Can we hack DNA to grow more food for a hotter, hungry planet?

December 15 2022, by Lisa M. Krieger

Credit: Pixabay/CC0 Public Domain

To feed a hotter and drier planet, Stanford scientists are building a smarter plant.

The team has genetically reprogrammed plants, nurtured in a laboratory chamber, to grow roots that are long or short, branched or slender—traits that change the ability to gather nutrients or water.

Controlling root growth could someday offer a powerful new tool for farmers, especially in drought or flood-prone areas with poor soil. During the coming decades, say experts, we will need to cultivate crops that can produce an unprecedented bounty in ever harsher and more unpredictable conditions, as the population climbs. If improved root structures can increase the yields of a food crop, perhaps more food can be put on tables.

"The goal of all of this work is to try to make plants that increase the sustainability of agriculture," said plant systems biologist and professor José Dinneny, whose work with bioengineering professor Jennifer Brophy was published in the journal *Science*.

The scientists altered the root structures by introducing DNA that changes the plant's genetic circuitry in response to environmental cues. Gene circuits act like electrical circuits and can be turned on or off to adjust behavior.

The goal is to design plants that are tailored to a specific environment—or, in the future, give plants the ability to adjust themselves.

They tested their strategy in a type of mustard called Arabidopsis thaliana because it's a fast and easy plant to grow. Now that researchers have proven that the idea works, they plan to apply it to commercial crops.

Out in the field, there might be less success. Living things respond to the wild environment in unpredictable ways. Other genes, and genetic networks, may require tinkering.

And critics such as the Center for Food Safety argue that there are better ways to fix the problem, such as improving soils or using conventional techniques to breed plants that can withstand the effects of the shifting climate.

For years, researchers have tried to improve plants by using traditional genetic engineering—introducing chunks of DNA from bacteria into a plant's genome to change a specific trait, such as pest and herbicide resistance. Corn, cotton and soybeans that are engineered to survive the weedkiller Roundup have become standard in American fields.

But the nascent field of "synthetic biology" is accelerating research by offering more sophisticated tools. It's now possible to construct or reprogram whole genomes—using made-to-order gene parts from foundries, or "fabs," much as industry orders up cast and machined metal parts.

"The synthetic biology industry is booming in the Bay Area, with many entrepreneurs programming biological functions into living cells," said John Cumbers, founder and CEO of SynBioBeta, a global network of biological engineers. "We can now readily engineer an enzyme or a cell to perform a particular function, like make a new bio-based chemical or material."

But until recently, the horticultural realm "has remained largely out of reach to scientists," he said. "It is one of the holy grails of the field of bioengineering—how can we program plants to grow into any shape we would like?"

The Stanford technique offers fine-scale and complex control, altering not just one gene but the behavior of a whole suite of plant genes to induce root-growing changes in varied environmental conditions.

The team built synthetic DNA that changes the circuitry by creating a genetic toggle switch, like a computer's logic gate, to turn genes on and off.

The genetic toggling allowed the team to adjust growth patterns, such as the number of branches in the root system, without changing the rest of the plant. For example, an "off" state created a layer of cells on the tip of a root that blocks further growth.

The team envisions programming crops to develop root systems that are more angled, so they dive deeper to find water or nitrogen, or more shallow, to prevent drowning during floods from lack of oxygen. Plants could be designed for density, sending down one long tap root that doesn't infringe on a neighbor.

Between 1960 and 2010, the "Green Revolution" boosted the world's food production by 175% by improving the use of fertilizer, high-yield varieties and irrigation techniques. But global crop yields are stalling.

Domestication has created plants that are inefficient consumers of water and nutrients, said Dinneny. They're designed for ideal environments.

If yields are improved, it will help preserve what remains of our wilderness, he added. "Unless we want to clear more forests to create more agricultural land," he said, "we're going to have to find ways of improving the way we grow plants for food."

But the project was greeted skeptically by critics such as Bill Freese, science director for the Center for Food Safety.

"I have a sense that it's very much like innumerable other examples of hits and misses, mostly misses, of research I've seen," he said. "I've seen so many pie-in-the-sky experiences that struggle because of technical obstacles."

The promise has faded from some genetically modified plants, said Freese. For instance, weeds are emerging that are resistant to the herbicide Roundup—so the engineered "Roundup Ready" brands of corn and soybeans are losing their usefulness. Farmers are now spending more on herbicides and labor costs to till the land, according to a Harvard report.

Rather than genetic fixes, we should focus on improving the environment, such as soil conditions, he said. "If you step back from the genes and look more holistically at the environment that the plant is growing in, sometimes you can find much simpler and more direct solutions."

Meanwhile, other research institutions are enlisting advanced genetic techniques in the race to improve plants. For instance, the Gates Foundation has funded the C4 Rice Project to improve the photosynthesis of rice by changing vein spacing. The Salk Institute's Harnessing Plants Initiative aims to alter the genetic pathways that control a plant's long-term storage of carbon.

Such research "is an elegant step toward a future world where we can readily design and build plants to perform a variety of other functional applications," said Cumbers.

Life is an incredible biological machine, said Cumbers, who imagines modifying the DNA code of plants to grow buildings to our design specifications, creating entire cities out of living, organic material.

"Imagine being able to plant an acorn and have it grow into a house," he said. "That seems like science fiction right now, but inside that acorn is the genetic code to make an oak tree—so what would it take to reprogram that DNA to build a house?"