BREAKTHROUGHS
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Image by David Bartus.

Cultivating Resilience

Researchers are using synthetic biology and CRISPR methods to help plants fight pathogens, improve crop yields, and store more carbon

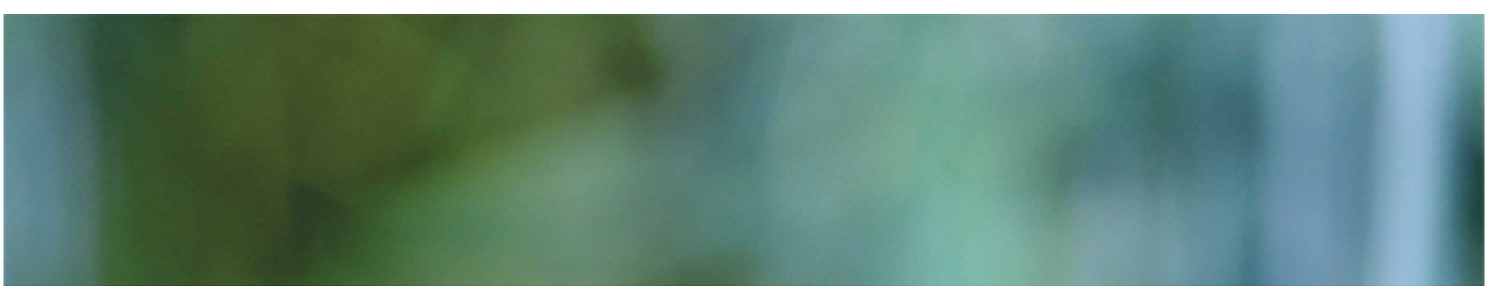
By Robin Donovan | Fall 2022 (/breakthroughs/fall-2022)

Gaze over a field of wheat rustling in the wind, and it's easy to get lost in the beauty of an idyllic, pastoral scene. Biologist Ksenia Krasileva (https://plantandmicrobiology.berkeley.edu/users/ksenia-krasileva) sees something different: a commodity crop grown repeatedly on the same tract of land, requiring herbicides, pesticides, and fertilizer. For over a century, agricultural producers have been planting genetically identical monoculture crops—like single species of corn, wheat, and other staples—to improve harvest yields. But the same genetic similarities that led to bountiful harvests also left our food systems susceptible to pests and pathogens. Hotter, drier growing seasons fueled by climate change have also added another layer of challenges.

Krasileva and other Rausser College of Natural Resources scientists affiliated with UC Berkeley's Innovative Genomics Institute (IGI) (https://innovativegenomics.org/) are working to address these issues through synthetic biology and CRISPR gene editing techniques. By developing cutting-edge methods to help plants resist pathogens, improve crop yields, and even remove carbon from the air, they are pioneering sustainable approaches to agriculture—a key part of the new bioeconomy. Their work offers promising advances for the planet by helping to slow global warming, supercharge photosynthesis, and alleviate world hunger.

Fighting plant pathogens

Fungal plant pathogens can seriously threaten farming productivity by causing significant—or sometimes total—destruction in fields. Rusts, a category of fungal pathogens named after their dust-like orange spores, can reduce crop output and spread over vast distances by air. Other fungal pathogens like rice and wheat blast are capable of ravaging entire fields and becoming resistant to commonly used fungicides. Humans can breathe in the pollen grain-sized fungal spores when plant epidemics occur, further underscoring the connection between plant health and human well-being.



As climate change intensifies, fungal pathogens like stripe rust have adapted faster than the field crops they afflict. Photos: iStock

A major problem, says Krasileva, an assistant professor in the Department of Plant and Microbial Biology (PMB) and the Center for Computational Biology, is that plants can't learn to fight new pathogens the way humans do. "Plants don't have circulating immune cells, which means they don't have adaptive immunity," she notes. "They're born with a set of genes that determine which pathogens they can recognize."

When a new pathogen is introduced, it wipes out susceptible plants that cannot recognize it. Individual plants that recognize the pathogen are able to mount an immune response and survive, passing these functional immune responses to future generations. Immunity happens, then, at the population level, shifting over generations rather than during the lifespan of an individual plant.

But pathogen recognition in plants requires genetic diversity. In modern farming, many crops are monocultures, or genetically identical plants, which are often planted year after year on the same swathes of land. “When you have a genetically uniform crop, pathogens have an advantage,” Krasileva says. “A virulence molecule outcompetes one genotype, and it’s got them all.”

Identifying genetic sources of disease resistance in plants’ wild relatives and integrating them into crops is a laborious process. Instead, Krasileva hopes to improve crop immunity by modifying immune receptors called NLRs, or nucleotide-binding leucine-rich repeat proteins, which act as molecular antennas capable of detecting pathogens and activating a plant’s immune system.

As part of their inquiry into plant diversity, Krasileva’s lab has been investigating various species of duckweed (https://plantandmicrobiology.berkeley.edu/news/2022/09/new-findings-detail-alternative-immune-pathways-in-duckweed-species), which are genetically simpler than many other plants and can reproduce very quickly, making them an excellent candidate for research. Erin Baggs (https://plantandmicrobiology.berkeley.edu/users/erin-baggs), a graduate student in Krasileva’s lab, has identified five duckweed species that lack most NLRs and other defense components previously thought to be indispensable in plants. These species seem to rely, instead, on antimicrobial peptides. Now, the team is also investigating how this natural defense barrier can play a role in plants fending off pathogens. “There are many ways organisms withstand pathogens and communicate with each other,” Krasileva says. “We’re just scratching the surface of that understanding. I am excited to learn more lessons from biodiversity.”

As the effects of climate change intensify, many fungal pathogens—like stripe rust—have adapted to survive in warmer and drier areas faster than the plants they affect. By better understanding the ways that plants, bacteria, and other organisms fight off disease, Krasileva hopes to add to the growing body of scientific knowledge that can help plants stay ahead of disease, even in the face of major change.

Faster photosynthesis

Another stream of research uncovering new understanding of plant functions, led by PMB professor Krishna Niyogi (https://plantandmicrobiology.berkeley.edu/profile/niyogi), focuses on increasing the efficiency of photosynthesis. Photosynthesis is the process by which plants convert water, sunlight, and carbon dioxide into food (sugars) and oxygen. When the sun is most intense, plants can’t use all the energy they absorb for photosynthesis. Instead, they dissipate the excess by giving off heat—a process plants can activate quickly but are mysteriously slow to turn off. This often results in wasted energy.

Now, Niyogi and his team have identified the genetic activities responsible for regulating this process. By inserting new genetic material that allows the plant to produce more of three key proteins involved, the researchers have been able to speed up the shut-off response—even when light levels fluctuate—which allows plants to retain as much energy as possible for the important work of growing via photosynthesis.

This discovery could have important implications for increasing crop yield and alleviating hunger around the world. The researchers started a decade ago with a pilot project to modify tobacco by inserting genetic material from *Arabidopsis*, a small flowering plant. After proving that the technique improved photosynthetic efficiency and biomass in tobacco—which was chosen because it is a crop plant that allows for faster experimentation—the team worked to show that the same gains could be achieved in a food crop. Niyogi’s lab and collaborators at the University of Illinois were able to modify soybeans to increase seed production by up to 30 percent using the same DNA construct, a first-of-its-kind finding recently published in *Science* (https://nature.berkeley.edu/news/2022/08/bioengineering-better-photosynthesis). “This advancement could provide a buffer against the effects of climate-linked crop impacts while potentially increasing yield for farmers who need to boost their output,” Niyogi says.

The three genes Niyogi and his collaborators modified are found in all plants. So, it’s possible that scientists could alter the

A research team led by professor Krishna Niyogi and researchers at the University of Illinois recently demonstrated that multigene bioengineering of soybeans improved photosynthesis and increased crop yields in field trials. Photo by Amanda Nguyen/RIPE Project.

expression of a plant's own genes to achieve the same outcome without incorporating DNA from other plant species.

A new IGI initiative in which Niyogi is involved focuses on editing sorghum and rice varieties to remove carbon from the atmosphere more efficiently by improving photosynthesis and increasing root biomass. The research is a collaboration including David Savage (https://mcb.berkeley.edu/faculty/bbs/savaged.html), a professor in the Department of Molecular and Cell Biology; Brian Staskawicz (https://plantandmicrobiology.berkeley.edu/profile/staskawicz), a professor in PMB and director of sustainable agriculture at IGI; Peggy Lemaux (https://plantandmicrobiology.berkeley.edu/users/peggy-g-lemaux), a professor of Cooperative Extension in PMB; Pamela Ronald (https://cropgeneticsinnovation.ucdavis.edu/about-ronald) (PhD '90 Molecular and Physiological Plant Biology), a professor at UC Davis; and Myeong-Je Cho (https://iep.berkeley.edu/content/myeong-je-cho), director of the IGI Plant Genomics and Transformation Facility. With Jennifer Pett-Ridge (https://nature.berkeley.edu/crosskingdominteractions/lab-members/jennifer-pett-ridge/) ('05 Soil Microbial Ecology) of Lawrence Livermore National Laboratory and Jill Banfield (https://ourenvironment.berkeley.edu/people/jill-banfield), a professor in the Department of Environmental Science, Policy, and Management, the team will work to optimize root development and root exudates that can promote carbon sequestration in the soil.

Acknowledging uncertainties

Even as they create exciting possibilities for addressing some of the world's largest problems, the scientific advances made possible with synthetic biology and CRISPR technology also bring with them uncertainties and potential risk.

Modified soybean plants from a field trial at the University of Illinois. Photo by Allie Arp/RIPE Project.

"When you deal with environmental applications of CRISPR, as opposed to human health ones, you are putting new or novel entities into the environment," says Nertila Kuraj (https://www.jus.uio.no/ior/english/people/aca/nertilak/), a postdoctoral researcher at the University of Oslo. "You don't know how they will adapt to the natural environment, how they will interact with other species in the ecosystem, and what the long-term impacts will be." While a visiting scholar at Berkeley Law, Kuraj collaborated with law professor Dan Farber (https://www.law.berkeley.edu/our-faculty/faculty-profiles/daniel-farber/#tab_profile) on a project aimed at assessing risk and uncertainty in regard to gene editing for environmental purposes.

"There should be transparency about how risk assessment and safety are established and defined," says Kuraj, who is working to connect social scientists concerned with the risks of genetically modified plant species with the researchers developing them. The IGI has also invested in such partnerships; its Public Impact Team is working to align societal values with genome-engineering advances through public dialogue and policy research.

At present, crops edited using CRISPR are regulated as genetically modified organisms (GMOs) in the E.U., but not in the U.S. The USDA allows plants to be modified using their own genetic material, as Niyogi is hoping to do with soybeans. He says the team's new methods can be layered with other promising approaches to alter the soybean's DNA using only genetic material from the soybean itself, rather than using *Arabidopsis* DNA. This process could allow it to be considered non-GMO in the U.S.

Despite being frequently misunderstood by the public, the GMO distinction holds importance for farmers, legislators, corporations, and consumers. For scientists, creating crops that address world hunger means steering clear of GMO designations whenever possible. Legislation lags scientific advances, so new regulations can quickly become not just unenforceable but obsolete.

Kuraj hopes that scientists and ethicists will maintain open communication with an eye toward allowing progress while staying transparent, incorporating social justice principles, and respecting Traditional Ecological Knowledge. She and Farber are planning an interdisciplinary conference to foster these types of conversations. “I think it’s possible to have the necessary degree of interdisciplinarity to understand each other,” Kuraj says, as she works to bridge plant biologists, CRISPR experts, and social scientists. “You have to foster it; it will not come out of nothing.”

RELATED READING

- Supercharging Plants and Soils to Remove Carbon from the Atmosphere (https://innovativegenomics.org/news/crispr-carbon-removal/)
- Can CRISPR Help us Deal with Climate Change? (https://news.berkeley.edu/2022/06/28/in-10-years-crispr-transformed-medicine-can-it-now-help-us-deal-with-climate-change/)

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