

Feeding THE Future

UC Davis researchers are exploring the survival strategies of wild and parasitic plants to help cultivate the climate-resistant food crops of tomorrow.

by Gregory Watry

To meet a projected population of 9.8 billion by 2050, global food production needs to grow an estimated 70 percent. Rising patterns of extreme weather are challenging food security. To adapt and feed the world, we need stronger crops.

A Shifting Environment

Glaciers are melting, sea levels are rising, wildfires are blazing and droughts are intensifying. Our earth is in an alarming state of flux. For food producers, these climatic shifts could prove devastating.

“Modern crop varieties are usually bred to a particular latitude and longitude as well as a particular climate pattern,” says Siobhan Brady, associate professor of plant biology. “When these patterns change, it can negatively affect plant growth. Too little water, too much water, high temperatures, increased levels of carbon dioxide—these can all alter plant yield.”

California is the nation’s leader in agricultural production and exports, with food producers generating \$45 billion in output in 2016. According to the Department of Food and Agriculture, the Golden State provides one-third of the country’s vegetables and two-thirds of its fruits and nuts.

“Over a few thousand years human beings have selected varieties with traits that have allowed agriculture to flourish and human civilizations to grow and evolve,” says Neelima Sinha, professor of plant biology.

Through domestication and selective propagation, agricultural producers have bred crops for efficiency, selecting lines that produce higher yields and better tastes. This interference by human hands has weakened some crops, causing some to lose adaptive traits that once helped them flourish in environments rife with stressors, like droughts and parasites. California’s intensified natural disasters and droughts undoubtedly spell trouble for the state’s crops.

UC Davis plant biologists are looking to wild relatives for hints to strengthen crops, with the hope that the key to resilience lies in their genetics.



College of Biological Sciences Associate Professor Siobhan Brady and Professor Neelima Sinha research and refine successful plant traits. *David Slipher*

Mining the Best Plant Traits

The arid Andean Region of South America is home to one tough wild tomato species. Drought-, salt- and pathogen-tolerant, *Solanum pennellii* is an ideal study in extreme plant adaptations. Strong roots and waxy-skinned fruits and leaves help *S. pennellii* cope with desert challenges. UC Davis researchers are immersed in understanding *S. pennellii*’s durability.

“The root structure is an understudied area of the plant,” says Brady. “It’s below ground, but it’s responsible for bringing up all the water and nutrients to the above-ground part of the plant, which in turn is necessary for our nutrition.” ▶

Brady studies *S. pennellii* and its domesticated relative *Solanum lycopersium*, the garden tomato. Unlike garden varieties, the desert tomato's roots continuously accumulate the compound *suberin* in its outer root layer, which enables water retention. The compound is only expressed in garden tomatoes during times of intense drought.

With cutting-edge genomics tools, Brady and her team seek the key to *suberin* production in the desert tomato. This data could help identify the mechanisms to introduce resilient root traits in other crops.

"If it can be expanded to other crops by breeding for a particular factor that might increase its presence, then it could provide the garden tomato's roots with more waterproofing and a better ability to withstand drought," Brady says.

Tricky Parasites

A shifting climate isn't the only threat to producing bountiful harvests. More than 4,000 different species of parasitic plants leech nutrients from host plants, leaving destruction in their wake.

"Parasitic plants are hugely significant in the world, especially in the lesser developed parts of the world," says Sinha. **"We have things like Striga, or witchweed, which causes incredible devastation."**

The parasitic plant genus *Striga* has been known to cause up to 90 percent loss in crop yields. According to the International Maize and Wheat Improvement Center, the weed affects more than 49 million acres of cropland in sub-Saharan Africa. It attaches to cereals like maize and sorghum, costing an estimated \$1 billion in losses annually.

Witchweed actively hunts its prey. When sorghum roots are low in phosphorous, they secrete a molecule

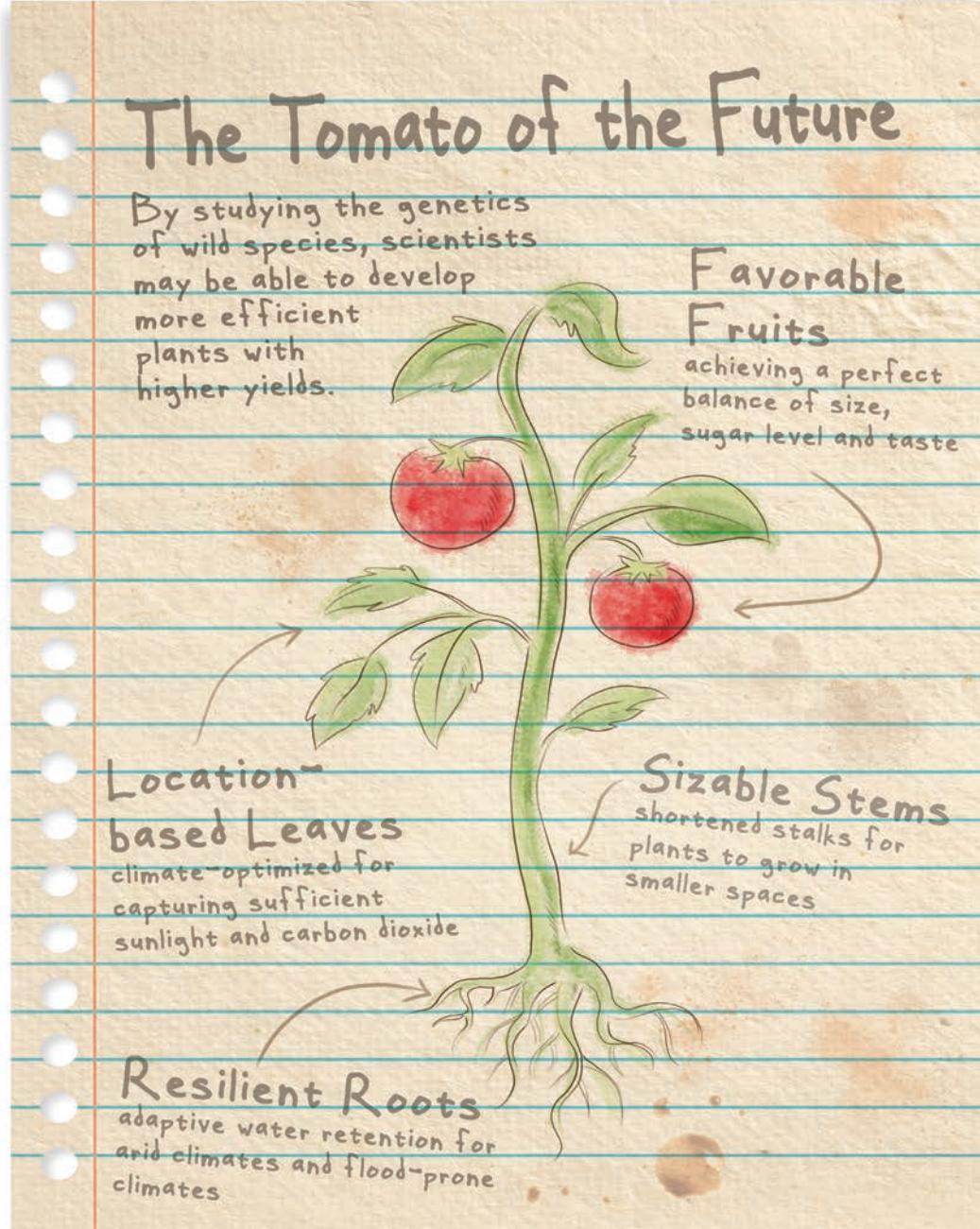


Illustration inspired by the field notebook of the late UC Davis researcher Sharon Gray.

called *strigolactone*, which tells the roots to uptake more of the nutrient. But *strigolactone* acts like a smoke signal for witchweed.

"Strigolactone can be hijacked by this parasitic plant," says Brady. **"When the *Striga* sense the *strigolactone*, it will grow towards the sorghum root, penetrate it and hijack all its resources."**

Since witchweed evolved in tandem with sorghum, some sorghum crops have developed resistance to the parasite. Around 70 percent show some degree of tolerance or resistance.

Brady and her colleagues investigate the genetic mechanisms of resistant sorghum strains. She recently started a project to genetically define how sorghum roots interact with the soil microbiome to either facilitate or suppress witchweed growth.

"There is one sorghum line which has been shown to be defective in *strigolactone* biosynthesis," says Brady. **"Without this hormone, the *Striga* roots can't emerge from their seeds, invade the host plant and take it over."**

Meanwhile, Sinha studies *Cuscuta*, also known as dodder. Common in

California, the parasitic plant grows like cobwebs of orange spaghetti as it envelops its host. Sinha studies the genetic interactions between dodder and host plants.

“This plant has no roots, and it doesn’t photosynthesize. It doesn’t have any leaves, so everything it needs to grow it gets from the tomato,” says Sinha. “It’s a significant problem for California agriculture.”

Like Brady, Sinha is trying to understand at the genetic level what makes certain crops resistant or susceptible to dodder. By investigating plant genomes, Brady and Sinha hope to find the genetic triggers that enable

plant defenses. With this knowledge, researchers could introduce these traits into our crops, ensuring their survival in a shifting climate.

Understanding the Language of Plants

Plants produce an array of chemical compounds to cope with environmental challenges. From defending against predators to attracting pollinators, these chemicals, called metabolites, number in the hundreds of thousands and vary from species to species. Each plant is unique in its chemical repertoire, making them the envy of organic chemists.

“To me, the chemistry in plants is much like a language,” says Philipp Zerbe, assistant professor of plant biology. “They use chemicals to communicate, where we use words.”

Zerbe works to decode the diversity of plants by mapping the genes, enzymes and pathways that form their complex metabolic machinery. He’s particularly interested in terpenoids, the largest and most diverse class of metabolites.

Terpenoids perform many functions, from regulating growth and development to protecting plants from environmental stresses like drought and salinity. ▶

The Phosphate Problem

During the Great Depression, President Franklin D. Roosevelt addressed Congress about the worrisome decline of soil quality in the United States. Many soil types were deficient in phosphorous, causing low yields and poor crop quality, Roosevelt explained.

Heeding these warnings, farmers applied high levels of phosphate-rich fertilizer on farmland. Food production soared, and by the end of the 20th century, use of such fertilizers had roughly quadrupled.

Today, non-renewable phosphate resources across the globe are rapidly depleting.

“We are wasting it,” says William Lucas, distinguished professor of plant biology. “Depending on what we do, we have maybe 50 years or so before we hit a bottleneck for crop production based on the availability of phosphate fertilizer.”

As traditional plant breeding efforts are performed in the presence of high levels of applied phosphate fertilizer, crop lines have emerged that use phosphorus inefficiently. To mitigate forthcoming phosphate shortages, researchers need to identify and restore the genes and regulatory networks that were lost through domestication.

“Fortunately, the tools are perfect today with genomics and functional genomics and network analysis,” says Lucas. “It’s the right time, but it needs a concerted research effort to develop high-yield crops capable of growth under significantly reduced levels of fertilizer application.”

A Northern California farmer examines the soil before crop planting. UC Davis Library Special Collections



A Genetic Look Under the Hood

In Philipp Zerbe's lab, student researchers Katie Murphy and Prema Karunanithi use CRISPR/Cas9 gene editing technology to uncover the molecular mechanisms of plant function.

Murphy, a plant biology Ph.D. student, likens CRISPR technology to automotive maintenance. It lifts the hood, allowing researchers to explore the plant's mechanics by "cutting" certain genes so they no longer work.

"Imagine you don't know how a car works, so you open the hood and cut one of the wires. Then you close the hood and start driving the car," Murphy says. **"When you try to use the brakes, they don't work. By doing that, you know whatever line you cut must have something to do with the brakes."**

Plants synthesize hundreds of thousands of different chemical compounds. To identify which genes help produce certain chemical compounds, the students sometimes place the genes in a model organism, such as the bacteria *E. coli*, and figure out what chemicals are produced. This gives them a clearer blueprint of the compound's synthesis.

"All domains of life produce these compounds, it's just that plants have a better diversity of these compounds," says Karunanithi, a biochemistry, molecular, cellular and developmental biology Ph.D. student.

While the students aren't placing new genes in crop plants themselves, one thing they ponder is how their research will inform the design of crops better suited to a changing climate.

"We all want a more sustainable food system that uses less chemical inputs, less water and less fertilizer," says Murphy. **"If we can make plants that can better defend themselves, we won't have to apply as many of those chemical inputs."**

◀ **Graduate student researchers Katie Murphy and Prema Karunanithi hand-pollinate corn hybrids.**
David Slipher



Understanding the Language of Plants *continued*

"If we can find the genes that are involved in this chemical defense, we can target these genes very precisely," says Zerbe. **"If we listen carefully and understand plants' language, we may translate this knowledge into new avenues to improve crop resistance and ultimately provide for our burgeoning population."**

To Zerbe and other biologists, the advent of targeted genome editing with technologies like CRISPR/Cas9 has been a game-changer. It's now possible for plant biologists to pinpoint the genes and pathways involved in

specific metabolite production, which could then be introduced into crop varieties.

"Our efforts at the moment are focused on trying to fundamentally understand the enzymatic circuitry that plants use to form the remarkable diversity of metabolites and how these contribute to plant health," says Zerbe. **"Some of these metabolites have been known for decades, but now we have the means to decode their production."**

As the earth's climate shifts, humanity must be proactive. To maintain food security, we must develop more resilient crops. Studying the strategies of wild and parasitic plants could prove essential in preparing our crops for a changing future.

At UC Davis, plant biologists are making the foundational, multidisciplinary discoveries that will help adapt food production to thrive in a new world.

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