BTI 07

Boyce Thompson Institute for Plant Research

2007 Annual Report

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Cover: BTI Postdoctoral Fellow Tracy Rosebrock

LETTER FROM THE PRESIDENT

Rising prices at the gas pump. Melting ice sheets. Economic uncertainty. What do they have to do with plant research? The answer lies in energy, one of the main topics of this year's annual report. Yes, we need fuel for energy, but fossil fuels come at a high price not just in terms of dollars, but also sustainability, geopolitical concerns, and the environment. In 2006, 251,300 hybrid vehicles were sold in the U.S. compared to only 17 in 1999. Clearly, the public is concerned about energy.

So how can plants help? Plants are amazing converters of energy. Their light-capturing reactions through photosynthesis operate at well over 90 percent efficiency. When you consider that only 17 percent of the energy in a barrel of oil actually turns the wheels of your car, the comparison is striking. Plants store sunlight as chemical energy in the form of sugars, carbohydrates and structures, such as cell walls. Biofuels are derived most easily from the sugars plants produce, but chemical conversions make it possible to obtain energy – in the form of ethanol – from virtually any part of a plant. Nonetheless, only about seven billion gallons of ethanol were produced from plants – mostly corn – in the United States last year. That may sound like a lot until you compare it to our total 2006 consumption of 138 billion gallons of transportation fuels.

Bioenergy is sometimes viewed as a magic bullet that can solve our energy problems, but it is not. Bioenergy represents only one piece of an energy pie that includes other renewable resources such as wind, solar and hydroelectric power. Nonetheless, research and development related to bioenergy will play a key role in coming decades, and will be a major focus of research investment. As a world leader in basic plant science research, BTI is well-positioned to tackle problems central to making bioenergy production affordable and sustainable. The Institute is also committed to reducing its own energy footprint and, in the process, setting an example for others to help find creative solutions to our energy problems. I invite you to read more in our feature article that begins on page 6.

In other news, BTI continued its long-term commitment to excellence in research by welcoming two new faculty members, Ji-Young Lee and Frank Schroeder, whose research is summarized inside this report. And early in 2008, Sorina Popescu, currently a postdoctoral fellow at Yale University, accepted an offer to join our faculty in the fall. I am proud to welcome these talented scientists who will bring new research vigor and directions to the Institute.

BTI's education and outreach programs were very active in 2007. Applications hit a record high for our summer internships, and we joined with the Museum of the Earth to present "s*L*owlife," an innovative multimedia exposé of how plants move. We continued our sponsorship of the local Science Cabaret, with its broad agenda to educate and entertain the general public, and of "MicrobeWorld," a popular drive-time program presented by National Public Radio. In 2007, a grant from the American Society for Plant Biologists enabled us to broaden the presence of plant biology in "MicrobeWorld" programming.

2007 also saw European approval of Cervarix™, a cervical cancer vaccine produced in a BTI-developed insect cell line. The story of Cervarix and our cell line was featured in the 2005 BTI annual report, and we are pleased this important new vaccine has obtained commercial approval.

There's a lot more news inside this year's report, and I invite you to explore it. 2007 was a great year for BTI, and I want to thank our scientists, support staff, friends and donors who made it possible.

David Stern

IN BRIEF

We are continuously looking for opportunities to increase the public interest and awareness of plant biology. We have found these opportunities within our own building, and elsewhere in the community, state and country through a variety of programs.

Vivian Smith
Colonel's Cup Winner
2007

Nature Explorers

Outreach

BTI/Museum of the Earth Exhibit

This year, our collaboration with the Museum of the Earth culminated with the gala opening of "s*L*owlife" (http://plantsinmotion.bio.indiana.edu/usbg), an exhibit highlighting the movement of plants. Over 200 visitors attended the January 19 gala, and more than 10,000 people visited the exhibit during its four months at the museum. Elizabeth Fox, BTI's Outreach coordinator, offered students several hands-on activities as part of the exhibit, such as making seed necklaces and extracting DNA from strawberries. BTI scientists Tom Brutnell, Georg Jander, Peter Moffett and adjunct member Owen Hoekenga described their research in the museum's "Natural History at Noon" seminar series.

MicrobeWorld

"Engaging, clear and informative…these bite size doses of science are just the thing for anyone on the go with a thirst for knowledge." This is how one radio listener described the BTI and American Society for Plant Biologists-sponsored "MicrobeWorld" segments aired in 2007.

Seventeen features, including such topics as "Virus Killer Cocktail," "Proteins and Parsley" and "The Role of Microbes on Healthy Coral Reefs" reached approximately 210,000 listeners daily through public and commercial classical music stations.

Science Cabaret

This eclectic program fuses art, entertainment and science. Sponsored by BTI, "Science Cabaret" is held monthly at a venue in downtown Ithaca. Since its inception in 2005, 19 events have drawn crowds of 60 to 150 people from a wide age range. The program's diverse scientific themes, musical acts and the approachable nature of the science presenters have cultivated a regular following, yet each event continues to draw new members of the community.

The 2006-2007 season included presentations about ants, plant movement, overeating, land restoration in Costa Rica, race relations, how fish surf through life, insects as B-movie monsters, climate change, and the synchronicity of life.

Nature Explorers Program

During the spring semester our popular program "Nature Explorers" expanded to Beverly J. Martin Elementary School in Ithaca, and became part of its after-school sessions. Each week, BTI volunteers exposed the students to such topics as the diversity of the *Solanaceae* family of plants and the importance of seeds. The program was exceptionally well-received so we returned in the fall. We also added a more rural school to our fall program – Dryden Elementary School – where we presented such topics as "How Plants Take Up Water," "All About Trees" and "How Termites Lay Trails, Find Food and Communicate through Scent."

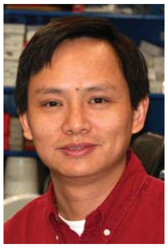
Internship Programs

Over 130 students applied for NSF-funded Plant Genome Research Program REU internships in 2007, and in the summer 17 students from around the country and two from Puerto Rico began their studies here. Fifteen BTI, Cornell, and USDA laboratories hosted the interns who explored such topics as cuticle biosynthesis in tomatoes and plant defense in tobacco and *Arabidopsis.* BTI also hosted three student interns from Ithaca-area high schools for six weeks in the summer. They were sponsored by a gift from Board member Carolyn Sampson. One of the 2007 interns, Samantha Goff, is now a freshman at Cornell University.

On August 10, our interns showcased their summer research at the sixth annual Colonel's Cup Challenge. Ashley Hipps, a Summer Undergraduate Research Program intern from Cornell, was awarded best poster. Vivian Smith, who said in her application that she had been advised "to pick an easier major than biology" and that "African-American females are not biologists," won the Colonel's Cup for best presentation. Vivian, who is a senior at Alcorn State University, wrote "…my summer at Cornell was one of the best experiences I've had. So, I want to thank you for choosing me to be a part of such a wonderful group of people." Many other students expressed their appreciation of the program as well. Zach King from SUNY-ESF wrote, "I wanted to thank you once again for allowing me to have such a phenomenal experience this summer at BTI. I have 'grown' a passion for plant science!"

Teacher Education

BTI also reaches out to high school teachers during the summer, helping them create plant science lesson plans. This year, six teachers visited BTI and developed course material based on the *Solanaceae* family of plants as model systems. The teachers also heard talks by BTI and Cornell



Fangming Xiao

Boyce Thompson Institute

Boyce Thompson Arboretum

scientists on topics including fruit ripening and plant disease. In praise of the program one teacher said, "…I learned a lot and can now incorporate more real-life knowledge into my teaching."

Other Outreach and "In-reach" Activities

BTI volunteers participated in a number of Cornell campus events in 2007, including "4-H Career Explorations University U" for students entering grades 8 and 9. They also hosted visits from home-schooled students and other groups.

Last year we focused on our own BTI community and "in-reach," as well. During the spring and fall semesters, BTI's support staff explored tissue culture techniques with Joyce Van Eck, learned more about biofuels from Tom Brutnell, and about insects from Alan Renwick.

Honors and Awards

Fangming Xiao, a postdoctoral fellow in Gregory Martin's laboratory, received the Lawrence Bogorad Molecular Plant Biology Award in 2007. The award was established to honor and celebrate Lawrence Bogorad, who was a scientist and longtime BTI Board member, for his accomplishments in science and his commitment to BTI. The Bogorad Award is given annually to an outstanding BTI postdoctoral fellow, following nominations by BTI faculty. Selection of a winner is based on such criteria as publications, research accomplishments, presentations, and other honors and awards nominees have won. The award, which recognizes research excellence in postdoctoral scientists at BTI, carries a modest cash prize.

Boyce Thompson Arboretum

Since its founding in 1929 by William Boyce Thompson, the 320-acre Boyce Thompson Arboretum (BTA) – a sister institution to BTI – has become an extraordinarily beautiful botanical garden and natural area enjoyed by more than 65,000 visitors each year. Located in Superior, Arizona, it also plays an important role in education and research. In recog-nition of its achievements, the Arboretum was reaccredited in 2007 by the American Association of Museums. BTA is one of only 775 accredited U.S. museums.

2007 was also an important year for grants. One from the Drachman Institute at the University of Arizona provides funds to develop a master plan for a multi-use area with a multi-use facility. Another from the Wallace Research Foundation funds continuation of BTA's work on *Legumes of Arizona – An Illustrated Flora and Reference.*

BTA also completed its first Long-Range Research and Conservation Plan. The plan calls for the Arboretum to focus on such program areas as seed banking, field testing, biomedical screening, floristics, taxonomy, and systematics. It also identified the plant family *Fabaceae* (legumes) as a focus of core activities.

For the future, BTA is considering a long-term project to examine biotic changes at the Arboretum as they relate to variations in climate. In all likelihood, BTA will partner with another organization that is experienced in this area.

The BTI Post-Graduate Society

Founded in 2004, the Post-Graduate Society (PGS) carries out its mission by providing opportunities for the BTI community to interact scientifically and socially, and by organizing events that specifically address the career development needs of young scientists. As an organization of postdoctoral fellows, graduate students and technicians, PGS promotes its members' professional development, fosters a sense of community among them, facilitates communication, and ensures their representation at BTI.

BTI Career Day

Career Day, organized by Sarah Covshoff, a graduate student in the Brutnell lab, was held in June. In 2007, the PGS partnered with the American Association for the Advancement of Science (AAAS) for the event, which had high attendance and received rave reviews from participants. The program featured a talk on non-traditional career paths for Ph.D.s by AAAS Outreach Coordinator Garth Fowler, Ph.D., and a panel discussion with speakers who received doctoral degrees in the sciences and then pursued a wide range of non-traditional careers.

PGS Retreat

In August, BTI scientific personnel gathered for the annual PGS-sponsored retreat. The one-day retreat featured talks by Larry Walker, Ph.D., Department of Biological and Environmental Engineering, Cornell, on biofuel production, and by Rebecca Nelson, Ph.D., Department of Plant Pathology, Cornell, and the McKnight Foundation, on

BTI Alumni Society

Ethanol manufacturing

Global warming and New York

"Science, Society and Self." PGS members also shared their research in a judged poster session and ended the day with social and sporting activities.

PGS-sponsored Lectures

These annual distinguished lectures are a great opportunity for the BTI community to hear from some of the world's most creative scientists. In 2007, distinguished lecturers were Maarten Koornneef, Ph.D., Max Planck Institute, Cologne, Germany, and Caroline Dean, Ph.D., John Innes Centre, Norwich, U.K. In addition to the seminar, PGS members were able to speak with the lecturers during lunches and happy hours.

Professional Development Lunches

The PGS-sponsored professional development lunches included talks by Maria Harrison, Ph.D., BTI, on writing CVs and resumes; David Way, Ph.D., Center for Learning and Teaching, Cornell, on preparing teaching statements; and Nancy Trautmann, Ph.D., Cornell Graduate Student School Outreach Project, on careers in outreach fields.

Seminars and Fun

PGS-invited speakers from Cornell and the surrounding area gave afternoon seminars followed by a social hour during which the BTI community discussed and debated the seminar topics.

The New BTI Alumni Society

2007 marked the establishment of the BTI Alumni Society, which aims to re-establish and strengthen BTI's contact with the hundreds of alumni who have learned at or served the Institute over many years. Society members include former service staff, technicians, postdoctoral fellows and research associates, as well as faculty who have either moved on to other institutions or have retired from BTI.

One of the Society's objectives is to bring alumni back to the Institute to see our new facilities. We also want to provide them with an opportunity to learn about current research, and to meet and socialize with other alumni. To do that, we will invite alumni from throughout the United States and the world to events organized especially for them. The events will feature seminars by Institute faculty and by alumni on their research or other accomplishments.

October 2007 marked the first Alumni Society event, which was attended primarily by alumni and friends from the central New York area. The all-day program featured a talk on global warming by David Eichorn, meteorologist at WSYR in Syracuse. Eichorn has been a long-time observer of climatic trends in central New York, and attended Al Gore's training session on climate change. His presentation covered the anticipated global and local effects of climate change, with an emphasis on what may happen in central New York.

The day's activities also included a tour of the Institute's newest facilities, mini-seminars by several BTI scientists, and a social event at the end of the day. About 50 alumni and friends attended this first annual Alumni Society event.

National Agricultural Biotechnology Council

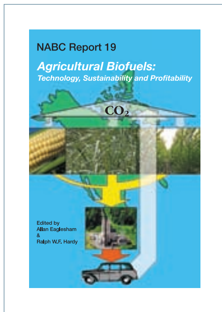
The National Agricultural Biotechnology Council (NABC), founded in 1989 by former BTI President Ralph Hardy, continues to operate from the Institute. In 2007, the NABC focused on bioenergy and the development of sustainable feedstocks.

As part of that focus, NABC released its bioenergy strategic plan, entitled "Agriculture and Forestry for Energy, Chemicals and Materials: The Road Forward." The plan (http://nabc.cals.cornell.edu) calls for U.S. agriculture and forestry industries to provide feedstocks sufficient for the production of more than 100 billion gallons of biofuel per year by 2035. It was signed by the NABC council members, including current BTI President David Stern, and was broadly distributed to decision-makers.

The NABC plan further recommends a national mobilization of academia, government and industry to generate the needed science and technology to achieve the 2035 goal. Benefits include enhanced national security, environmental and agricultural sustainability, and rural development. The plan targets a cost of $1 per gallon for biofuel production, and calls for the U.S. to devote 50 - 100 million acres of underutilized land for the production of biofeedstocks.

A new "golden age" is envisioned for domestic agriculture and forestry, providing the sustainable feedstocks and products that will help address many of the most challenging societal concerns of the 21st century. Accordingly, NABC is focusing its 2007 and 2008 meetings on these new megatrends for agriculture and forestry.

A best place to work for postdocs



Bioenergy: The Road Forward

BTI in the News

From being named a best place to work by *The Scientist* magazine to an announcement of a $1.8 million NSF grant, BTI enjoyed the news spotlight in the following 2007 articles:

"Cornell and BTI receive $1.8 million from National Science Foundation to continue tomato sequence project," ChronicleONLINE, January 30, 2007 (www.news.cornell.edu/stories/Jan07/SolanacaeNSF.kr.html): The principal investigator on this grant, which continues the International Tomato Sequencing Project, is Jim Giovannoni of BTI, USDA and Cornell. The goal of the project is to sequence the entire tomato genome and make the information part of the public database supporting research in the *Solanaceae* family of plants. The original $4 million NSF grant was awarded in 2004.

"Best Places To Work for Postdocs, 2007," *The Scientist*, May 2007: *The Scientist* magazine named BTI one of the top 15 places in North America for postdoctoral fellows to work. The publication conducts an annual survey to determine the fellows' satisfaction with their employer institutions. They rate their institution in 11 categories, including how satisfied they are with the facilities, the quality of mentoring, and opportunities for career development. Congratulations to our faculty and staff for this significant achievement.

"A Plea for Wider Ethical Responsibility," Carl Leopold, American Society of Plant Biologists, *ASPB News*, Vol. 34, No. 1: 13: In the March issue of *ASPB News*, BTI Emeritus Scientist Carl Leopold urged his fellow scientists to broaden their view on ethical responsibility. Leopold warns scientists and others that we must focus on ethics associated with our own impact on the environment or face the consequences. In the article he asks, "Can we claim that our science and our technologies will allow us to adapt to the collective changes that we are imposing on our environment?...It is possible that Global Bioethics may be the most important concern in contemporary human history."

Automating BTI's Business System

Our Business Office has deployed Microsoft Business Solutions Serenic Navigator, a state-of-the-art, not-for-profit accounting system, which has made more data available to us than ever before. Our challenge is to develop new uses for this material, harness the power of the software and put it in the hands of our scientists.

To address this goal, we began a business systems modernization project in 2006. By the time the project is complete, our processes for billing, reviewing account information and purchasing will be significantly more streamlined and more accessible. Reducing the amount of paper-based record keeping will save the Institute time and money, develop new skills among our Business Office staff and affirm BTI's social and ethical responsibility to go "green." Our scientists will also benefit by having budget information more readily available, and a better environment in which to work.

Automating our business systems is a multifaceted project with four primary components:

- **Web-based internal services billing module:** This project is complete and provides us with an internal billing system that is integrated with our accounting system.
- **Online purchasing:** This system will integrate our purchasing, inventory control and accounting systems; it will allow purchasing from vendors or inventory with a common user interface; and it will provide the ability to replicate, place and track purchases from outside vendors via the Web.
- **Online account access:** With online accounts, our managers are now able to electronically generate project cost reports with Web-based, real-time, user access to all their account information. Future system enhancements will make report generation easier and provide electronic billing capabilities linked to the accounting system.
- **Streamlined business processes:** BTI's business systems and processes will be further enhanced through the User Manager, which will control user information for all electronic systems, manage passwords, provide user accounts and manage access to building services.

When Gre

“In the middle of every difficulty lies an opportunity.”

– Albert Einstein

The United States alone emitted over 7.2 billion metric tons of greenhouse gases into the atmosphere in 2005. Three-quarters of greenhouse gas emissions world-wide result primarily from the burning of fossil fuels for energy.

As responsible citizens of the U.S. and the world, we must dedicate ourselves to reducing the amount of energy we consume. We must also support the development of automobiles and equipment that run more efficiently. One short-term solution is to supplement – and later replace – a portion of our current energy sources with fuels made from plants and plant material. BTI intends to contribute, through basic research, to the development of biofuel raw materials – known as biofeedstocks – that can be grown in a sustainable manner.

“Though reducing energy consumption should be everyone’s foremost goal,” says BTI President David Stern, “biofuels can eventually replace a significant proportion of the liquid fossil fuels that will still be required. Biofuels have long been available, but they now have an opportunity to become cost-competitive with oil. BTI and other research institutions have the ability and the obligation to contribute to 21st-century energy solutions.”

There are significant scientific, environmental and technological hurdles to overcome, however, if the government’s goal to replace 30 percent of current U.S. petroleum consumption with biofuels by 2030 is to be achieved. Among other things, meeting the benchmark will require significantly increased grain yields, use of no-till methods on all cropland, and dedication of at least 55 million acres of idle cropland and pasture to perennial grasses. While this is feasible in principle, there are sustainability issues.

Basic plant research will not provide all the answers, but insight into the molecular basis of plant processes can lead to applied strategies for optimizing plants as biofuel sources in ways that are sustainable. Because of the significance of this topic, it is worth highlighting how some BTI scientists are contributing to the bioenergy issue.

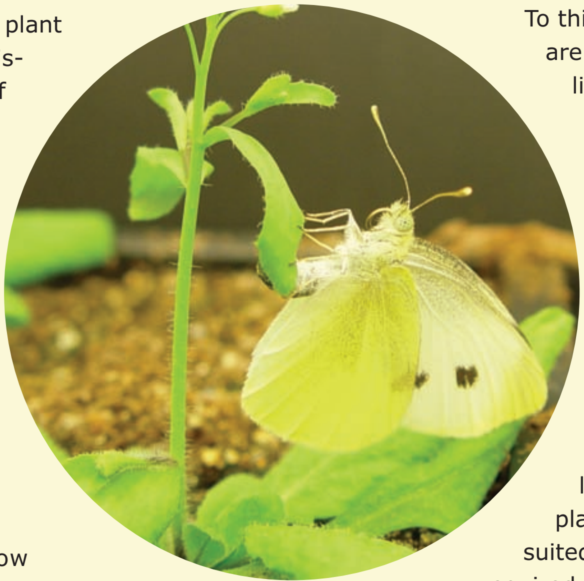
en is Gold

How BTI research applies to the bioenergy revolution

More eco-friendly ways to battle insects and disease

Growing more crops per acre is essential for reaching the U.S. biofuel objective, but this strategy can also lead to increased insect populations and, therefore, increased crop damage and disease. If producers respond by using more chemical inputs, such as insecticides, to control pests, agricultural sustainability will suffer.

But, in potentially applicable research, several BTI teams are studying how plants naturally defend themselves against disease, while others are finding new ways to transfer disease resistance from one plant to another. Dan Klessig made breakthrough discoveries about how a plant acquires systemic immunity to disease when only a small portion of its tissues have been infected (page 16). Peter Moffett's laboratory (page 17) is also studying disease resistance from a different angle. He and his colleagues want to know how plants sense the presence of a specific pathogen and then mobilize a defense against it. Recently they discovered a protein present in all plants that is key to the process.



Greg Martin's laboratory (page 17) is working to understand how plants lose immunity to a particular disease. His team has discovered that certain bacteria have evolved the ability to sabotage the plant's immune system. Knowing how plants acquire systemic immunity, how they recognize the presence of pathogens, and how pathogens overcome a plant's defenses could eventually lead to the engineering or enhanced breeding of biofuel crops that can be grown more densely with fewer pesticide applications.

Research that explains how plants naturally protect themselves from insect pests is important to our clean energy goals as well. Georg Jander's team (page 15) is working with *Arabidopsis* plants and white cabbage butterflies to better understand the biochemical arsenal plants deploy against insects. This could suggest new ways to control pests by enhancing the plant's natural resistance to insect attack.

More efficient use of sunlight

Another effect of packing more plants onto every acre is loss of yield through shading: less space between plants reduces the amount of sunlight each plant receives. A better understanding of how plants harvest sunlight and use its energy could maximize yields and minimize the negative effects of overcrowding.

To this end, several BTI laboratories are studying the molecular basis of light-related processes in plants, such as photosynthesis and light signaling pathways. While Haiyang Wang's group (page 19) is using the model plant *Arabidopsis* to study each step in a plant's light responses, Tom Brutnell's laboratory (page 13) is looking for ways to apply this knowledge to enhance corn and related biofuel crops. Work by both teams may lead to the development of crop plants and grasses that are better suited to the crowded conditions required for biomass production.

Understanding the regulation of photosynthesis – the process through which plants use sunlight to incorporate carbon dioxide into sugars – could lead to plants that are more efficient. To that end, Brutnell's team is also studying a type of photosynthesis, called C4, which is used by corn and many perennial biofeedstock grasses, such as switchgrass and Miscanthus. In related research, BTI President David Stern (page 18) has already made important discoveries about how plants regulate their fixation of CO_2 – information that could help enhance their ability to incorporate even more carbon dioxide from the air.

(Continued on next page)

BTI Sponsors Biofuels Symposium

On December 14, 2007, BTI hosted a mini-symposium entitled "Biofuels and Bioenergy: Developing the Infrastructure for Global Change." The symposium featured speakers from Cornell University, the Cornell Agricultural Experiment Station at Geneva, the campus Institute for Genomic Diversity, and the Carnegie Institute of Science at Stanford University.

The speakers covered a wide variety of topics related to bioenergy, including the use of sorghum and switchgrass, New York's production of bio-feedstocks, the use of geospatial modeling in biomass feedstock production, the role of the Geneva Experiment Station, and an overview of the economics of biofuels.

A highlight of the day was Jocelyn Rose's announcement of the "Cornell Initiative for Sustainable Bioenergy Crops." The principal objective of the new initiative is to encourage the development of bioenergy. With BTI as a partner, the Cornell Initiative will sponsor a seminar series that will bring scientists, investors and politicians to the campus, providing insight into the major scientific issues involved and information about funding that is available to faculty and students. The Initiative will also provide a portal for outsiders to learn about bioenergy-related activities and research on the campus, and it will develop new bioenergy courses for students. Cornell also recently established the "Center for a Sustainable Future," which has a broader, but overlapping, mission. These two new programs reinforce BTI and Cornell's commitment to sustainability in research and in practice.

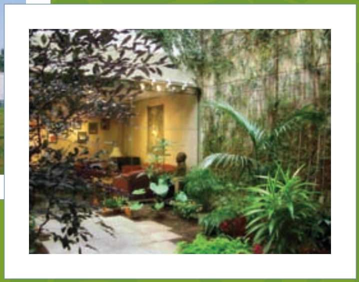
Less fertilizer

Dense growth also means that plants must compete with each other for essential nutrients, which growers mitigate by using nitrogen and phosphate fertilizers. However, not all the fertilizer can be absorbed by the plants and the remainder can trigger algae blooms in lakes and streams through run-off. Maria Harrison's laboratory (page 15) is working to understand a natural plant/soil fungus relationship in which the fungi provide the plant with naturally-occurring phosphate from the soil in return for carbon. Her laboratory's future discoveries could lead to crop plants that use naturally-occurring soil phosphate more efficiently and completely, which would have positive implications for increasing yields without a concomitant increase in chemical fertilizer use.

The Role of BTI

BTI research into how plant processes are regulated at the molecular and chemical levels may help overcome some of the challenges involved in the effort to replace fossil fuels with biofuels. At the same time, making the Institute's facilities and ways of doing business more eco-friendly will help BTI fulfill its societal responsibility to become more efficient in its use of energy by lowering its "carbon footprint."

"BTI, as a leading plant science research institute, has an important role to play in bioenergy research – an area we've identified as a high priority as we plan for the future," says Stern. "We are also doing everything we can from an institutional standpoint to reduce our consumption of energy and other non-renewable resources."



Atrium

The "Greening" of BTI

From its tropical plant-draped atrium to its light-infused greenhouses, BTI has always featured the color green. But in the last several years, we have made a number of infrastructure and other improvements that are turning the Institute green from an energy use point of view. According to BTI President David Stern, it's as important to reduce the Institute's own energy footprint as it is to sponsor basic research that will lead to more sustainable agriculture. "Attention to the environment and energy usage starts in our homes and in our workplaces," he says.

Since 2003, the Institute has reduced its energy consumption, as measured by BTU's, by nearly 60 percent. Under the guidance of Larry Russell, director of operations, BTI replaced all its growth chambers with more energy efficient models, installed a state-of-the-art system to control conditions in the greenhouses, improved window insulation and installed an R-25 roof. We also installed Hawkeye sensors that reduce the volume of ventilation air exhausted through the fumehoods when the lights in the labs are turned off, and we improved the performance of the myriad valves, switches and pumps that create the climate in our building.

In other efforts to be green, we no longer use Styrofoam cups, we purchase compostable plates and utensils, we have mandated double-sided printing, and we require everyone to use paper containing a significant portion of post-consumer waste.

Future plans include:

- Using cold outside air to produce chilled water for temperature and humidity control in greenhouses and growth chambers
- Replacing our hot water system with an on-demand system
- Installing shade cloth and retractable, insulated barriers in a few greenhouses and then assessing the energy savings they provide
- Studying the feasibility of a heat recovery system

2007 PUBLICATIONS: A FRUITFUL YEAR

In 2007, BTI researchers published more than 50 scientific papers in a wide variety of prestigious journals, including Science, Nature, Proceedings of the National Academy of Sciences, Plant Cell, The Plant Journal, *and* Journal of the American Chemical Society.

Five of the articles appeared in Science *and* Nature *and reported on highly significant basic science breakthroughs at the molecular level. Following are summaries of the five papers:*

Science

Methyl Salicylate Is a Critical Mobile Signal for Plant Systemic Acquired Resistance. S.-W. Park, E. Kaimoyo, D. Kumar, S. Mosher, and D.F. Klessig (5 October 2007) Science *318, 113-116.*

Working with tobacco plants as a model system, Dan Klessig and his colleagues identified a compound, called methyl salicylate (MeSA), that is critical for turning on defenses against infection throughout a plant. Scientists have been searching for this mobile messenger for more than a quarter of a century because its existence as a signaling, or communication, compound helps explain how an entire plant acquires resistance to a disease when only a small portion of its tissues have been infected. Understanding how this system works could one day lead to crops that more effectively protect themselves from disease – an advance that could make agriculture more sustainable than it is today.

The Chlamydomonas *Genome Reveals the Evolution of Key Animal and Plant Functions. S.S. Merchant, et al (12 October 2007)* Science *318, 245-250.*

Co-authored by David Stern and scientists from many other institutions, this paper describes research on the genome of a unicellular green alga (*Chlamydomonas reinhardtii*), which is a eukaryotic cell (a cell with a nucleus). This alga diverged from land plants over a billion years ago and is actually half plant and half animal, which makes it an excellent model system for the study of chloroplast-based photosynthesis (plant) as well as cell motility (animal). The authors report that they sequenced the genome of *Chlamydomonas* and identified genes that in all likelihood are associated with the function and biogenesis of chloroplasts and flagella in eukaryotic cells. Theirs and other research with this alga has advanced our understanding of eukaryotes, revealed previously unknown genes associated with photosynthesis, and has important information about flagellar function.

A High-Resolution Root Spatiotemporal Map Reveals Dominant Expression Patterns. Siobhan M. Brady, David A. Orlando, Ji-Young Lee, Jean Y. Wang, Jeremy Koch, Jose R. Dinneny, Daniel Mace, Uwe Ohler, Philip Benfey (2 November 2007), Science *318, 801-806.*

BTI scientist Ji-Young Lee co-authored this paper with her post-doctoral advisor, Philip Benfey, of Duke University. In it, Lee and others report on their use of microarray techniques to better understand how and why stem cells and tissue in plants will suddenly begin to divide and specialize. Though we usually think only of mammals as having stem cells, plant stem cells are always present in the tips of stems, shoots and roots. When they divide, they generate daughter cells, which differentiate according to their location. This process enables plants to grow continuously. Using *Arabidopsis* root as a model system, Lee's lab is studying the underlying genetic factors that cause plant stem cells in procambium/cambium tissue to divide and generate specialized vascular tissues. The paper in *Science* describes a series of experiments that provided new information about gene expression and regulation in every cell type and in the differentiation process of roots – knowledge that is essential to understanding and influencing how plants grow.

Transposase-derived Transcription Factors Regulate Light Signaling in Arabidopsis. *Rongcheng Lin, Lei Ding, Claudio Casola, Daniel R. Ripoll, Cedric Feschotte, Haiyang Wang (23 November 2007)* Science *318, 1302-1305.*

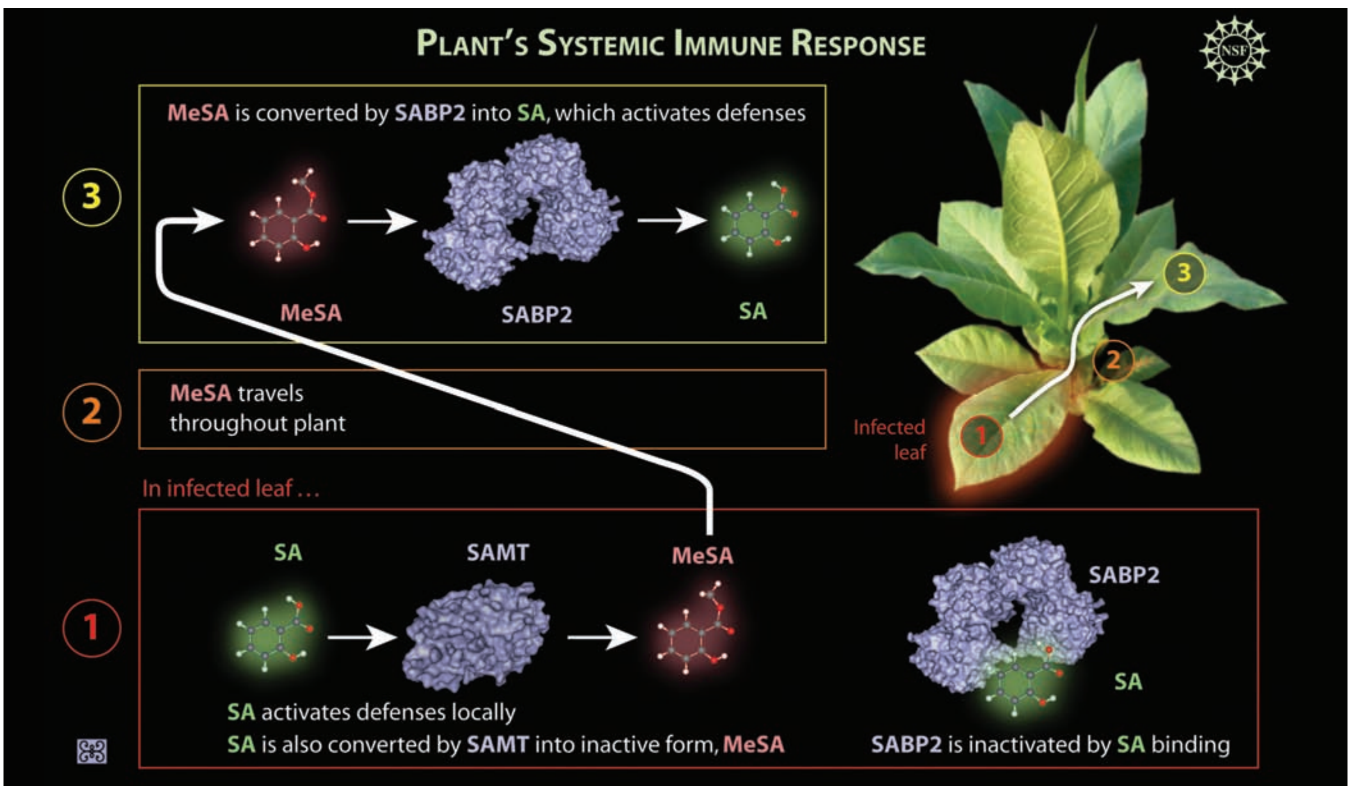
Plants respond to light by growing, flowering and leaning toward their light source. In this paper, Haiyang Wang and colleagues report important findings about the process that controls how plants respond to light, and perhaps even how such responses evolved. They showed that when far-red light photons hit specialized proteins (photoreceptors) in the cell, the photoreceptors are activated and move into the nucleus of the cell, which in turn triggers the plant's light response. The scientists found that two additional proteins, named FHY3 and FAR1, act in the nucleus to regulate the production of other proteins essential for the nuclear translocation of the photoreceptors. These findings add an important new dimension to our understanding of how light responses are achieved. The ability to fine tune a plant's response to light could significantly benefit agriculture by leading to plants that yield more, produce more biomass or could be grown in greater numbers on a fixed amount of land.

Nature

A bacterial E3 ubiquitin ligase targets a host protein kinase to disrupt plant immunity. *Tracy R. Rosebrock, Lirong Zeng, Jennifer J. Brady, Robert B. Abramovitch, Fangming Xiao and Gregory B. Martin (19 July 2007)* Nature *448, 370-374.*

There's a battle underway between plants and disease-causing bacteria in which the bacteria mimic a certain protective plant protein, causing the plant's immune system to disarm itself. It's a clever game in which the plant's inability to defend itself ensures the survival of the bacterium. How this system works between tomatoes and a bacterium that causes tomato speck disease is explained in this *Nature* paper by Greg Martin and his associates. Among other findings, the paper reports that the tomato's resistance to the disease is probably an ancient defense strategy, and that the bacteria have only recently evolved the ability to thwart it. Understanding the strategies pathogens use to overcome plant immunity may lead to crops that have more effective, longer lasting resistance – an advance that could lead to more productive varieties and less dependence on pesticides.

All of the papers published by BTI researchers between 2001 and 2007 can be accessed at http://www.bti.cornell.edu/listpubs2.php



MeSA is a critical mobile signal for plant immunity.

ARRIVALS AND DEPARTURES

In 2007, two new faculty members joined BTI, 15 post-doctoral fellows from 10 different countries arrived, and eight postdoctoral fellows and research associates left the Institute for positions in a wide variety of academic institutions and corporations.

Two Scientists Join BTI Faculty

Ji-Young Lee, Ph.D., and Frank Schroeder, Ph.D., joined BTI in 2007, which increased the number of principal investigators on our faculty to 14.

Dr. Lee studies the evolution of root development across plant species. Root development occurs in response to both internal signals and external environmental changes, and various plant proteins regulate the activity of genes during the process. Understanding the function of these proteins in plant regulatory networks is the focus of her work.

Dr. Lee completed her Ph.D. at the University of California, Davis, where she worked with Dr. John Bowman. She conducted her postdoctoral work at Duke with Dr. Philip Benfey.

Dr. Schroeder, who previously collaborated with BTI Scientist Georg Jander, Emeritus Scientist Alan Renwick and former BTI Scientist Alice Churchill, studies the structure and function of small molecules from plants, arthropods, fungi and bacteria. His work has applications in the design of new pharmaceuticals, and he holds four patents related to the use of natural compounds for pest control, as herbicides and for therapeutic purposes.

Dr. Schroeder received his undergraduate and Ph.D. degrees from the University of Hamburg, Germany, where he worked with Dr. Wittko Francke. He then joined Dr. Jerry Meinwald's lab at Cornell University as a postdoctoral fellow. In addition to his BTI faculty position, Dr. Schroeder currently works in collaboration with Dr. Meinwald and Dr. John Clardy at Harvard Medical School.

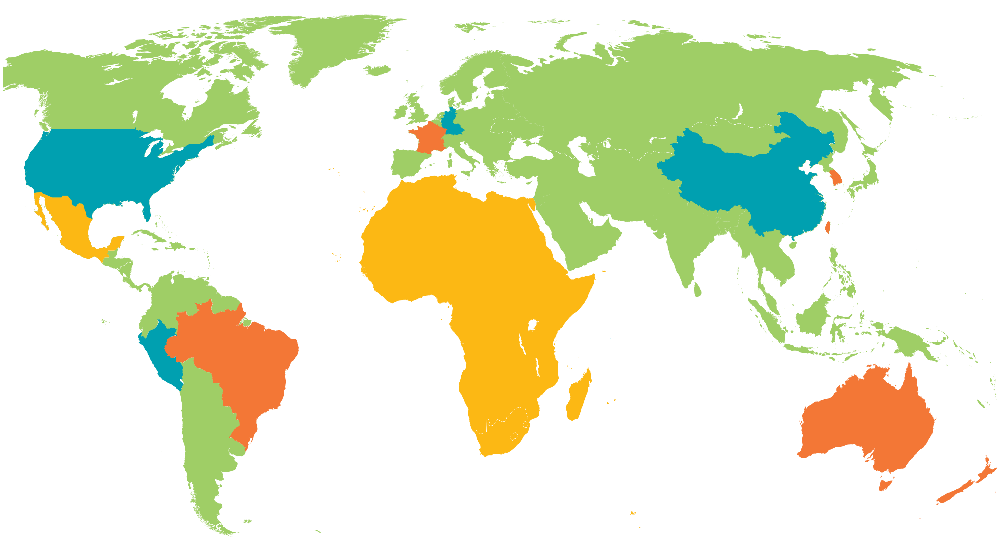
Both Dr. Lee and Dr. Schroeder, who began their work at BTI in the summer, bring new areas of expertise to BTI that enhance current research programs.

Postdoctoral and Research Associate Departures

Launching new scientists into academic and corporate careers is one of BTI's most important educational roles. The Institute is proud to announce that eight of our post-doctoral fellows and research associates left us in 2007 for challenging new scientific positions at a variety of institutions. These scientists joined Monsanto, DuPont, Genscript, TORAY Biotech, Organogenisis, Michigan State University, Indiana University and University of Zambia.

Postdoctoral Arrivals

Fifteen postdoctoral fellows arrived at BTI in 2007 from 10 different countries.
France • Germany • China • Korea • Taiwan • Mexico • Brazil • Peru • New Zealand • USA



BTI's new postdoctoral fellows received their Ph.D.s from the following institutions:

Laboratoire des Interactions Plantes Micro-organismes, France

Huazhong Agricultural University, China

Max Planck Institute, Germany

Seoul National University, Korea

Cornell University, New York

Lab of Molecular Ecophysiology, France

USDA, Maryland

SUNY ESF, New York

French National Education and Research Department, France

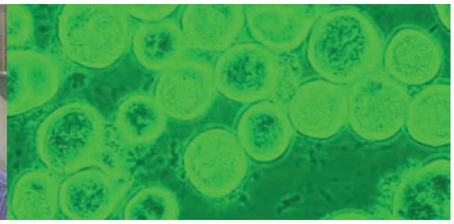
Oregon State University, Oregon

Kansas State University, Kansas

Environmental Associates, New York

How do viruses infect insect pests?

Gary Blissard, Ph.D.
Vice President for Research and Scientist, BTI
Adjunct Professor, Dept. of Microbiology and Immunology and Dept. of Entomology, Cornell University

Certain viruses are our allies in the fight against insect pests. Research that leads to a better understanding of the viral infection process could in turn lead to more environmentally friendly, natural insect control.

Among other research projects, **Gary Blissard** is studying how certain viruses, called baculoviruses, infect insects. He and his colleagues have focused on how a particular baculovirus envelope protein, called GP64, enables the virus to invade an insect cell, insert its DNA into the cell, and then multiply and exit in massive numbers.

Blissard's group has 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 receptors on the surface of the host insect cell, which is the first step in the process of infection. In 2007, Blissard's lab identified the particular portion of GP64 that is responsible for this binding activity.

After the virus binds to the host cell, it enters the cell where it is surrounded by the cell's membrane. To cause infection, the virus must fuse with that membrane and deliver its DNA into the cell nucleus. Having proved that GP64 is independently able to fuse membranes, Blissard's team is now investigating how this process occurs.

The third step in the infection cycle calls for new virus particles to emerge, or "bud," from the cell surface. To determine whether GP64 played a role in virus budding, Blissard's lab "knocked out" the gene for the GP64 protein, which severely limited virus budding, and the remaining new virus particles were not infectious. These studies show that GP64 plays a critical role in the assembly of the new virus particles. Current studies aim to understand these three major functions of GP64 in much greater detail.

Knowing how baculoviruses infect insect cells may enable scientists to improve the virus' insect control capabilities, which could reduce the use of chemical pesticides. But this work also has other exciting applications, such as in gene therapy. Because baculoviruses cause disease only in insects and because they are highly effective at entering cells and depositing DNA in the cell nucleus, they may be excellent vehicles for inserting beneficial new genes into mammalian cells – an advance that could improve our ability to safely correct genetic disorders in humans.

How does maize produce beta-carotene?

Tom Brutnell, Ph.D.
Associate Scientist, BTI
Adjunct Associate Professor, Dept. of Plant Biology and Dept. of Plant Breeding and Genetics, Cornell University


Two BTI laboratories – Brutnell and Van Eck – are studying the genetic basis of beta-carotene production in certain staple foods (see Van Eck, page 19). Beta-carotene is a carotenoid and is the precursor to Vitamin A, which can prevent eye diseases and health disorders that currently plague hundreds of millions of children in the developing world. In their studies with maize, which is low in beta-carotene, **Tom Brutnell's** laboratory is working to enhance beta-carotene production in that crop – research that could lead to more nutritious varieties of corn, and healthier diets for some of the world's poorest people.

Brutnell's team previously proved that the enzyme lycopene beta-cyclase is required for the first step in beta-carotene production in maize. However, his laboratory recently showed that co-expression of the lycopene beta-cyclase enzyme with another enzyme, called lycopene epsilon-cyclase, leads to the accumulation of lutein rather than beta-carotene in seed tissues. This is because epsilon-cyclase is often expressed at high levels in seed tissues, where it competes with the beta-cyclase for the lycopene.

Next, Brutnell discovered rare alleles, or alternative forms of the epsilon-cyclase gene, that are associated with high levels of beta-carotene production. Brutnell's laboratory then used a polymerase chain reaction assay to monitor levels of the epsilon-cyclase enzyme transcripts during maize seed development. These studies confirmed that the gene's expression levels are consistently low in maize lines that produce high amounts of beta-carotene, and high in lines that produce high levels of lutein. Therefore, the ability to single out rare maize alleles with low epsilon-cyclase production could lead to the development of lines that produce more beta-carotene.

To that end, the team developed a polymerase chain reaction toolkit – currently being tested in Mozambique – that enables African corn breeders to identify these rare alleles in North American germplasm and then cross these plants with lines that have been adapted for optimal growth in Africa. The assay is relatively inexpensive, and will help African breeders generate high beta-carotene-producing lines of corn.

How are massive plant genomics data organized and interpreted?

Zhangjun Fei, Ph.D.
Assistant Research Scientist, BTI

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 all of 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 biological research. **Zhangjun Fei's** 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. He also has developed analytical and data-mining tools that allow scientists to efficiently extract biological information from the database for use in their research.

Fei has collaborated with the Giovannoni laboratory at BTI to develop databases that contain information on the expression of more than 10,000 tomato genes, as well as profiles of tomato fruit nutrition and flavor-related metabolites, during different developmental stages, upon various stresses, and in different genetic backgrounds. As a part of International Cucurbit Genomics Initiative (ICuGI), the Fei lab has also developed a database, along with its corresponding interface and tools, for the organization of all the genomics information gathered to date on the cucurbit family of plants, which includes melon, watermelon, cucumber and pumpkin, among others.

Work in Fei's laboratory is providing tools and resources that organize genomics information about an organism into a form scientists can easily use to analyze and visualize the data they've gathered.

How do fruits ripen?

Jim Giovannoni, Ph.D.
Adjunct Scientist, BTI
Plant Molecular Biologist, USDA-ARS Plant, Soil and Nutrition Laboratory
Adjunct Professor, Dept. of Plant Pathology, Cornell University

Learning the genetic basis of fruit ripening could significantly impact the quality and availability of certain foods. This knowledge would be particularly useful in countries where food spoilage due to over-ripening is a cause of hunger.

Jim Giovannoni's laboratory at BTI is working to understand the process by focusing on the genes and regulatory networks that control fruit ripening in tomato – knowledge that will have applications in other plants such as pepper, peach, pineapple, banana, strawberry and melon. Because many fruits ripen in response to the release of the hormone ethylene, understanding the mechanism that controls the plant's sensitivity to ethylene can lead to basic knowledge about the ripening process.

In studying mutant tomato plants that produce only unripe tomatoes, Giovannoni's team discovered an alteration in a gene called *Gr*, or *Greenripe*, that causes overproduction of a certain protein in the fruit that decreases the fruit's sensitivity to ethylene. So, though the plants produce ethylene in normal amounts, the fruit does not respond to it and, therefore, fails to ripen. Being able to control the production of this protein, which would make the fruit under- or over-sensitive to ethylene, could lead to the ability to speed or delay the ripening process.

Giovannoni further found that overproduction of the Gr protein throughout the plant has no effect on any part of the plant except the fruit. This discovery is important because it indicates there are constituents specific to the fruit involved in its response to ethylene.

The next step in the research is to develop transgenic tomato plants in which the *Gr* gene has been "knocked out," or disabled, so that the plants are no longer able to produce the Gr protein. This work will demonstrate whether or not normal *Gr* expression plays a significant role in ripening. Giovannoni predicts that these plants will be highly sensitive to ethylene and will, therefore, ripen early.

The ability to control the ripening process by controlling the ethylene response could lead to fruit, such as strawberry, papaya and even tomato, that have a longer shelf life. Because ripening is directly related to fruit flavor, texture and nutrient content, these discoveries could lead to higher quality food as well.

How do soil fungi supply plants with mineral nutrients?

Maria Harrison, Ph.D.
Scientist, BTI; Adjunct Professor, Dept. of Plant Pathology and Plant Microbe Biology, Cornell University


In nature, certain plants and fungi have evolved a complex, symbiotic relationship in which the plants provide the fungi with carbon while the fungi provide the plants with phosphate needed for cell function and growth. Understanding this relationship could result in scientists' ability to develop plants that require fewer applications of phosphate fertilizers.

Working with soil fungi called arbuscular mycorrhizal fungi and a model legume, *Medicago truncatula*, **Maria Harrison's** laboratory is unraveling the mechanisms underlying mineral transfer from fungus to plant. The fungi, which are ubiquitous in soil, live in close proximity to the plant's roots. The fungal spores grow on the root surface and, in response to a signal from the plant, grow into the cells of the root. Once there, the plant forms a membrane, called the arbuscular membrane, through which the mineral exchange occurs.

Harrison theorized that a particular transporter protein in the arbuscular membrane mediates the movement of phosphorus from the fungus into the plant cell. In 2007, her team demonstrated that this theory was correct. When the plant gene that produces the transporter protein in question was "knocked out," or disabled, phosphate in the arbuscule did not cross into the plant cell.

Harrison's research yielded another, somewhat surprising result. She discovered that in the mutant plant, the arbuscules die very quickly. One interpretation is that the plant, on detecting that the phosphate transfer is not occurring, responds by triggering the death of the arbuscule. Understanding how and why this occurs will be a next step in her research.

Today, growers use fertilizers derived from rock phosphate to enhance plant nutrition, but rock fertilizer reserves are being depleted and, at the current rate of use, they will last only an additional 90 years. Furthermore, excessive application of phosphate fertilizers contributes to the pollution of 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 friendly, sustainable agriculture.

How do plants ward-off insects?

Georg Jander, Ph.D.
Assistant Scientist, BTI
Adjunct Assistant Professor, Dept. of Plant Biology, Cornell University


Understanding how plants protect themselves from insects could lead to the development of crop plants such as canola or cabbage that produce naturally-occurring insect deterrents. Such an advance could significantly reduce the amount of man-made, chemical insecticides released into the environment.

Georg Jander is studying a mechanism by which *Arabidopsis* plants fend off attacking caterpillars. It involves chemicals produced by the plant – called glucosinolates – which actually attract certain insects, but when these chemicals are broken down by enzymes in the plant or in the insect gut, smaller molecules are released that are natural insect repellents.

It's known that white cabbage butterflies avoid laying eggs on glucosinolate-producing plants where caterpillars are already feeding. Although earlier work at BTI proved that intact glucosinolates attract egg-laying cabbage butterflies, Jander theorized that a glucosinolate breakdown product was acting as the deterrent. The molecule, called indole-3-acetonitrile, is produced when an enzyme in the caterpillar's gut reacts with indole glucosinolates in the plant tissue to reduce their toxicity. When the caterpillar regurgitates on the plant, the molecule is left behind. Jander theorized that this molecule signals cabbage butterflies that caterpillars are present, which deters them from laying eggs.

Working with *Arabidopsis* plants and white cabbage butterflies, Jander's lab proved that indole-3-acetonitrile in fact deters egg laying. They also found that some *Arabidopsis* plants naturally produce this molecule in the absence of caterpillar feeding. As a result, Jander believes that nitrile production by the plant is an adaptive mechanism to reduce the caterpillar population on the plant by reducing the number of eggs laid on it.

In other *Arabidopsis* plants, glucosinolates are converted into indole-3-carbinol when insects feed on them. This molecule reacts with other compounds in the plant to produce new molecules that are toxic to many insects, but attract egg-laying cabbage butterflies. Since indole-3-actonitrile and indole-3-carbinol are produced from the same starting material, plants seem to face a defensive trade-off concerning which one to produce. Jander theorizes that a plant's habitat and the prevalent insect threat determine which molecule is produced in greater abundance.

IN THE LABS

How do plants acquire immunity to disease?

Dan Klessig, Ph.D.
Scientist, BTI
Adjunct Professor, Plant Pathology, Cornell


When we hear the phrase "acquired immunity," we usually think of humans and vaccinations, but plants also can acquire immunity (more often referred to as "resistance") when a pathogen invades the plant. Understanding how this system works could lead to crops that more effectively protect themselves from disease.

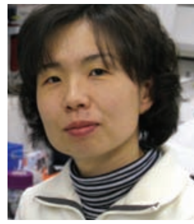
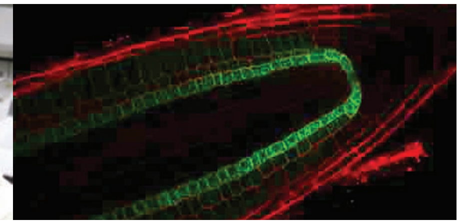
Dan Klessig's laboratory studies this phenomenon. In earlier work, his group and others proved that an aspirin-like compound called salicylic acid (SA) is produced at the site of infection. Some of this disease-fighting hormone activates the plant's local defenses and some is converted into methyl salicylate (MeSA), an inactive form of SA. Studies by others subsequently showed that SA is required in uninfected distant tissue, as well, for the plant to develop systemic acquired resistance (SAR) against secondary infection, but that SA is not the mobile molecule for SAR. This finding suggested there must be another, mobile molecule that carries the message from the infected tissue to other parts of the plant.

In an important breakthrough this year, Klessig's team discovered that MeSA is the mobile molecular messenger. His group found that a plant enzyme, SABP2, converts MeSA into SA, and that this activity is required in the distant tissue but is inhibited in the infected tissue. They further showed that MeSA travels through the phloem, or transporting tissue, from the site of infection to the distant tissue. They also demonstrated that an enzyme called SAMT, which converts SA into MeSA, is needed only in the infected tissue. These findings established that after a pathogen attacks, some of the SA synthesized at the site of infection is converted by SAMT into MeSA. MeSA is then transported through the phloem to distant, uninfected parts of the plant where SABP2 converts it back into disease-fighting SA, thereby turning on the plant's defenses in those tissues. Therefore, MeSA is central to the plant's SAR.

Klessig notes that MeSA may be only one of several molecular messengers involved in the process. Nonetheless, his group's discovery of MeSA as a mobile messenger, and the enzymes that regulate its level, explains for the first time how molecular information produced at the site of infection is communicated throughout the plant to provide it with acquired immunity.

How do stem cells divide and differentiate in *Arabidopsis*?

Ji-Young Lee, Ph.D.
Assistant Scientist, BTI

In response to certain genetic cues, stem cells in animals can differentiate into a wide variety of specialized cells. Plants, too, have stem cells that divide and differentiate into specialized cells in response to currently unknown, genetically-based developmental cues. Understanding these cues is essential to understanding – and influencing – how plants grow.

Ji-Young Lee is studying the genetic factors that cause plant stem cells in procambium/cambium tissue to divide and generate specialized vascular tissues, called xylem and phloem, using *Arabidopsis* root as a model. Because procambium/cambium tissue is widely present in all vascular plants, the knowledge she obtains from *Arabidopsis* will be transferable to many plant species.

In *Arabidopsis*, approximately 500 genes in the procambium/cambium tissue are highly expressed and work in regulatory networks that cause stem cells to generate xylem and phloem. Using gene expression data already in hand, Lee is trying to determine the function of each of the genes in the underlying regulatory network. Through microarray technology combined with genetics, her goal is to identify the transcription factors, their developmental functions, and their targets. Lee's laboratory is also studying stem cell activity as it relates to tree growth, using the *Populus* tree as a model system.

The potential applications of Lee's work are far-reaching. Understanding the mechanisms that cause vascular tissue stem cells to divide and differentiate in *Arabidopsis* and *Populus* will shed light on stem cell regulation in other herbaceous plants and woody trees. With that knowledge, scientists may one day be able to influence the growth rate of trees and grasses, which could in turn increase the amount of biomass they produce for use as biofuel, feed, or other purposes. Because the molecular mechanisms underlying stem cell regulation in animals and plants are similar, Lee's research may help advance knowledge about stem cell regulation in humans.

How do bacteria overcome a plant's disease defense system?

Gregory Martin, Ph.D.
Boyce Schulze Downey Scientist, BTI
Professor, Dept. of Plant Pathology and Plant-Microbe Biology, Cornell

There's an arms race underway in the plant world in which plants and disease-causing bacteria are continually evolving ways to outsmart each other. Plants have developed a defense system that enables them to resist disease, but some pathogens have evolved survival methods that undermine this system. Understanding the details of this race for dominance could lead to crop plants with more effective, natural resistance to disease.

Gregory Martin's laboratory studies a bacterium called *Pseudomonas syringae*, which causes bacterial speck disease of tomatoes. When *P. syringae* invades a tomato plant, it injects a disease-promoting protein called AvrPtoB into the plant cells. However, the plant is ready and waiting with the protein Fen, which was recently discovered by Martin's team. Fen recognizes AvrPtoB and, in doing so, activates the plant's defense system.

Fighting back, *P. syringae* has cleverly engineered AvrPtoB to act as a tomato E3 ligase, a protein that tags other proteins to be destroyed. When AvrPtoB binds the Fen protein, Fen is tagged and the plant's own system takes Fen to the cell's "garbage bin" before Fen can activate the plant's defenses. This eliminates the plant's ability to resist speck disease and ensures the survival of the bacterium.

In further studies, Martin's laboratory found that the *Fen* gene is present in many wild species of tomatoes suggesting it is an ancient plant defense strategy. But if the bacterial protein AvrPtoB is so effective at destroying the Fen protein, why would the *Fen* gene be so prevalent? Martin answers that there are some strains of *P. syringae* that produce a version of AvrPtoB that cannot destroy Fen, and, therefore, cannot turn off the plant's defense system. Consequently, he reasons that the bacteria have only recently evolved the version of AvrPtoB that can sabotage the plant's defenses.

Martin's work helps to explain how the plant/pathogen arms race works at the molecular level and sheds new light on how disease-resistant plants can suddenly become susceptible again. Understanding the strategies pathogens use to overcome plant defenses against disease may lead to crops that have more effective, longer lasting resistance – an advance that could lead to more productive varieties and less dependence on pesticides.

How do plants protect themselves from disease?

Peter Moffett, Ph.D.
Assistant Scientist, BTI
Adjunct Assistant Professor, Dept. of Plant Pathology, Cornell University

Though plants do not have an adaptive immune system like animals do, plants have evolved a defense mechanism of their own that protects them from disease. **Peter Moffett** is studying one such system using a disease resistance gene from potato.

All plants have a unique repertoire of several hundred disease resistance genes, each of which produces a resistance protein that protects the plant from specific pathogens. But this system works only if the resistance protein recognizes a protein from the pathogen, called an avirulence protein. Moffett is working to understand how this recognition event occurs and how it elicits a protective response in the plant.

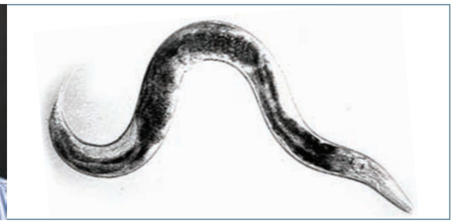
Moffett's research team has discovered that the resistance protein they study actually works in concert with another protein, called RanGAP2, which is present in all plants. He found that RanGAP2 physically interacts with the appropriate resistance protein, and allows it to sense the presence of a particular pathogen. RanGAP2 activates a protein called Rx when a virus attacks a potato cell, but if the cell is attacked by a nematode, RanGAP2 activates a protein called Gpa2. Working together, RanGAP2 and the resistance protein initiate a programmed response that will kill the cell and, with it, the pathogen.

Most recently, Moffett's laboratory discovered how the Rx protein interacts with RanGAP2 to signal the cell that a pathogen has invaded. This discovery is important because any plant can defend itself against most pathogens, but only if it can recognize the pathogen. Understanding how RanGAP2 works in concert with resistance genes like *Rx* and *Gpa2* to recognize a specific pathogen, may enable scientists to adjust a plant's defense system to mobilize against pathogens it couldn't previously recognize. This, in turn, may lead to a new way to transfer naturally-occurring resistance to a particular pathogen from one plant into another – an advance that could have important agricultural implications.

IN THE LABS

How do secondary metabolites affect human health?

Frank Schroeder, Ph.D.
Assistant Scientist, BTI



The relevance of nucleic acids, proteins, and carbohydrates for all aspects of biology is well established, but the varied and often unexpected roles of so-called "secondary" metabolites are just now being discovered. Secondary metabolites regulate development and immune responses in plants and animals (such as hormones) and also play an important role in the interactions of different organisms with each other. Identifying secondary metabolites and determining their function is an important area of biomedical research that can help scientists better understand diseases such as bacterial infections, diabetes and cancer, as well as the phenomenon of aging.

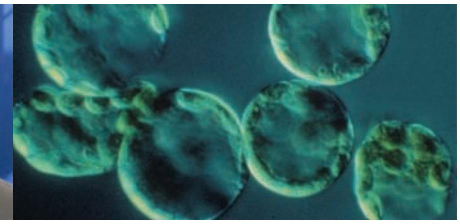
Secondary metabolites are very different from proteins and nucleic acids. They constitute a chemically diverse class of compounds, which have so far resisted systematic analysis. **Frank Schroeder's** laboratory is developing new analytical methodology based on a technique called NMR spectroscopy, which promises to greatly simplify scientists' ability to identify the chemical structure of these compounds and find their biological functions. Using this approach, Schroeder's team is investigating the role of secondary metabolites in specific aspects of plant and animal biology.

In one area of research, Schroeder is investigating secondary metabolites produced by the nematode *Caenorhabditis elegans*. Nematodes are roundworms that are about 1 mm in length and ubiquitous in the soil. Scientists believe that many of the physiological pathways in *C. elegans* are analogous to corresponding 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 10 years ago, little is known about its secondary "metabolome." Recently, Schroeder's group identified several new compounds that influence mating behavior, as well as pathways involved in nematode development and life span regulation. The ultimate goal of this research is to identify the entire *C. elegans* secondary metabolome for chemical structure and biological function.

In other research, Schroeder and colleagues recently used his NMR-spectroscopic approach to identify a previously unknown human hormone that controls the excretion of sodium via the kidneys. This discovery may one day lead to a new approach for treating high blood pressure.

How do plants regulate the enzyme that fixes CO_2?

David Stern, Ph.D.
President, BTI
Adjunct Professor, Dept. of Plant Biology, Cornell University



Through photosynthesis, plants use sunlight to convert carbon dioxide and water into sugar and then release oxygen into the air. This process is critical to the plant's production of energy, and to the balance of CO_2 and oxygen in the earth's atmosphere. If the ability of plants to absorb and sequester CO_2 could be improved beyond their natural capacity, plants could play an even more important role in helping to mitigate global warming.

In one research project, **David Stern's** laboratory has concentrated on understanding the molecular regulation of CO_2 fixation, which occurs in the chloroplasts of plant cells. It has long been known that plants rely on an enzyme called ribulose bisphosphate carboxylase/oxygenase (Rubisco) to sequester CO_2, and that a tremendous amount of the plant's energy is required to produce the enzyme. It was also known that to conserve energy, plants carefully calibrate how much Rubisco they need at any point in time. What was not known – and recently investigated by the Stern laboratory – is how Rubisco production is regulated in the chloroplast.

The Rubisco molecule is composed of eight large subunits (LS) produced in the chloroplast and eight small subunits (SS) produced in the cytoplasm of the cell. The SS molecules migrate into the chloroplast from the cytoplasm where they join with the LS molecules to form Rubisco. But how does the plant regulate Rubisco production when LS and SS are produced by two different genes in two structurally separate parts of the cell?

In research with transgenic tobacco plants, Stern and his colleagues showed that when an LS molecule cannot find an SS molecule to combine with, the LS molecule binds to its own messenger RNA, which in turn blocks, or prevents, the RNA from translating into more LS. In effect, the LS molecule shuts down its own production to save energy needed for other processes. This is called auto-regulation, and it controls the amount of Rubisco a plant produces.

Other scientists had encountered problems when they attempted to over-produce Rubisco, because their efforts resulted in a Rubisco-production shutdown that was not fully understood. With the lab's discovery of the regulatory process, scientists may one day be able to modify plants to produce extra Rubisco, which would enable them to sequester more CO_2. The result should be increased yields and, perhaps, reduced CO_2 in the atmosphere.

How do potatoes produce and accumulate beta-carotene?

Joyce Van Eck, Ph.D.
Senior Research Associate, BTI

According to the World Health Organization, 100 to 140 million children in the developing world suffer from Vitamin A deficiency, which can cause blindness and death. **Joyce Van Eck's** laboratory is developing ways to produce potatoes with higher beta-carotene content – the precursor to Vitamin A – which could help alleviate this serious health issue. In related work, Tom Brutnell's research team is investigating beta-carotene production in maize (see page 13).

Van Eck's laboratory helped develop two lines of modified potatoes that accumulate more beta-carotene than conventional varieties. Van Eck "knocked out," or silenced, a gene in one line that converts beta-carotene into zeaxanthin, a carotenoid that is not converted into Vitamin A. She theorized and proved that silencing the gene would cause the potatoes to accumulate more beta-carotene. In the other line, Van Eck inserted a gene called *Or* from a naturally occurring orange cauliflower, which caused the modified potatoes to accumulate more beta-carotene than unmodified potatoes.

Van Eck's laboratory is working to understand the molecular pathway involved in carotenoid production in potatoes. In analyzing the *Or* lines, the scientists discovered that early in the pathway (about four steps before beta-carotene is produced), certain genes caused the accumulation of some carotenoids, but limited the accumulation of others. As a result of this discovery, Van Eck's lab inserted certain genes into silenced lines and *Or* lines earlier in the pathway to counteract the limiting effect she had found.

Potatoes from these newly modified lines have been harvested and early analyses have been completed. Though initial results are encouraging, Van Eck is waiting for data from the second and third analyses to confirm success. If the plants do produce significantly higher amounts of beta-carotene, the next step will be field trials to ensure that yield, plant health and other factors are not affected in the modified potatoes.

In the meantime, Van Eck is working with the International Potato Center in Peru. Together, they are preparing for the eventual introduction of the more nutritious potatoes into developing countries where Vitamin A deficiency is a significant problem.

How do plants perceive and respond to far-red light?

Haiyang Wang, Ph.D.
Assistant Scientist, BTI
Adjunct Assistant Professor, Dept. of Plant Biology, Cornell University

Plant growth and development are largely dependent on a plant's response to light. The color or wavelength of light, it's intensity, direction and duration influence when, how fast, how tall and in what direction plants will grow, and when they will flower. But understanding fully how plants "see" and respond to light is an enduring mystery.

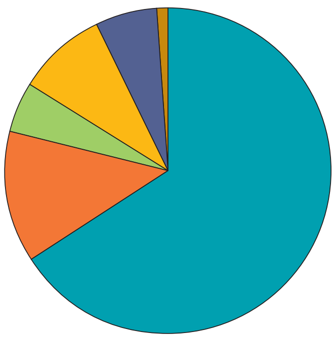
Haiyang Wang is studying how plants sense and respond to far-red light (light in the visible spectrum that we see at sunrise and sunset), using *Arabidopsis* plants as a model. When far-red light photons hit specialized protein photoreceptors in the cell called phytochrome A or PHYA, the receptors are activated. Activated PHYA molecules then move from the cytoplasm of the cell into the nucleus where they orchestrate the plant's physiological response to light by regulating gene expression. What causes the photoreceptor to move and how the process is regulated is not well understood.

Wang's laboratory is studying the biochemical function of two proteins, FHY3 and FAR1, that appear to be essential for the light response chain of events. They found through a series of biochemical, genetic and cell biological studies that these proteins can bind as transcription factors directly to the regulatory regions of two direct target genes, *FHY1* and *FHL*, and cause the genes to express products required for PHYA to accumulate in the nucleus.

This discovery, recently reported in *Science*, has important evolutionary significance because the two proteins appear to be related to certain enzyme products of transposable elements, which are residents of the genome that can "jump" from one place to another. Wang's research indicates these "jumping genes" may actually have evolved into important cellular genes, which, in this case, allow the plant to respond to its light environment.

The ability to fine tune a plant's response to light could significantly benefit agriculture. Such adjustments could lead to plants that yield more, produce more biomass or could be grown in higher density.

GIFTS AND GRANTS



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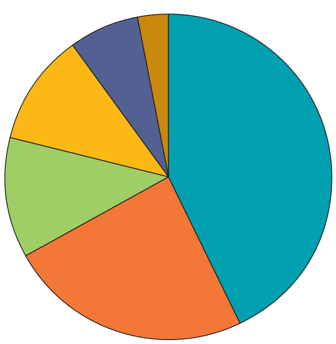

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