High-yield agriculture

A century of plant genetics at CSHL seeds new approaches

In the summer of 1905, on a small patch of land next to what is now the Carnegie Building at Cold Spring Harbor Laboratory, a 31-year old scientist named George Shull began to grow maize, or corn, in a series of experiments that would change the face of modern agriculture. This year, CSHL scientists made two fundamental discoveries that continue the legacy at the Laboratory that began with Shull to improve the world's food supply.

Soon after completing his doctoral thesis at the University of Chicago, Shull had taken charge of plant research at the Station for Experimental Evolution, one of two Long Island institutions that would merge half a century later to form CSHL. His goal had been to publish experimental support for Charles Darwin's theories of evolution. But what he actually accomplished had an even greater impact. Based on one of Darwin's ideas, he devised a practical solution to boost agricultural productivity.

A dormant idea feeds a hungry world

In 1876, Darwin wrote of a curious phenomenon, hybrid vigor, or heterosis, to describe his finding that the hybrid offspring of cross-pollinated plants grew much taller than the inbred offspring of self-pollinated plants. The idea remained latent, however, until Shull followed up on it 30 years later.

Self-pollinating a corn plant for generations, Shull found, resulted in inbred offspring that got progressively smaller in each generation, producing smaller corncobs with fewer seeds. But when Shull inter-crossed two such poorly yielding varieties, the hybrid progeny spectacularly outperformed their parents in growth and yield.

Shull realized that his initial regimen of inbreeding had separated a genetically diverse corn plant into an array of "pure" lines, which could then be "crossed" to produce vigorous hybrids. Here then was a way to increase crop yield, a goal that corn breeders had been pursuing for thousands of years. In a 1908 paper titled "A pure-line method for corn breeding," Shull modestly wrote, this "method … may perhaps give results worth striving for."

It did, and in the most profound way imaginable. By the 1930s, most farms in America were using Shull's method to grow high-yield corn. This method significantly contributed to the war effort and the rehabilitation of postwar Europe in the late 1940s. In the last 50 years, the heterosis concept, which was successfully applied to other crops such as rice, has been the driving force behind rising agricultural yield and global food security.

Unraveling the genetics of hybrid vigor

"Ironically, though, there's still no consensus on what causes heterosis, or hybrid vigor," says plant geneticist Zachary Lippman, an assistant professor at CSHL, who is about the same age today as Shull was when he made his ground-breaking discovery. "But we are starting to identify the genes and mechanisms that drive and control it." This information will help exploit heterosis in a systematic, scientific way and maximize its benefits.

A field adjoining CSHL's Carnegie Building was the site of George Shull's corn breeding experiments in the early 1900s.

In 2004, Lippman — who had just received his doctorate from CSHL's Watson School of Biological Sciences — moved to Israel to hunt for vigor-boosting genes in tomato plants. Three years later, he and his postdoctoral advisor, Professor Dani Zamir of Hebrew University, found six promising leads. While five remain uncharacterized, the sixth led to a gene that increased tomato yield by a dramatic 60%. Interestingly, the gene encodes the florigen protein, which controls when and how plants make flowers (which in turn produce fruit.)

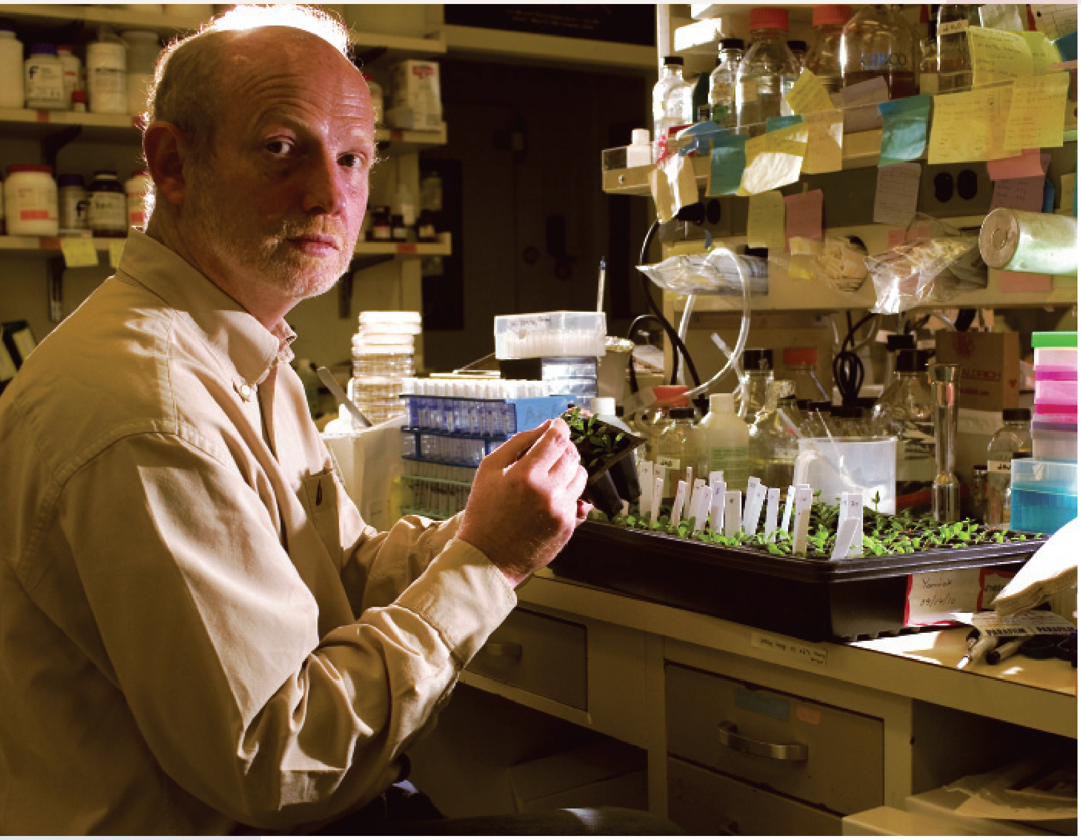
Their discovery is the result of a novel approach that does not require technology that is currently used to produce genetically modified crops, which some find objectionable. Rather, it relies on classical breeding principles that any backyard gardener would recognize.

Lippman accepted a faculty position at CSHL in 2008. Quickly setting up operations with start-up funding from CSHL trustee Jacob Goldfield, he confirmed the "overdominant" gene's vigor-boosting power in different varieties of tomatoes. He also confirmed it in plants grown in different climates and soil conditions, such as at CSHL's own Uplands Farm and at the Cornell Horticultural Station at Riverhead, NY.

Published in early 2010, this work, which could potentially impact the billion-dollar tomato industry as well as efforts to mass-produce other flowering plants, was enthusiastically hailed by the international news media. The newspapers made much of the "the flower power gene" that could turn an average tomato plant into "a bionic fruit factory."

The gene, which boosted yield and sweetness, in fact goes by the typically subdued scientific name, *single flower truss* (*sft*). It increases yield only in hybrids that have one normal copy and one mutated copy of the gene.

"As in the Goldilocks story, there can't be too much or too little, but just the right amount of florigen to get maximum yield," explains Lippman. "A mutation in a single copy of the *sft* gene results in the exact dose, thereby driving hybrid vigor." In a spin-off project, Lippman has now joined forces with CSHL Professor David Jackson to investigate if there is such a "dose effect" that can increase yield in a major crop species such as corn.



Rob Martienssen in the lab with *Arabidopsis*, the mustard plant that served as a test-bed for his experiments with apomixis.

Genetically locking in hybrid vigor

Like most cereal crops, corn reproduces sexually. For farmers, this is a disaster, as it forces them to spend an estimated $30 billion annually on fresh stocks of quality-controlled seeds that will produce a uniform field of crops with a desirable trait such as high yield. Farmers can't grow these seeds themselves because sexual reproduction — the random mixing of DNA from male (sperm) and female (egg) gametes, or sex cells — will likely wipe out the very trait desired.

If Lippman's work on the genetics of heterosis points the way to superior crop yields, then the work of CSHL Professor Rob Martienssen could lead the way to locking in high yield or any other valuable trait. Then farmers wouldn't have to buy new seeds every year. Martienssen studies the biological role of mobile bits of DNA known as transposons — the "jumping genes" discovered 60 years ago by CSHL geneticist Barbara McClintock, who won the Nobel Prize for her work in 1983.

"She was really visionary," says Martienssen, who was mentored by McClintock early in his career. "In an era when none of today's genetic and genomic tools existed, she was able to conclude that transposons are important in plant development."

Martienssen's work has revealed a great deal about how transposons, which can damage DNA when they are active, are "silenced" in plant sex cells via a process known as RNA interference. Two years ago, while identifying the genes in this pathway in pollen-derived sperm cells, he made a surprising observation that genetically linked transposon silencing to a plant's ability to sexually reproduce.

His lecture about this work at the National Polytechnique Institute in Irapuato, Mexico sparked a collaboration with Jean-Phillipe Vielle-Calzada, a researcher who has spent years trying to turn sexually reproducing plants into asexual reproducers by inducing them to undergo apomixis. A little-known trick that exists in nature, apomixis — which occurs in some 350 families of plants, including the humble dandelion — essentially allows plants to make exact genetic replicas of themselves, asexually.

Early in 2010, the scientists reported results suggesting that the mustard plant — a sexual reproducer — is unable to reproduce via apomixis because of a gene called *Argonaute 9*, which is well known for its role in silencing transposons. Mutating this gene, however, unleashed transposon activity as well as the hallmarks of apomixis within the plant's reproductive organs.

"Making an apomictic high-yield hybrid is of course the ultimate goal," says Martienssen. "Then you'd never have to rely on laborious crosses again. Our work in the mustard plant was just the first step. We're still some ways off from perfecting the process to get completely viable asexual seeds and applying this to other crops."

But he's optimistic about their chances of getting there. In the summer of 2011, he and other CSHL plant geneticists will be hard at work in CSHL's fields, trying to harvest an apomictic corn plant. **Hema Bashyam**

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