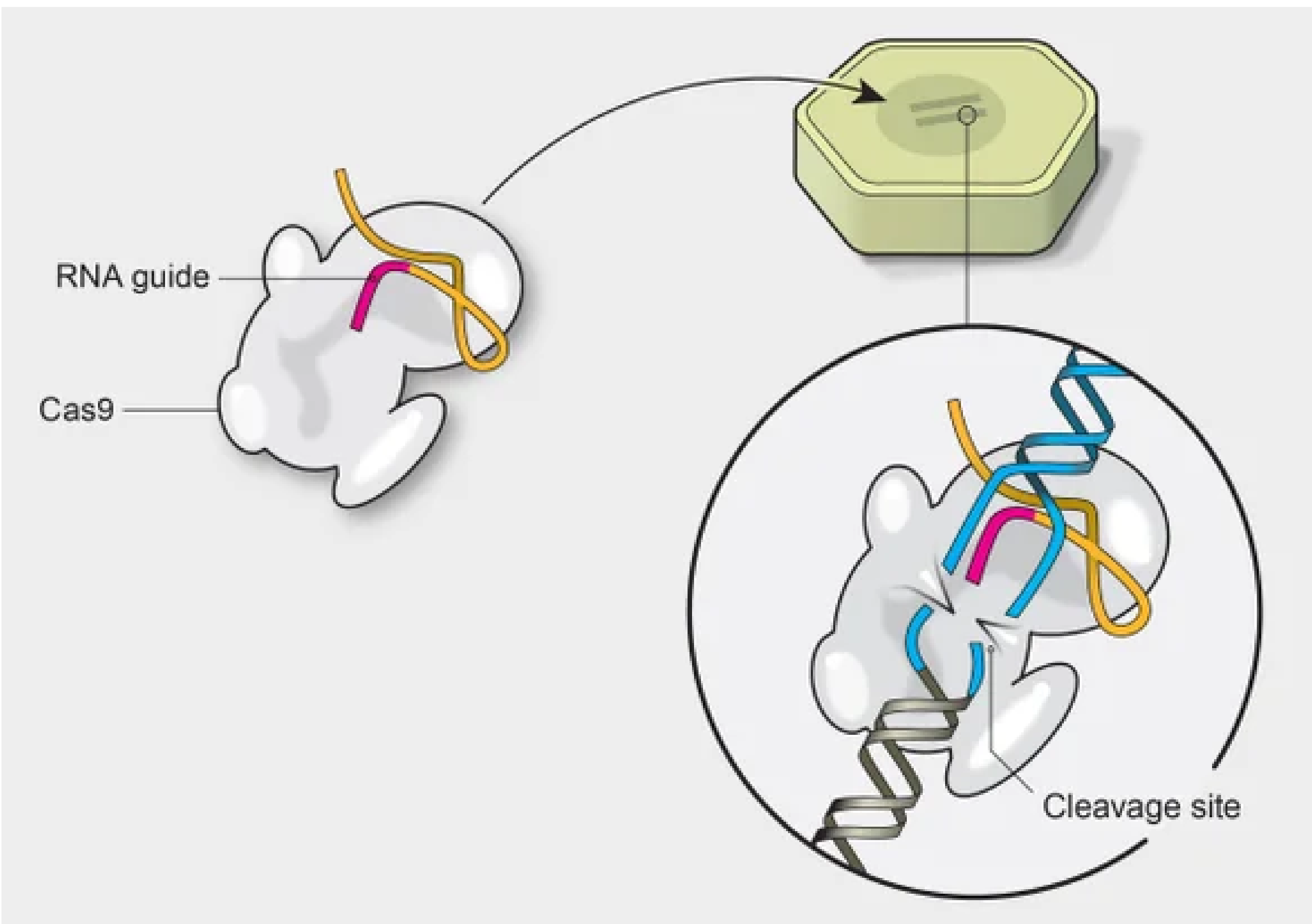
SA Visual

A Visual Guide to Genetic Modification

Infographic compares CRISPR technology to other GM methods used in crops

STAFF | By Amanda Montañez on March 3, 2016



In this month's issue of *Scientific American*, Stephen S. Hall tells the story of how the revolutionary gene-editing tool known as CRISPR could transform the agricultural industry. Using mushrooms as his primary example, Hall paints a cautiously optimistic picture of how this particular mode of genetic modification could benefit small farmers, as opposed to the multinational corporations typically associated with GMOs. Given the widespread skepticism toward GM products, the challenge will be to dispel public notions of CRISPR as a more advanced, and thus potentially scarier, form of genetic engineering.

Using the principles of genetics to alter crops is not new, of course—in fact, it goes back to Gregor Mendel and his famous crossbred peas. There exists a general understanding that what we now know as GMOs—genetically modified organisms—are different from what Mendel created. But how, exactly, are they different, and why does the distinction matter? Moreover, what sets CRISPR apart from other GM technologies?

Fortunately, there's an infographic to answer all of these questions. The graphic below, created by Jen Christiansen as part of the March print feature "Editing the Mushroom," provides an elegant explanation of three main categories of genetic modification. Using consistent, tangible examples and an accessible visual language, this graphic demystifies GM technology and underscores CRISPR's potential as a more precise, and in fact *less* disruptive way to improve crops than science has ever offered before.

People have been cultivating crops for thousands of years, and for all that time they have aimed to identify and incorporate beneficial traits (higher yields, for example, or disease resistance) into existing plant varieties. First they used conventional crossbreeding. In the early 20th century scientists learned to deliberately mutate the DNA of existing plants and hope for desirable traits to appear at random. Today new "precision breeding" techniques such as CRISPR enable scientists to mutate specific genes or insert new genetic traits with unprecedented precision. Yet *all* these techniques alter the DNA of the plants, so what counts as a genetically modified organism (GMO), anyway?

Key Concepts

Mutagenesis Since the 1920s agricultural scientists have deliberately mutated the DNA of plant seeds with x-rays, gamma rays or chemicals and then grown the plants to see if they have acquired beneficial traits. If so, the mutated plants can be crossbred with existing varieties. Plants created this way are not considered GMOs by the U.S. Department of Agriculture.

Gene Silencing For the past decade scientists have been able to turn off genes that confer unwanted traits by introducing a disruptive form of RNA into plant cells. This "interfering" RNA (or iRNA) is engineered to disrupt a specific sequence of DNA underlying an undesirable trait. Several food crops, including nonbrowning potatoes and apples, have been created in this way. The USDA does not call them GMOs.

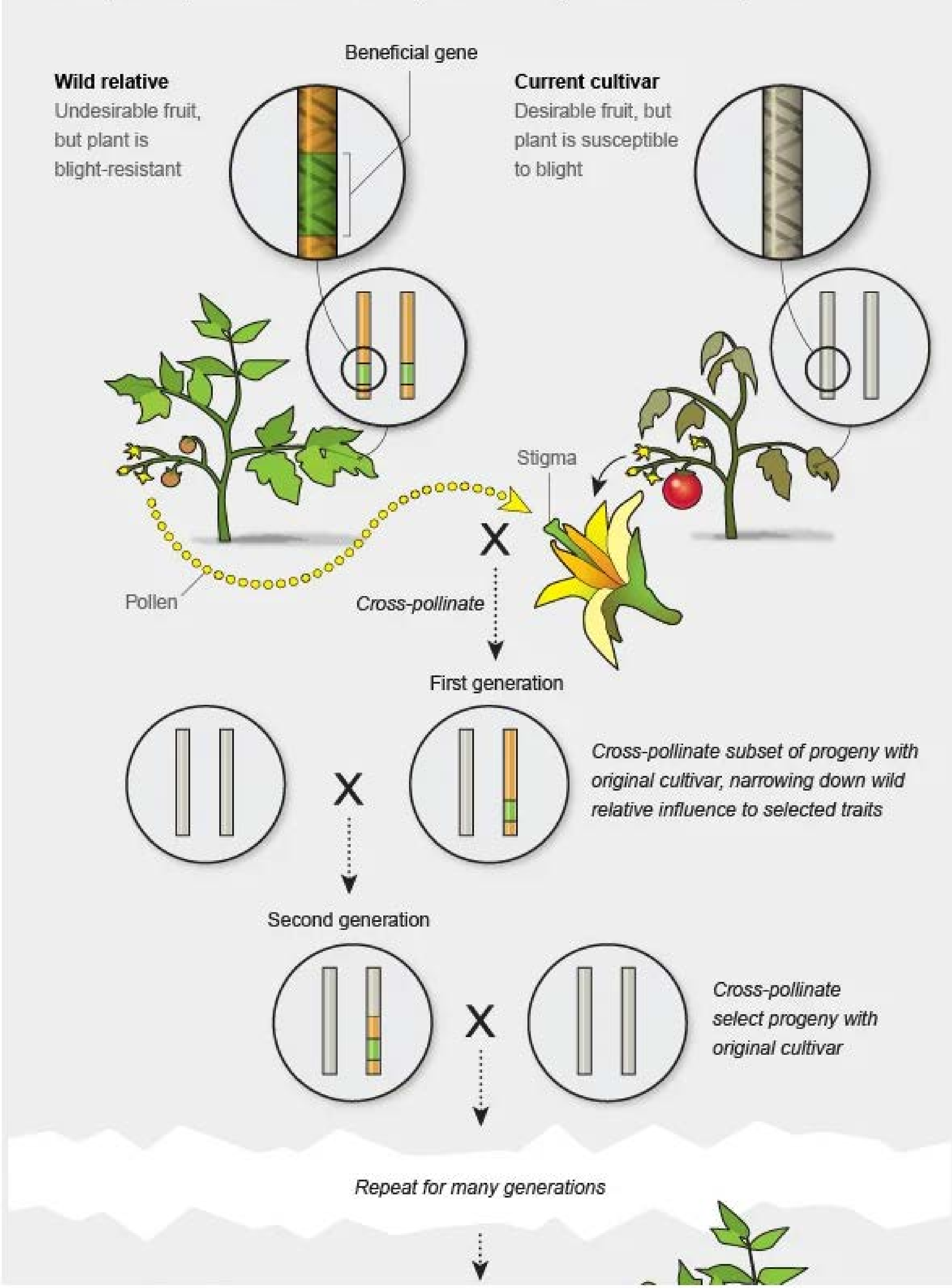
Cisgenesis This process involves introducing a specific gene from a related plant species. The transfer is typically accomplished by a plant-infecting microbe called *Agrobacterium tumefaciens*, which can insert the gene into a semirandom spot in the plant's DNA. The USDA reviews cisgenic plants on a case-by-case basis to determine their regulatory status.

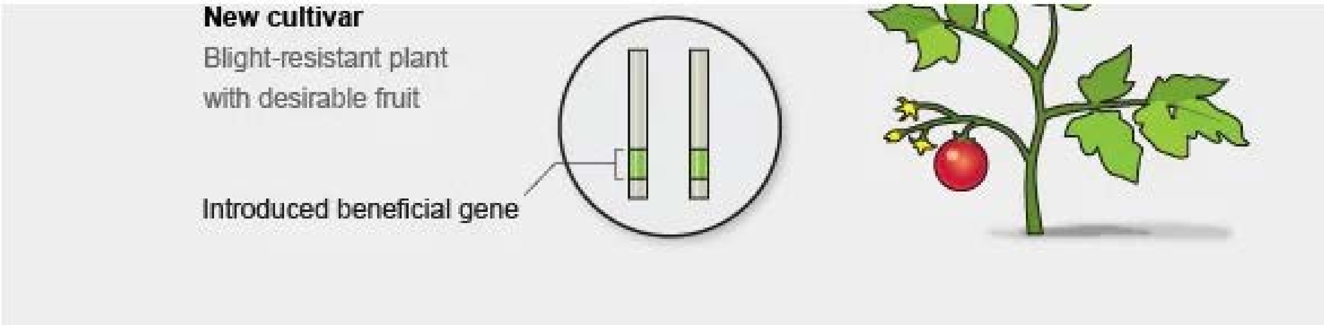
Transgenesis The technique involves the transfer of foreign DNA encoding a desired trait into an unrelated plant species. As in cisgenesis, *A. tumefaciens* is used to smuggle in the foreign DNA when the bacterium infects a plant cell. Examples of transgenic crops include corn into which a herbicide-resistant gene has been inserted. Ninety percent of all soybeans grown in the U.S. are transgenic; the USDA considers transgenic plants to be GMOs.

Conventional Crossbreeding

Includes selective breeding and crossbreeding following mutagenesis. During natural breeding, large segments of chromosomes—up to millions of base pairs—are introduced along with the desired trait into a domesticated cultivar. Subsequent crosses typically reduce the amount of transferred DNA, but the insert often remains hundreds of thousands of base pairs long and can drag along undesirable genes ("linkage drag") in the process. A 2010 genomic analysis of *Arabidopsis* (considered the "mouse model" of plants) showed that conventional breeding introduced approximately seven spontaneous new mutations per billion base pairs of DNA in each generation.

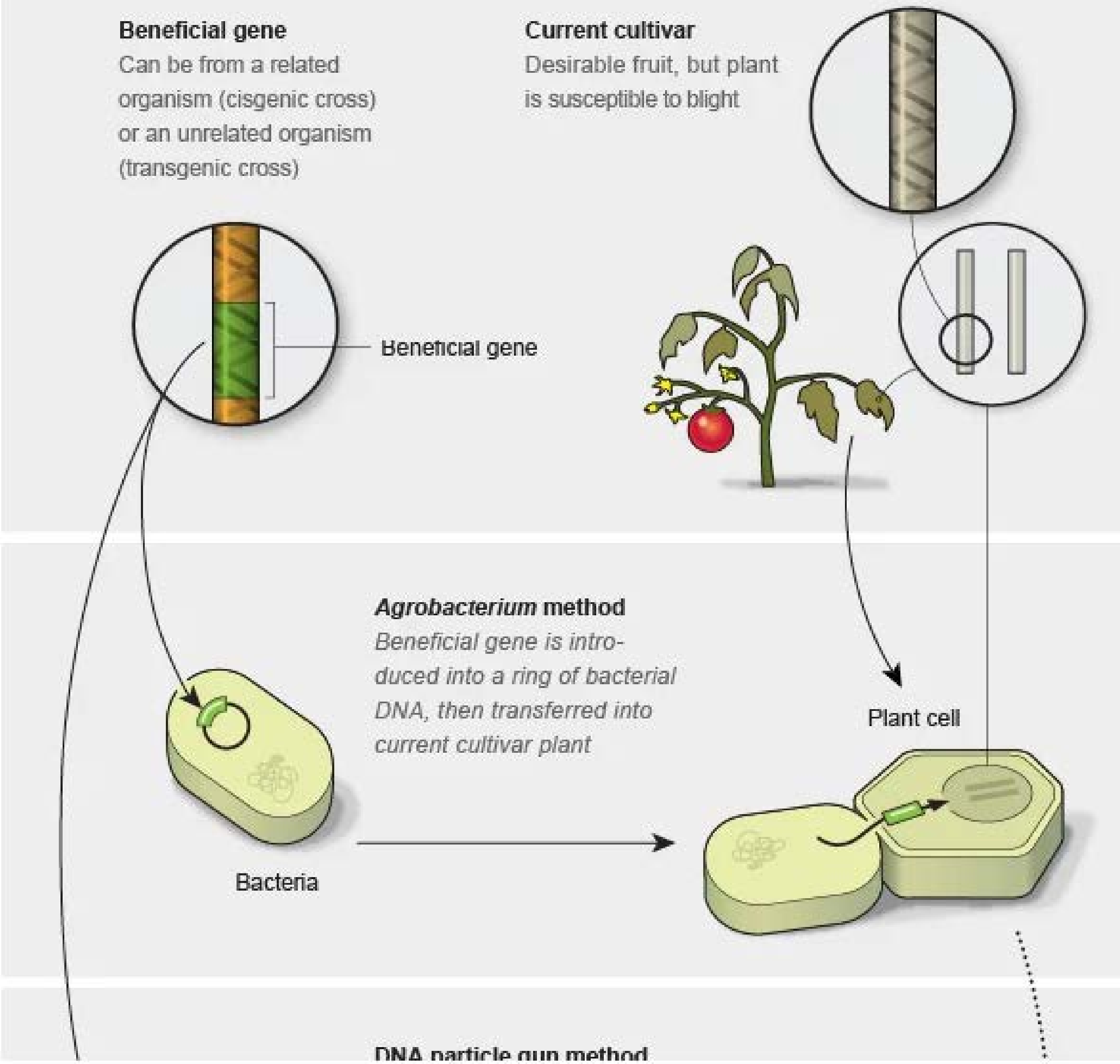
mately seven spontaneous new mutations per billion base pairs of DNA in each generation.

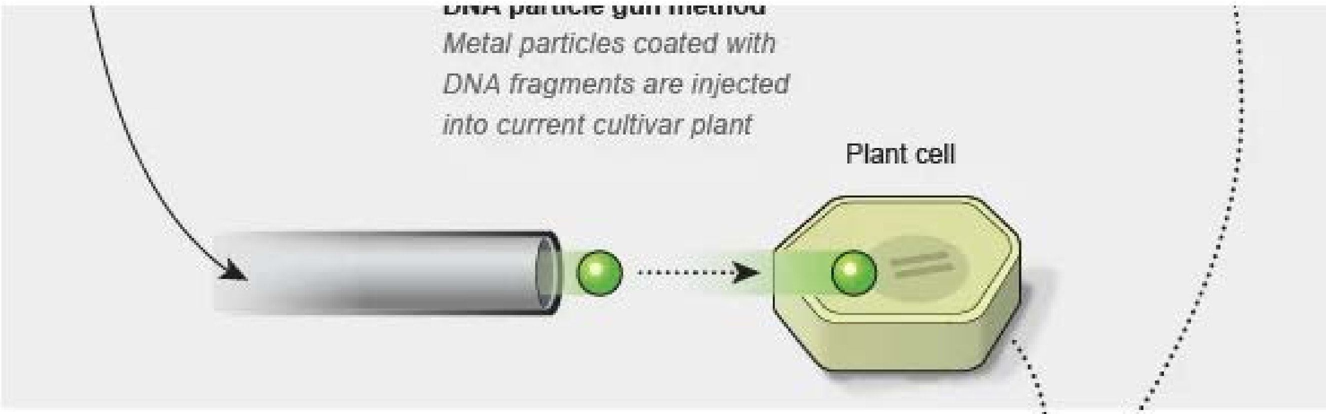


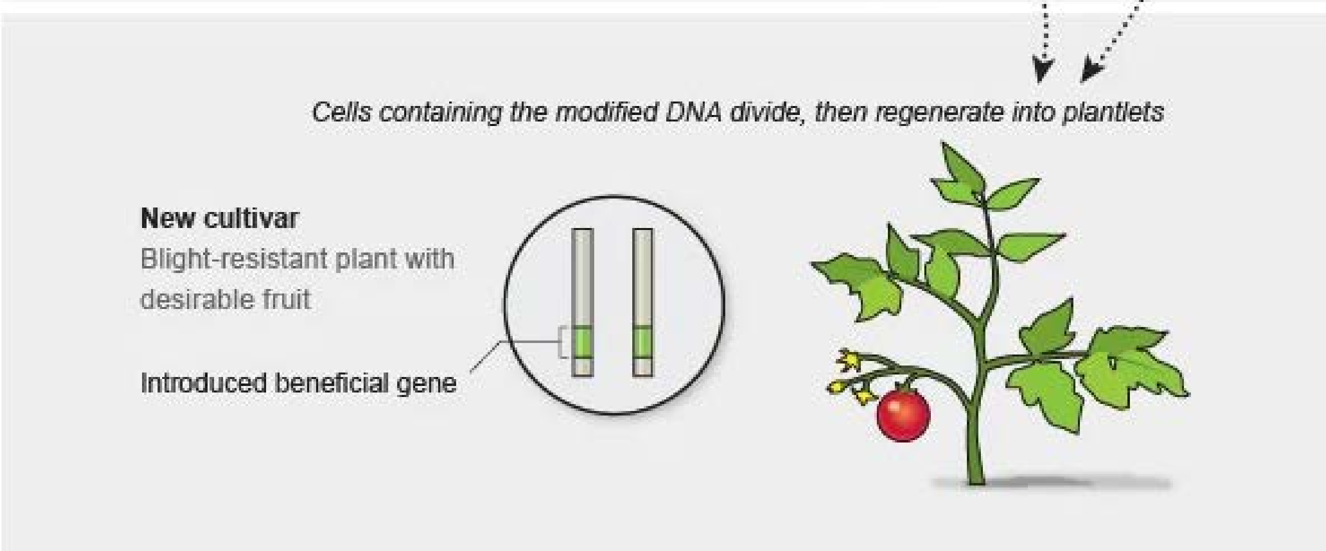


First-Generation Genetic Modification

In the 1980s agricultural scientists created the first wave of genetically engineered crops, using either biological agents (*Agrobacterium*) or physical force (so-called DNA particle guns) to insert new genes into plant cells. The genes could be foreign (transgenic) or from a related species (cisgenic).

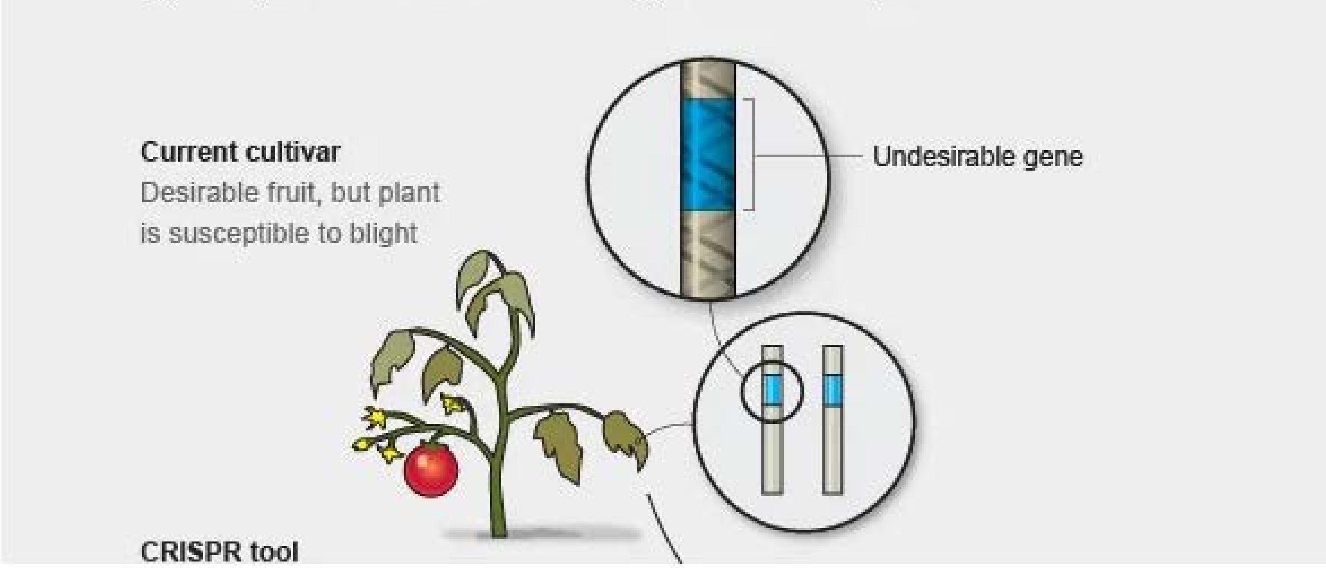


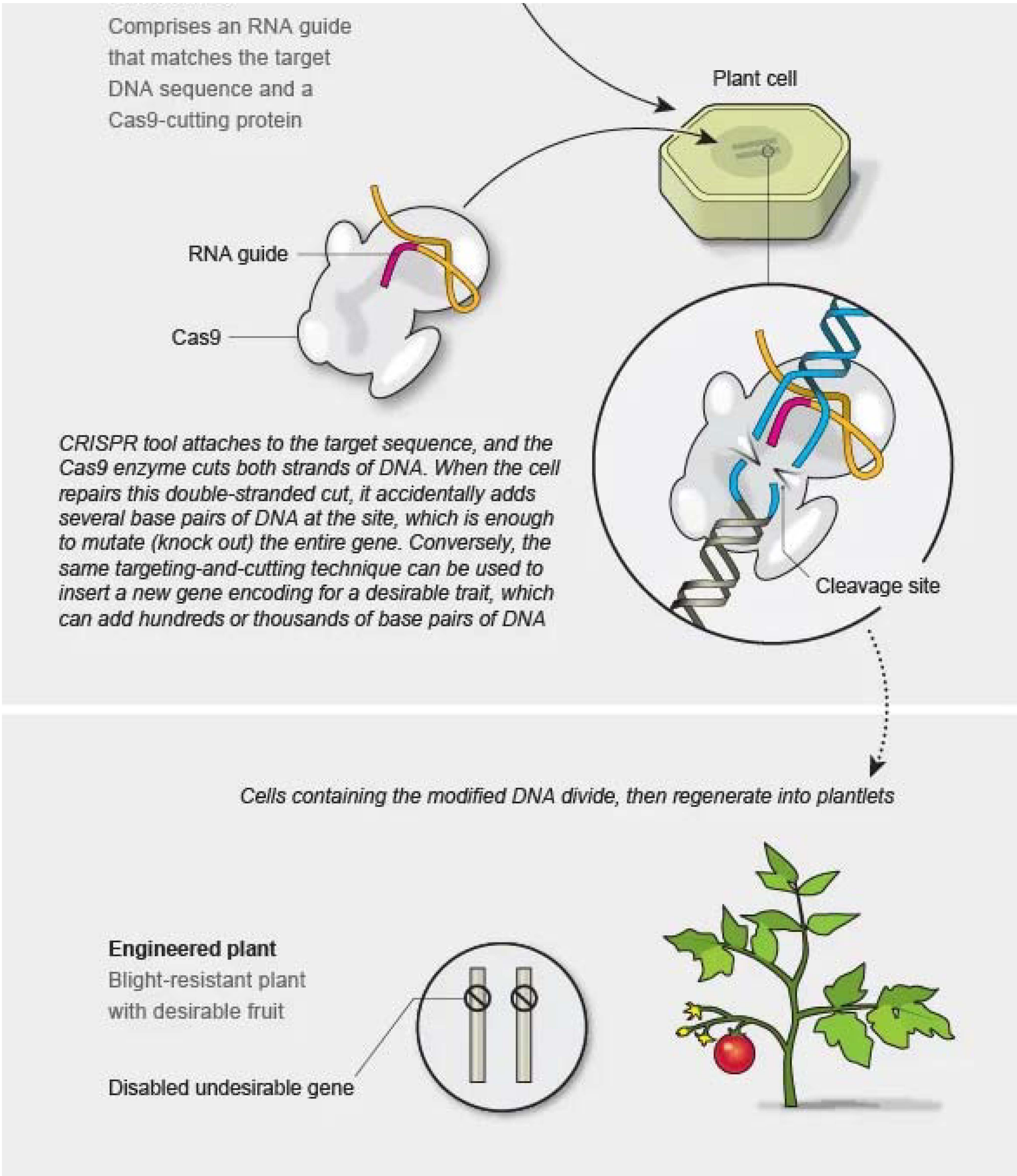




Second-Generation Gene Editing

With precision gene-editing technologies (zinc fingers, TALENs and CRISPR), biologists can target a specific gene and either deactivate it (*depicted below*) or replace it. A replacement gene can come from an unrelated species (transgenic) or from a related variety (cisgenic). Although CRISPR can be targeted to a specific location, its accompanying Cas9 enzyme occasionally makes unprogrammed, "off-target" cuts; limited data indicate that off-target cuts are rare in plants.





Graphic by Jen Christiansen

ABOUT THE AUTHOR(S)

Amanda Montañez

Amanda Montañez is an associate graphics editor at Scientific American.