fall into two size classes, and mutations that swap bases of similar size are more common than mutations that switch base sizes. Second, during protein synthesis the first and third members of a codon are much more likely to be misread than the second one. When those mistake frequencies are factored in, the natural code looks even better: Only one of a million randomly generated codes was more error-proof.

That suggests, Freeland says, that the code has been optimized over the eons and isn't simply the product of chance. Lehman agrees that the one-in-a-million result looks impressive, but cautions that the statistics could be misleading. A high degree of similarity within one clan of amino acids could account for the code's apparent resistance to error, and the rest of the code could be random, he says.

With both the genesis and history of the code looking less and less accidental, Landweber and Freeland plan to collaborate next year, hoping to "build a grand scheme of the code's raison d'être," Landweber says—whether it be accident or design.

–GRETCHEN VOGEL

MEETING PLANT PHYSIOLOGY

Plant Biology in the Genome Era

MADISON, WISCONSIN—More than 2000 plant scientists dug in here from 24 June to 1 July for two back-to-back meetings: the 9th International Conference on *Arabidopsis* Research and the annual meeting of the American Society of Plant Physiologists. While some researchers put the wealth of data from genome projects to creative uses such as making vitamin-fortified plants, others use it to enhance work on such questions as how flowers form.

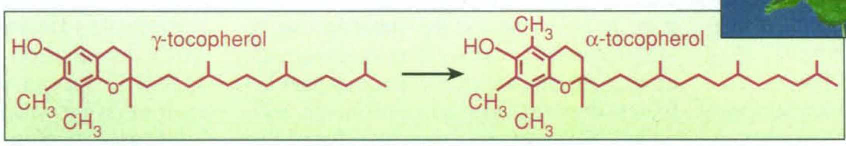
Engineering Plants, From A to Zn

In the past 2 decades, genetic engineers have brought us plants that resist disease and herbicides, plants that produce drugs, and even plants that make plastic. Now they have hit on what observers say is a very obvious and good idea: altering plant genomes to crank out increased amounts of vitamins and minerals.

A handful of academic and industry labs around the world are working on such "nutritional genomics," as biochemist Dean DellaPenna of the University of Nevada, Reno, calls it. DellaPenna himself is coaxing plants to churn out more vitamin E in a form that the human body can easily use, while other projects still in the works focus on vitamin A and iron. The market for such fortified plants might be health-conscious consumers who dislike taking vitamin pills, or those in the developing world who lack access to the necessary micronutrients, DellaPenna said at the meeting.

In the case of vitamin E, DellaPenna noted that an average U.S. diet provides the tiny amount needed to keep blood cells and neurons functioning. But many consumers are loading up on vitamin E supplements in response to recent reports that large doses of vitamin E and other antioxidants might protect against cancer and heart disease. "You'd need to eat one to one-and-a-half kilograms of spinach daily, or 3000 calories of soybean oil, to get the therapeutic dose," said DellaPenna.

So he and David Shintani of his lab tweaked the experimental plant *Arabidopsis*, a member of the mustard family, to increase its production of the most useful form of vitamin E, a ring and chain of carbon known as α-tocopherol. They found that *Arabidopsis* seeds normally produce γ-tocopherol, one enzymatic step short of α-tocopherol. To find the gene responsible for that key enzyme, they hunted through the sequenced genome of the photosynthetic bacterium *Synechocystis* for a known gene that operates earlier in the pathway. Then they tested nearby genes until they found the one that codes for the enzyme, γ-tocopherol methyltransferase. Finally they scrolled through the growing database of *Arabidopsis* genes and found its version of the gene, apparently lurking unexpressed in the plant seeds.



DEVERE PATTON

No more pills? Researchers tweaked the *Arabidopsis (right)* genome to produce α-tocopherol, or vitamin E.

The two next hooked the gene to a regulatory sequence that specifies expression in the plant seed and engineered the whole package back into developing *Arabidopsis* plants. The result was a 10-fold increase in the amount of α-tocopherol in the seeds. "The bulk of the γ-tocopherol is converted to α-tocopherol," DellaPenna reported. The offspring of the first-generation plants also produced more vitamin E in their seeds.

The effort is "an intelligent use of genomic information" with practical promise, says plant scientist Chris Somerville of the Carnegie Institution of Washington's plant laboratory at Stanford University. The next step is to similarly engineer a food plant such as soy, which already makes a small amount of α-tocopherol in its seed. "I'm sure it'll be in crop species very quickly," says Somerville.

Plants expressing increased amounts of other micronutrients may not be far behind. For example, Ingo Potrykus at the Swiss Federal Institute of Technology in Zurich and his colleagues have been working to engineer rice to produce vitamin A. They're using genes from bacteria and daffodils, which make the carrot-colored carotenoids that provide vitamin A. If they are successful, vitamin A–rich rice could help alleviate deficiencies of the vitamin in regions where rice is the dietary staple.

Iron—the most common nutritional deficiency worldwide—is another target, plant biologist Mary Lou Guerinot of Dartmouth College in Hanover, New Hampshire, told the meeting. She hasn't engineered iron-fortified plants yet, but so far they have identified an *Arabidopsis* gene that codes for a protein that allows the plant to take up iron from the soil. They have also just found a similar group of transporters for zinc, another necessary micronutrient. Manipulating these transporter proteins could allow them to boost the amount of minerals a plant takes in, she says. If such work eventually produces fortified crops, there may be an alphabet of new reasons to eat your vegetables.

Shaping a Flower's Heart

The bud of a flower is a picture of petaled symmetry, a look that it usually maintains even as the bloom opens and then fades. But a new look at an early, crucial stage in flower development reveals an asymmetry deep in the heart of the flower, plant anatomist Judith A. Verbeke of the University of Arizona, Tucson, reported at the meeting. In an elegant if painstaking set of experiments, she showed that a flower's cup-shaped inner sanctum, called the carpel, has a lopsided beginning: One half forms first and then later drives an unusual developmental process in which cells in both halves redifferentiate. In the end, the two smaller carpels fuse into a single, symmetrical vessel that will hold the plant's seeds.

Not-so-twin peaks. As the periwinkle flower *(left)* forms, one bit of carpel tissue leads the way *(below)*.

PHOTOS: J. VERBEKE

Fused carpels—which allow fruits like tomatoes to grow large rather than being split into several smaller seed chambers—were a key evolutionary innovation and help distinguish flowering plants from more primitive gymnosperms such as conifers which have naked seeds, notes plant developmental biologist Ian Sussex of Yale University. The lopsided developmental progression seen in the carpel will also likely appear among other parts of flowering plants, says Verbeke: "I think [the pattern] will be absolutely general."

Verbeke made her discovery in an ornamental plant that is already famous: the Madagascar periwinkle, *Catharanthus roseus*, the source of two valuable anticancer drugs. She and her colleagues have spent more than a decade studying the early developmental stages of the plant's half-dollar–sized blooms and had already revealed one surprise: An as-yet-unknown substance from the developing carpel causes a cluster of epidermal, or surface, cells to switch fate abruptly and redifferentiate into parenchyma cells, a common internal cell type that allows a tight seam between the two parts to form (*Science*, 5 May 1989, p. 580). The fusion seems to require the unusual redifferentiation of cells already committed to a particular developmental path.

Verbeke's group probed this process further with a slew of intricate microsurgical experiments on the barely visible emerging flower bud and turned up a distinct biochemical difference in the two parts of the carpel. The researchers put an extract collected from developing carpels onto test carpels, using wisps of a polycarbonate membrane to transfer the extract and maneuvering the tissue and membrane with tiny instruments cut from razor blades or sheared from needles.

The technique is so tricky that Verbeke calls it "nuts," but others appreciate it: "It's a really beautiful system for identifying temporal differences in development," says plant geneticist Gregory Copenhaver at the University of Chicago.

When the carpel extract was randomly placed on emerging carpel halves, the cells redifferentiated in only 50% of the trials, Verbeke reported. Similarly, when one of the carpel halves was successfully transplanted onto other flower buds, cells changed course only half the time, indicating that only one of the halves was responding to the chemical signal. The distinction between the two halves was sewn up when Verbeke and her colleagues examined emerging buds under an electron microscope: They saw that one of the carpel halves pops up before the other. Additional experiments confirmed that this older tissue is what later induces redifferentiation in the "younger" half.

This early developmental difference between two halves of the carpel is also turning up in genes at the molecular level. Verbeke and colleagues found that some messenger RNA sequences were expressed only in the "older," inducing half of the carpel. So far these sequences have shown little resemblance to any in the plant data banks. The next step, says Verbeke, is to identify the powerful inducing substance, which seems to be a protein—and could be one more claim to fame for Madagascar's periwinkle.

—CHRISTINE MLOT

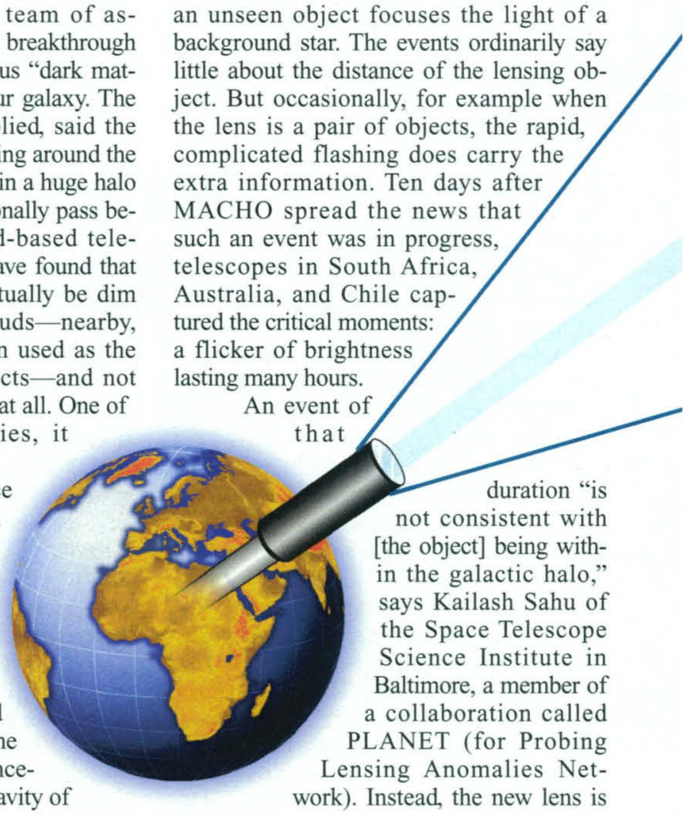
Christine Mlot is a science writer in Madison, Wisconsin.

ASTRONOMY

A Dark Matter Candidate Loses Its Luster

The dark objects thought to inhabit the Milky Way's halo, accounting for its missing mass, may actually be dim stars in nearby galaxies

More than 2 years ago, a team of astronomers announced a major breakthrough in the search for the mysterious "dark matter" that makes up most of our galaxy. The flashing of distant stars implied, said the team, that the matter is swarming around the visible disk of the Milky Way in a huge halo of dark chunks, which occasionally pass between the stars and ground-based telescopes. Now, several teams have found that the unseen objects might actually be dim stars in the Magellanic Clouds—nearby, dwarf galaxies that had been used as the backdrop to reveal the objects—and not dark matter in the Milky Way at all. One of astronomy's great mysteries, it seems, is still unsolved.



The confounding evidence came just last month, when the original team, called the MACHO Collaboration (for Massive Compact Halo Object), alerted other astronomers to an unusual brightening of one of the stars in the Small Magellanic Cloud (SMC). Such brightenings—the basis for the original announcement—take place when the gravity of an unseen object focuses the light of a background star. The events ordinarily say little about the distance of the lensing object. But occasionally, for example when the lens is a pair of objects, the rapid, complicated flashing does carry the extra information. Ten days after MACHO spread the news that such an event was in progress, telescopes in South Africa, Australia, and Chile captured the critical moments: a flicker of brightness lasting many hours.

An event of that duration "is not consistent with [the object] being within the galactic halo," says Kailash Sahu of the Space Telescope Science Institute in Baltimore, a member of a collaboration called PLANET (for Probing Lensing Anomalies Network). Instead, the new lens is