2013

ANNUAL REPORT

INNOVATION

INVESTMENT

INSPIRATION

BTI

MISSION

To advance and communicate scientific knowledge in plant biology to improve agriculture, protect the environment, and enhance human health.

VISION

The Boyce Thompson Institute will be known internationally for research excellence in plant biology and for discoveries that benefit society.

INNOVATION

INVESTMENT

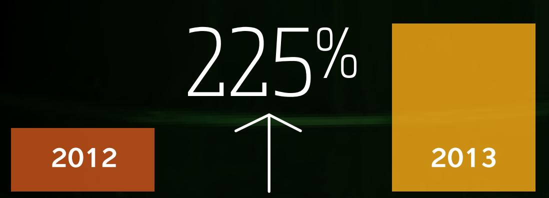
INSPIRATION

INSIDE BTI

"I want to do something to get to the bottom of the phenomena of life processes and I think a good place to study them would be in the realm of plants."

William Boyce Thompson

FINANCIAL SPOTLIGHT



$602,515 — $1,354,796

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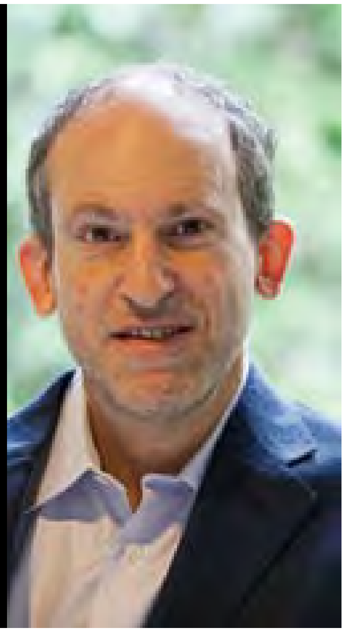
"Agriculture, food supply, & social justice are linked."
William Boyce Thompson



This year, we want to take you beyond the press releases and beyond the scholarly publications to an exploration of how our Institute holds itself accountable to the great faith our supporters place in plant research to address the Grand Challenges of the 21st century. We've asked ourselves, how do the three I's identified as the theme of this year's Annual Report — Innovation, Investment and Inspiration — accomplish BTI's mission of advancing and communicating scientific knowledge in plant biology for the purpose of improving agriculture, protecting the environment, and enhancing human health? **Innovation** leads to new discoveries, which in turn **inspire** individual careers, and ideas for problem solving. When those ideas are implemented, or when those individuals in turn inspire others, the return on **investment** is realized.

RESEARCH: RETURN ON INNOVATION

While BTI research is diverse and extended through global connections, the whole of plant science consists of an extremely broad array of disciplines ranging from ecology to molecular biology, agricultural sciences, energy sciences, and computational biology. One of the most significant external activities of the President's office this year has been helping to achieve a consensus among many of these voices as to the most promising research directions for the coming decade. A document entitled *Unleashing a Decade of Innovation in Plant Science: A Vision for 2015-2025,* was broadly disseminated in July 2013, and has been used to inspire and educate granting agencies, policymakers, and academic leaders. The "Decadal Vision" serves as a scientific road map to strengthen our ability to understand, predict, and alter plant behavior to meet the planet's food, energy, and environmental demands in the face of climate change and a burgeoning population.

The Decadal Vision takes the view that while we should continue to delve deeply into the intricacies of the relatively well-studied agricultural and model plant species, nature has created a tremendous diversity whose potential is virtually untapped. Earth hosts some 400,000 plant species: through the ages, some 7,000 have been consumed as food and perhaps 20,000 used in some therapeutic context. Plants, in some capacity, have learned to thrive in virtually all environments on planet Earth, and are the foundation for all life. These chemical wizards have created as many as 500,000 unique compounds, the vast majority of whose biological role and therapeutic potential is unknown.

Despite there being so much yet to learn, however, researchers face a great challenge even in interpreting existing information about plants. New technologies have led to a torrent of new data — a force that threatens to become a flood in the absence of adequate tools and strategies for managing large storehouses of information. The Decadal Vision thus points to computational biology as a critical frontier, both in its ability to derive meaning from Big Data, but also in developing better connections between biologists and programmers. Such connections will mitigate the ever-increasing reliance on technological devices, where the end user too often cannot critically evaluate the information provided.

IMPACT: RETURN ON INVESTMENT

History reminds us that the returns on investing in research are profound. From the Green Revolution to landing on the Moon, from completing the human genome sequence to the happenstance discovery of penicillin, the most far-reaching impacts on society can inevitably be traced back to scientific voyages into uncharted waters. The Decadal Vision reminds its readers that discoveries made in plant research can help address our greatest global challenges. The flat federal investment in research has taken a great toll on innovation: jobs have been lost, laboratories closed, and programs shuttered. BTI is extremely fortunate in that during such a difficult time, our faculty has remained competitive for funding and that we continue to garner support from our endowment developed through the generosity of private donors. Still, the missed opportunities are many, and the seeds we fail to plant today will create a dearth of innovation in the years and decades to come.

In the end, however, it's not how far we reach, but how far that reach carries us, that proves the measure of an organization. Meeting 21st century challenges will demand that our plant scientists put their best skills to work, and are given the space, support, and technologies to innovate. In the pages that follow, we describe some of the fruits of our labor in 2013, and how it connects both within the scientific community and to the populace at large. The return is, we feel, inspiring.

EDUCATION: RETURN ON INSPIRATION

A much-discussed component of the Decadal Vision is its call to reimagine graduate training in the plant sciences. A particularly telling statistic is that five years after receiving a Ph.D. in the United States, only about one of six recipients has a traditional tenure-track faculty position. Though some of the other five may still be seeking such a position, many of them are gainfully employed in industry, law, venture capital, journalism, teaching, advocacy, or government service. Because of these many career options and the prognosis that academic jobs will remain in short supply, the Decadal Vision argues that doctoral candidates should be supplied with the multiple skills required for scientific success in the Digital Age. Indeed, both NIH and NSF have very recently rolled out programs that recognize and attempt to mitigate this problem. One mechanism by which BTI is working to fill the skills gap is through its Postgraduate Society, which encourages graduate students and post-doctoral fellows to learn about alternative career paths, teach community college courses, create communications for public dissemination, and assist with social media. Many BTI postgraduates also learn mentoring skills through participation in the various activities of BTI's Center for Plant Science Teaching and Learning.

> Plants, in some capacity, have learned to thrive in virtually all environments on planet Earth, and are the foundation of all life.

Sincerely,

David B. Stern, Ph.D.
President & CEO

CHAIRMAN'S LETTER

For 90 years, BTI scientists have been world leaders in plant science research and education. The range of our faculty's expertise in examining basic plant function spans all aspects of plant research, including epigenetics, computational biology, chemical biology, plant disease, and nutrition. Over the years, BTI research has led to significant discoveries in basic biology, agriculture, the environment and human health — like our role in the development of the cervical cancer vaccine, Cervarix©. And now, as we look forward to the next ten years, we see exceptional and exciting opportunities. There is so much yet to be learned, and there are so many questions yet to be answered.

But why does plant science matter? What is in it for those of us who are not scientists? Plants and plant products support all life on Earth and literally sustain human existence. As we are confronted with a growing global population, increasing environmental uncertainty due to climate change, and a need for more progressive medicines, solutions are waiting to be found in plants. Together with our great colleagues and partners at Cornell University, BTI is preparing to initiate an extraordinary new effort to lead plant sciences through the next century, by directing the plant research community towards universal goals.

Declining federal support for basic science research has led to more competition and less funding for academic research. Although this trend has been going on for several years, President David Stern and his leadership team anticipated the change and were able to minimize stagnation through evaluation and proper planning. However, we must ask, did beneficial, life-altering discoveries remain hidden due to constrained financial resources? Were great student minds unable to participate fully in the research process due to lack of funding? We hope not.

In a financial climate such as this, private donations to BTI are more and more crucial to our success. For example, in 2013 private donations helped two bioinformatics laboratories start new projects and allowed four high school students to participate in a competitive summer internship program. These contributions—from individuals and organizations that believe in our work—had a very tangible impact on our research and education programs.

> In a financial climate such as this, private donations to BTI are more and more crucial to our success.

BTI has no student body from which to draw tuition. We rely upon government grants, our endowment, and the generosity of private gifts to further our work. As you read through our 2013 Annual Report, I hope you are moved to support BTI. Join our prestigious researchers and educators as we make significant contributions in plant science, look to cultivate new minds, and serve as a constant supply of plant science knowledge — all imperative for facing society's daunting global challenges.

Ezra Cornell
Boyce Thompson Institute
Board Chairman

A Message from Dr. Karen Kindle, Vice President for Research

Basic research — research with a primary goal of understanding the fundamental workings of living things — is BTI's primary focus, driven by the curiosity and passion of BTI scientists. Innovation occurs when a scientist envisions how a basic research discovery might be used to solve a practical problem. Connecting discoveries to innovation is at the heart of BTI's mission.

Plant research discoveries have the potential to address some of the most important problems facing our world and its growing population: food and energy security, environmental degradation, and an increased incidence of infectious as well as metabolic diseases. The Bill and Melinda Gates Foundation (BMGF) has committed more than $2 billion to fund agricultural research focusing on problems faced by small holder farmers. One such project, in Associate Professor Zhangjun Fei's laboratory at BTI, is funded by a joint BMGF-National Science Foundation grant and will analyze DNA sequence information to identify viruses that infect sweet potatoes in Africa.

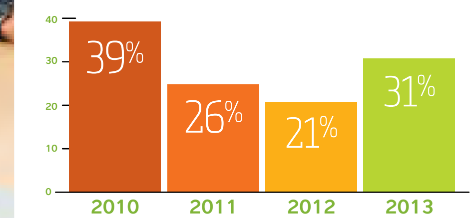
> "Support from foundations and industry diversify our sources of funding, also encouraging faculty to carry out the kind of experiments that lead to innovations."

2013 has been a productive year for basic research at BTI, with more than 80 peer-reviewed research papers published in scientific journals. Some of these research findings have potential practical benefits, as well. For example, William H. Crocker Scientist and Professor Maria Harrison's group published a paper about a protein that regulates the association of phosphate-scavenging fungi with their legume hosts. Phosphate is likely to become a limiting resource in the future, and understanding this plant-fungus interaction may suggest approaches to help plants take up phosphate more efficiently. Another discovery has potential pharmaceutical applications. Associate Professor Frank Schroeder's laboratory has identified small molecules from nematode worms that help worms resist stress and live longer. The pathway affected is conserved in evolution, suggesting the possibility that similar molecules could extend human lives. These and other 2013 discoveries are described in greater detail elsewhere in this report (see Research Highlights on page 10).

Another measure of the quality of our basic research programs is the success of BTI faculty in competing for federal grant funds, even in the context of very tight budgets at federal granting agencies. So far, 12

BTI Professor Dr. Daniel Klessig and Professor Emeriti Dr. Robert Granados talk to Director of Technology Transfer Paul Debbie about some potential research applications in BTI's consultation space.

FUNDED PROPOSAL SPOTLIGHT



PERCENT OF PROPOSALS FUNDED

grants have been awarded or recommended for funding in 2013, compared to 8 in 2012 and 11 in 2011. Some applications are still pending. We anticipate that research funding will continue to be competitive in 2014 and are constantly on the lookout for new funding opportunities.

One such opportunity is foundations and companies that take basic research discoveries and test their potential to solve a problem in the field or become a product. Prior to becoming VP for Research, I worked with BTI's technology transfer group to reach out to agricultural companies and market our technology. These connections, some from my years of working in the industry, have led to several collaborations and consulting opportunities for our scientists.

At the same time, BTI scientists are showing increased interest in developing applications for their basic research and soliciting support from non-federal funding sources. For example, BTI Assistant Professor and USDA scientist Michelle Cilia has initiated a project funded by the California Citrus Research Board to study citrus greening disease, a severe threat to orange production in all citrus growing regions of the world, including Florida and California. The Atkinson Center for a Sustainable Future at Cornell University is funding a joint project between BTI Associate Professor Frank Schroeder and Alfred H. Caspary Professor of Immunology Judith Appleton at the Baker Institute (Cornell). They are investigating the efficacy of small molecules discovered in nematodes as vaccines against veterinary nematode pathogens.

Not only does support from foundations and industry diversify our sources of funding, but it also encourages faculty to carry out the kind of experiments that lead to innovations and provides training for students who choose to pursue careers as entrepreneurs or in industry.

BIOGENIC: produced or brought about by living organisms

Lessons from Worms: How to Reduce Stress and Live Longer

While biological research often focuses on the role of relatively large macromolecules, including DNA and proteins, BTI researchers from the Schroeder laboratory study the structures and biological functions of biogenic "small molecules" (BSMs), which are roughly 100 times smaller than a typical protein. BSMs play important roles in many biological processes, so identifying them and studying their interactions with other biomolecules is important. In 2013, the Schroeder laboratory extended their findings about a specific family of these chemicals — called ascarosides — that are synthesized by tiny roundworms, and affect various aspects of their development and behavioral responses.

Normally, the adult life cycle for these worms, called nematodes, lasts about two weeks. However, these recent findings suggest that the worms may live longer when they are exposed to ascarosides. The study, "Pheromone sensing regulates *Caenorhabditis elegans* lifespan and stress resistance via the deacetylase SIR-2.1," was published online in the Proceedings of the National Academy of Sciences USA in March 2013. Since humans have a very similar pathway that is also involved in aging, these molecules could be active in humans. The paper was co-authored by Andreas Ludewig, BTI postdoctoral scientist; Yevgeniy Izrayelit, Cornell doctoral student; and Frank Schroeder, BTI faculty member and project leader.

"It seems that the ascarosides offer stress-resistance mechanisms that ultimately slow aging, a process that could lead to a better understanding of human aging and how it may be delayed."
– Dr. Frank Schroeder, BTI Associate Professor

Postdoctoral scientist Dr. Daniela Floss and BTI William H. Crocker Professor Dr. Maria Harrison reviewing images in BTI's Plant Cell Imaging Center.

DELLA proteins promote beneficial root-fungus interactions

BTI William H. Crocker Professor Dr. Maria Harrison and her research team study a beneficial fungus that forms a close symbiotic relationship with plant roots. This fungus is effective at helping plants thrive in nutrient-poor conditions, especially when phosphate is limiting. A better understanding of the association could reduce the high levels of synthetic fertilizers currently used in agriculture. This fungal-plant interaction is referred to as arbuscular mycorrhizal (AM) symbiosis. During the symbiosis, the fungus develops highly branched tree-like structures, called arbuscules, in the plant's root cells. These structures are key to the symbiosis as the fungus transfers phosphate from the soil into plant cells through the arbuscules. In exchange, the plant feeds the fungus with sugars.

The team's research in 2013 sheds light on the role of DELLA proteins in this symbiosis. DELLA proteins perceive and are inactivated by plant hormones called gibberellins, which stimulate plant growth. When a plant is phosphate-starved, DELLA proteins become more abundant, which inhibits plant growth. However, at the same time, DELLA proteins stimulate arbuscule formation, which promotes nutrient acquisition, promoting plant growth. The Harrison's laboratory discovery thus indicates that plant hormone regulation and AM symbiosis are intimately connected. Maria Harrison explains, "Once arbuscules have formed, phosphate can be delivered through the symbiosis, and the plant will grow. A feedback loop, involving gibberellin levels, ensures that the system remains balanced."

"These findings also have potentially interesting implications for agriculture," commented Daniela Floss, a postdoctoral scientist in Dr. Harrison's laboratory and a first author of the paper. "...many of the Green Revolution wheat varieties contain dominant mutant DELLA proteins, which not only promote plant growth but also enhance the beneficial fungi in the soil."

Martin laboratory looks into cell death

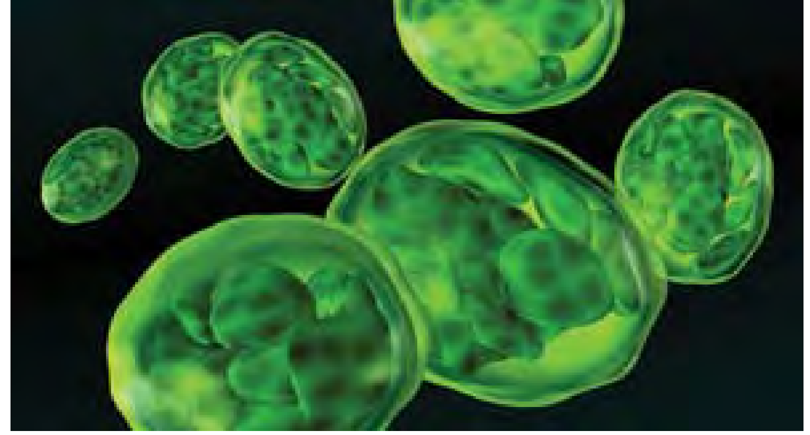
Researchers in BTI's Martin laboratory combined efforts with scientists from Kyung Hee University and Seoul National University to investigate a cascade of plant protein activation underlying a crucial plant immune response known as programmed cell death. Programmed cell death fights off bacterial pathogens by killing portions of the plant tissue that become infected. Because this natural defense mechanism alone is not enough to prevent pathogen damage, farmers still suffer from crop losses, even with the help of other disease control methods. By piecing together the molecular components of the cell death process, researchers in the Martin laboratory are making valuable contributions to the growing body of knowledge of these functions. This working knowledge could help in the development of disease resistant crops or other tools for farmers to limit loss. Results included the discovery of two amino acids that are required for a specific protein to carry out its role in the cell death process. The full study is available in the May 2013 issue of FEBS Letters.

Boyce Schulze Downey Professor Dr. Gregory Martin and postdoctoral scientist Dr. Sarah Hind touch base with Paul Debbie during their weekly laboratory meeting.

Researchers find small molecules that affect insect resistance in Maize

An international collaboration of plant scientists, led by BTI postdoctoral scientist Lisa Meihls in Georg Jander's laboratory, gained new insights into plant defense. Specifically, the researchers uncovered a biochemical pathway underlying the maize defense response to the corn leaf aphid *Rhopalosiphum maidis*, a harmful sap-sucking insect. A close look at the collection of small molecules (metabolites) in different strains of maize showed that a particular compound, a benzoxazinoid, is central to defense against the aphid. Further, this study revealed an intriguing trade-off in plant defense. At any time, maize can be resistant either to aphids or another harmful pest, caterpillars, but not both. The team also identified the gene responsible for controlling the production of the defense compounds.

This biochemical and genetic information could enable breeders to cultivate more resilient crops, an objective that is ever more critical as the growing world population puts pressure on agriculture production. The study was published in The Plant Cell in the June 2013 issue. After finishing her postdoctoral appointment at BTI, Lisa went on to work as a Research Entomologist as the USDA-ARS in Columbia, Missouri. The research project at BTI is being continued in the Jander laboratory by postdoctoral scientist Vered Tzin.



Chloroplasts act as cellular sentinels of light stress

All cells within a given plant contain the same genes. Roots, leaves, and flowers look different because different genes are active, or 'expressed' in different tissues. Gene expression also changes with plant age and in response to environmental cues, such as water availability and light intensity.

Though most genes reside in the nucleus, energy-generating organelles (mitochondria and chloroplasts) also contain DNA. Mitochondria and chloroplasts are assembled from proteins encoded in the nucleus as well as proteins encoded by their own DNA. It has been known for a long time that nuclear-encoded proteins regulate the expression of mitochondrial and chloroplast genes. More recently, it has been discovered that signals emanating from chloroplasts and mitochondria also control the expression of nuclear genes, a process called retrograde signaling.

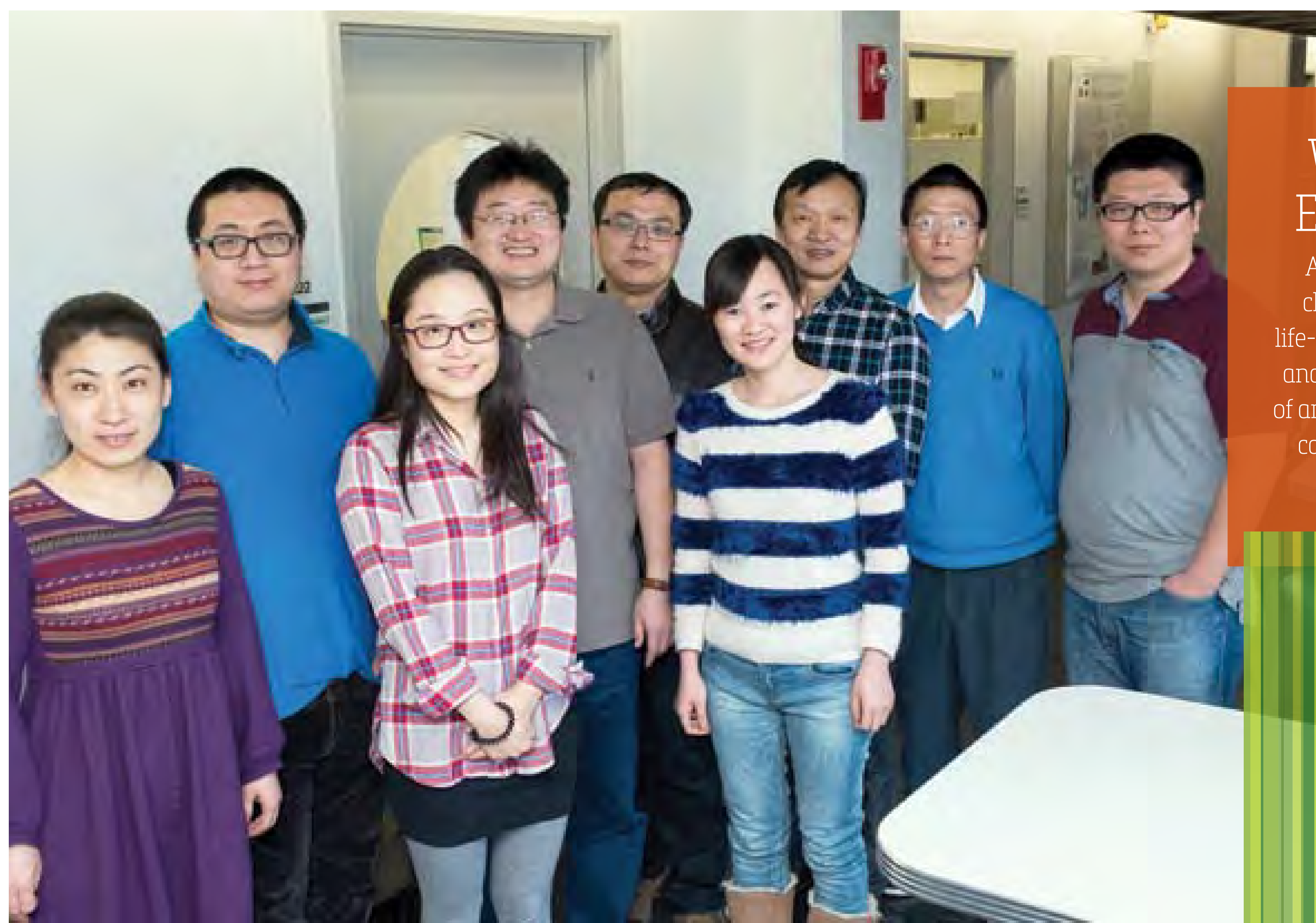
Dr. Klaus Apel's laboratory at BTI has been using Arabidopsis mutants to study retrograde signaling. High light stress causes an increase in a highly reactive derivative of oxygen, called singlet oxygen, which appears to be one chemical signal for chloroplast retrograde signaling. In a paper published in July in Photosynthesis Research, Apel and Dr. Chanhong Kim, a BTI research associate, showed that there are multiple retrograde signaling pathways. Which ones are activated depends on the developmental stage of the plants when they are subjected to conditions that cause light-induced stress.

The Giovannoni and Fei groups show that the 'second code' in the genome controls tomato fruit ripening

Work from BTI's Giovannoni and Fei laboratories provides insights into fruit development and ripening. Using tomatoes, the researchers found that changes in the pattern of a specific DNA modification, called cytosine methylation, occur throughout the genome during different stages of growth. The location of all the cytosine methylation positions in the genome is termed a 'methylome,' which is sometimes called the second genetic code on top of the nucleotide sequence. Their findings revealed over 52,000 regions in the genome where cytosine methylation significantly changed during fruit development. Additionally, the group pinpointed critical regions where this second code might regulate tomato ripening. Continued investigation of the cytosine methylation effects on DNA expression during fruit growth could greatly benefit crop improvement strategies that are currently relying on DNA sequence data alone. This work was published in January 2013 in the journal Nature Biotechnology.

WHAT IS AN EPIGENOME?

A record of the chemical changes to DNA – due to life-time activities such as diet and exposure to pollutants – of an organism; these changes can be passed down to an organism's offspring.



Members of the Fei laboratory at BTI. Dr. Zhangjun Fei and his laboratory focus on developing computational tools and resources to analyze and integrate large-scale datasets to help researchers understand how genes work together to comprise functioning cells and organisms. Because of the nature of their work, the group often collaborates with both internal and external laboratories.

Paul Debbie, BTI's Director of Technology Transfer

2013 TECHNOLOGY HIGHLIGHT

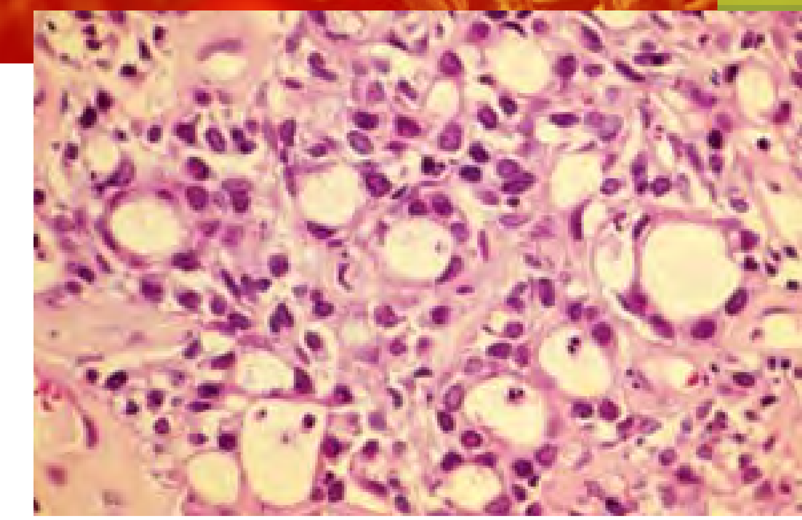
11 NEW INVENTION DISCLOSURES

6 NEW PATENT APPLICATIONS

1 NEW PATENT

TECHNOLOGY TRANSFER 2013

BTI is dedicated to making sure that our research at the Institute leads to improving agriculture, enhancing human health, protecting the environment, or a combination of the three, and this is accomplished — in large part — by our Technology Transfer Office (TTO). Director of Technology Transfer Paul Debbie works with BTI scientists, commercial partners, and humanitarian organizations to identify and protect BTI technology and to translate the Institute's scientific advances into beneficial uses for society. To that end, in 2013 BTI filed 11 new invention disclosures and 6 new patent applications. In addition, the lengthy road to patent attainment ended successfully for one BTI invention this year when the U.S. Patent and Trademarks Office issued BTI a final US patent. Two of the many exciting and ongoing projects pursued in BTI's Technology Transfer Office office in 2013 were the protection of plants from parasitic infection and disease by means of novel small molecule compounds and the discovery of new and improved cell lines for the production of proteins for pharmaceutical and therapeutic uses.



Novel small molecule compounds to protect plants from parasitic infection and plant disease

Soybean cyst nematode is a huge agricultural problem in the US and in other countries. Crop losses in the US are approaching one billion dollars per year. In an effort to stop this loss and solve other related problems in agriculture, BTI is exploring the possibility of using newly discovered compounds identified by Associate Professor Frank Schroeder's laboratory as a preventative measure or treatment for nematode infections. In collaboration with Professor Daniel Klessig's laboratory, the team has also discovered that these same compounds and similar compounds may be used to treat plants for improved immunity against many different pathogens, including those that cause devastating diseases in potato, tomato, and barley. The Institute has filed several patent applications on various aspects of this new technology.

Upper left: soybean field; Upper right: cervical cancer cells

New and improved cell lines for production of proteins for pharmaceutical and therapeutic uses

In 2009, the U.S. Food and Drug Administration approved the first ever product produced in insect cells for use in humans. The product was Cervarix©, a bivalent vaccine for the prevention of cervical cancer that is used in over 100 countries across the world. The vaccine is produced in the HighFive™ cell line, which was developed at BTI in the laboratory of Dr. Robert Granados in the late 1990s and patented by the Institute. In 2007, a problematic discovery was made that the cell line harbored a latent insect-specific virus. However, new BTI research in Professor Gary Blissard's laboratory has led to the development of a virus-free version of the HighFive™ cell line. This cell line is proving to be more effective than the original cell line in the production of proteins, as well as having the added benefit of being free of the latent insect virus. BTI has filed several patent applications on this cell line, as a result of both Professor Blissard's work and related discoveries.

BUILDING OPPORTUNITIES

The transition between a postdoctoral appointment and a principal investigator is a complex one. The role of the postdoctoral scientist is to think critically, perform research, and write scientific papers, yet principal investigators at colleges or universities are expected to join committees, advise undergraduates, identify external funding, and — of course — teach. Conventional training programs for graduate students and postdoctoral scientists often provide too little experience in administrative, teaching, writing, and mentoring skills to make this transition seamless. BTI is fortunate to have a Post Graduate Society (PGS) that enables its postdoctoral scientists and graduate students to share their research, develop skills in writing, teaching, and mentoring and network with other researchers through PGS-sponsored events and activities that promote career development.

Hands-on experience in the labs, sustained mentorship, and training in scientific communication, contribute to the success in the STEM field for these students.

Above: Cornell University graduate student Natalie Henkhaus — who studies with BTI Professor Dr. Eric Richards — teaching the 2013 *Expand Your Horizons* program at BTI in May 2013. Below: Research Associate Amber Hotto working with President David Stern. Amber taught the TC3 Introductory Biology class in 2013.

Collaboration with a local community college

Over the past 5 years, BTI has worked with Tompkins Cortland Community College (TC3) to offer Biology 101, an introductory biology course, every semester. The class, taught by BTI research associates and postdoctoral scientists, is geared towards students not majoring in biology and includes a two-hour lecture and a two-hour laboratory per week.

Teaching an entire class, while already committed to 40+ hour work week, can seem overwhelming to many scientists. To ease the situation, PGS members are permitted to host classes at BTI, presenting classes in BTI conference rooms and in the Helen and Georg Kohut teaching laboratory. In addition, they may teach classes alone or in collaboration with other PGS members. Previous course instructors act as mentors and share teaching materials. The opportunity to teach in a formal classroom setting enhances the postdoctoral scientist's repertoire of skills in teaching, presentation, and peer collaboration — all essential for success as a principal investigator.

Dr. Susan Strickler teaching a Plant Bioinformatics course open to BTI and Cornell University researchers.

Committed to professional development in the sciences

Interdisciplinary skills are not only valued, but necessary to function in today's cutting-edge research environment. The knowledge of technologies, algorithms, databases, and computational tools to manipulate, process, and analyze biological data are one such skill set for biologists. Graduate programs in biology typically are designed to train students in a specialized research topic to develop expertise. Researchers from the Mueller laboratory host an annual BTI Plant Bioinformatics course that is open to all BTI scientists and students. The course is designed to teach scientists about the latest developments in high-throughput methods including next-generation sequencing and processing tools. Each class includes a lecture and extensive hands-on exercises that cover the entire processing pipeline from raw experimental data to validated analysis results. The course is very popular and has enabled a number of junior as well as established scientists to explore new experimental avenues to answer their research questions. Moreover, this course creates a platform for specialists from different areas, namely molecular and computational biology, to interact with each other and pursue collaborative research at BTI.

Left to right: Postdoctoral scientist Marina Pumbo from the Martin laboratory working with 2013 REU Intern Tesia Posekany; Director of Education and Outreach Tiffany Fleming talking to science educators about BTI teacher development programs.

EDUCATION AND OUTREACH

2010 – 2013 INTERN ALUMNI HIGHLIGHTS

110 Prizes, grants, or other recognition for their research

56 Presentations at professional meetings such as Society for the Advancement of Chicanos and Native Americans in Science and the American Society of Plant Biologists

37 Co-authored publications

To further enrich our research environment and help prepare the next generation of scientist, BTI offers a nationally recognized education program for teachers as well as undergraduate and high school students, which uses and develops the mentoring skills of our graduate and postdoctoral scientific staff. In this highly competitive program, students and teachers from across the country spend several weeks at BTI each summer, learning laboratory skills in plant research that can bridge into the classroom and future careers. The programming includes six-week internships for local high school students who are introduced to experimental science. 2013 marked the end of a three-year cycle for the National Science Foundation's Research Experience for Undergraduates (REU) program at BTI (which has been renewed for five additional years beginning in 2014).

Recent Intern Alumni Moving Forward

Valeria Mijares, a 2013 REU intern in Georg Jander's laboratory has published the results of her summer research "Near-isogenic lines for measuring phenotypic effects of DIMBOA-Glc methyltransferase activity in maize" in the journal Plant Signaling and Behavior. Associate Professor Georg Jander and postdoctoral scientists Lisa Miehls and Vered Tzin were co-authors.

2013 Cornell University student Valeria Mijares working with postdoctoral scientist Vered Tzin from the Jander laboratory during her 2013 internship.

100 Middle and High School Students Conduct Epigenetics Research

In 2013, Professor Dr. Eric Richards, Education and Outreach staff and partner teachers launched a new classroom-based research project on epigenetics with middle and high schools students in New York and Connecticut. In July, partner teachers received educational training, curriculum development support, and materials to lead epigenetics experiments in their classrooms. To date nearly 100 students have participated in the project and discovered how epigenetics is involved in gene regulation in *Arabidopsis thaliana* and other organisms like mice and humans.

Above: Bioenergy and Bioproducts Education Teaching Partners Workshop. Right: 2013 high school interns Felix Fernandez-Penney and Sierra Denesevich working in the BTI greenhouses.

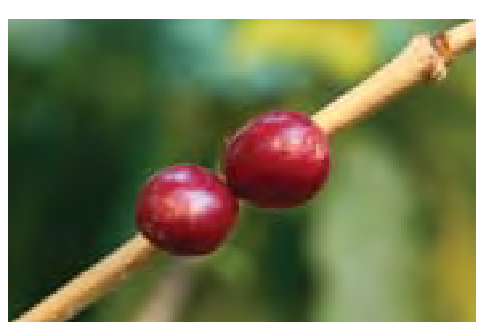
"This was a very different experience, as most of my research has been extensively focused on field work and modeling. Having never stepped into a laboratory setting, this internship has given me a tremendous amount of insight of what exactly goes on inside the lab. Agriculture and plant research go hand in hand, and it is simply amazing how much research goes behind the crops that will feed this country."

Valeria Mijares (2013 BTI Summer Intern and Cornell University Student)

In 2013 BTI held two public events with over 300 participants: **From Root to Branch: The Reach of BTI Research** and **From Gene to Bean to Global Scene.** These programs have been worthwhile outreach efforts effective in connecting BTI research to societal impact.

From Root to Branch: The Reach of BTI Research explored the work of four project leaders: Professor James Giovannoni, Associate Professor Georg Jander, President David Stern, and Professor Eric Richards. Dr. Karen Kindle spoke about the potential and tangible utility of new technologies devised from recent Institute research projects. Over 120 patrons attended the event.

From Gene to Bean to Global Scene highlighted the work of Assistant Professor Lukas Mueller and postdoctoral scientists Suzy Strickler in mapping out the *Coffea arabica* coffee species in the context of a broader discussion of coffee research: from tasting to marketing to human development to conservation. With financial support from Wegmans, BTI collaborated with local coffee roasters Gimme! Coffee, the Cornell Lab of Ornithology, Cornell University's School of Hotel Administration and the Dyson School for Applied Economics. Over 120 attendees started the evening with a cupping, or coffee tasting, hosted by Gimme! Coffee's baristas before listening to researchers discuss their work. Besides being well attended, the event generated important local and national press coverage.



Clockwise: BTI President David Stern with long-time BTI friend Marian Cutting; BTI patrons enjoying a cupping by Gimme! Coffee at the Beck Center; *Coffea arabica*; BTI supporters Lynn Leopold and Dr. Andre Jagendorf.

"Given the central role that food plays in human welfare and national stability, it is shocking – not to mention short-sighted and potentially dangerous – how little money is spent on agricultural research." Bill Gates

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NUMBER OF CORNELL UNIVERSITY GRADUATE STUDENTS WORKING WITH BTI FACULTY IN 2013

Joshua Judkins, Ph.D., expected 2014, Graduate Student in the Schroeder laboratory

Next step: Postdoctoral Fellow at Pfizer Neuroscience with Dr. Doug Johnson

Sydney Campbell, B.A. Chemistry and Chemical Biology, Biology, 2013, Undergraduate Researcher in the Schroeder laboratory

Next step: Cell and Molecular Biology Graduate Program at the University of Pennsylvania, concentration in Cancer Biology

Yevgeniy Izrayelit, Ph.D., expected 2014, Graduate Student in the Schroeder laboratory

Next step: Postdoctoral Research Associate, Brown University, Center for Biomedical Engineering, with Dr. Ian Y. Wong

Scientifically Competitive, But Welcoming...

A Unique Home For Research Relevant To Human Health

When Yevgeniy Izrayelit was deciding on a graduate school, he was interested in biomedical research that would have a direct impact on improving human health. He had just stepped away from medical school, because he felt the medical training experience was moving him away from the empirical research that initially drove him towards studying human health. Now, with a clean slate, he was searching for the perfect fit for his research interests and aspirations.

Yevgeniy soon found himself — while visiting the Cornell University Department of Chemistry and Chemical Biology — in a bowling alley with graduate students from BTI's Schroeder laboratory. Inish O'Doherty '13 and Ry Forseth '12 insisted that Yevgeniy talk to Associate Professor Frank Schroeder and visit the lab at BTI. Working with Frank, they thought, would foster Yevgeniy's enthusiasm while at the same time provide a competitive and innovative research environment. Dr. Schroeder arranged some time the following morning for a chat. During the meeting, Yevgeniy was immediately taken by Dr. Schroeder's passion for research,

his lab environment, and the subject matter—the study of biogenic "small molecules". These molecules play important roles in many biological processes relevant to human health, so exploring their structure and function was exactly the type of research that motivated Yevgeniy to attend Cornell University.

Fast forward several years and Yevgeniy is scheduled to graduate from Cornell University in May 2014 with his Ph.D. in Chemistry and Chemical Biology after working in the Schroeder laboratory for five years. As the first author on three research papers and the co-author on four more, Yevgeniy looks back on his time at BTI with gratitude for Dr. Schroeder and the BTI research environment. He found the scientific research culture to be competitive and driven, yet welcoming and nurturing. Interactions and feedback from other faculty members and peers throughout the building made his research that much stronger. Scientific venues like the Monday morning seminar series and the BTI Retreat were invaluable for his growth as a scientist. The coffee and tea station, and all the interactions with BTI scientists and staff there, was also a great energizer.

"Because BTI pulls from several disciplines and takes advantage of many of Cornell University's diverse departments, it creates an incredibly unique research dynamic that makes groundbreaking research possible." Yevgeniy Izrayelit, Cornell University, Ph.D. student working in the Schroeder laboratory.

What were his biggest successes at BTI? Yevgeniy is excited to have discovered a male sex pheromone in the model organism **C. elegans** and is very proud to have been part of the Schroeder laboratory during Dr. Schroeder's successful tenure review. Yevgeniy also truly enjoyed mentoring two Cornell undergraduate students, Margaux Genoff and Sydney Campbell.

In the summer of 2014, Yevgeniy will move on to work in Dr. Ian Wong's laboratory at Brown University in the Center for Biomedical Engineering as a Postdoctoral Research Associate. He will be studying cancer biology by using 3D cell culture to explore how tumor cells interact with their micro-environment. As Yevgeniy leaves BTI, his fond memories and gratitude for Dr. Schroeder, his labmates, and the rest of the BTI community will remain strong—and he reminds us all that as we strive for excellence, not to lose site of the rallying chant of BTI's intramural softball team, the BTI Bombers: "B is for fun, T is for fun, I is for Institute!"

KEEPING AN OPEN MIND

Xuemei Chen
Professor and Howard Hughes Medical Institute-Gordon and Betty Moore Foundation Investigator
University of California, Riverside
National Academy of Sciences

A life-long fascination with the natural world has propelled Dr. Xuemei Chen on a dizzying journey: from undergraduate student at the Peking University in China, to graduate student in the Stern laboratory at the Boyce Thompson Institute, to postdoctoral scientist at California Institute of Technology and ultimately a tenured professor at one of the world's most renowned plant science departments. Add to that her compelling work with noncoding RNAs and plant development and a **2013 selection into the National Academy of Sciences**, and it's easy to see why Dr. Chen has unquestionably become a BTI alumna of note.

Chen worked with David Stern at BTI from 1991 to 1994 as a PhD student in the Biochemistry graduate program. "I was really interested in plant molecular genetics," comments Chen. "There were few faculty working on plants at that time. David actually joined the program as a faculty member after he accepted me into his laboratory." When asked how her time at BTI affected her later career trajectory, Chen recollects, "I really treasure the training I received at BTI. David was a great mentor to me — he gave me guidance and encouragement but also allowed me independence. Working on the mechanisms of plastid gene expression in David's laboratory made me fully appreciate the importance of post-transcriptional gene regulation."

"Overall, I thought I received a rounded training that well prepared me for my career. I learned my ABCs of molecular genetics through course work, became aware of cutting-edge research through attending the Biochemistry and Plant Biology seminar series, gained valuable experience in manuscript preparation, and developed oral presentation skills by giving yearly talks both at BTI and in the Biochemistry department at Cornell University."

Another valuable aspect to Chen's experience at BTI was getting to know so many fellow researchers, many of whom Chen considers now to be leading scientists in various disciplines. She recalls memorable social activities as well, such as cross-country skiing outings organized by the Steve Howell laboratory.

Chen's research since becoming a lead investigator in her own right at the University of California, Riverside has engaged in two major directions. "In one," describes Chen, "we are studying the biogenesis, degradation, modes of action, and biological functions of noncoding RNAs. In the other, we are dissecting the mechanisms underlying stem cell maintenance and/or termination. We mainly use *Arabidopsis thaliana* as the model, but we also apply insights learned from Arabidopsis to animal systems."

Chen's advice for future plant scientists? "I tell my students that this is truly an exciting time to be a plant cell biologist, given all the technological advances we have at our disposal to do research. I also tell them that keeping an open mind can help you make truly original discoveries."

Adam Bogdanove
Professor
Plant Pathology and Plant-Microbe Biology
Cornell University

In 1998, Adam Bogdanove had been working with principal investigator Gregory Martin for only one year. But already he had formed such an admiration for Martin's research that the young postdoctoral scientist was willing to relocate from Indiana to New York when Martin accepted an invitation to move his lab from Purdue to BTI.

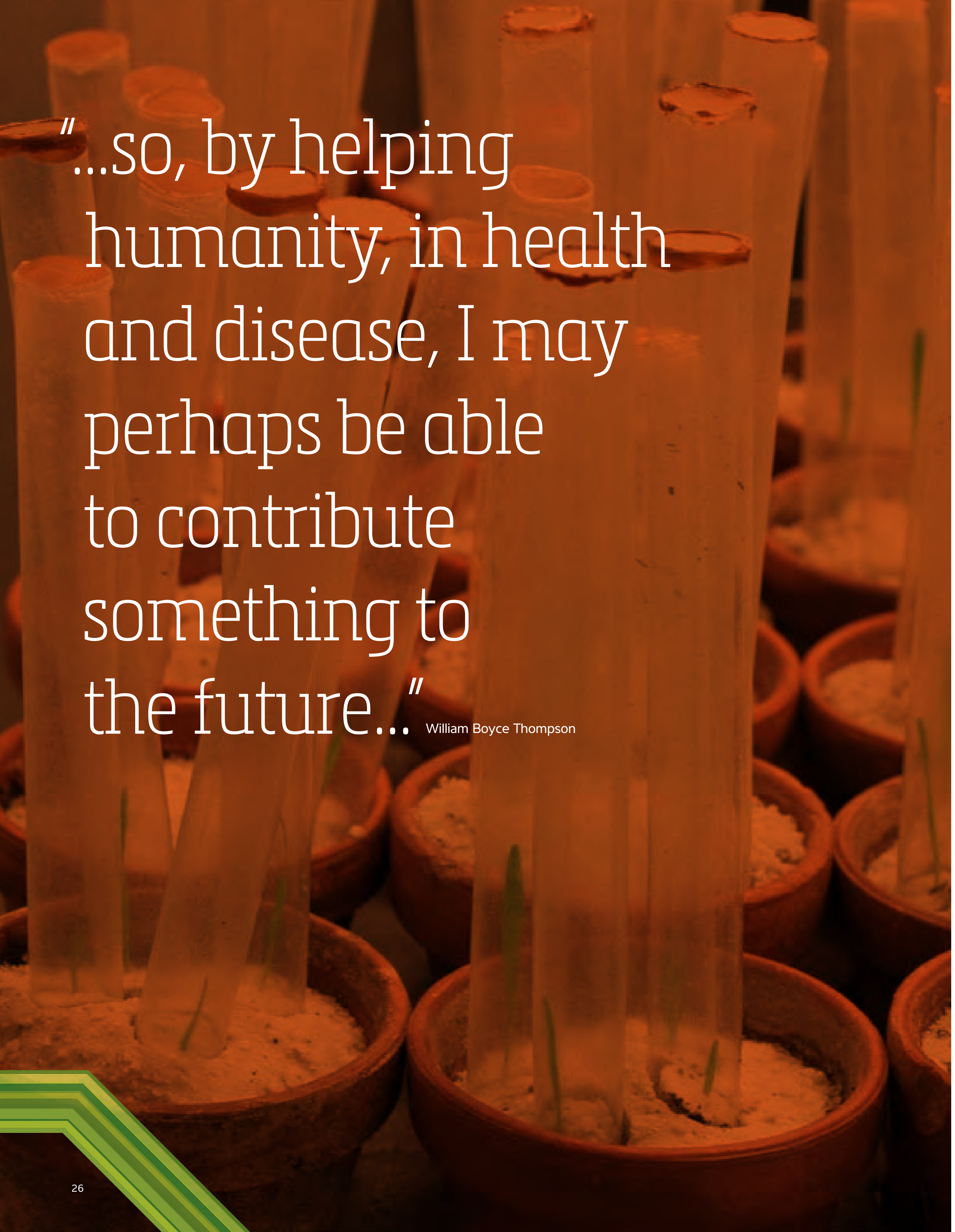
Dr. Bogdanove currently serves as Professor in Cornell University's Department of Plant Pathology and Plant-Microbe Biology, having recently moved his own lab across the country from Iowa State to Ithaca. He sees his time at the Boyce Thompson Institute as having provided him with a critical, formative experience.

"When I was at BTI, I already knew that I wanted to be a Principal Investigator running my own lab. The mentorship I received from Greg Martin was really outstanding. I took from the experience specific ideas about how to be a good mentor myself." From an institutional perspective, at BTI Bogdanove learned not only about how to conduct sound science, but how to perform administrative functions. He highlighted the benefit of BTI's internal grant program for postdoctoral scientists, which offers micro-scale experience in competitive funding. The opportunity is still available through support from the Triad Foundation.

One of the features of BTI that Bogdanove touts most is the organization's management. "I admire how well the Institute is run, with the greenhouse facilities being onsite and the administrative staff running a tight ship. Years later, when I became a project leader myself at Iowa State, I knew from BTI how influential an organization, its facilities, and its staff could be on the quality of research. It gave me a standard to compare things against." Also, Bogdanove feels that the environment at BTI is highly conducive to quality interactions among scientists. "Research topics of the project leaders span the breadth of plant science. There is great internal diversity, and it's rewarding to be around people you can learn from. This close-knit community is one of BTI's unique features."

Bogdanove is a plant pathologist by trade — meaning that he is interested in understanding plant diseases and how those diseases might be managed or prevented. The Bogdanove laboratory deals primarily in basic research, guided by the goal of finding useful information to disease control and prevention. His research specialty lies in plant disease caused by bacteria called Xanthomonas and the TAL effector proteins they use.

What is the BTI's role in the future of plant research, according to Bogdanove? **"BTI should continue to capitalize on its strengths. It is small enough to be efficient, and the location of so many world-class laboratories in one place allows it a unique synergy."**



"...so, by helping humanity, in health and disease, I may perhaps be able to contribute something to the future..."

William Boyce Thompson

From William B. Thompson's cornerstone contribution in 1924 to the support we receive today, BTI science is made possible, in part, through the generosity of donors who appreciate the importance of basic research and its usefulness in solving larger global issues, are committed to training the next generation of scientists, and wish to play an active role in our process of discovery.

We take this opportunity to thank and recognize the following individuals and organizations that made gifts in 2013. To learn more about the benefits associated with giving to BTI, as well as designated opportunities such as sponsoring a laboratory, specific research projects, or student interns, please call our development office at **(607) 254-2923.**

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Gifts in Kind

Cornell University
Gimme! Coffee

GIFT DESIGNATIONS

In support of The Gene To Bean To Global Scene Public Event
Gimme Coffee
Cornell University
Wegmans

In support of the Laboratory of Zhangjun Fei
Vilmorin & Cie.

In support of the Laboratory of Lukas Mueller and tomato genome studies
Douglas Maxwell

In support of Research Programs
Kathryn W. Torgeson

In support of Outreach Programs
Joan and Rich Curtiss

In support of the Summer Internship Program
Kraig and Dolores Adler
Carolyn Sampson
Ithaca Garden Club
Greg Galvin

MEMORIALS AND TRIBUTES

In honor of Dr. Mary Clutter
Dr. Machi Dilworth

In memory of Dr. Richard Back
Christine Bonville
Doreen Gantz
Cynthia and Edwin Haley
David Mecca
Vincent Sperrazza

In memory of Alan Bell
Brian Bell

In memory of Ursula Bruns, who loved plants of all kinds
Peter J. Bruns and Jennifer Shea

In memory of Dr. Harry P. Burchfield
Eleanor Storrs Burchfield

In memory of Dr. David Garrity, Blissard Laboratory postdoctoral scientist '94–'97
John Wyatt and Vanessa Greenlee

In memory of A. Carl Leopold
Lynn B. Leopold

In memory of Leonard Weinstein
David Fernandez, Cayuga Landscape Company
Robert and Roberta Kohut
Sylvia Weinstein

Planned Giving

Having a strong and healthy endowment is key to producing a robust research program focused on the fundamental discovery of plant functions, and providing the grounds for solutions — through BTI research — to many of our global and society issues. Planned gifts to our endowment can be established in ways that benefit BTI as well as you, your family, or another charity. If you are interested in learning more about how to include BTI in your estate plans, please contact our development department.

Questions about giving to BTI?

Contact:

Bridget Rigas
Vice President for Communications and Development
(607) 254-2923
bmr6@cornell.edu

You can always give online at **www.bti.cornell.edu/donate**

John and Mayfred Hirshfeld
Mayfred "Freddie" Stimming Hirshfeld, passed away on May 19, 2012, and in her honor, her late husband set up a trust for several local not for profits in Ithaca, including the Boyce Thompson Institute.

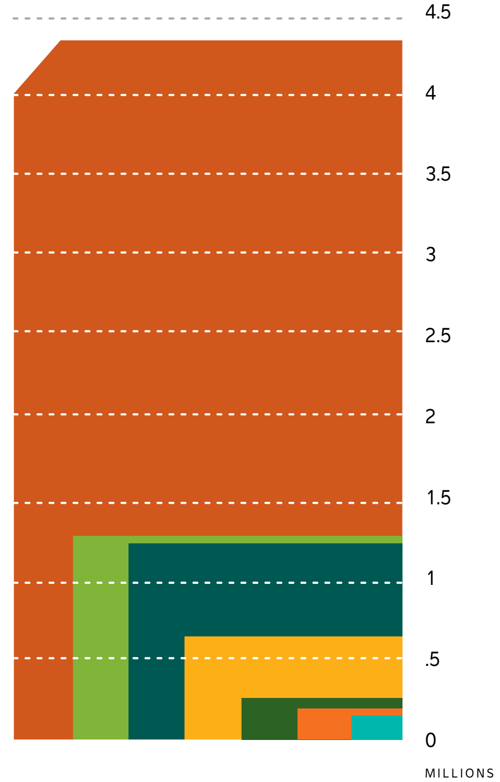
John Hirshfeld (Cornell '30, MD '34) was an avid gardener who loved everything from cut flowers to cultivating an over abundance of fruits and vegetables. Dr. Hirshfeld always found solace in gardening and truly felt that plant research was important for ensuring a better future. He saw a sense of real hope for the world through understanding more about plants and their functions — a sentiment not too far away from that of BTI founder William B. Thompson.

BTI is humbled and grateful for the Hirshfelds' very generous estate gift of $153,180. This gift to the BTI endowment will support our scientists in self-directed research projects — those directed through curiosity — which are where many great discoveries are born.

The Boyce Thompson Institute for Plant Research receives a substantial portion of its research funding through grants from the federal government, private foundations, corporations, and individuals. The following section lists new research awards that were received in 2013.

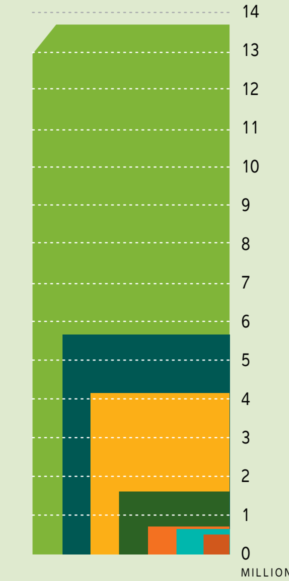
New Research Grants Awarded in 2013

GOVERNMENT	
National Science Foundation	$ 1,359,186
United States Department of Agriculture	$ 1,354,796
FOUNDATIONS	
Triad Foundation	$ 250,000
Other Foundations	$ 118,792
CORPORATIONS AND OTHER SUPPORT	
Corporate Funding	$ 179,600
Other Support	$ 618,587
TOTAL NEW RESEARCH GRANTS AWARDED	$ 4,375,961



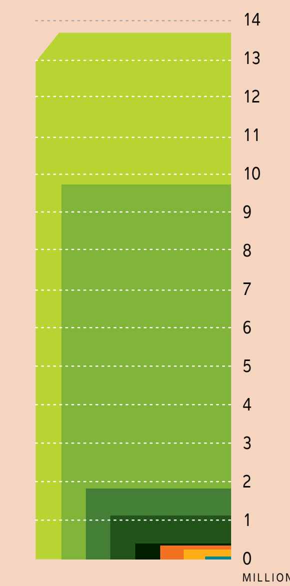
2013 Income Sources

Federal Government (42%)	$ 5,827,000
Institutional Endowment (30%)	$ 4,091,000
NYS Land Grant Provision (12%)	$ 1,685,000
Foundations (5%)	$ 663,000
Other Private Sources (6%)	$ 862,000
Unrestricted Revenues (5%)	$ 749,000
TOTAL OPERATING INCOME	**$13,877,000**



2013 Expenses

Research Activities (71%)	$ 9,831,000
Research Support (8%)	$ 1,047,000
Research Facility Expenses (3%)	$ 428,000
Administration (14%)	$ 1,922,000
Intellectual Property (2%)	$ 273,000
Communications, Website, and Education (2%)	$ 343,223
Fundraising (>1%)	$ 32,777
TOTAL OPERATING EXPENSES	**$13,877,000**



Klaus Apel, Ph.D.
Professor, BTI
Professor Emeritus of Plant Genetics, Swiss Federal Institute of Technology (ETH) Zürich, Switzerland

Plants can endure extreme environmental stress (heat, drought, cold, or intense light) through genetically controlled defenses, such as wilting, loss of leaves, or stunted growth, but these defenses can also reduce yields, among other effects. As a result, one effect of global climate changes could be reduced food production just when the world's population is burgeoning.

Understanding how plants sense and respond to environmental stress at the genetic level is the ultimate objective of Klaus Apel's laboratory at BTI. His findings could enable scientists to mitigate the negative results of stress, such as yield loss, or fine-tune a plant's ability to cope with an adverse environment.

It turns out that chloroplasts—the tiny organs that contain chlorophyll and carry out photosynthesis—play an important role in a plant's ability to sense environmental stress. Conditions such as drought, heat, cold, and intense light interfere with the normal photosynthetic process in the chloroplasts, which leads to over-production of sometimes toxic forms of oxygen, called reactive oxygen species (ROS).

High levels of ROS were previously considered detrimental to the cell. However, recent work with an Arabidopsis mutant by Apel and his research group indicates that the release of one ROS, called singlet oxygen, in the chloroplast, actually triggers a variety of positive stress adaptation responses in the plant. These responses include slowed plant growth and the activation of a broad range of defense genes, which normally are turned on to deter pathogens.

In further work, Apel's group proved that certain genetic mutations in Arabidopsis eliminate the plant's stress responses without interfering with the release of singlet oxygen. It appears these mutations prevent the plant from sensing the presence of singlet oxygen, which, in turn, prevents symptoms of stress. Apel's group has identified these mutated genes, which is a first and crucial step toward understanding the genetic basis of the stress response in plants.

The results of Apel's work could lead to plants that cope better with environmental stress. Ultimately, such a discovery could help increase food supplies or predict a plant's susceptibility to environmental changes.

Gary Blissard, Ph.D.
Professor, BTI
Adjunct Professor, Microbiology and Immunology and Entomology, Cornell University

How do viruses infect insects?

Certain viruses are our allies in the fight against insect pests. Research that leads to a better understanding of how these viruses interact with insects will result in environmentally friendly and sustainable methods of insect control and advances in human health.

In one research project, Gary Blissard has been studying how certain viruses, called baculoviruses, infect and interact with insects. He and his colleagues have focused on how a particular baculovirus envelope protein, called GP64, enables the virus to invade an insect cell, multiply, and then exit in massive numbers.

Blissard's group found that GP64 has three major functions in the viral infection cycle. First, they showed that GP64 is an attachment protein — a protein that enables the virus to bind to the surface of the host insect cell, which is the first step in the process of infection. Blissard's laboratory identified the particular portion of GP64 that is necessary for this binding activity and they also found that the virus can bind to artificial membranes that are devoid of protein, explaining how the virus gets into many diverse cell types.

After the virus binds to the surface of the host cell, it is taken into the cell by a process call endocytosis, which surrounds the virus with a cellular membrane. To cause infection, the virus must escape by fusing its membrane with the cellular membrane. Blissard's group has studied and identified critical amino acids in the GP64 protein, that are necessary for both the initial interaction between virus and host membrane, and for fusion of the two membranes.

After the viral DNA is released into the cell nucleus, the virus takes over the cell and transforms it into a factory specialized for virus production. How does this occur? To answer this complex question, Blissard's group performed a transcriptome analysis of the viral infection. This technique allowed them to simultaneously monitor the activity of approximately 156 viral genes in the entire virus genome. Simultaneously, they also monitored the reactions of tens of thousands of host cell genes. This has resulted in an unprecedented new appreciation of the complexity of interactions between the two DNA genomes (virus and insect cell) over the course of the entire infection cycle: from the first few hours through several days, when the cell has been completely conquered by the virus.

Knowing how baculoviruses enter and then take over insect cells should enable scientists to improve the virus' insect control capabilities, which could reduce the use of chemical pesticides and lead to safer and more sustainable agricultural practices. This work also has other exciting applications, such as in gene therapy. Because baculoviruses cause disease only in certain insects, and because they are highly effective at entering cells and depositing DNA into the cell nucleus, baculoviruses are excellent vehicles for delivering beneficial genes into mammalian cells. Understanding how the baculovirus enters cells in general, and how they deliver their DNA payload, will also advance their use in mammalian cells as DNA delivery vehicles, and could improve our ability to safely correct genetic disorders in humans through gene therapy.

The Blissard group is also now applying technology developed for studies of baculovirus envelope protein GP64, to the study of an envelope protein of an important human pathogen, Dengue virus. Their goal is to understand how human viruses such as Dengue are able to interact with and move through the cells of the insect gut, a process that permits virus transmission through the insect and to the next human host. Studies of these virus-insect interactions will be important for understanding both plant and animal viruses that use insects as vectors for their dissemination.

Dengue fever is a *mosquito*-borne tropical disease caused by the *dengue* virus. The Blissard laboratory studies virus-insect interactions that will be important for understanding both plant and animal viruses that use insects as vectors for their dissemination.

Carmen Catalá, Ph.D.
Senior Research Associate, BTI
Senior Research Associate, Plant Biology, Cornell University

How do plant hormones control fruit development?

When home gardeners or horticulturalists grow plants from stem cuttings, they often dip the cut end of the stem in a white powder that encourages the stem to develop roots. The white powder is a hormone, called auxin, which plays an important role in plant growth and development. Auxins also influence cell division and differentiation, which is why the powder form used by gardeners helps the stem cutting to start growing root cells.

It's also known that auxins, particularly indole-3-acetic acid, are central to the development and ripening of fruit, such as strawberries and tomatoes. Work on auxins conducted with strawberries has proven that the hormone is produced in the tiny seeds that speckle the outside of the berry, and that this auxin helps the fruit grow. But very little is known about the molecular basis of auxin production, transport, and signaling in fleshy fruit-producing plants. This is the area of research that Carmen Catalá is pursuing at BTI. Until now, the majority of research into auxins has been done in the model plant Arabidopsis, which is a flowering plant that only produces a dry fruit. Catalá is applying knowledge gained about auxins in Arabidopsis and using new molecular techniques to understand exactly how the auxin indole-3-acetic acid works in tomatoes. Catalá aims to discover how and where this auxin is produced in the fruit, how it is transported to the different fruit tissues, and how it signals the cells in that tissue to grow, develop, and ripen. What her group learns in tomatoes will be applicable to other fleshy fruits as well.

Knowing at the molecular level how auxins help plants set fruit and how they influence fruit development and ripening could one day lead to higher quality fruits. And, because auxins directly stimulate or inhibit the expression of specific genes, understanding how to control the production or transport of these hormones could lead to fruits with improved flavor, texture, or other unique qualities.

Another area of research in the Catalá laboratory focuses on the discovery of genes and networks regulating tomato fruit morphology. In tomato domestication and extensive selection for fruit characteristics has given rise to large variations in fruit morphology. One of the objectives of this research is to gather information about genes that are expressed during tomato fruit development and that control fruit growth and shape. As part of this project the Catalá laboratory is generating maps of tissue and cell-specific gene expression in the developing tomato fruit using Laser Capture Microdissection, a technique that allows the isolation of specific cells or tissues from plant organs. This research is generating unprecedented data sets that will provide the basis for exploring key aspects of fruit biology.

Michelle Cilia, P.h.D.

Assistant Professor, BTI
Research Molecular Biologist, USDA, Agricultural Research Service; Adjunct Assistant Professor, Plant Pathology and Plant-Microbe Biology, Cornell University

How do pathogens commandeer plants and insects to promote their own transmission?

Pathogens cause millions of dollars of damage to food crops every year and are often at the root of food shortages in developing nations. Despite their importance to human wellbeing and the global economy, little is known about the relationships between plants, pathogens, and the insects that spread these diseases.

Michelle Cilia, who joined BTI in January 2013, has a collaborative position between BTI, the Department of Plant Pathology and Plant-Microbe Biology at Cornell University and the USDA Agricultural Research Service to develop a research program that tackles the fundamental biology of insect vectors and the plant pathogens they transmit. Using a combination of traditional approaches and new, cutting edge mass spectrometry techniques, the Cilia laboratory will study the three-way relationships between pathogen, plant, and vector to come to a comprehensive understanding about how insects transmit pathogens. Cilia hopes to identify ways in which the system might be manipulated to prevent infection, protecting crops and the communities that rely on them.

As an important first step towards achieving her goals, Cilia initiated a collaboration with the Bruce laboratory at the University of Washington to use advanced technologies to study how plant and insect proteins physically interact with viruses. Using a new technique called Protein Interaction Reporter (PIR) technology, Cilia and her colleagues mapped the structure of two key virus proteins and identified the surface features that are functionally important to the virus. The work is the first to provide these types of measurements on any infectious virus particle and the first structural insights into a virus in the family Luteoviridae, an economically important family of plant pathogens. Her team was recently funded by the National Science Foundation's program on Integrated Organismal Systems and will use PIR technology to develop new ways to block the virus from infecting plants.

Cilia recently started a project funded by the California Citrus Research Board to help the state combat citrus greening disease. Citrus greening disease is associated with a bacterial pathogen that is transmitted by an invasive insect called the Asian citrus psyllid. This tiny insect transmits the bacterium to all varieties of citrus. Citrus greening causes fruit deformities and ultimately tree death. The disease has spread to every major citrus growing region in the world and is entrenched in every citrus-growing county in the state of Florida. In a coordinated, multi-institutional and multi-state effort, Cilia and her colleagues will investigate how genes, proteins, and metabolites orchestrate citrus greening infections. They will use this information to develop early-infection biomarkers to alert growers and greening researchers of an infection before a tree shows symptoms. Cilia's team will also investigate how the bacteria associated with citrus greening use proteins to gain entry into the Asian citrus psyllid, similar to how a lock and key fit together.

Cilia is interested in using her technologies to help small holder farmers improve agriculture in the developing world. Via the National Science Foundation's Basic Research to Enable Agricultural Development program, she is working with a team of scientists in the US and Africa, where insect vectors are responsible for transmitting viruses to a variety of security crops. A major obstacle in vector management is that not all members of a vector species are able to transmit viruses. Cilia and her colleagues discovered a panel of protein biomarkers that can distinguish between insects that can transmit viruses and those that cannot. Cilia is exploring how to use these proteins in a simple assay to identify populations of insects that may threaten crops.

Cilia's long-term research plans will enable us to understand the co-evolutionary race between plants and pathogens at the molecular level and to develop practical strategies that can be transferred to growers for disease and vector management.

Zhangjun Fei, Ph.D.

Associate Professor, BTI
Adjunct Associate Professor, Plant Pathology and Plant-Microbe Biology, Cornell University

How can scientists access and use massive amounts of plant genomics data?

Consider that just one tomato plant contains about 35,000 genes that express thousands of different proteins. Then consider how many different plants are currently under study, and it's easy to understand the enormity of the data generated in biological research.

Organizing that data and making it accessible for further research is an area called bioinformatics. The interface between biology, statistics and computer science, bioinformatics develops computational tools and resources that organize massive amounts of data into usable sets so that the knowledge contained in them can be retrieved, analyzed, and applied in biology research. The Fei laboratory at BTI develops both the databases and the interfaces needed to help scientists understand how genes work together and how they form functioning cells and organisms. Dr. Fei also has developed analytical and data-mining tools that allow scientists to efficiently extract biological information from the database for use in their research.

The Fei laboratory also uses next generation sequence technologies combined with bioinformatics tools to facilitate crop improvement. Fei has co-led an international consortium to sequence the watermelon genomes. By analyzing a high-quality reference genome and reseqeunced genomes of 20 watermelon accessions, Fei and others found that during watermelon domestication, although fruit quality such as sugar content has been substantially improved, a large portion of disease resistant genes have been lost. This information can help breeders to recover some of these natural disease defenses while retaining the high fruit quality of watermelon. Fei has also co-led an international consortium to sequence the kiwifruit genome and found that the recent whole genome duplication events in kiwifruit have produced additional gene family members that are involved in regulating important fruit characteristics, such as fruit vitamin C, flavonoid, and carotenoid metabolism.

Fei lab is currently using the deep small RNA sequencing approach to pan-African sweet potato virome and global virus distribution of tomato. Using this approach, Fei and his collaborator at USDA identified a novel tomato virus that can't be discovered using traditional approaches.

Fei has collaborated with the Giovannoni laboratory at BTI to investigate the role of epigenome in tomato fruit development and ripening using genomics and bioinformatics approaches. They found a link between methylome dynamics and fruit maturation.

Information uncovered in the Fei laboratory may help breeders recover natural disease defenses while retaining the high fruit qualities in watermelon.

Jim Giovannoni, P.h.D.

Professor, BTI
Plant Molecular Biologist, USDA-ARS
Adjunct Professor, Plant Biology, Cornell University

What is the genetic basis of fruit ripening and nutritional quality?

Fruit is a major source of nutrients and fiber in the human diet, so a better understanding of how fruit develops and ripens at the genetic level could significantly impact the quality and availability of food. This knowledge would benefit countries where food spoilage, due to over-ripening, is a root cause of hunger and where nutritional requirements are not currently being met.

Jim Giovannoni's laboratory at BTI is working to understand fruit development and ripening by focusing on the genes and regulatory networks that control these processes in fleshy fruits, such as tomatoes, bananas and melons. The laboratory has focused on identification of genes necessary for regulation of the ripening process and has recently identified several new transcription factors essential to the process. These include a gene called TAGL1, which is necessary for both the fleshy expansion of pre-ripening fruit as well as the later ripening process, in addition to two negative regulators of ripening, AP2a and ERF6. In the last year, the laboratory also reported a gene termed UNIFORM RIPENING that influences fruit pigmentation and defines a gradient of ripening along the longitudinal axis of the fruit and a similar gene (GLK1) that impacts leaf pigments and photosynthesis.

Activities in the last year include cooperation with other BTI scientists and collaborators at the University of Oklahoma and Colorado State to refine the genome sequence of tomato. The laboratory continues to use this sequence as the basis of novel discoveries on the role of changes in the epigenome in controlling fruit ripening.

Current research includes efforts to discover how the epigenome may contribute to additional aspects of fruit biology in fruit species beyond tomato and how the TAGL1, AP2a and ERF6 genes function in context with fruit development and ripening genes previously identified and described by the Giovannoni laboratory and others. Work continues in testing for similar genes and functions in species beyond tomato. Results of this research may lead to new molecular strategies for improving fruit quality and shelf life, which can, in turn, positively impact food security and human nutrition.

Maria Harrison, Ph.D.
William H. Crocker Scientist and Professor, BTI
Adjunct Professor, Plant Pathology and Plant-Microbe Biology, Cornell University

How do soil fungi supply plants with mineral nutrients?

Plants and certain fungi called arbuscular mycorrhizal (AM) fungi, have a complex, symbiotic relationship in which plants provide the fungi with carbon while the fungi provide plants with phosphate needed for cell function and growth. Understanding this relationship may enable crop production with fewer applications of phosphate fertilizers.

Working with an AM fungus and a legume plant, *Medicago truncatula*, Maria Harrison's laboratory is unraveling the mechanisms underlying mineral nutrient transfer from the fungus to the plant. AM fungi are ubiquitous in soil and live in close proximity to plant roots. In response to a signal from the plant, the fungi grow into the roots and establish themselves inside the root cells. The plant surrounds the fungus in a membrane, called the periarbuscular membrane, and nutrients are exchanged across this membrane.

Several years ago, the Harrison laboratory identified phosphate transporter proteins that capture phosphate delivered by the fungus and move it into the root cell. The phosphate transporters are located exclusively in the periarbuscular membrane. Harrison's group is intrigued by the specificity of the location and carried out studies to determine how the phosphate transporters are sent to this specific location. Using proteins tagged with a fluorescent protein called green fluorescent protein (GFP), they were able to show that the timing of transporter protein production and changes in the direction of protein secretion in the cell, enable the proteins to be placed specifically in the periarbuscular membrane. Identifying the signals that trigger these cellular changes is the focus of her research.

Today, farmers use fertilizers derived from rock phosphate to enhance plant nutrition, but these reserves are being depleted; At the current rate , reserves will last approximately 90 years. Furthermore, excessive application of phosphate fertilizers contributes to the pollution of lakes and streams. Harrison's work may lead to plants that can use naturally occurring phosphate in the soil more completely and efficiently through enhanced symbiotic relationships with fungi—an advance that would lead to more environmentally sustainable agriculture.

Georg Jander, Ph.D.
Associate Professor, BTI
Adjunct Associate Professor, Plant Biology, Cornell University

How do plants defend themselves against insect herbivory?

As the human population increases, so does the demand for food, yet there is a finite amount of arable land available for agriculture. To meet present and future needs, scientists are working to develop more efficient and more sustainable agricultural production methods that will enable increased food production from current agricultural acreage.

One way to do that is to reduce yield losses due to insects, which feed on the plants and spread diseases. In fact, insects reduce annual crop yields by 15 percent per year worldwide, despite the implementation of a large variety of control methods by farmers. Therefore, understanding the interactions between plants and insects and how plants ward off insect attack is an attractive way to increase crop yields. With that goal in mind, Georg Jander's laboratory is studying the biochemistry and molecular biology of plant-insect interactions.

Plants are not passive targets for insect herbivores. Rather, plants recognize that they are being attacked and respond by altering their metabolism to deter further insect feeding. The Jander laboratory is identifying previously unknown toxic and deterrent plant metabolites, as well as their biosynthetic pathways, which are up regulated in response to insect feeding.

In one research approach, members of the Jander laboratory are investigating natural variation in maize resistance to aphids and caterpillars. Genetic mapping has identified specific genes that make some maize varieties to be more resistant to insect feeding. This insect resistance can be a very dynamic process. For instance, one maize line that is quite resistant to caterpillar feeding is not inherently better defended, but responds more rapidly to a caterpillar attack by producing defensive toxins. However, the induction of these caterpillar-specific defense responses can make plants more sensitive to aphid feeding. A detailed knowledge about such defensive tradeoffs will make it possible to breed insect-resistant maize plants in a more targeted manner.

As part of a new project in 2014, the Jander laboratory will investigate interactions between potato plants and the Guatemalan tuber moth. This insect pest can be a devastating problem for potato farmers in Central and South America. The identification of natural tuber moth resistance mechanisms in potatoes will make it possible to increase the productivity of this important crop plant. Interestingly, if only a small number of tubers on a given potato plant is infested by tuber moths, the remaining tubers can become larger. Future research in the Jander laboratory will be directed at studying the plant response, commonly called overcompensation, to identify specific growth-promoting changes in potato metabolism that are induced by tuber moth feeding.

Daniel F. Klessig, Ph.D.
Professor, BTI
Adjunct Professor, Plant Pathology and Plant-Microbe Biology, Cornell University

Understanding plant immunity for sustainable agriculture and food security

From viruses to bacteria to fungi, plant pathogens are a constant in agriculture, but the chemical control methods farmers have long relied upon are not sustainable over the long term. To ensure the quality and reliability of the global food supply while preserving food safety and environmental quality, plant research must explore new, sustainable means for protecting plants from microbial predators. Daniel Klessig's laboratory is focused on understanding how plants protect themselves from pathogens. With an eye toward developing sustainable control methods, Klessig and his colleagues apply a broad range of techniques to identify components of the plant immune system, including the key hormone salicylic acid, and determine how they work.

Recent work in the Klessig laboratory has focused on the CRT1 (Compromised for Recognition of Turnip Crinkle Virus) protein in the model plant Arabidopsis. Klessig's team first identified the protein in a search for signaling components of the plant's immune response. Sequencing of the gene for CRT1 shows that it belongs to the Microchidia (MORC) family of proteins, which are found in plants, animals, and microbes and are associated with DNA modification and repair. Using Arabidopsis mutants, Klessig and his colleagues showed that plants that lack a functional gene for CRT1 have compromised levels of resistance to pathogens. CRT1 is required not only for recognizing viruses, the results show, but functions in response to a broad spectrum of pathogens, including the bacterium **P***seudomonas syringae* and the fungus-like *Hyaloperonospora arabidopsidis*. What's more, CRT1 is involved in many different layers of plant immunity, including effector-triggered immunity, pathogen-associated molecular pattern-triggered immunity, basal resistance, nonhost resistance, and systemic acquired resistance. Since CRT1 binds DNA and relocates to the nucleus of the cell upon pathogen attack, it likely carries out important nuclear functions during the plant's immune response. This work is the first evidence that a MORC protein plays a role in immunity.

Moving forward, Klessig expects that an understanding of CRT1 and its roles in multiple levels of immunity will lead to development of plant varieties that can fend off harmful microorganisms without the use of chemicals that can be harmful to humans and the environment. Unexpectedly, further research revealed that while CRT1 plays a positive role in immunity in Arabidopsis (and also potato), in other plant species such as barley and tomato CRT1 negative regulates immunity. For example, inhibiting the expression of CRT1 results in enhanced resistance to powdery mildew in barley and to late blight in tomato.

Gregory Martin, Ph.D.
Boyce Schulze Downey Professor, BTI
Professor, Plant Pathology and Plant–Microbe Biology, Cornell University

How do bacteria infect plants and how do plants defend themselves from attack?

The Martin laboratory studies the molecular basis of bacterial infection processes and the plant immune system. The research focuses on speck disease which is caused by the infection of tomato leaves with the bacterial pathogen *Pseudomonas syringae* pv. *tomato*. This is an economically important disease that can decrease both the yield and quality of tomato fruits. It is also an excellent system for studying the mechanisms that underlie plant-pathogen interactions and how they have evolved. Many experimental resources including an increasing number of genome sequences are available for both tomato and **P. s.** pv. **tomato**. Current work relies on diverse experimental approaches involving methods derived from the fields of biochemistry, bioinformatics, cell biology, forward and reverse genetics, genomics, molecular biology, plant pathology, and structural biology.

In the tomato-Pseudomonas interaction, the plant responds rapidly to a potential infection by detecting certain conserved molecules expressed by the pathogen. At this stage the pathogen uses a specialized secretion system to deliver the virulence proteins AvrPto and AvrPtoB into the plant cell. These proteins suppress early host defenses and thereby promote disease susceptibility. Some tomato varieties express a resistance gene, *Pto*, which encodes a protein that detects the presence of AvrPto or AvrPtoB and activates a second strong immune system that halts the progression of bacterial speck disease.

The Martin laboratory is currently studying many aspects of the molecular mechanisms that underlie the bacterial infection process and the plant response to infection. One project takes advantage of the genetic natural variation present in wild relatives of tomato to identify new genes that contribute to plant immunity. These genes provide insights into the plant immune system and also can be bred into new tomato varieties that have enhanced disease resistance. A second project relies on next-generation sequencing methods to identify tomato genes whose expression increases during the interaction with **P. s.** pv. **tomato**. The expression of these genes is then reduced by using virus-induced gene silencing to test whether they make a demonstrable contribution to immunity. A third project is using photo-crosslinking and other novel biochemical methods to isolate plant proteins that play a direct role in recognizing the conserved bacterial molecules that activate the early plant immune system.

The long-term goal in this research is to use the knowledge gained about plant-pathogen interactions to develop plants with increased natural resistance to diseases. Such plants would require fewer pesticides, produce economic and environmental benefits, and provide food for consumers that has fewer pesticide residues.

Lukas Mueller, Ph.D.
Assistant Professor, BTI
Adjunct Assistant Professor,
Plant Breeding and Genetics,
Cornell University

How will researchers store and retrieve scientific information in the future?

Consider that thousands of scientists are working worldwide to identify all the genes in a wide variety of plants. Then, consider that a plant such as tomato has about 35,000 genes, some of which function in complex networks. And then consider that new genetic discoveries are being made every day on how these genes are regulated and how they interact. How can all this information be efficiently stored, updated, and made accessible to scientists in a timely manner so they can use it and build on it? This is the question that Lukas Mueller's laboratory at BTI is answering. Among other projects, Mueller's group coordinates the Solanaceae Genomics Network—a database of all the genetic information known about solanaceous plants, such as tomatoes and peppers. The database and software designed for the Solanaceae have recently been adapted for cassava in a new project, Nextgen Cassava, to create the Cassavabase database (http://cassavabase.org/). Cassavabase is specifically designed for cassava breeders in Africa with the goal to apply new breeding paradigms to cassava to accelerate breeding in this crop. He's also involved in a number of genome sequencing projects, most notably the tomato genome project, which is a collaboration with scientists from 16 countries.

Mueller is developing software that will make it easier for scientists to access vast amounts of genomic data. He's also working to make it simpler for scientists to annotate, or update, the data as they make discoveries. It's similar to the idea that gave rise to Wikipedia — an encyclopedia that can be added to or revised by anyone who reads it. The difference is that Mueller's software and the database it runs are specifically designed for complex biological data.

Until the advent of the Internet, scientists could only share the results of their research with others through personal communications and by publishing in scientific journals. But neither method enables colleagues to access all the data that supports the results. With the software Mueller is developing, scientists and breeders not only can see the results of others' work, they can also see and use the source data. Mueller's goal is to make these databases so easy to use that they will become the primary place for storing, sharing, updating, and accessing genomics information. At that point, the practical applications of this work will multiply. For instance, plant breeders could use the database to more quickly develop new varieties of crops with innovative genetic characteristics to increase yield and/or enhance nutritional quality.

George Popescu, P.h.D.
Senior Research Associate, BTI

The power of molecular methods and of computing technology has increased exponentially in recent years, empowering science to delve into new, unexplored questions in biology. Scientists can now apply computational approaches to studying complex phenomena, teasing apart dense networks of interactions in ways that would have been impossible only 10 or 20 years ago.

George Popescu's laboratory at BTI uses computational approaches to study biological networks and processes in order to understand evolution and dynamics at the molecular and cellular levels. Using the methods of systems biology, Popescu seeks to infer functional protein interactions, analyze the structure of biochemical networks, and study the dynamics of plant signaling networks.

In sequence-based work, Popescu's laboratory is developing methods for pinpointing networks of regulatory genes by comparing the conserved portions of many different plant genome sequences and integrating that information with data that shows when and to what degree plants use those genes. Popescu's work addresses fundamental questions in plant research using computational and analytic methods.

In recent work, Popescu and his colleagues identified several new components of the Arabidopsis thaliana immune response pathways. Using a functional protein microarray, a tiny chip with over 5,000 different Arabidopsis proteins arranged in a grid on the surface, the researchers identified specific plant proteins that interact with FLS2, a critical receptor in Arabidopsis thaliana, and transport it to the cell membrane, where it can play its role in plant immunity. High-throughput assays developed with the same plant protein microarray led to identification of other key proteins involved in plant's response to biotic and abiotic stress, including two metaloendopeptidases, TOP1 and TOP2, that mediate Salicilic Acid-dependent signaling.

Recently Popescu predicted a signaling network that contains nine Ca2+ sensors for PEN3, a membrane-localized transporter, revealing the importance of Ca2+ signaling in plant innate immunity. By developing models of cellular circuits responsive to plant stress factors, the Popescu laboratory hopes to elucidate the cellular functions of newly identified targets and to explore their roles in plant immunity.

Sorina Popescu, P.h.D.
Assistant Professor, BTI Adjunct Assistant Professor,
Plant Biology and Department
of Plant Pathology and
Plant-Microbe Biology,
Cornell University

How do plants sense their environment?

Although plants lack eyes, ears, nose, and toes, they are continuously attuned to their surroundings. Plants are able to sense environmental factors such as heat, cold, humidity, and the presence of enemies, just as well as humans, if not better.

A communication system, called signal transduction, mediates the dialog between plant cells and their immediate surroundings. Signaling relays on kinases, proteins with enzymatic functions which transmit signals over long distances within the cell. Special proteins called receptors have a sentinel function, continuously surveying the environment and ready at the smallest provocation to alert an orchestra of second-tier sentinels located inside the cells. Plants are dependent on this communication system because their basic cell functions, growth and survival depend on it.

The Popescu laboratory studies the rich and complex system for signal sensing and intracellular transduction in tomato and the model plant Arabidopsis. In her work, Popescu is employing special techniques that allow her to survey hundreds of proteins. Popescu discovered that she could "print" as many as 5,000 minute protein samples on one microscope slide (the microarray), and that these tiny amounts of protein could then be used in other research that would reveal the function of each protein. Using this technique, Popescu and other scientists have been able to more comprehensively study protein function. With another technique developed in her laboratory, Popescu is able to screen interactions between tomato kinases and pathogen proteins directly in live tomato cells. Now, Popescu and others can easily discover the plant molecules targeted by pathogens and the impact that plant-pathogen molecular interactions have on plant immunity. As a result, her work has significantly expanded the universe of study involving proteins and their functions.

Understanding how plants respond and acclimate to stress is a first step toward meeting agricultural and health challenges as the world faces increasing population, urbanization, and climate change. Popescu studies plant signaling to understand how proteins assemble in pathways and to decipher how discreet errors in the signaling system could impact signal flow and ultimately, cellular responses to stress. Her work has tremendous practical potential, as it may lead to engineering synthetic signaling pathways in plants, for higher tolerance to diseases and environmental stressors.

Eric J. Richards, Ph.D.
Professor, BTI
Adjunct Professor,
Molecular Biology and
Genetics, Cornell University

Is there more to inheritance than genetics?

As is widely known, excessive exposure to the sun's radiation can cause normal skin cells to become cancerous. In this case, cancer occurs because radiation causes changes in the cell's DNA sequence (mutations) within genes that regulate cell division. But cancer and other diseases can also occur when certain genes that might have protected the cell are "silenced" or turned off. In this case, the protective genes become unreadable by the cell and disease can result. Understanding how these genes become unreadable is the goal of a research area called epigenetics.

Eric Richards' laboratory studies epigenetics in the model plant Arabidopsis. "Epi-" means "on top of" or "in addition to," so epigenetic traits exist on top of, or in addition to, the cell's DNA sequence. Epigenetics research seeks to understand the molecular mechanisms that change the information contained in the DNA (making it unreadable) without changing the underlying DNA sequence. Richards focuses on one of these mechanisms, called DNA methylation, in which a small chemical group is added to one of the DNA bases (cytosine). Both the gene and its new methylation state can be passed on to new generations of cells and, in some cases, organisms. Consequently, alterations in DNA methylation might play important roles in inheritance and adaptation, just as mutations do.

The Richards laboratory is working to understand how, where, and when DNA methylation occurs, its consequences on the organism, and to what extent variation in methylation is passed on to future generations. Richards is studying this process in plants because they can survive major epigenetic alternations that other organisms, such as mice, cannot.

Understanding the basic biology of DNA methylation in plants could have applications to human health, including the detection and prevention of disease. Epigenetics also has important potential applications in agriculture, because epigenetic modifications can affect important traits in crop species (e.g., disease resistance and flowering time). Consequently, advances in epigenetics could lead to higher quality food and increased yields.

Frank Schroeder, Ph.D.
Associate Professor, BTI
Adjunct Professor,
Chemistry and Chemical
Biology, Cornell University

Missing pieces in the chemistry of life: biogenic small molecules control development and aging

The relevance of nucleic acids, proteins and carbohydrates for all aspects of biology is well established, but the varied and often unexpected roles of biogenic small molecules are just now emerging. Biogenic small molecules regulate development and immune response in plants and animals (as hormones, for example) and also play an important role in the interactions of different organisms with each other.

Biogenic small molecules are very different from proteins and nucleic acids, which are derived from polymerization of a limited set of building blocks. In contrast, biogenic small molecules are a chemically much more diverse class of compounds that have so far resisted systematic analysis. Frank Schroeder's laboratory is developing analytical approaches based on nuclear magnetic resonance (NMR) spectroscopy, which aim to greatly increase scientists' ability to identify the chemical structures of these compounds and to find their biological functions. Using this approach, Schroeder's team is investigating the role of biogenic small molecules in specific aspects of animal, microbial, and plant biology, including signaling processes related to aging.

In one area of research, Schroeder is investigating biogenic small molecules produced by the nematode *Caenorhabditis elegans*. Nematodes are roundworms that are roughly 1 mm in length and ubiquitous in the soil. Many of the physiological pathways in **C. elegans** are analogous to corresponding signaling pathways in higher animals, and as a result, nematodes have become an important model system for human disease and aging.

Although the entire *C. elegans* genome — about 20,000 genes — was sequenced more than 15 years ago, little is known about the entirety of its small molecules, usually referred to as the "metabolome." Over the past six years, the Schroeder group identified a library of several 100 compounds that regulate nematode lifespan, development, and several different social behaviors. These studies revealed that **C. elegans** uses a modular "chemical language" to communicate a large variety of different messages. The ultimate goal of this research is to characterize the signaling pathways in which the identified **C. elegans** small molecules act, and to identify biosynthetic pathways, specific receptors, and downstream molecular targets.
Schroeder and colleagues recently used their NMR-spectroscopic approach to identify a large group of small molecules produced by a filamentous fungus, the human pathogen *Aspergillus fumigatus*. *A. fumigatus* is the causative agent of invasive aspergillosis and uses specific small molecules, called virulence factors, to overcome the immune responses of its mammalian hosts. Schroeder's research showed that this pathogenic fungus produces a much greater number of small molecule virulence factors than previously suspected. Knowledge of the structures and biosynthetic regulation of these small molecules provides insight in host pathogen interactions and may contribute to new approaches for the treatment of fungal infections.

David Stern, Ph.D.
President & CEO, BTI
Adjunct Professor,
Plant Biology,
Cornell University

How do plants coordinate genes in different compartments?

As long as two billion years ago, a bacterium capable of photosynthesis was engulfed by another single-celled organism, forming the first photosynthetic eukaryote. Eukaryotes differ from simpler bacteria because they have multiple genetic compartments within the cell. In the case of modern plant cells, there are three genetically active compartments: the nucleus, the mitochondria, and the chloroplasts. While the nucleus contains most of the plant's genes, the organellar (mitochondrial and chloroplast) genomes are also essential, because they specify proteins needed for respiration and photosynthesis, respectively. The Stern laboratory studies processes in plant chloroplasts, including carbon fixation and gene expression, and is also seeking to adapt the chloroplast to bioenergy production.

One long-time interest of the laboratory is enzymes called ribonucleases (RNases), that break down RNA chains. RNases both create the correct forms of RNA chains such as the RNA components of ribosomes, and also are required to recycle RNA to recover the embedded phosphorus, nitrogen, and carbon. Chloroplasts feature an "alphabet soup" of RNases, and the Stern laboratory is working to untangle the web of enzyme activities. How do these enzymes divide their work, and why does their absence cause such enormous stress to the plant – to the point where embryos and seeds are unable to develop? By using biochemical and genetic approaches, as well as high-throughput sequencing methods, some of the answers are being discovered.

In another project, the Stern laboratory is attempting to solve the decades-old problem of how the enzyme Rubisco, which incorporates atmospheric carbon dioxide into sugar backbones, is assembled. Because Rubisco is both essential and the most abundant enzyme on Earth, but also inefficient, plants invest a great deal of nitrogen and energy to synthesize it. Scientists have long wished for a "test-tube" method to optimize Rubisco, but because its assembly path isn't known, this is not yet possible. The Stern laboratory has now identified two previously unknown proteins that form part of this path, which could lead to a breakthrough in Rubisco biology and potentially improve plant yield.

As mentioned above, chloroplasts are the site of photosynthesis, where the sun's energy is used to create sugars, which in turn are incorporated into food, feed, and fiber. In one project, the photosynthesis machinery is being altered to create the potential for a "green battery" where chloroplast "juice" can be used directly to produce electricity. In a second project, genes from an alga that is very difficult to grow but makes unique hydrocarbons that can be very easily converted into diesel fuel, are being moved into other algae that are easily grown under controlled conditions, giving the potential for high-value bioenergy production. Both of these projects involve collaboration with engineers, who have created electrochemical cells and microfluidic devices to partner with genetic and molecular tools.

Joyce Van Eck, Ph.D.
Assistant Professor, BTI
Director, BTI Center
for Plant Biotechnology
Research

In plant research, time is of the essence. That's one reason BTI's scientists use model systems as stand-ins for the real thing: model plants that are smaller and quicker to mature and form seeds that are easier for researchers to grow and manipulate than the crops they represent. Model plants are particularly crucial to plant biotechnology, where they enable scientists to try out concepts and techniques that can be directly applied to solve real-world problems with crop plants.

Joyce Van Eck's laboratory is focused on applying the techniques of genetics and biotechnology to plant research, often using these model species to achieve their goals. Through metabolic engineering, Van Eck and her laboratory work on manipulating or inserting genes of interest into model species to investigate their potential for improvements in yield, vigor, and other measures of plant success.

Van Eck has recently been involved in an effort to enhance the utility of the model plant green millet (*Setaria viridis*). Like maize, sugarcane, and other grasses, green millet uses C4 photosynthesis to incorporate carbon into plant tissues, making it more efficient at using water and nitrogen than C3 plants. But unlike the economically important crops, green millet – a common weed – has a small genome, is relatively small in size, and has a rapid life cycle. Van Eck and her colleagues have successfully developed transformation systems by which temporary or permanent genetic changes can be introduced to the plant, making it a pliable system for learning about the features of C4 plants that enable their higher efficiency. Developing these and other techniques that enhance the usefulness of green millet as a model will enable Van Eck and her colleagues to further the effort to introduce C4 traits into C3 plants for the sake of improving the efficiency and yield of those crops.

Van Eck has also been involved in work with cell cultures from the Pacific yew tree, a species best known for its production of paclitaxel (Taxol®), which is used as a chemotherapy drug. Van Eck's laboratory has developed a consistent and repeatable transformation system for yew cell cultures that allows researchers to manipulate the plant's genes, making genetic engineering in yew cells possible. Moving forward, Van Eck and her collaborators are continuing work to explore the mechanisms by which the cells make paclitaxel, with the ultimate goal of enhancing the ability to manufacture the drug.

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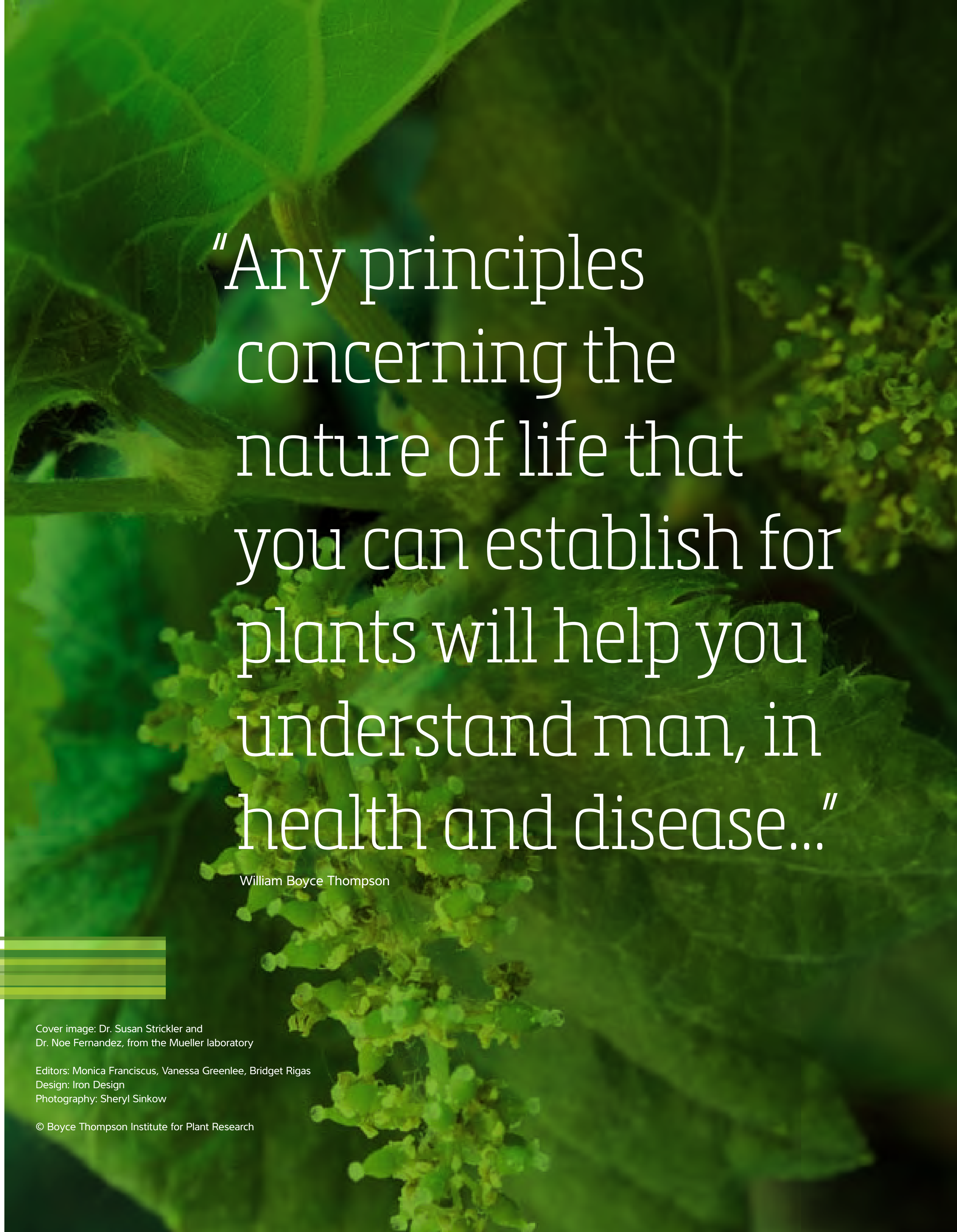

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William Boyce Thompson

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Boyce Thompson Institute for Plant Research
533 Tower Road
Ithaca, NY 14853
(607) 254-2923
bti_comm@cornell.edu
www.bti.cornell.edu