



AGRICULTURE

The Plant Breeder and the Pea

K. B. Saxena has spent his career trying to boost yields of pigeon pea, a crop relied on by hundreds of millions of marginal farmers. At last, he's succeeded

When he decided on his life's work as a plant breeder, K. B. Saxena made an unlikely choice. The year was 1974, and new varieties of rice and wheat were boosting production and cutting hunger around the world. With a newly minted Ph.D. from one of India's top agricultural universities, Saxena could have worked on any of these blockbuster crops. Instead, he picked a gangly, unrefined plant called pigeon pea.

Although still barely known in the West, pigeon pea (*Cajanus cajan*) is the main source of protein for more than a billion people in the developing world and a cash crop for countless poor farmers in India, eastern Africa, and the Caribbean. This hardy, deep-rooted plant doesn't require irrigation or nitrogen fertilizer, and it grows well in many kinds of soil. "It's such an important crop, and it had been neglected," Saxena says.

During a 30-year career at the International Crops Research Institute for the Semi-Arid Tropics (ICRISAT) in Patancheru, India, Saxena helped create nearly a dozen kinds of pigeon pea that mature sooner and resist diseases better than do traditional varieties. Yet the big prize—high-yielding hybrids—never seemed within reach. "People had lost hope that yield could improve," says Saxena, who narrowly escaped being laid off a decade ago and barely managed to keep his

program going during hard times at ICRISAT.

Now, hope is back. Two years ago, Saxena's group finally succeeded in creating the first commercially viable system in the world for producing hybrid legume seed. It couldn't have come at a better time: India faces a pigeon pea shortage severe enough that the government banned exports of it and other so-called pulses last year. Last month, ICRISAT announced that one of its most promising hybrids can achieve yields nearly 50% higher than those of a popular variety. "This will become the forerunner of a pulses revolution in India," predicts M. S. Swaminathan, a plant breeder considered one of the chief architects of the original green revolution. The first seeds should reach farmers next year, and Swaminathan himself is working on a project to make sure even the poorest can afford them.

Deep roots

Saxena was inspired to become a plant breeder when he was in high school. His older brother, a maize breeder, would take him into the research fields and explain what he was doing. "All that stimulation came from my brother," Saxena says. "He encouraged me a lot." And with the green revolution at its height, plant breeding was a hot field. After finishing a Ph.D. in cereal grains, Saxena joined ICRISAT in 1974, which had been

In bloom. K. B. Saxena (right) and colleagues bred countless varieties of pigeon pea to create new hybrids.

founded just 2 years earlier to improve five semiarid tropical crops: sorghum, pearl millet, chickpea, groundnut, and pigeon pea.

There wasn't much competition to work on pigeon peas, Saxena recalls. Crops took 6 to 9 months to mature, slowing the pace of research. And they grew to 2 to 3 meters tall, their pods covered in a sticky gum. "It will spoil all your clothes in an hour," Saxena says. "No one wanted to work on such a dirty crop."

But sensing an opportunity—and loving the dahl made from pigeon peas—he plunged in. By the 1980s, the small team of plant breeders at ICRISAT—together with researchers at the Indian Council of Agricultural Research (ICAR)—had developed early-maturing varieties that can be harvested in only 3 months. That meant an entire crop of nitrogen-fixing pigeon pea can be planted before the wheat crop in northern India, helping to restore fertility to the soil. New varieties also featured improved resistance to fusarium wilt and the dreaded sterility mosaic virus known as "the green plague." But yields hardly budged, rising to an average of 700 kilograms per hectare.

The way to smash through the yield barrier is by creating plants with hybrid vigor. This is a well-known phenomenon in which the first generation of offspring exhibit vastly superior traits—yield, or overall health, for example—than those of either parent. The process starts with picking the best plants from each generation and breeding them so that all the progeny of each have dependable traits, then crossing them. This is relatively straightforward and can be done by hand in the greenhouse.

But making enough hybrid seed to sell requires an easy way to prevent plants of each parent variety from fertilizing themselves. (Each plant carries both male and female sex organs.) Breeders like to create so-called male sterile plants that can't make viable pollen but can still be fertilized by pollen from certain other varieties. In corn and rice, varieties had been bred to produce sterile pollen by the 1980s.

Breeding sterile plants in pigeon pea and other legumes has proven much more difficult. For starters, the male and female parts exist within the same flower. That means researchers must pollinate the delicate ovaries by hand, and sometimes only a few percent can be successfully fertilized. This and other challenges kept hybrids off the agenda of most legume breeders. "It's theoretically possible,

but it's hard to do," says Harbans Bhardwaj, a plant breeder at Virginia State University, Petersburg, who has worked with pigeon pea.

Proof of principle came in the late 1980s. Working with ICAR institutions, Saxena and his ICRISAT colleagues found varieties with nuclear genes that conferred male sterility. Hybrids from this line boosted yield by up to 30% and did well in field trials. But the males weren't always sterile—sometimes just a fraction of the male flowers lacked pollen. Because not all the seeds produced from them were high-yielding hybrids, companies were not interested in commercializing the plants.

Other setbacks put the project in jeopardy, too. In the late 1990s, ICRISAT began to have major budget problems (*Science*, 2 January 1998, p. 26), and management decided to drop pigeon pea research. Saxena pleaded his case, but the pigeon pea team was still cut deeply; the three other breeders were laid off, as were seven of 10 technicians. After drumming up external funding from companies, Saxena rebuilt the program.

The big advance came from finding plants with genes in their cytoplasm that confer male sterility. Unlike nuclear genes, which are segregated during meiosis, the cytoplasm is passed down through the eggs to all the progeny, so the offspring of plants with the particular cytoplasmic genes will all be male-sterile.

Some hints of cytoplasmic male sterility had come early on, when breeders managed to produce plants with sterile pollen by fertilizing wild pigeon peas with pollen from a cultivar. But the plants also had sterile ovaries. Saxena expanded this effort with other wild species. Each year, the group made thousands of experimental crosses and planted the seeds. Every plant was inspected when it flowered—an onerous task, as a hectare can contain up to 60,000 individual plants. In March 1996, a research assistant struck gold when he located plants with no pollen in any of their flowers—a sign of cytoplasmic male sterility. He dashed off on his motorbike to relay the news. "It was very exciting," says Saxena. "People were really smiling in the field." Further testing revealed that the sterility was indeed passed on through the cytoplasm.

Still, success came slowly. Some lines created plants that were male-sterile when grown in winter but would somehow produce fertile pollen in the summer. "Sometimes we got frustrated," Saxena says. Out of five lines

they developed, only one turned out to be stable enough. In order to perpetuate these plants, they also had to find a maintainer line—a nearly identical plant with pollen that would fertilize the plants but yield seed that would grow up into male-sterile plants. The final component was a restorer line, a variety that can fertilize the male-sterile plants so that the progeny will bear seeds. New traits, such as disease resistance, are bred into either or both of the parent lines to produce hybrid seed for farmers.

By 2004, the system was up and running (*Euphytica*, October 2005, p. 289). "This is a breakthrough in plant breeding," notes



Seeing green. Extra yield from hybrid varieties of pigeon pea could raise the income of farmers, such as these pea farmers in Eastern Kenya.

Latha Nagarajan, an agricultural economist at the International Food Policy Research Institute in Washington, D.C. "The possibilities are endless."

Starter seed

Of some 300 hybrids tested so far, the best—called ICPH 2671—yields up to 3 tons of pigeon peas per hectare—48% more than a widely used variety known as Murati. "It's a quantum jump in yield," says Swaminathan, who thinks that yields could even be doubled with improved cultivation and pest management. He notes that legumes require careful attention to phosphorus, and Indian soil is often poor in micronutrients that pigeon pea needs, such as zinc and boron, so

educating farmers about soil nutrition will be important.

In addition to yield, Saxena says that this hybrid also does better against drought and resists diseases better than do the standard lines. "This system that Saxena has developed will benefit the small subsistence farmers and consumers," says Sharad Phatak, a horticulturist at the University of Georgia, Tifton. If 15% to 20% of the acreage is planted with hybrids, he reckons, it might take care of the pigeon pea shortage.

There is, however, a downside: Unlike traditional varieties, hybrid seed must be bought every year, because only the first generation has the hybrid vigor. Most of those seeds will come from companies, which makes some observers worry that small farmers won't be able to afford them. ICRISAT has provided the male sterile system, which is in the public domain, to a consortium of 15 Indian seed companies so that they can create their own hybrid pigeon pea varieties. Several companies are also preparing to sell ICPH 2671, and Saxena estimates that the seed will cost about \$3.25 a kilo, about 50% more than standard cultivars. He says it's likely that some government agencies will sell the seed at half price to poor farmers.

Swaminathan isn't taking any chances, however. His foundation, based in Chennai, is beginning a project to train women to produce the hybrid seed themselves from ICRISAT seeds. Beginning in June, agronomists will go to villages about 180 km south of Chennai and teach some 100 women, mostly the wives of subsistence farmers. The goal is for them eventually to sell hybrid seed in their neighborhoods. "The principle is social inclusion and technology access for all," Swaminathan says. "You can keep the cost of seed low and increase employment in villages."

Meanwhile, Saxena, now 58 and 2 years from retirement, spends half his time promoting the sterile lines to breeders at universities and companies, as well as encouraging farmers to try them out. He's also involved in promoting the use of pigeon pea in other countries, such as China, where it's used in several ways but mainly as a quick fix for soil erosion. Although Saxena's work may not trigger the dramatic agricultural revolution that he witnessed at the beginning of his career, it could still improve the lives of hundreds of millions of people.

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