Science Societies

Fighting climate change? Ask the extended family for advice

Researchers explore crop wild relatives for 13 crops in search of new sources of genetic diversity

By DJ McCauley

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Fernando Guerrero Zurita, a student from Universidad Nacional Agraria La Molina, evaluated water stress tolerance of sweetpotato crop wild relatives under the direction of Bettina Heider of the International Potato Center using accessions from a crop wild relative pre-breeding project. Photo by Michael Major for Crop Trust.

- A new *Crop Science* special section sponsored by the Global Crop Diversity Trust presents 19 articles on research from all stages of the pre-breeding pipeline using crop wild relatives from 13 different crops.
- The articles focus on how genetic diversity in crop wild relatives can help breeders overcome challenges presented by a changing climate.
- Here, we discuss researchers' findings using novel sources of genetic diversity in sorghum, carrot, and sweetpotato.

These days, I find myself hypersensitive to changing weather. Working from home has forced me to pay more attention to my surroundings, and I wonder: how can I be more resilient despite these difficult conditions?

It's this question (admittedly, in an entirely different context) that researchers seek to answer in a new *Crop Science* special section titled, "Adapting Agriculture to Climate Change: A Walk on the Wild Side."

"Heat stress, salt in irrigation water, rising ocean levels—even the range of pests and diseases is changing with the climate and temperature," Marilyn Warburton says. Warburton just finished her term as *Crop Science* editor (now serves as president-

elect of CSSA) and co-authored the introduction to the special section (
https://doi.org/10.1002/csc2.20418).

Over the course of centuries, human beings carefully domesticated crops, selecting for favorable traits. In the process, we lost some of the genetic diversity that can lead to more resilient crops in the face of biotic and abiotic stresses due to a changing climate.

An extensive team sponsored by the government of Norway and coordinated by the Global Crop Diversity Trust (or the Crop Trust, for short) has spent the last 11 years undertaking the difficult, time-consuming, costly, and risky work of finding novel genetic material that can be used to incorporate climate-resilient attributes into existing crops. These teams are examining crop wild relatives for helpful traits in a process called "pre-breeding."

What makes the work so difficult?

"There are two major obstacles for pre-breeding," says Benjamin Kilian, the Crop Wild Relative Project manager at the Crop Trust. "There's identifying major genes and allelic traits, then there's transferring those traits into the breeding pipeline. For a crop like banana, that can take 20 years to complete,"

The Crop Trust has taken on the difficult—but highly rewarding—task of supporting pre-breeding projects all across the globe. In fact, the Crop Trust is working with more than 100 partners in over 50 countries. Here, we'll examine three studies focusing on carrot, sweetpotato, and sorghum from the *Crop Science* collection of open access articles.

Queen Anne’s Lace: Carrot’s Secret Cousin

For all the times I’ve tucked a sprig of Queen Anne’s lace in a wildflower bouquet as a kid, Philipp Simon has plucked it off the roadside 100-fold. That may be a conservative estimate.

“That’s wild carrot!” Simon exclaims. “It’s kind of a fun one because people might know about wild relatives, but you can’t always look out your window and say, ‘there it is.’ But if you pulled it up, it wouldn’t really look like cultivated carrot at all.”

Queen Anne’s lace has small, shallow, pale white roots—a far cry from the cheery orange taproot we expect in cultivated carrot. But even with its comparatively dreary roots, wild relatives of carrots can confer a number of beneficial traits to their cultivated relatives. As a long-time researcher and leader of the Carrot and Garlic Genetics Project for the USDA-ARS, Simon seeks these beneficial traits.

Philipp Simon (second from left) from the USDA, leads an international carrot pre-breeding project. Here, Simon is in a test field in Bangladesh, where blue labels identify different carrot cultivars provided as seeds by the USDA genebank and are being used by *the training team to initiate the production of seed crop. Photo courtesy of Crop Trust.*

Though he hadn't traveled much before his post with the USDA-ARS, Simon has now seen much of the world on collecting expeditions to track down wild relatives of carrot and garlic. Researchers like Simon trace their way to the "center of origin" of domesticated species when choosing places to go looking for wild relatives. The earliest days of carrot farming began somewhere in Central Asia or Northern Africa—places Simon has spent a fair amount of time.

"These collecting expeditions focus on wild relatives, but also on visiting local markets or perhaps talking to local farmers that have samples of seed. Seed from these farmers is really valuable because in many cases, those local varieties of the crop are being lost."

Carrots are among one of the top 10 vegetables produced globally. They're a good source of provitamin A carotenoids—the substance that gives them their orange color. Vitamin A deficiency can cause such debilitating symptoms as blindness and increased risk of infection and is common in parts of Africa and Southeast Asia. It most severely impacts pregnant women and children. The availability of affordable, nutritious varieties of carrots is one way to help these susceptible populations increase their vitamin A intake through food.

But carrots, like many other crops, struggle to produce decent yield in adverse growing conditions. In their contribution to the *Crop Science* special section, Simon partnered with colleagues in Pakistan and Bangladesh to test out wild carrot against modern carrot for new sources of abiotic stress tolerance (**https://doi.org/10.1002/csc2.20333**). The team used 64 different germplasm accessions of crop wild relatives of carrot, testing them in varying levels of drought, heat, and salt stress in test fields in Bangladesh and Pakistan and then comparing them to a control group grown in the greenhouse in Wisconsin.

Carrots were grown over the winters of 2015–2018 in fields where the negative impacts of abiotic stress on yield were already observed. Plant height and leaf number—reliable indicators of overall growth—were scored 60 days after planting. For trials under heat stress, the researchers planted a bit earlier in the year. For plants under drought stress, they stopped irrigating 15 days after planting. Finally, the team measured soil salinity and found that the salinity stress fields had about three times the salt content as the other trial environments.

Even after such harsh treatment, researchers noted a number of plants that survived and made it to the seed production stage.

“My collaborators intercrossed these varieties amongst each other and with local cultivated carrots because in the end, that’s where the payoff is going to be,” Simon says. “In Bangladesh, some of my collaborators already have carrots from this program that are being released for production. That diverse germplasm has actually been moved forward to the point of new cultivars.”

Ipomoea batatas shows well-developed large storage roots while crop wild relative species I. cynachifolia, I. trifida, and I. leucantha have no storage roots. Photos by Stella Nhanala.

Sweetpotatoes and Drought Tolerance

Like carrots, sweetpotatoes [*Ipomoea batatas* (L.) Lam] are the product of a root storage system gone wild. Well, domesticated, if we're getting technical.

Unrelated to regular old Russets, sweetpotato's tasty storage roots serve as a staple crop worldwide, particularly in Asia, sub-Saharan Africa, and the South Pacific. Like carrots, sweetpotato cultivation faces increasing abiotic pressure.

If you were looking for the hub of sweetpotato cultivation in the United States, look no farther than North Carolina. In fact, researchers at North Carolina State University (NC State) in collaboration with scientists at the International Potato Center in Lima, Peru, headed up a Crop Trust study examining the impact of drought on cultivated sweetpotato, testing it against its wild relatives, *I. cynanchifolia*, *I. leucantha*, *I. trifida*, and *I. triloba* (**https://doi.org/10.1002/csc2.20363**). Like Queen Anne's lace, these wild relatives don’t produce storage roots but may be valuable for finding diverse sources of other traits.

In this study, researchers selected a handful of wild relatives and tested them in the greenhouse, creating watering cutoffs to see how long a sweetpotato can go before it dies back. What the team found surprised them. In fact, they discovered that cultivated sweetpotato demonstrated a higher tolerance to drought conditions than their wild counterparts.

“We think that the storage roots aren’t just good for human consumption, but they play an important role in drought tolerance, too,” says Stella Nhanala, a current doctoral student at NC State and first author on the paper. “We think they performed better than the wild relatives because those wild relative genotypes we evaluated *don’t* have storage roots.”

Nhanala’s doctoral research was supported by funding from Crop Trust to examine drought tolerance in sweetpotato. She’s nearly completed her work and intends to return to her home country, Mozambique, and continue working on drought tolerance in important agricultural crops.

“This study was very exploratory,” says Craig Yencho, a distinguished professor and program leader of the Sweetpotato and Potato Breeding and Genetics Programs at NC State. “We really don’t know much about the sweetpotato, particularly those in the ‘ *batatas* complex,’ and we’re just beginning to evaluate the biotic and abiotic constraints for this plant.”

Yencho touches on two challenges sweetpotato breeders face. First, it’s a particularly complex polyploid crop that tends to subvert Mendelian genetics. Sweetpotato has 6 copies of each of its 15 chromosomes, resulting in a whopping 90 chromosomes to work with—there are lots of possible genetic combinations. It's highly complex and highly variable, and recombination during breeding phases could lead to loss of desirable traits or the re-appearance of undesirable traits. Second, when breeding for drought tolerance, researchers paradoxically need to think about flood tolerance, too.

"In North Carolina, for example, we could be planting under drought conditions, then hurricane season comes around and drops 10 inches of rain," Yencho says. "We could have a crop sitting there, ready to harvest, and then lose it due to flooding."

This study demonstrates the "risky" side of pre-breeding that the Crop Trust's Kilian mentioned: though crop wild relatives could be the answer to increasing genetic diversity and combating problems facing modern agriculture, they might just as easily show how far we've already come from those small-rooted wild relatives.

Testing Sorghum Crop Wild Relatives and Landraces in Kenya

Sorghum near Kakamega County, Kenya. Photo by Michael Major for Crop Trust.

For producers in Kenya, drought negatively impacts sorghum, which is their second most important grain crop after maize. A team of plant science researchers from a swath of institutions—the University of Nairobi, International Crops Research Institute for the Semi-Arid Tropics (ICRISAT), and the Kenya Agricultural and Livestock Research Organization (KALRO)—set out to find new sources of the "stay-green" trait that indicates sorghum is resisting death due to drought.

"The average rainfall in a season in Kenya is 250 mm, and it's poorly distributed and irregular," explains Kahiu Ngugi, a co-author on the paper as well as a plant breeder and associate professor at the University of Nairobi. "Though farmers prefer to grow maize to sorghum, sorghum…guarantees at least some grain yield, even in the worst drought-affected seasons."

In their recent *Crop Science* study, Ngugi and his co-authors gathered a swath of 16 improved sorghum varieties, 9 landraces, and 17 crop wild relatives to test against known sources of stay-green traits (**https://doi.org/10.1002/csc2.20300**). Unlike wild relatives, landraces are domesticated, locally adapted crops that haven't undergone formal genetic improvement.

Though scientists have already identified three stay-green sources—B35 and E36-1 from Ethiopia and SC56 from Sudan—the goal is to avoid dependence on a narrow genetic base, broadening their knowledge of stay-green traits to help farmers continue producing grain yields even under increased drought stress.

The selected genetic material was tested under water-stressed trials where the sorghum was watered for 14 days after seeding to encourage germination and then received no irrigation thereafter. Then the team rated the sorghum for its display of the stay-green trait, genotyped all the varieties, and discovered 20 additional markers associated with increased drought tolerance. Nine local landraces and two crop wild relatives were identified with far better performance than the previous genotypes associated with stay-green traits.

"What surprised me most was there are many local landraces and crop wild relatives that are more drought tolerant than the

conventionally used drought-tolerant sources, like B35 and E36-1,”

Ngugi says. An added bonus: those highly resistant phenotypes also produced greater yield than traditional sorghum sources.

The team’s next steps include identifying specific single-nucleotide polymorphism (SNP) markers to make it easier to integrate the newly identified traits into locally adapted lines.

“If funds and time allow, we need to test these genotypes across many locations and in many replications to obtain credible genotype by environment data,” Ngugi says.

The team has made incredible strides with just one study of sorghum crop wild relatives and landraces, tapping into new sources of genetic diversity for a highly relevant grain. Soon, Ngugi hopes to take the findings from this exploratory study and combine increased drought tolerance with other important sorghum characteristics, like increased disease and pest resistance.

Keep Walking on the Wild Side

These three studies, all coordinated by the Crop Trust, exhibit both the pitfalls and triumphs of exploratory pre-breeding research. Moving forward, Kilian is hopeful the Crop Trust can continue to coordinate groundbreaking pre-breeding projects using crop wild relatives.

The Crop Trust has not only made it possible for a vast number of scientists and farmers to complete important work that uses native genetic diversity and combats climate change, but the organization has helped its partners build their research capacity. Over its first 11 years, institutions partnering with the Crop Trust have trained 50 graduate students so far.

Though the initial tenure of the project is up, Kilian is hopeful that the government of Norway will sponsor further work to advance the preliminary findings and success stories set out in *Crop Science.* The Crop Trust is also hoping to add more donors and sponsors to expand its partnerships on a global scale. So far, the Templeton World Charity Foundation is its newest sponsor, supporting pre-breeding projects on finger millet and grass pea and building on the successes of the Crop Wild Relative Project.

Kilian has ambitious plans for the future. “We want to invest in genotyping to make pre-breeding and breeding faster; we want to work on speed-breeding technologies to decrease the amount of time it takes to work with a variety and integrate new genes,” he says. “We want to go for another 10 years and build on the pre-breeding work that’s already been completed.”

Dig Deeper

The ***Crop Science*** special section, “Adapting Agriculture to Climate Change: A Walk on the Wild Side,” can be found at **https://bit.ly/3aZrsZ5**. Also, back in September 2020, our podcast, ***Field, Lab, Earth***, interviewed Philipp Simon, co-author of one of the *Crop Science* articles mentioned here, to talk about carrot stress tolerance and wild relative breeding. You can listen to that that episode at **https://bit.ly/3pehFDR**. The podcast is found at https://fieldlabearth.libsyn.com or through your favorite podcast provider.

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