LISTEN TO PLANT BREEDERS TALK ABOUT FOOD SECURITY, AND THE message becomes loud and clear: Substantial improvements are needed in current crops to achieve higher yields and sustainable farming. To achieve those gains, agricultural companies have turned to robotics and other measures to streamline breeding programs. And researchers are finding creative ways to introduce and use genes. The point is to make a plant that’s tough, productive, and healthful. Here’s a quick look at just some of the most desired plant improvements—and the techniques that might make them possible.

LOFTY GOALS

1. Improve the nutrient content of seeds and edible plant parts. Vitamin A fortification is already here; soybeans with omega-3 fatty acids are on the way. More vitamins and higher protein content are other goals. For biofuels, the right mix of plant cell–wall components is needed to ease processing.

2. No more sex. Hybrid seeds often produce more vigorous plants, but the seeds of those hybrids are often inferior. Farmers can’t always afford to buy new hybrid seeds. One proposed solution is to get hybrids to reproduce asexually, through a process called apomixis. Having apomixis in rice, for example, could save small farmers $4 billion a year. (An alternative to apomixis is to tweak the genetics of annual crop plants—which die each year—so that they become perennials.)

3. Install warning lights. A pigment gene that turns on in times of stress could cause a crop’s leaves or stems to change color—and alert farmers to take remedial action. Some think that sensors installed in soils or the air could also do this job.


5. Longer shelf life. Enhanced control of ripening and senescence could reduce the amount of spoiled harvest.

6. Improve nitrogen efficiency. Fertilizers are costly to farmers and the environment. Improving a plant’s uptake and use would be a big help. Better yet, build into the plant the genes necessary to carry out nitrogen fixation—a job that may one day fall on artificial chromosomes.

7. Tougher pest defenses. Adding genes for toxins that kill only pest insects or nematodes can help, as can the addition of genes that attract the enemies of these pests.

Researchers’ wish list includes traits that could boost plant productivity. New technologies are needed to make some of these advances possible.
TECHNOLOGIES FOR A BETTER FARMING FUTURE

Artificial Chromosomes
If one gene is good, more genes are better. That’s the mantra of plant biologists working to improve crops. Already, companies have engineered varieties that carry both herbicide and insect-resistance genes. Ultimately, researchers have set their sights on tweaking complex multigene processes, such as nitrogen fixation, which might involve 20 genes, or a special type of photosynthesis called C4 that works particularly well in tough conditions. Coordinating the expression of whole suites of genes, however, is an easier feat if the genes are grouped together. Here’s where artificial chromosomes come into play.

Such “minichromosomes” come in several flavors. A company called Chromatin, for instance, has developed a way to attach useful suites of genes to a “platform” made from a ring of maize DNA. It encodes the repetitive regions of the centromere, the region near the middle of chromosomes that is important during DNA replication. Once loaded with the desired genes, the ring is put into the target plant.

Several teams are also making use of a plant’s own “extra” DNA—such as the B chromosome in maize, or extra chromosomes in tetraploid versions of barley, rice, or Arabidopsis. They insert DNA containing the desired genes and the repetitive sequence of a telomere, which caps off chromosomes. That DNA inserts into the plant’s chromosome and truncates it, creating a new minichromosome.

These techniques are promising, but it’s not clear how stable the minichromosomes will be over multiple generations—or if the right amount of gene expression will be maintained over time.

RNA Interference
One innovative approach to helping plants fend off enemies is to have the plant make small RNA molecules that neutralize the pathogen or pest. Called RNA interference (RNAi), the strategy involves adding genes that generate RNA that disables target genes. These small RNAs can diffuse from the plant into a parasite or deactivate viruses in the plant itself.

Researchers have already shown that they can use RNAi to make Arabidopsis plants resistant to the root-knot nematode and reduce the symptoms of cassava mosaic virus by interfering with genes for a protein essential for virus replication. RNAi also should work against other so-called single-stranded DNA viruses, such as the cassava brown streak. Other researchers have used RNAi to shut down a detoxification gene in bollworm, a cotton pest—making the insect more susceptible to gossypol, a toxin produced by cotton.

Still, a National Research Council report from 2008 called RNAi’s potential “preliminary,” particularly with respect to large-scale agriculture.

Targeted Gene Replacement
Researchers typically fly blind when they try to add or modify plant genes, because they can’t be sure where the gene they are inserting will end up. They often have to laboriously screen thousands of mutants to find the right one. Now, however, researchers are perfecting ways to place new genes precisely where they want them. These techniques could ease the process of improving crops by allowing researchers to alter a particular gene’s sequence or its regulatory DNA instead of depending on genes from other species.

In one new approach, several groups are harnessing proteins called zinc fingers, which recognize and attach to specific DNA sequences. By joining the zinc finger to an enzyme that cuts DNA, researchers can slice through DNA at precise locations, providing ready places for new DNA to settle in.

Other groups are taking a cue from a bacterial pathogen, Xanthomonas. Late last year, two teams discovered how this pathogen promotes infection by homing in on and controlling specific plant genes. The bacteria make a protein with an amino acid sequence that includes a series of “repeats.” Each repeat has a particular amino acid at positions 12 and 13 and thus recognizes a specific base, enabling the protein to latch onto its target DNA. Both teams have figured out how to customize these proteins to find specific DNA sequences, potentially providing another way to add new genes or make modifications to specific parts of a chromosome.

A third approach involves endonucleases, which naturally cleave DNA at specific spots. These proteins recognize long stretches of DNA and can target unique spots along a genome.

Robotics
Automation is helping plant breeders trim years off the process of developing crop varieties tailored to local conditions. In automated greenhouses, seedlings travel along conveyor belts as they grow, passing through stations where they are exposed to drought, heat, or other conditions. The plants are then photographed and monitored, all without human help. The controlled conditions help breeders find individuals with the best traits without field testing. Automated systems are also helping breeders skip the time-consuming process of growing seedlings as they search for desirable genetic combinations. Monsanto, for example, has developed “chippers,” robots that take a slice off individual corn kernels or soybeans—sparring the germ that’s the business end of the seed. The slice goes to the lab for DNA fingerprinting to determine its mix of genes; the rest of the seed is carefully stored. Later, if breeders are interested in that genetic variant, they can electronically request and automatically retrieve the stored seed. They no longer have to wait for seeds to sprout to see which ones have the traits they want.

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