistant crops.**

But there’s more: many defense molecules that are harmful to caterpillars turn out to be useful for us.

“Take flavonoids, they are antioxidants for humans. Other defense compounds are used in chemotherapy drugs. Then there are substances like nicotine, caffeine, or morphine. All these are managed by similar plant defense mechanisms.”

Currently, some pharmaceuticals are harvested from plant cell cultures grown and treated in laboratories. “Perhaps we could someday grow entire plants, stimulate their defenses, and then harvest some compound for mass production.”

The benefits seem endless. But one thing is sure: the more we dig into plant defenses – and MYCs are just one part of a much larger puzzle - the more complex their picture looks.

Acknowledgement: This work was primarily funded by the **US Department of Energy, Office of Science**.
Banner image by **Aaron Burden**/**Public Domain**

Gregg Howe earns University Distinguished Professor title

7/7/17

Igor Houwat

Figure 1 Banner image by Harley J Seeley

Gregg Howe has been named University Distinguished Professor. He is among ten MSU faculty members who have earned the distinction.

The title of University Distinguished Professor is among the highest honors that can be bestowed on a faculty member by the university. Those selected for the title have been recognized nationally and internationally for the importance of their teaching, research and outreach achievements.

Gregg is an internationally recognized leader in research on plant hormone biology and plant-insect interactions. Howe uses a combination of genetic, cell biological, molecular, and biochemical analyses to study how plants use defensive compounds to thwart insect attack. He was also recently named an MSU Foundation Professor.

The MSU Board of Trustees voted on and approved their ten recommendations on June 21. Those holding the professorship will receive, in addition to their salary, a stipend of $5,000 per year for five years to support professional activities.

A reception to honor the newly designated University Distinguished Professors will be held in November.

A new chloroplast 'app' for making biofuels

7/11/17

Igor Houwat, Kun Wang, Christoph Benning

Seed oil, aka vegetable oil, is a basic part of food. Scientists have been experimenting with harvesting that oil to make biofuels that could someday power our jets and cars.

But seed oil production is complicated, and **we still have a lot to know about how the oil is produced and managed** before we can reap the benefits.

What we do know is that the precursors for seed oil come from many sources in a plant cell. And **Kun (Kenny) Wang** and the **Benning lab** have recently identified a new, potentially significant one.

The study is published in the journal ***The Plant Cell***.

Dial phones and Smartphones

In middle school, we learn that different parts of the cell do specific things. *Mitochondria make energy. The cell wall protects the cell.* And so on.

These definitions hold true, but they are a bit like describing this:

Figure 1 Defining cell parts simply is a bit like describing old dial phones that can only do one thing. In reality, cell parts are more like smartphones. CC0/Public Domain

Old dial phones can do only one thing: phone calls.

Cell components are like smartphones, more complex. Although they keep their original purpose (phone calls), they have a lot of apps that do useful things unrelated to making calls.

That's true for the chloroplast. It is mainly known as the source of photosynthesis, the process that sustains life on Earth. Now, we are finding that it also has an app to help produce seed oil.

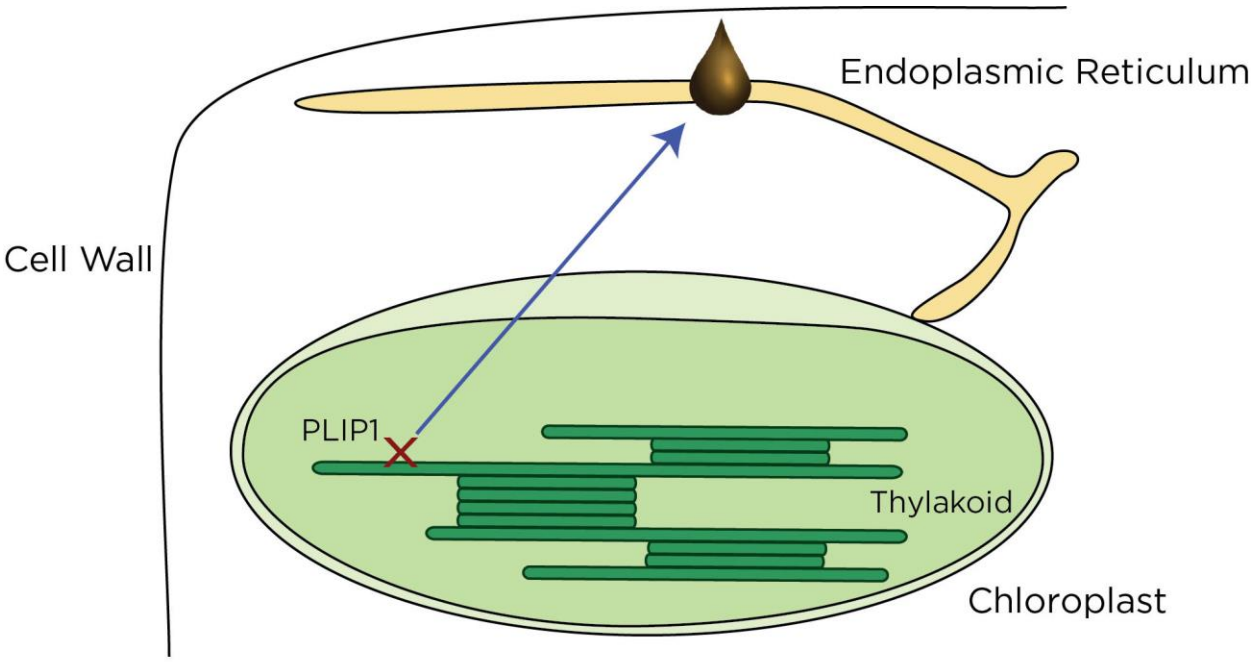


Figure 2 PLIP1 degrades internal chloroplast membranes surrounding the thylakoids. The left over lipid products are transported to the endoplasmic reticulum, where they eventually turn into seed oil. Source: Christoph Benning. Oil drop by User:Slashme (Own work) [Public domain], via Wikimedia Commons

"Previously, people thought that oil production was largely based in one cellular component, the massive cellular factory known as the endoplasmic reticulum," Kenny, a graduate student in the **Department of Biochemistry & Molecular Biology**, says.

"We are finding that the chloroplast also helps in ways we did not think of before."

The chloroplast's oil app

Seed oil is made out of lipids: small molecules found in fats, oils, and waxes, and that make up the boundaries of all living cell components. **The main reason they are interesting for biofuels is that they store energy**.

"We identified a new enzyme – which we call PLIP1 (PLASTID LIPASE 1) – that breaks down lipids that make up the chloroplast's internal membranes – the thylakoids, to be precise," Kenny says.

Left over lipid products are then transported to the endoplasmic reticulum, where they become building blocks for seed oil.

“This use and recycling of lipids is part of a process that keeps chloroplast membranes finely tuned to any developmental or environmental changes. The interesting part, though, is how this seemingly unrelated process connects to making seed oil.”

To confirm the function, Kenny found a plant that had much less PLIP1 - basically, a buggy app - meaning that lipid breakdown products couldn’t move as much out of the chloroplast.

“With less PLIP1, young embryos developed slower than normal. Seed weight and seed oil content were also reduced. We saw PLIP1 mostly active in the younger stages of a plant’s life cycle, during seed production.”

All roads lead to Rome: PLIP1 and biofuel production

Kenny wants to increase the number of PLIP1s in plants targeted for biofuels. The idea goes that more of them leads to more lipid products for more seed oil harvested.

Cell components are like smartphones, more complex... They have a lot of apps that do useful things unrelated to making calls.

One advantage with PLIP1 is that **it is found in most land plants**, which makes it easy to experiment on different species, including crops like **sorghum or switchgrass**.

PLIP1 also seems **responsible for 10% of the lipid precursors that end up as seed oil**.

“That might seem like a low number. However, seed oil is made from many sources, and the main one is responsible for 20-40% of final product. In that light, 10% is significant.”

For context, **the USDA reports that US soybean (another common oil crop) production was estimated at over 4 million bushels, for a forecasted value of $38 billion in 2016**.

Kenny’s mentor, Christoph Benning, says that 10% of soybean yield could amount to a humungous contribution.

But the road ahead is tricky. Kenny has already tried dialing up the PLIP1 app in one plant, but that somehow turned on another app that does plant defense. The result: a smaller plant with less seed oil.

“Oil production and defense functions don’t co-exist well. We have a few ideas to bypass this caveat, and we’ve already filled out a patent application to try this strategy in a new plant. We still have a lot to learn about how lipids are made and moved.”

Banner image of smartphone, **CC0/Public Domain**. This work was primarily funded by the **US Department of Energy, Office of Science**. The authors would also like to thank **John Froehlich** for his contribution.

Protecting plants from the power of sunlight

7/13/17

Igor Houwat, Steffie Tietz, David Kramer

It's 11pm. You don't feel good. Your palms are clammy, your mind is racing, and you just can't fall asleep. As a precaution, you measure your vitals. Blood pressure is 160/95, worriyingly high. You take another measurement ten minutes later: still high.

The first thing the following morning, you are on your way to the doctor's, drumming up scenario after nightmarish scenario about what went wrong. But when you get examined, your numbers look fine.

Blood pressure can change drastically over hours or even minutes, but that pales in comparison to plant status, which can shift in a fraction of a second as light flickers or wind blows.

Research is showing that the speed at which plants adjust to changes in their surroundings is vital to their health. But a major problem for scientists has been measuring these changes.

Steffie proposes a way to measure, in realtime, how plants prevent burn out from too much sunlight.

The **Kramer lab** is blazing the trail to solve this puzzle, driven by an ambitious goal. They want to improve plants' photosynthesis in order to increase crop yield, so we can better cope with the pressures of feeding billions more people with limited arable land; or of powering our cars and planes with biofuels, in order to curb pollution.

In a new study, published in the journal ***Plant, Cell and Environment***, Steffie Tietz, a former post-doc in the Kramer lab, proposes a way to measure, in realtime, one of those changes: how plants prevent burn out from too much sunlight.

NPQ: sunlight protection

In order to capture real-time measurements, our research methods need revising, Steffie says.

"Most previous scientific work has been done in laboratories, where conditions are highly controlled. But nature is very different, and we are finding that many lab experiments don't accurately reflect what happens to plants in their natural habitats."

That's because life for a plant is a constant struggle. Light intensities flicker as clouds cover the sun, rain comes and goes, caterpillars get hungry. And plants can't run when things get bad.

So, plants have evolved intricate strategies to adjust to continuously changing surroundings. One of these, called non-photochemical quenching (NPQ), protects plants from too much sunlight.

"NPQ tells us how much light plants are getting rid of when they are exposed to a lot of it," Steffi says. "Otherwise, plants can get burned out, even die."

It turns out plants have to switch between gathering light and getting rid of it, tens of times, every millisecond, just to survive day by day!

Figure 1 These plants are related, but those that can't manage environmental stress might not survive. Source: Donghee Hoh, Kramer lab

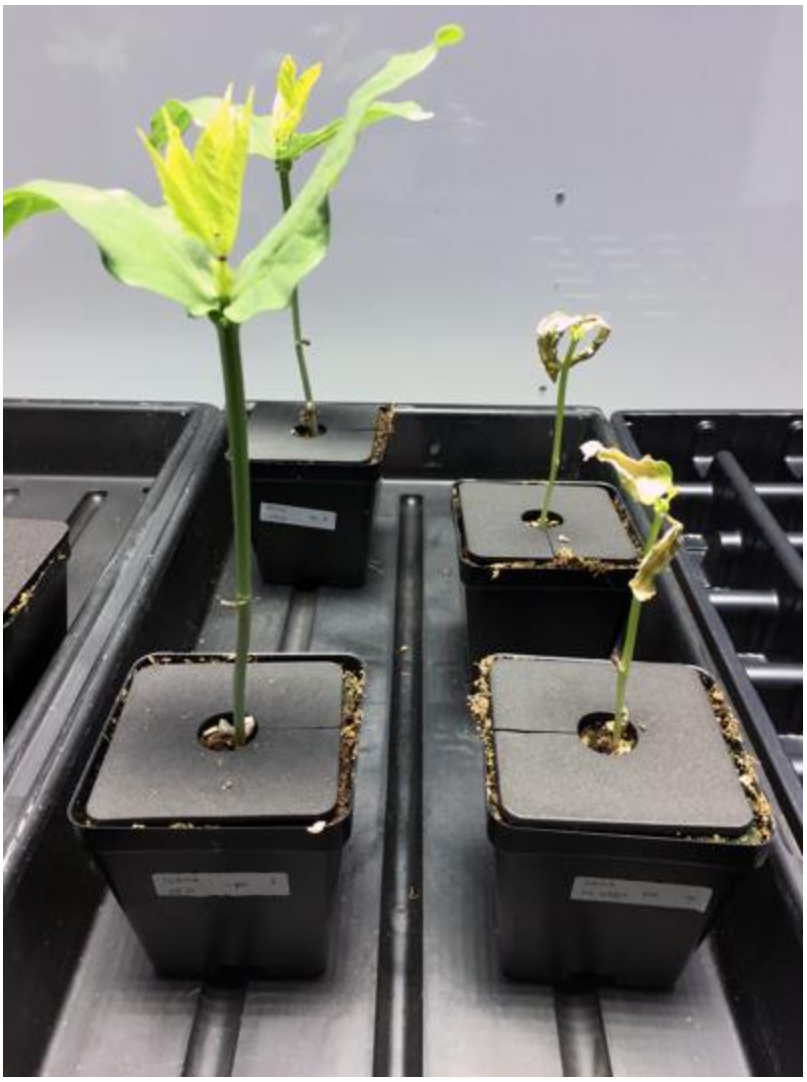


Figure 2 Plants on the right died since NPQ failed when hit by a different stress, cold temperature. Source: Donghee Hoh, Kramer lab

But protection comes at a cost. Getting rid of light, plants' main source of energy, can potentially slow down photosynthesis.

And the system is not foolproof. When light or other conditions fluctuate faster than the plants can handle, they never really adjust well, which can be both wasteful and dangerous.

“It’s like driving down a twisty road with a slow steering wheel. We either have to slow our speed way down and get to our destination late, or we risk crashing.”

Improving the balancing act

The Kramer lab is trying to find the genes that control the speed of NPQ so they can make plants with faster response times. That means less light wasted and more energy produced.

To do this, they need to measure NPQ in a large number of different plants under different conditions.

But the standard techniques take far too long, up to hours, and they can only measure one leaf at a time. “This really slows down research, and we end up missing a lot of the important responses in the entire plant,” says Steffie

It’s like taking 2 hours to measure your blood pressure - almost anything you do, like moving, eating a snack, getting spooked by a scary clown… would mess the results.

Another issue with the older methods is that they sometimes confuse other processes for NPQ. For example, if leaves move during testing, or the chloroplasts change their positions within the leaves, the measurements can be far off.

Taking a proper reading

The Kramer lab specializes in tackling this type of scientific problem. Kramer has gathered scientists, engineers, programmers, and product developers to create **technologies that are teaching us about plants and how they survive in their surroundings**.

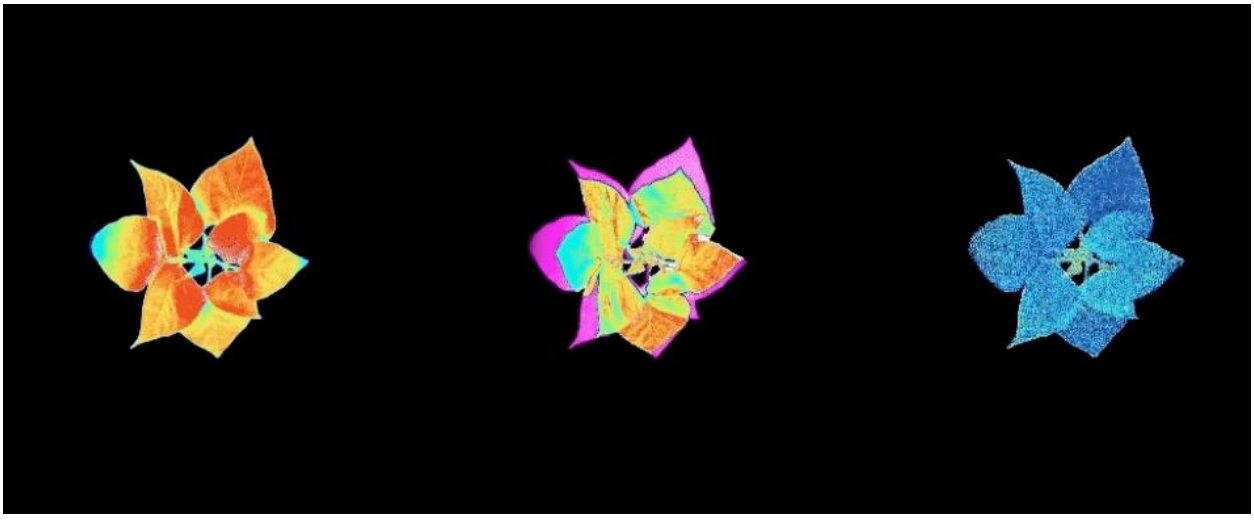


Figure 3 Movies from the new tech. The plant to the right shows the new NPQ method. Around daybreak, the color is blue, meaning NPQ is low. As the sun rises, the leaves open up and the color turns into red, indicating higher NPQ levels. Source: Jeff Cruz, Kramer

Based on some equations that Kramer solved, Steffie and her lab mates developed a new method that can make movies of photosynthesis and NPQ in hundreds of plants, simultaneously.

The experiments take seconds, rather than hours to complete, and the method is not prone to the errors found in the old techniques.

Crucially, Steffie says, she has shown that these **methods make reliable measurements in the real world**, either through lab simulations or **directly in the field.**

“This means that we can see how the plants respond in the field, where it really matters. We can then use this information to guide farmers to breed better crops in particular environments, even down to the level of individual farms.”

The ideal is to incorporate NPQ measurements in future studies on food crops, like corn or beans, that sustain communities worldwide. Steffie thinks scientists will jump on board. **The method is already**

being employed worldwide in hundreds of labs and smallholder farms, and it is easily adaptable to commonly used scientific devices (Licor, Hansatech, Walz).

On their end, the Kramer lab is already taking the NPQ pulse of **algae, another abundant photosynthetic organism ripe for biotech and renewable energy applications**.

Banner image of sun flare by **NASA Solar Dynamics Observatory**. This work was primarily funded by the **US Department of Energy, Office of Science**.

Taylor Weiss to join Arizona State University in August

7/27/17

Igor Houwat

Taylor Weiss, a post-doc in the **Ducat lab**, will be joining the Arizona State University as an Assistant Professor in the **Ira A. Fulton School of Engineering**.

As a member of the Algae/Water-Food-Energy-Environmental Nexus, he will be researching the design of artificial and synthetic algae-bacteria consortia for the scaled production of natural biocommodities with a special focus on medicinal applications.

Taylor joined the Ducat lab at the PRL in 2014 to work on biotechnological projects, notably one where he **engineered a community of bacteria to cooperatively create bioplastic**, ultimately using only light for energy and carbon dioxide and water as raw materials. Taylor's biotech work might significantly increase the feasibility and reduce the costs of producing environmentally-friendly plastics and other green products.

He has also worked on developing cultivation methods and optical instruments that can simplify, expand, and improve algal bioproduction research.

"It's been wonderful working at a facility that constantly operates at the forefront of photosynthesis research and has given algae an equal role to plants in this endeavor," Taylor says. "I am thrilled that work which was started at the the PRL will continue to inspire my ASU research and be spun into new and exciting directions."

"We are delighted that Taylor will starting his own group in Arizona State, along with the many fine scientists working in algal biotechnology there," Danny Ducat says. "While we will surely miss him around the lab here, I look forward to seeing how he will take his many creative ideas in a new direction and will be eagerly awaiting to hear of his new successes."

Originally a Michigan native, Taylor earned his B.S. in Biochemistry from the University of Rochester in New York and his Ph.D. in Biochemistry from Texas A&M University, where he was also awarded an NIH Molecular Biophysics Training Fellowship. Before coming to the PRL, he was also a post-doc at Washington University, Saint Louis.

He has published a dozen peer-reviewed articles, all in relation to algal biology and metabolites, and has been an invited speaker at more than a half-dozen national scientific forums.

Congratulations, Taylor!

Han Bao wins Gordon Research Conference award

9/7/17

Igor Houwat, Han Bao

Han Bao has won one of three poster awards at the 2017 Gordon Research Conference on Photosynthesis.

Her poster, titled “Functional Characterization of a new family of Orange Carotenoid Proteins”, showcased the discovery of a new family of light-sensitive proteins in cyanobacteria.

This work is part of the **Kerfeld lab’s** research into creating new strategies for producing renewable energy and the development of optogenetic tools for medical applications. Optogenics is a new field that uses **light to control aspects of cellular function in living beings**.

“I am delighted to win to the poster Award again in GRC photosynthesis 2017,” Han says. “I really appreciate the recognition from the photosynthesis research community. It would not have been possible to achieve this without the help and support of my colleagues in the Kerfeld lab and at the PRL.”

“Han’s work is a terrific example of young woman making the most of her opportunities to learn diverse techniques at the PRL as a post-doc and combine them with the expertise she gained during her PhD,” says **Cheryl Kerfeld, Hannah Distinguished Professor of Structural Bioengineering** at the MSU-DOE Plant Research Laboratory. “Her identification and study of new families of the OCP has implications for biotechnology as well as contributing to the basic understanding of how photosynthesis works at the molecular level.”

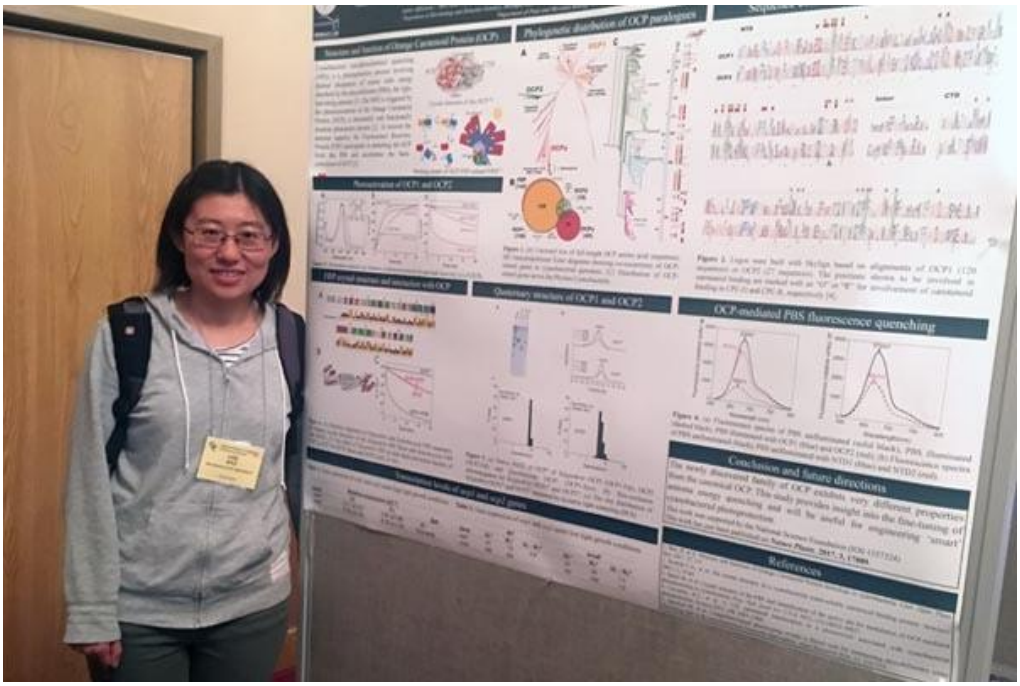


Figure 1 Han by her poster. By Tina Dominguez Martin, Kerfeld lab.

Gordon Research Conferences is an organization that organizes over 365 prestigious international scientific conferences in different disciplines. The **Photosynthesis GRC** series brings together scientists with interests in solar energy conversion, energy and electron transport, and the molecular physiology of photosynthetic organisms, among others.

Han received her Ph.D. in Chemistry at the Chinese Academy of Sciences in Beijing. She then joined Robert Burnap's lab at Oklahoma State University in 2012. Currently, she is a post-doc in the Kerfeld lab, where she studies the Orange Carotenoid Protein mediated non-photochemical quenching mechanism of cyanobacteria.

Perspectives on building nanofactories for energy and medical uses

9/12/17

Igor Houwat, Eric Young

At the MSU-DOE Plant Research Laboratory (PRL), we are gathering scientists with varied areas of expertise to tackle key science problems through many angles – problems that are too large to address in single, isolated labs.

A major challenge, supported by the US Department of Energy's Office of Basic Energy Sciences, brings together 4 labs to understand, and, someday, build nanofactories, inspired by nature, to develop renewable energy sources addressing climate change or new chemicals for industrial or medical purposes.

Nanofactories in nature are found in many bacteria, and they have evolved to make a wide range of products, depending on the host's needs. After all, **bacteria that make these structures are highly diverse** and found everywhere on the planet, **from polar ice to scalding hot springs**.

For example, one nanofactory produces energy out of carbon dioxide and sunlight in bacteria that live in waters like oceans and alpine lakes.

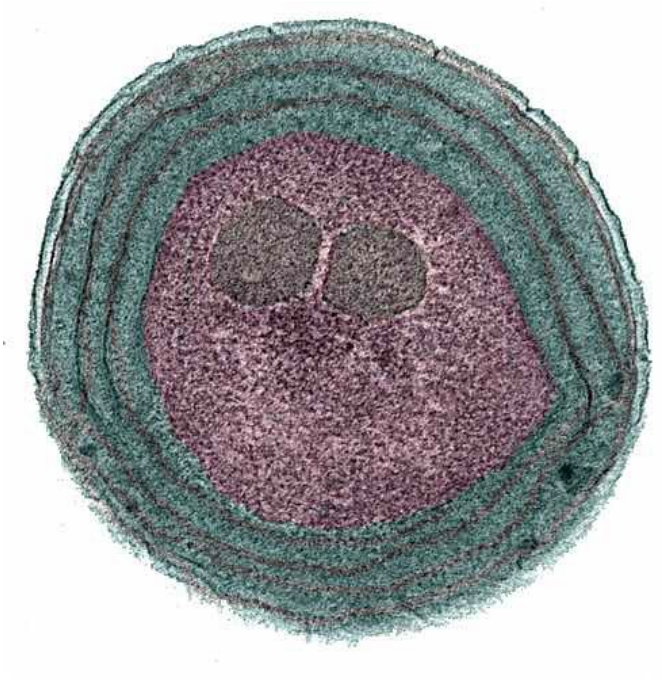


Figure 1 Cyanobacteria, formerly known as "blue-green algae," are one of the types of bacteria we are studying. Each is 25 times smaller than a human hair, and their nanofactories (the two circles in the middle) help their hosts capture sunlight and CO2 to be converted into useful energy. By Eric Young

Another, in gut bacteria, isolates a toxic molecule, a smart trick that protects the host from poisoning itself, while helping it beat out other competing bacteria.

Special protein walls

What makes these nanofactories distinct, compared to normal cellular processes, is that they are protected by walls made of protein. This isolates them into small compartments inside the hosts (hence the 'official' name: *bacterial microcompartments*, or *BMCs* for short), which comes with some perks:

1. **The wall controls what raw material (**metabolites**) comes in and what product comes out**. This allows the cell to carefully control the reactions inside, with no unwanted interference.
2. **The wall concentrates all production in one space**, like bringing all employees together on one car assembly line. That increases productivity and speed.

The PRL wants to eventually repurpose these nanofactories to make things they usually don't in nature, like:

- **Renewable materials**, such as **biofuels, plastic, or rubber, which currently come from trees and fossil fuels**;
- **Medical applications that neutralize harmful bacteria or target difficult diseases**.

The first hurdle is figuring out how the protein wall is built.

"We know that all these nanofactory walls are made of three flavors of proteins found throughout nature: BMC-H, BMC-T, BMC-P" according to Eric Young, a grad student in the **Ducat lab**. "They all fit together, like Lego bricks, and just like Legos, they can be used to build many different types of structures."

"If we can figure out how these different proteins interact with each other, we would have a "Lego-like" assembly toolbox for making custom nanofactories and other types of assemblies. Then we can tailor what types of applications we use them for."

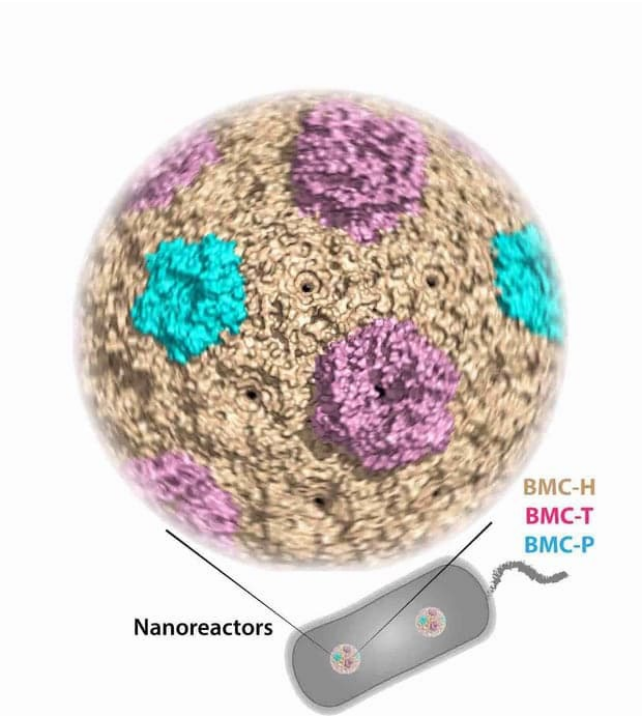


Figure 2 Zooming into a bacterial nanofactory wall, each is made up of three types of proteins, BMC-H, BMC-T, and BMC-P, fitting together like Lego blocks. By Eric Young

Nanofactories in different shapes for more functions

Just recently, the **Kerfeld lab** revealed **our first view of the compartment wall and how the three types of Lego bricks fit together** (see below). Understanding how the pieces of the wall fit together will help us tinker with how to build custom structures.

But Eric and other members of the team are tackling this concept differently. Instead of studying all three proteins, they are looking into what would happen if the individual protein Lego bricks assembled by themselves, without the other flavors.

“This approach revolves around using individual proteins as a way to build different nanostructures inside of cells, as new assembly lines for diverse applications. They would look different from the main nanofactory compartment.”

In other words, the more options we have for building nanofactories, the more applications we can imagine.

Eric’s recent focus has been on the BMC-H brick.

“Originally, we thought all BMC-H Lego bricks would form these striking, large nanostructures when put together in a cell. This didn’t happen in the case of one type of BMC-H brick. These different BMC-H bricks assembled into some striking shapes, from tubes, rods, to even ‘Swiss rolls’ (think of a rolled-up carpet).”

This result is leading the team down a line of thinking that subtle differences in the bricks lead to changes in how they assemble. And something unique about each protein flavor leads to them forming different shapes.

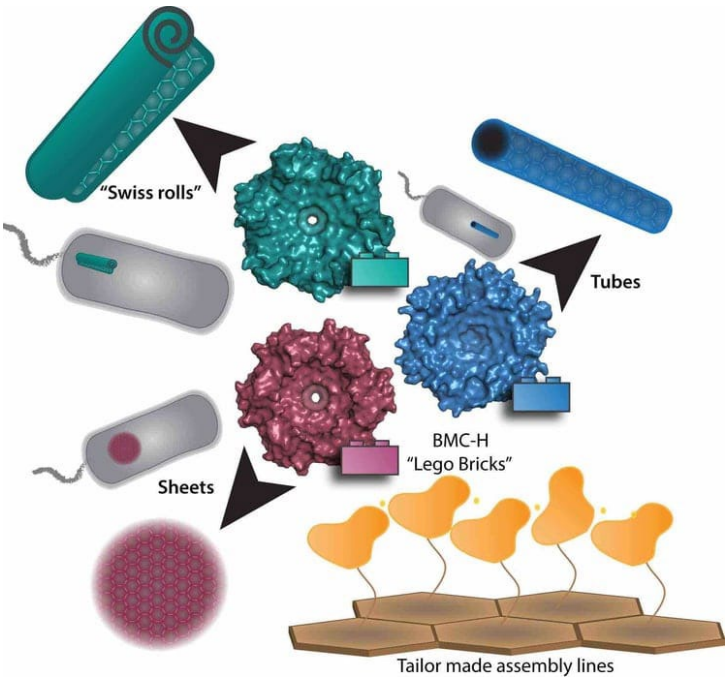


Figure 3 Different BMC-H bricks (center) join together to create different stuctures, like "Swiss rolls," tubes, and sheets (edges). Scientists want to engineer these structures into molecular assembly lines for custom renewable energy or medical applications. By Eric Young

Some of these subtle differences occur at the junctures where the individual bricks come together.

“For example, we used computer simulations, with help from **Oak Ridge National Lab**, to further investigate two of the BMC-H Lego bricks. Amazingly, the simulations suggest that the brick which assembled into tubes inside living cells, also preferred to associate at an angle in the simulations. This provides a clue as to why this particular BMC-H curls in on itself to form a tube when many of them are connected in a series.”

Eventually, the **team hopes to codify what they like to call “design principles”** – basically, a set of predictive rules for how the various Lego bricks like to assemble.

These principles would suggest how to accurately build new structures and design useful functions into them.

“For example, a tube shape could be used as a tiny pipeline inside the cells, allowing raw precursors to flow in and products—like biofuels or medicines—to flow out,” Eric says.

Or, he adds, structures like rods and sheets could be used as surfaces to program new function into the cells – think like little molecular switchboards!

“We have already made some good strides by realizing that subtle differences can change how the individual blocks assemble. Now, we are using knowledge of the structure of the protein to change properties of the blocks, in a “design, build, test, repeat” cycle, to tease out the rules of assembly.”

Banner image: Huge mats of brilliant bacteria and algae live on the edges of this hot spring, in this aerial photo from Yellowstone National Park. Some of these organisms contain special nanofactories that help them survive in the extreme heat; By **Jim Peaco**, National Park Service, Public Domain.
This work was primarily funded by the **US Department of Energy, Office of Basic Energy Sciences**. Eric’s paper is published in ***Frontiers in Microbiology*** under a special issue of “Novel Metabolic Engineering Approaches for Producing Novel Chemicals.”

Turning the evolutionary clock back on a light-sensitive protein

9/19/17

Igor Houwat, Sigal Lechno-Yossef

We are inching closer to the day where we can use light to help cure diseases. The key is harnessing the power of proteins that are sensitive to light.

The **Kerfeld lab** studies the orange carotenoid protein (**OCP**), unique to cyanobacteria (previously known as blue-green algae), which are organisms that are prodigiously productive at photosynthesis.

The OCP and its homologs, protect cyanobacteria when they are **exposed to too much sunlight, which would otherwise damage the photosynthetic systems**, and if extreme, damages the cell itself.

And just as shining light triggers the OCPs activity, scientists want to use that response to activate engineered, custom health technologies (**jump to section**).

But first, we need to understand how OCP and its relatives work, according to Sigal Lechno-Yossef, a post-doc in the Kerfeld lab.

In her latest study, published in ***The Plant Journal***, Sigal shows how the two parts of the OCP interact when split apart. She also manages to create new, synthetic OCPs by mixing and matching the building blocks from different types of the OCP found in nature.

Reversing evolution

In nature, proteins are made up from a limited number of domains – think of them as Lego blocks – that combine in different ways.

The OCP is made out of two blocks, called C-terminal domain and N-terminal domain, spanned by a carotenoid pigment that bolts the two parts together.

This is how they work (see both caption and gif):

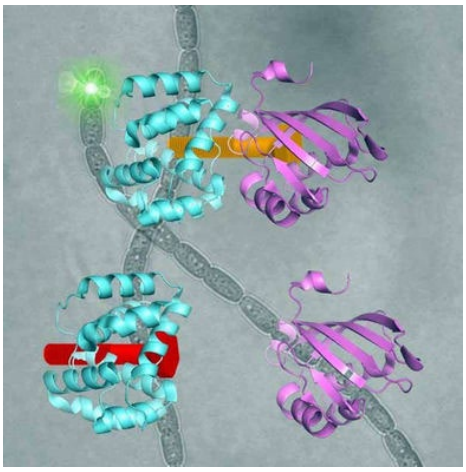


*Figure 1 The OCP domains are joined by a carotenoid bolt (orange in top of figure). When light shines, the domains separate in order to activate the OCP's protective functions (bottom of figure). When the work is done, and it is darker again, the OCP reassembles. By Sigal Lechno-Yossef, **Kerfeld lab***

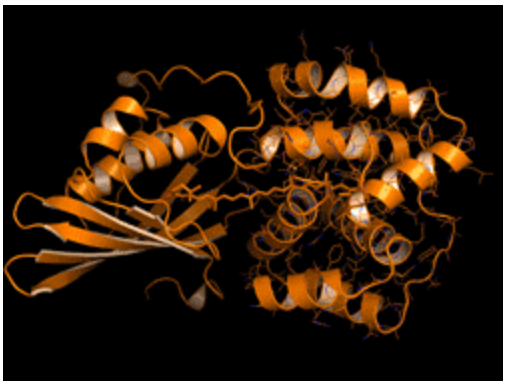


Figure 2 By Kerfeld lab

Sigal and her colleagues in the Kerfeld Lab suspect that the OCP, as we know it today, is the result of ancestors of the two domains joining together, millions of years ago. In evolution, genes for proteins that work collaboratively sometimes become permanently fused into a single, larger protein.

Sigal reversed this evolutionary event in the lab – call it devolution. “We wanted to better understand the evolution process of the OCP from domain homologs found in cyanobacteria today,” Sigal says.

The **scientists broke down the connecting carotenoid bond to split apart an OCP protein**. **Then, they put both domains into a test host to see if they would find each other and connect again** – basically retracing what they think was the evolutionary process.

“Without carotenoid, the two parts stayed separate. Once we put in the carotenoid, they latched onto each other. We basically created multiple synthetic versions of the OCP!”

The synthetic OCP reactions were *similar* to their natural cousins' in the presence of light. But for some reason, probably in the fine details of their structures, only one of the synthetic versions came back together in the dark.

As a bonus, **even though the two OCP domains remained separate without the carotenoid bolt, that configuration yielded some interesting insights**.

“In the OCP, the N-terminal domain binds to the carotenoid more strongly,” Sigal says. “When we isolated the domains, we found that, the C-terminal domain, when on its own, can bind to the carotenoid.”

Proteins similar to the C-terminal domain are widespread in plants, bacteria, and some animals, which opens new possibilities to explore engineering applications in a range of organisms, beyond bacteria.

Using light in synthetic biology

Cheryl Kerfeld, principal investigator at the Kerfeld lab, thinks that precise knowledge of the structures of the various OCP building blocks makes them especially amenable to engineering.

The long-term goal is to use the OCP and its separate subcomponents in new, synthetic systems, specifically optogenics, **a recently developed technique that uses light to control processes in living cells**.

See how shining light controls a fly's escape response, in the video below.

https://youtu.be/I64X7vHSHOE

Optogenetics, **highlighted in a 2010 *Science* article on Breakthroughs of the Decade,"** is showing us how the brain works, how we learn, or how we wake up. Scientists hope that targeting specific brain cells will help us cure Parkinson's or Alzheimer's, even combat mental illnesses.

Light-sensitive proteins, similar to the OCP, are key to activating and controlling events in optogenetic applications. Although OCP has yet to be tried in a specific optogenetic application, the Kerfeld Lab thinks their properties make them likely to be useful.

"OCPs respond faster to light, compared to the current light-sensitive proteins used in optogenetic experiments," Sigal says. "They are also so flexible in how they break apart and come back together. They are a great candidate."

She adds, "Now that we've shown we can make artificial hybrid OCPs, we have a wider range of options." For example, if a patient requires multiple doses of medicine, their intake could be controlled with a synthetic OCP that assembles and disassembles to control dosages.

Or, OCP domains could be used separately, for example, as a kill switch for treatments that require single doses, as opposed to multiple cycles.

"We are still in the theoretical phase of imagining applications, but we are not far from where we can start experimenting with synthetic systems."

Banner image of fiber optic lights available through **CC0 Creative Commons** license. This work was primarily funded by the **US Department of Energy, Office of Basic Energy Sciences**.

Identifying a new family of light-responsive proteins

10/2/17

Igor Houwat, Han Bao

When Han Bao started looking for a new cyanobacteria species to study, she had no idea that the perfect candidate was just upstairs.

Han is part of the **Kerfeld lab's** project around the orange carotenoid protein (OCP), a protein that responds to light from the environment to protect its hosts, cyanobacteria (formerly known as "blue-green algae").

The interest in the OCP is two-fold: first, it plays a prominent role in cyanobacterial photosynthesis, and the Kerfeld lab wants to understand how it works.

They then want to use that knowledge to re-engineer this protein for applications in renewable energy and medicine.

And after Han and her labmates conducted a bioinformatical analysis on cyanobacterial genomes (a genome is a complete copy of an organism's DNA blueprint), she found out the **Montgomery lab**, also at the MSU-DOE Plant Research Laboratory, specializes in a species that would facilitate her study of a new family of OCP proteins she identified.

Her study, **published in the journal *Nature Plants*** (**the article made the journal cover**), introduces and describes this new family, called OCP2.

An increasing number of cyanobacteria genomes

"Most of the previous studies on the OCP focus on the one found in a cyanobacterium called *Synechocystis*," Han says. "This OCP, known as OCP1, is very well studied."

But over the past five years, hundreds of cyanobacterial genomes have become available for analysis.

The data is showing scientists how today's OCPs, and their domain homologs, have evolved over billions of years in different cyanobacteria, **gradually diversifying and specializing in different functions**.

After all, cyanobacteria are sophisticated organisms, living in dramatically different environments around the planet, from freezing arctic regions to hot springs in Yellowstone National Park.

OCPs have adapted accordingly to protect cyanobacteria from harmful light exposure. And their functional diversity is interesting for developing renewable energy or devising new healthcare tools, which is why the Kerfeld lab want to understand how various OCP families work.

Introducing OCP2

"**We did a bioinformatics analysis to analyze all cyanobacteria genomes available in the database**," Han says. "**We found two new OCP families**, beyond the well-studied OCP1. We focused our attention on OCP2, found in the cyanobacterium, *Fremyella*, which is studied by the Montgomery lab."

Interestingly, OCP evolution has led to both OCP1 and OCP2 being present in *Fremyella*, creating a great opportunity to compare both families in one organism.

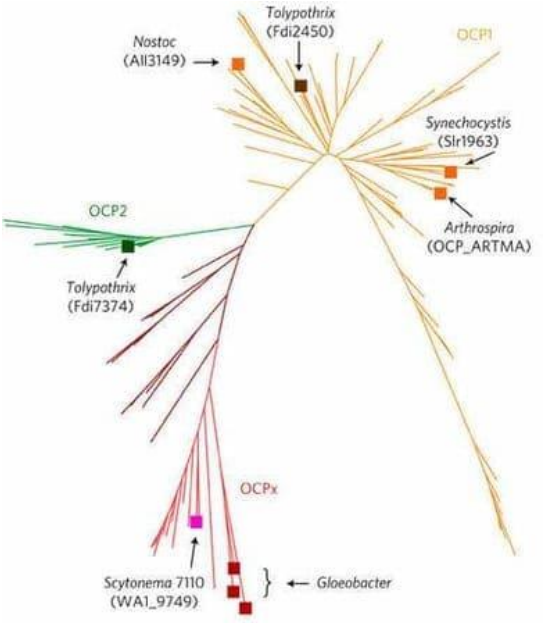


Figure 1 The tree shows the evolution of OCPs in cyanobacteria, starting with the ancestral Gloeobacter (bottom). OCP2 (green) occurs earlier on, and thus is more primitive, than OCP1 (yellow). Fremyella, (in this chart, Tolypothrix) encodes genes for both OCP types. By Kerfeld lab. ***Reprinted by permission from Macmillan Publishers Ltd****: **Nature Plants 3, Article number: 17089**, copyright (2017, **Nature Publishing Group**).*

"We found that OCP2 has different properties compared to OCP1. For example, **OCP2 reacts much faster** to changes in environmental light conditions."

On the other hand, **OCP2 needs a comparatively higher light intensity before it is activated** to protect the cyanobacterium, while OCP1 can protect it at lower light intensities.

OCP2's structure is also simpler than OCP1's. **Han and the Kerfeld lab think such characteristics suggest OCP2 is a more primitive protein.**

"We have more evolutionary evidence to back that claim. We know OCP1 has evolved to interact with another protein in *Fremyella*, called FRP (fluorescence recovery protein). What FRPs do is speed up the OCP1's recovery in the dark. But, OCP2 does not interact with FRP."

Here's what she thinks happened. OCP1 evolved to interact with FRP as a way to add a layer of regulation, in its quest to protect cyanobacteria.

Although that additional interaction slows down OCP1, it makes it better — more refined—or "smarter" at its job.

A good analogy is bureaucratic red tape: the interaction with FRP is like an extra layer of paperwork, which slows down a company's activities. But usually, established bureaucracies are more stable.

But OCP2 being primitive does not mean it is less useful, especially when considering synthetic biology applications.

“Different families have uniquely interesting characteristics. **Another study in our lab just showed how OCP1 and OCP2 work differently when we break them apart and look at them**. Their different properties will be useful to **engineer varying applications, dependent on each family’s strengths**.”

The Kerfeld lab is on the hunt for more OCP families, beyond OCP2, in its continuing quest to build a structural and functional knowledge base about this protein.

Banner image by **gn dim** on **Unsplash**. This work was primarily funded by the NSF and the **US Department of Energy, Office of Basic Energy Sciences**.

Taking the brakes off plant production: not so good after all

10/10/17

Igor Houwat, Atsuko Kanazawa, David Kramer

When engineers want to speed something up, they look for the “pinch points”, the slowest steps in a system, and make them faster.

Say, you want more water to flow through your plumbing. You’d find the narrowest pipe and replace it with a bigger one.

Many labs are attempting this method with photosynthesis, the process that plants and algae use to capture solar energy.

All of our food and most of our fuels have come from photosynthesis. As our population increases, we need more food and fuel, requiring that we improve the efficiency of photosynthesis.

But, **Dr. Atsuko Kanazawa** and the **Kramer Lab** are finding that, for biological systems, the "pinch point" method can potentially do more harm than good, because the pinch points are there for a reason! So, how can this be done?

ATP synthase: an amazing biological nanomachine

Atsuko and her colleagues at the MSU-DOE Plant Research Laboratory (PRL) have been working on this problem for over 15 years. They have focused on a tiny machine in the chloroplast called the ATP synthase, a complex of proteins essential to storing solar energy in “high energy molecules” that power life on Earth.

That same ATP molecule and a very similar ATP synthase are both used by animals, including humans, to grow, maintain health, and move.

In plants, the ATP synthase happens to be one of the slowest process in photosynthesis, often limiting the amount of energy plants can store.

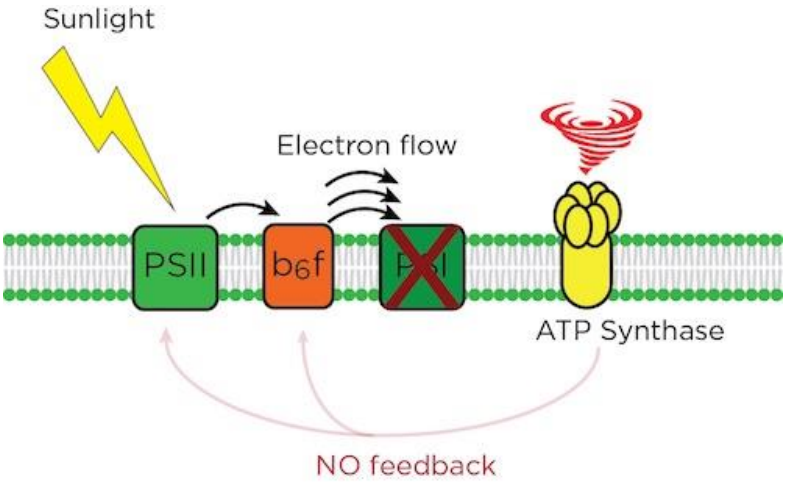


Figure 1 Photosynthetic systems trap sunlight energy that starts the reaction to move electrons forward in an assembly-line fashion to make useful energy compounds. The ATP synthase is one of the "pinch points" that slows the flow as needed, so

*plants stay healthy. In cfq, the absence of feedback leads to an electron pile up at PSI, and a crashed system. By MSU-DOE Plant Research Laboratory, except **tornado graphic**/**Pixabay License***

Kicking up the gears of plant production

Atsuko thought, if the ATP synthase is such an important pinch point, what happens if it were faster? Would it be better at photosynthesis and give us faster growing plants?

Years ago, she got her hands on a mutant plant, called *cfq*, from a colleague. "It had an ATP synthase that worked non-stop, without slowing down, which was a curious example to investigate. In fact, under controlled laboratory conditions – very mild and steady light, temperature, and water conditions – this mutant plant grew bigger than its wild cousin."

But when the researchers grew the plant under the more varied conditions it would experience in nature, it suffered serious damage, nearly dying.

"In nature, light and temperature quality change all the time, whether through the passing hours, or the presence of cloud cover or winds that blow through the leaves," she says.

Plants slow photosynthesis for a reason!

Recent **innovations from the Kramer lab are enabling Atusko and her colleagues to probe into how real environmental conditions affect plant growth**.

Atsuko's research now shows that the **slowness of the ATP synthase is not an accident; it's an important braking mechanism that prevents photosynthesis from producing harmful chemicals**, called reactive oxygen species, which can damage or kill the plant.

"It turns out that sunlight can be damaging to plants," says Dave Kramer, Hannah Distinguished Professor and lead investigator in the Kramer lab.

"When plants cannot use the light energy they are capturing, photosynthesis backs up and toxic chemicals accumulate, potentially destroying parts of the photosynthetic system. It is especially dangerous when light and other conditions, like temperature, change rapidly."

The ATP synthase senses these changes and slows down light capture to prevent damage. In that light, the *cfq* mutant's fast ATP is a bad idea for the plant's well-being.

"It's as if I promised to make your car run faster by removing the brakes. In fact, it would work, but only for a short while. Then things go very wrong!" Dave says.

"In order to improve photosynthesis, what we need is not to remove the brakes completely, like in *cfq,* but to control them better," Dave says. "Specifically, we need to figure out how the plant presses on the brakes and tune it so that it responds faster and more efficiently," David says.

Atsuko adds: "Scientists are trying different methods to improve photosynthesis. Ultimately, we all want to tackle some long-term problems. Crucially, we need to continue feeding the Earth's population, which is exploding in size."

The study is published in the journal, ***Frontiers in Plant Science***.

Banner image by Romain Peli on **Unsplash**, www.unsplash.com/photos/-1x5HVtV7fk?utm_source=unsplash&utm_medium=referral&utm_content=creditCopyText. This work was primarily funded by the **US Department of Energy, Office of Basic Energy Sciences**.

Grad student Isaac Osei-Bonsu wins conference award

10/12/17

Igor Houwat

Isaac Osei-Bonsu has won a poster award at the 2017 “Feed the Future” Legume Innovation Lab (LIL) conference, which took place in Ouagadougou, Burkina Faso.

Isaac’s oral and poster presentations focused on his research to improve photosynthetic performance in cowpea crops that are sensitive to heat stress, an important breeding goal.

“This is my first poster award at an international conference. It was really exciting for me,” says Isaac, who is a graduate student in the **Kramer lab** and at the **Department of Plant Biology**. “It is a good boost for my career and a sign of greater things to come, because I know I can improve on my presentations in the future. I can do better.”

“Isaac’s research requires that he master a wide range of highly technical methods and concepts, and apply them to both basic research questions and practical applications,” says Isaac’s Ph.D. advisor, David Kramer. “What’s remarkable is that Isaac was able to explain all this in a really engaging way, especially because the audience at the meeting came from very diverse backgrounds and many different countries.”

The “Feed the Future” is a program funded by USAID under the US government’s Global Hunger and Food Security Initiative. The program has been engaging universities, institutions and private organizations in the US, Africa and Central and South America to improve the quality and management of legumes, and contributing to the well-being of local people. **Michigan State University is one of the leading institutions contributing research and new technologies to the world**.

Isaac obtained his BSc and MPhil degrees, both in Botany, from the University of Ghana, graduating with First Class Honors degree for his BSc. He worked for close to 3 years with the CSIR-Crops Research Institute in Kumasi, Ghana before winning a Legume Innovation Lab Scholarship (**Legume Scholars Award**) to pursue a PhD with Dr. Kramer at MSU.

Better together: a bacteria community creates biodegradable plastic with sunlight

10/23/17

Igor Houwat, Taylor Weiss

https://youtu.be/FimnlTX-19s

A short video summary of how a synthetic microorganism cooperative produces cheap biodegradeable bioplastics.

By MSU-DOE Plant Research Laboratory

Cheap plastics abound, and they're a mixed bag – pun intended.

The IV container that saves a life ends up on a landfill. Or that milk jug from the store ends up floating gently down a stream, with dozens others.

For all their convenience, plastics are massive environmental headaches.

“The main problem is that most synthetic plastic is not completely biodegradable. It cannot be broken down by living organisms, which is why it lasts for hundreds of years after being discarded,” says **Taylor Weiss**, a former post-doc in the **Ducat lab**.

Scientists are trying to synthesize environmentally-friendly plastic alternatives, using bacteria.

And it exists: 100% biologically-derived. 100% biodegradable.

But it is too expensive to mass market.

Now, in a study, published in the journal **Metabolic Engineering**, Taylor and the Ducat lab propose a **new production method, powered by sunlight and an ancient microorganism, that could significantly cut costs**.

Figure 1 Cyanobacteria are abundant on Earth and can thrive in many areas which are hostile to plants, like this bloom on Lake Erie. By NASA/Public Domain

Cyanos: micro powerhouses

“Present bioplastic production relies on feeding plastic-producing bacteria with large quantities of sugars from crops, like corn or sugarcane,” Taylor says. “But these crops also feed people and animals, **so we risk competing for limited agricultural resources and driving food prices up in the long term**.”

A promising alternative is working with cyanobacteria, microorganisms that harness sunlight to produce chemical compounds, through photosynthesis.

Cyanos (for short) thrive in environments hostile to crops, like iceberg walls or the edges of hot springs, minimizing competition for agricultural land.

That's why they're hot in the biotech industry, with scientists wanting to genetically tweak them to create products for human consumption, like electricity, biofuels, even food and oxygen **for future manned outposts on Mars**!

A bioplastic consortium engineered

There's a catch. Cyanos are great at photosynthesis, but not so much at making bioplastics.

Current methods where cyanos do it all - collect the sun’s energy, the carbon, and the create the bioplastic - end up inefficient.

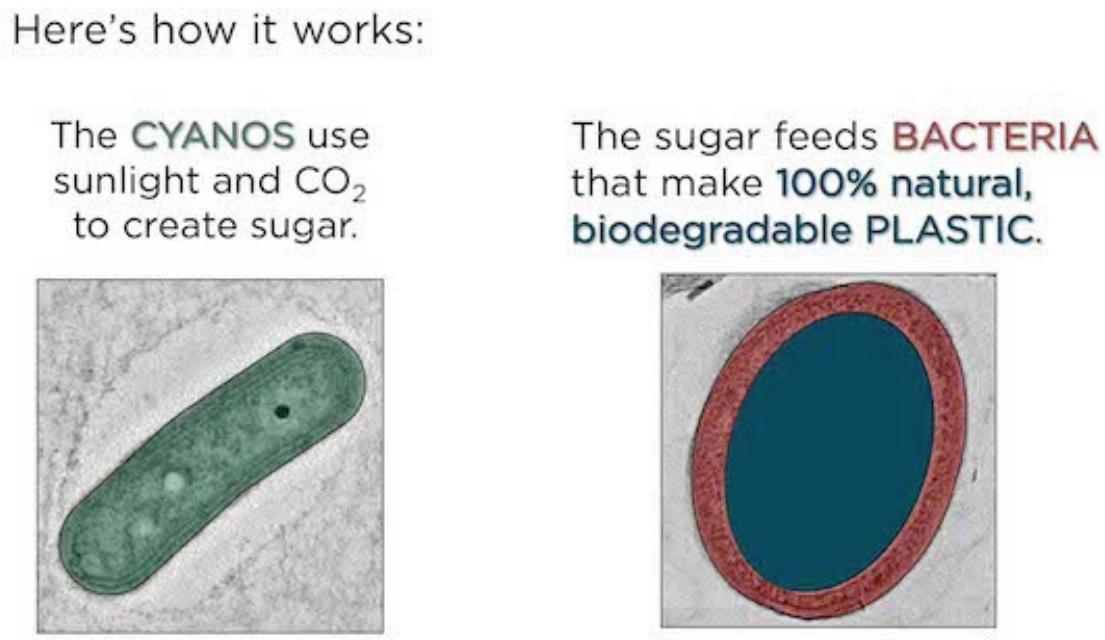


Figure 2 A snapshot of the microorganism cooperative. Cyanos (green) make sugar, which is leaked into a surrounding medium. Special bacteria (red) eat the sugar, which powers bioplastic production (blue). By Taylor Weiss

So, Taylor and his colleagues thought, why not split the workload with other organisms?

They started out with a cyano strain that naturally produces sugar. They tweaked them to constantly leak the sugar into a surrounding salt water medium.

Then, they paired the cyanos with natural bacteria that make bioplastic. The bacteria fed on the leaked sugar, which is to bacteria what honey is to bears. (***For more, see the video above.***)

Over five months of testing, the pairing turned out prolific and robust:

- Processed biomass contained a near constant 30% bioplastic content, four times more than the best cyano working alone.
- Production rates were over twenty times faster.

The system is also relatively inexpensive to maintain.

"Harvesting bioproducts is a common costly bottleneck," Taylor adds, "It involves collecting and regrowing microorganisms from scratch, each production cycle. But, we trap our cyanos in a hydrogel bead for reuse after each harvest."

Also cutting costs was the fact the plastic-producing bacteria thoroughly outcompeted other unwelcome contaminating bacteria trying to get to the sugar, without the need for human support.

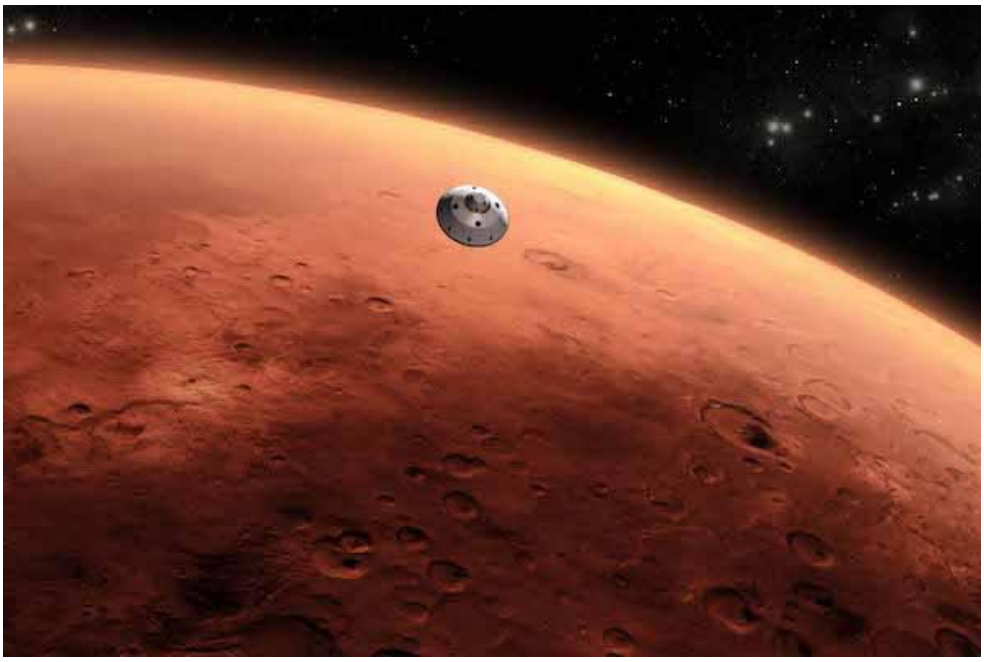


Figure 3 Perhaps we'll use cyanos to someday provide food and oxygen on Martian outposts. By NASA/Public Domain

From plastic to perfumes and medicines

Taylor's **cooperative seems to continuously improve with time, without human meddling**.

Working with one organism can be hard, because it typically prioritizes its health and growth over producing for us.

“But **this pair has complementary strengths**: the cyanos are constantly producing sugar, and the bacteria are constantly beefing up on it, which encourages the cyanos to keep producing.”

Looking ahead, **Taylor wants to improve productivity and diversify the bioproduct line**.

“We’ve laid the foundation for a “plug-and-play” system where a cyano can be gradually upgraded to produce more sugar. We eventually want to pair it with diverse specialist bacteria to create many cheaper, green bioproducts like fuels, fragrances, dyes, and medicines.”

“Ultimately, we aren’t just creating alternatives to synthetic products. We’re figuring out how to ask Nature to do what it does best: figure out the problem for us.”

This work was primarily funded by the **National Science Foundation**. The MSU-DOE Plant Research Laboratory also relies on major funding from the **US Department of Energy, Office of Science, Basic Energy Sciences**.

How to build artificial nanofactories to power our futures: Logistics

10/31/17

Igor Houwat, Jeff Plegaria

When we buy a new phone or laptop online, we assume it will be delivered to our doorstep in a matter of days.

But we mostly miss the complex logistics that make this happen: ships, planes, trains, and trucks that move products, starting from raw materials in mines, to factories for assembly, to warehouses for storage, and up to our doorsteps.

Scientists at the MSU-DOE Plant Research Laboratory are trying to **build artificial nanofactories to sustainably produce industrial materials or medical tools**.

And like with getting new phones, these artificial nanofactories of the future will need an army of "nano" vehicles to deliver valuable chemical products.

But we don’t know enough about the logistics just yet.

It turns out bacteria in nature have the blueprint for us to copy. They house nanofactories, **called bacterial microcompartments (BMCs)** - that fill many purposes, depending on the host.

In cyanobacteria, for example, BMCs build useful compounds from carbon dioxide pulled from the atmosphere. Or, some pathogenic bacteria use them to outcompete "good" bacteria.

In a new study, published in the journal ***Biochemistry***, Jeff Plegaria and the **Kerfeld lab** reveal the structure and function of a widespread BMC protein that contributes to the logistics of creating products, taking us closer to repurposing BMCs for our own uses.

Describing the Fld1C flavoprotein

Jeff and his colleagues noticed that many natural BMCs – especially a type that degrades carbon to help make useful energy compounds – contain genes for flavoproteins right next to the primary genes responsible for constructing and operating the BMCs.

Primary genes include instructions for building and managing BMCs, transporting materials back and forth, and so on.

And being close to the core genes meant flavoproteins play an important role within BMCs.

So, what do flavoproteins do?

"They are electron transfer proteins found in many bacteria and other biological pathways in nature. **Electron transfer, or flow, is a fundamental process in nature**," Jeff says.

"**Understanding electron flow in BMCs is crucial, because it is part of the assembly line that leads to the creation of final chemical products**. But, we still don't know much about how flavoproteins work in BMCs."

In the study, Jeff zoomed in on one BMC flavoprotein, which his group named Fld1C.

They were able to characterize it, revealing its structure, describing its physical features, and confirming its ability to take part in electron transfer reactions.

"With help from scientists at **Argonne National Laboratory**, we generated an agent that can pass an electron on to a willing acceptor. We successfully showed our Fld1C flavoprotein accepting an electron from that agent."

"Understanding these logistics – how electrons flow in and out of BMCs – is vital to building and controlling synthetic BMCs for custom applications."

Such applications could include **producing industrial materials like rubber or petroleum, without relying on fossil fuels**.

Or we could build medical tools that disarm BMCs in "bad" bacteria – like Salmonella – and prevent them from wreaking their havoc.

Banner image: Ships help handle the complex logistics to deliver products to consumers. Future artificial nanofactories will also need a chain of logistical "nano" vehicles to deliver products. By **Max Pixel**/CC0 Public Domain. This work was primarily funded by the **US Department of Energy, Office of Basic Energy Sciences**. The authors would also like to thank **Dr. Michaela TerAvest** for helping characterize the flavoprotein redox properties and the **Argonne National Laboratory** for help with confirming electron transfer reactions.

Sheng Yang He and Gregg Howe named 2017 Highly Cited Researchers

11/16/17

Igor Houwat

For the third year in a row, **Sheng Yang He** and **Gregg Howe** have been named Highly Cited Researchers by Clarivate Analytics (formerly done by Thomson Reuters).

According to Clarivate Analytics, this distinction is for, "research that ranks among the top 1% most cited works in [their] fields and during [their] year of publication, earning the mark of exceptional impact... for [their] dedication and focus to expanding the sphere of human knowledge."

Dr. Howe's research focuses on how plants protect themselves from pests and herbivores, while Dr. He's focus is on plant defense against pathogens.

This acknowledgement continues a good year for both researchers.

Dr. Howe was recently named University Distinguished Professor, while Dr. He was re-appointed a Howard Hughes Medical Institute investigator earlier this year.

Banner image of Arabidopsis thaliana by **Dawid Skalec** [**CC BY-SA 4.0**], via Wikimedia Commons.

Fighting plant disease at warm temperatures keeps food on the table [VIDEO]

11/27/17

Igor Houwat, Bethany Huot

https://youtu.be/iLfo-FrKD5s

- The study, published in Nature Communications, shows how high temperature weakens plant defenses while, separately, strengthening bacterial attacks.
  By MSU-DOE Plant Research Laboratory.

Plant disease is one of the most important causes of crop loss worldwide, and pathogenic bacteria and unfavorable climate are two major culprits.

Sometimes, climate and bacteria come together, with devastating consequences.

One of the best historical examples of this is the Irish Potato Famine. Beginning in 1845, Ireland experienced the “perfect storm” of unusually cool, damp weather that provided prime growing conditions for an exotic pathogen that destroyed the potato crop. With their primary food source ravaged by disease, a million Irish people died from the ensuing famine.

On the other end of the thermometer, warmer temperatures also can cause extensive crop loss.

Bethany Huot, a post-doc in the **He lab**, now shows how **hot weather weakens plant defenses and, separately, strengthens bacterial virulence.** The study is published in **Nature Communications**.

For more, **check out the video above** or **read the original story on MSU Today**.

How plants 'muscle up' as they prep for the cold

12/7/17

Igor Houwat, Yong Sig Kim

Plants, like humans, do not like very hot or cold weather. Temperature extremes are a major factor that determines where plants grow and that can limit agricultural production.

For example, **according to the EPA**, in 2010 and 2012, high nighttime temperatures affected corn yields across the U.S. Corn Belt, and premature budding due to a warm winter caused $220 million in losses of Michigan cherries in 2012.

Since plants cannot move when the weather gets unbearable, they have evolved fascinating molecular strategies to survive.

The **Thomashow lab** at the MSU-DOE Plant Research Laboratory specifically focuses on how plants handle cold weather.

In their latest study, published in the journal ***The Plant Cell***, they further our understanding on how a **plant protein, called CAMTA, helps plants fortify themselves as they anticipate long periods of cold**, like, say, three to four months of winter in the American Midwest or Northern Europe.

The long-term goal behind the research is to **breed or create plants with higher tolerance to wild swings in temperature**, which would improve crop yield for food and bioenergy purposes.

Intersection of cold protection and bacteria defense systems

*Figure 1 By **Lum3n.com**/Public Domain.*

Yong Sig Kim, a post-doc in the Thomashow lab, says, “CAMTA proteins are universally found across plants, and they help turn on genes that impart freezing tolerance to these plants.”

In the new study, the scientists show that **CAMTA proteins also control how plants defend against harmful bacteria, when it gets cold**.

Under long-term cold conditions, plants build up high levels of salicylic acid (SA), a compound that protects against bacteria, even if the plants aren’t under attack.

“At warm temperatures, however, CAMTA proteins block the system that produces SA. When it gets cold, long enough, an unknown signal is generated that modifies CAMTA to allow SA production to turn on.”

The scientists identified **the N-terminus, the start of CAMTA proteins, as responsible for stopping SA production**, under warm conditions.

In the cold, the **C-terminus, the end portion, detects a signal, possibly a rise in cellular calcium levels, that enables SA to be produced**.

This observation reverses current accepted models, which proposed instead that the C-terminus blocked SA production.

Why muscle up in the cold?

But how does temperature tolerance relate with defense against bacteria, in the first place?

“That is a very intriguing question. SA doesn’t protect the plant from the cold, per se. Instead, we think the plants enhance their immune systems in the cold as a general preemptive strategy.”

This is the idea: **Although plants take measures to survive the cold, they still get injured**, and their structures are destabilized, which makes them more vulnerable to bacterial infection.

So, **weakened plants keep their guard up as a precaution**, rather than waiting for an attack before activating their defenses, the latter which could be too little, too late.

It’s like how we humans take preventative measures to stay healthy: eat well, sleep eight hours, hydrate, etc. Slack off on some steps, and we likely get the sniffles.

Yong Sig concludes, “We have delved further into CAMTA and provided more evidence for its activity. Plant defense science is gradually revealing how protection mechanisms against the elements and against other living beings are seemingly interrelated.”

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*Banner Image by **Pixabay**/Public Domain.*

MSU 2017 team wins silver medal at synthetic biology competition

12/11/17

Bjoern Hamberger, Igor Houwat

Figure 1 Banner image: a packed hall in Boston for an iGEM presentation, by iGEM Foundation and Justin Knight, CC BY 2.0 .

The International Genetically Engineered Machines (iGEM) competition:

- **Brings together students** from around the world to design biological solutions for some of humanity's toughest problems.
- **Over the summer, iGEM teams design and build genetically engineered systems** in fields including health and medicine, manufacturing and bioenergy.
- The teams **also contribute to the synthetic biology community** by adding new parts to the growing 'Registry of Standard Biological Parts,' a physical and digital library of DNA sequences with well characterized functions.

MSU's second-ever iGEM team just came back from Boston **with a Silver Medal from the iGEM global competition.**

The team was made up of seven students from Chemical Engineering, Biochemistry and Molecular Biology, and Animal Science, ranging from a graduating senior to a high school student about to enter MSU this January.

Motivated by the Flint water crisis, the group set out to **develop new technology for water testing: a biosensor for detecting dangerous contaminants in the environment.**

Based on this unique ability to find 'clues' in the water, the **project was dubbed 'Shewlock Holmes,'** a nod to the microbe the students worked with, a bacterium called *Shewanella oneidensis*.

Shewenella is rare among microbes in its ability to transport electrons across its membranes. **The team hijacked the transport system so it only turns on in the presence of a chosen contaminant.** That way, it works like a smoke or carbon monoxide detector.

After successfully showing that the genetically engineered 'Shewlock' could detect and report hydrogen peroxide, the team then aimed to make the measurement system smaller, more affordable, and sensitive to a broader range of contaminants.

Bjoern Hamberger, one of the project mentors says, **"The students built a sensor toolbox of 9 modules, each that senses a different contaminant.** The modules can be exchanged like Lego bricks, so Shewenella is customized for different detection purposes."

Figure 2 The Shewlock Holmes team, from left to right: Ciara Fromwiller, Serenity Tyll, Cody Madsen, Michaela TerAvest, Danny Ducat, Noelia Bravo, Brian Amburn, Donna Liebelt (advisor). Not included: Bjoern Hamberger, Tim Whitehead. By Shewlock Homes.

The Shewlock Holmes **team also tested their project for public safety**, an important part of iGEM's 'human practices.'

A big public concern is the possible release of biotechnologically engineered organisms into the environment. The team found that **“Shewlock” could be completely inactivated by a simple drying procedure**, without needing any special equipment.

Another iGEM ‘human practice’ includes **educating kids and college students about synthetic biology**.

The MSU team shared their project at the Michigan Science Center in Detroit, and also joined the MSU Women in Engineering Summer Camp. Additionally, they organized and hosted the 2017 upper Midwest iGEM meetup at MSU, inviting other teams in the region for a day of presentations, commiseration, and fun.

Keep your eyes open: **recruiting for the fully funded spots on the 2018 team begins January!** Last year, MSU’s first ever team **got bronze**. Second year: silver. Will third be gold?!

This year's professor mentors were: **Michaela TerAvest**, **Tim Whitehead**, **Danny Ducat**, and **Bjoern Hamberger**.

Bethany Huot wins 2017 Kende award

12/12/17

Igor Houwat

Bethany Huot is the recipient of the **2017 Kende Award**, which **recognizes the best doctoral dissertation in the plant sciences at MSU from the previous two years**.

In addition to a monetary award, Bethany presented a seminar on her research on December 11. She recently **published an article in *Nature Communications*** showing how **hot temperature simultaneously weakens plant immune systems and strengthens pathogenic bacteria**. The result is a double dose of danger to plants (**see video here**).

Bethany says, “One of the highlights at the PRL was the 2015 Golden Anniversary celebration. A key message I took away from listening to founding PRL members is that great explorers are most productive when given a vibrant, collaborative community in which they can thrive rather than merely survive.”

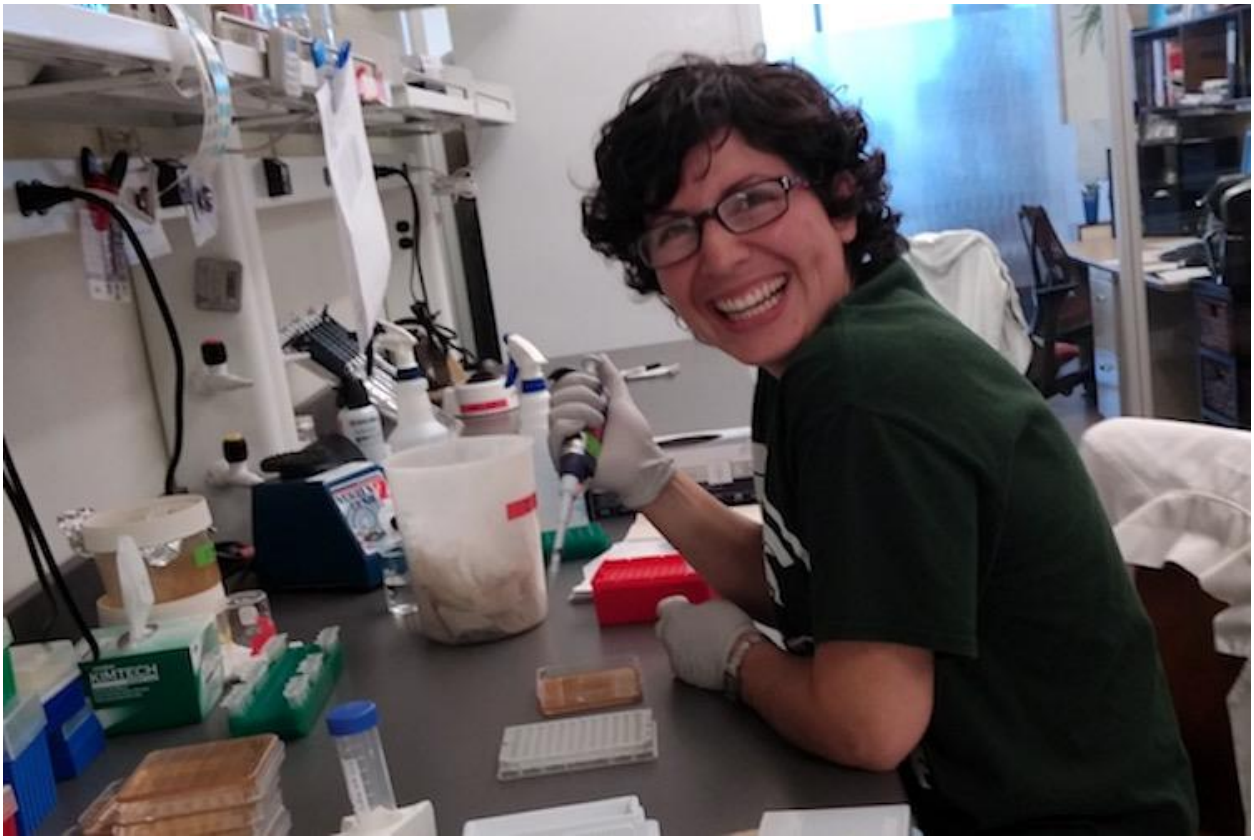

Figure 1 Bethany Huot at the bench. By Brian St. Aubin.

“Dr. Natasha Raikhel, a former PI, emphasized that it takes a lot of effort and leaders with commitment and vision to both establish and maintain such an environment."

"I think the collective contribution to plant science made by the PRL for over 50 years shows that the effort is well worth it. I am grateful to have been part of this community."

"... Great explorers are most productive when given a vibrant, collaborative community in which they can thrive rather than merely survive."

Sheng Yang He, Bethany's mentor, says, "It was a uniquely rewarding and memorable experience to be Bethany's mentor, along with Beronda Montgomery. Smart, articulate, and with a shining personality, Bethany is in a league of her own. Her dissertation was beautifully done, and results will likely have long-lasting impact on plant resilience research.

Bethany obtained a B.S. in biology from Western Michigan University Lee Honors College before coming to MSU, where she got a PhD in Cell & Molecular Biology while working in the **Montgomery** and **He** labs.

What's next for Bethany?

"My two passions are community-building as a means of enhancing scientist development and productivity, and plant science research tackling major obstacles to address global food insecurity. Ultimately, I would like to have a position from which I can do both."

Growing a garden in space

12/19/17

Igor Houwat, Evan Angelos

Figure 1 Banner Image by NASA, Public Domain

The public buzz is building as technological advances get us closer to sending man to Mars – and sometime in the future, to colonizing it. But how do we survive, once we get there?

To answer that, scientists are working through a laundry list of problems, not least of which: **how to grow fresh produce on Mars, or anywhere else in that Great Beyond**.

It's already hard enough to grow crops on Earth. And in space, plants face zero gravity, radiation, super cold temperatures, and unusual light intensities.

One way to figure this out is to grow plants on a space station and see how they manage. That is exactly what the **Brandizzi lab, alongside NASA, are doing**. The lab recently sent seeds from different genetic backgrounds to space, **grew them in microgravity for two weeks**, and just got them back for testing.

Testing plants for gravity stress

Evan Angelos, a grad student in the Brandizzi lab, says “Our lab studies a plant response to environmental stresses called the unfolded protein response – UPR for short.”

Here’s the UPR in a nutshell: On Earth, when surroundings are hostile to plants – say too much heat – they produce defective bookmark iconproteins, which causes those plants to become sick, and in some extreme cases, to die. **The UPR kicks in as an emergency stopgap telling the plant to stop making bad proteins and to resume making good ones.**

In space, it seems the UPR has a role to play.

“We previously found evidence which indicates that under altered gravity conditions, the UPR is activated, **meaning there might be some stress response involved in adaptation to different types of gravity situations**,” Evan says.

This past August, Evan flew to the Kennedy Space Center to prepare the plants for launch on a Dragon Capsule (**see launch video**). In space, resident astronauts moved the plants to the International Space Station and grew them for 14 days.

Then they froze and stored the plants on a capsule which was sent back to Earth, crashing into the Pacific Ocean. After being picked up by boat and shipped to the Kennedy Space Center, the plants have made their way back to Evan’s lab.

Figure 2 Evan Angelos on the lab bench. By Brandizzi lab

“They have been perfectly preserved. Now, **we’re going to compare the space plants with other plants, from the same backgrounds, which have grown in the same hardware down on Earth at the Kennedy Space Center**.”

Specifically, Evan and the team will examine how the plants' genetic responses are impacted by the stresses of space life.

Even to the naked eye, it is clear which plants are from space and which from Earth. "The space plants are snaking through the growth media because they obviously had no clear direction on where to grow in that environment, while the Earth plants were perfectly upright, as expected."

He adds, "After growing and researching thousands of plants, it's very exciting to experience something which is clearly out of this world." And out of this world plants will accompany us, if we are to make that trip to Mars.

First, let's make sure they won't mind the ride.