Background: The Science of Seed

Modern U.S. agriculture owes much to the application of science. Scientific discoveries in the fields of chemistry, engineering, and biology have contributed to the development of a highly productive and technologically innovative modern agricultural sector. Central to this modernization process has been the application of science to modern plant breeding.

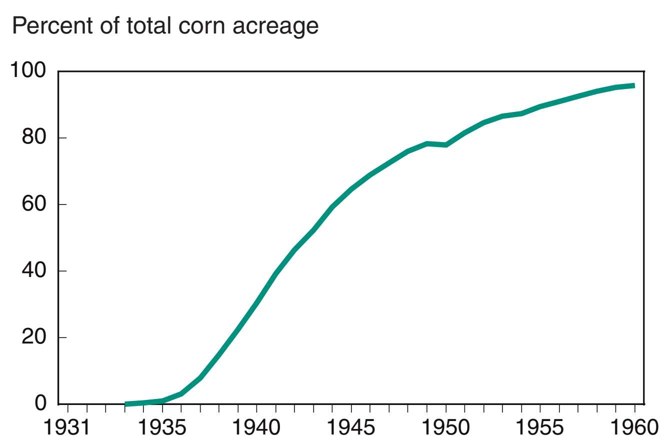
The first application of modern scientific methods to plant reproduction is credited to Gregor Mendel in the mid-19th century (Sears, 1947). Up to then, farmers engaged in plant breeding in a less systematic or conscious manner, usually by exploiting chance mutations and natural selection processes. Mendel's research focused on the identification of particular traits in garden peas, and the ways in which such traits were inherited by successive generations. Mendel's work on the laws of heredity, though lost for 34 years, eventually gave rise to extensive scientific research into the inheritance of traits in other plants and crops (Jenkins, 1936, p. 483).

A significant portion of this later research focused on corn and corn hybridization. Essentially, hybridization is a traditional breeding process in which inbred lines are crossed to create seed varieties with greater yield potential than exhibited by either parent (see box on terms and concepts). Hybridization allows breeders to enhance biological characteristics more predictably and more quickly than natural selection or chance mutations. Breeders also protect their intellectual property by keeping knowledge of their hybrid varieties from being passed on to others. Early 20th century studies, including De Vries and Correns (1900) on the inherited nature of corn endosperm texture, Shull and East (1908) on hybrid vigor arising from their experiments in corn breeding, and Jones (1918) on the commercial potential of higher yielding hybrid corn, led to major breakthroughs in plant breeding (Heisey, 1999).

By the late 1920s, hybrid corn breeding programs were showing signs of success, particularly large increases in yields. Corn, as an open-pollinated crop, was well suited to the inbreeding-hybridization process. From the perspective of the farmer, hybrid corn seed had many advantages, including higher yield potential, greater uniformity in maturity, and resistance to lodging, making large-scale mechanization possible (Sprague, 1961, p. 107). From the perspective of the seed firm, hybridization had two commercial advantages. First, simple examination of a hybrid seed does not reveal its lineage, thus offering companies proprietary control over the seeds they develop. Second, the enhanced vigor of hybrid seed is not transmitted to its offspring, thereby requiring farmers to buy new seed every year to ensure continued vigor. Crops cultivated from seed saved from a hybrid crop grown in the previous year are typically less vibrant and significantly lower in yield.

The application of science to plant breeding, and specifically to corn, was a timely development in U.S. agriculture. In the early 20th century, corn was the dominant field crop in U.S. agriculture. Yet, despite the crop's importance, corn yields were stagnant at the time. Publicly supported research and development of hybrid corn seed, an effort later taken over by commercial seed companies, helped reverse this trend during the 1930s (Airy et al., 1961, p. 145). The first seed company was organized for the commercial production of hybrid corn in 1926, but hybrid corn seed production only began to expand in the early 1930s, as several new firms began production (Jenkins, 1936, p. 479). By 1960, the share of corn acreage cultivated with hybrid seed in the United States had reached 95 percent (fig. 2), and almost all open-pollinated (OP) corn cultivated in the United States was

Figure 2
Adoption of hybrid corn



Source: *Agricultural Statistics,* NASS, USDA, various years.

Term and Concepts

Plant breeding concepts: "The essence of plant breeding is the discovery or creation of genetic variation in a plant species and the selection from within that variation of plants with desirable traits that can be inherited in a stable fashion. The plant breeders' final selections of superior plants will form the basis of one or more plant varieties. Plant breeders use all available technology both to create genetic variation and to select from within that variation.

"Different types of plant variety have been developed, depending upon the physiology of the plants of each species and the ways in which the plants of the species can be reproduced. For example, varieties of rose and potato can be reproduced vegetatively, that is to say, can be reproduced by using a part of a plant as the basis for producing another complete plant. Rose varieties can be reproduced by propagating a bud or a cutting from a plant of the variety. Potato varieties are normally reproduced by propagating a tuber of the variety.

"Varieties of grasses and most vegetables and cereals are reproduced sexually, that is by pollination of the female part of a flower (the stigma) by pollen from the male part of a flower (the anther). Here, however, one must make a distinction. The plants of some species, for example wheat, will tolerate, through successive generations, the fertilization of the stigma by pollen from the anthers of the same flower or from another flower on the same plant without loss of vigor. Plant varieties of such species can be based upon a single plant or on a small number of plants which will reproduce themselves precisely through successive generations. All the plants of a variety of this kind, known as "self-pollinated" varieties, will be genetically the same or very similar.

"The plants of many species are not adapted to self-fertilization or cannot tolerate self-fertilization through successive generations and will become less vigorous if forced to self-pollinate (they will suffer from "inbreeding depression"). In these plants, the female part of the flower must be fertilized by the pollen from another flower, or from a flower of another plant. Varieties of such species, known as "cross-pollinated" varieties, are populations of plants based upon the controlled cross-pollination of a sufficient number of selected diverse, superior plants to secure enhanced performance without suffering in-breeding depression.

"Yet a further category of variety is based upon the controlled cross-pollination of parent lines, so that the seed resulting from the cross-pollination inherits its genetic make-up from the parent lines. Such varieties, known as "hybrids," will typically exhibit greater vigor ("hybrid vigor") than the parent lines on which they are based, resulting, for example, in plants with higher yields, better resistance to stress, etc. The same controlled cross-pollination must be repeated each time the seed of those varieties is produced." (UPOV, 2003).

Agricultural biotechnology is the application of scientific techniques, including genetic engineering, to create, improve or modify plants, animals and microorganisms. Agricultural biotechnology improves upon conventional techniques, such as selective breeding, by enabling scientists to move genes and the desirable traits that they express with greater efficiency and precision (USDA, 2003).

Genotypes are the genetic traits or characteristics expressed by a particular variety (UPOV).

Germplasm is the genetic material that contains a variety's inherited characteristics.

Cross-pollinating species are those in which the pollen is primarily dispersed from one plant to another.

Self-pollinating species are those in which the pollen is primarily dispersed within the same plant.

Organisms are living things that may be categorized for purposes here as plants, animals, or microorganisms, including bacteria. An organism is categorized based on such factors as its structure, mobility, source of nutrition, or cell structure (UPOV; USDA 2000).

Sexual reproduction includes any production of a variety by seed but does not include the production of a variety by tuber propagation (PVP Act, Chapter 4, Sec. 41, USDA, Agricultural Marketing Service (AMS), 2001).

Tuber propagation means propagated by a tuber or a part of a tuber (PVP Act, Chapter 4, Sec. 41, USDA, AMS, 2001).

Variety refers to a plant grouping within a single botanical taxon [taxonomic group] of the lowest known rank, that, without regard to whether the conditions for plant variety protection are fully met, can be defined by the expression of the characteristics resulting from a given genotype or combination of genotypes, distinguished from any other plant grouping by the expression of at least one characteristic and considered as a unit with regard to the suitability of the plant grouping for being propagated unchanged. A variety may be represented by seed, transplants, plants, tubers, tissue culture plantlets, and other matter (PVP Act, Chapter 4, Sec. 41, USDA, AMS, 2001).

replaced by hybrids by the 1960s (Fernandez-Cornejo et al., 1999; Shoemaker et al., 2001, p. 9).

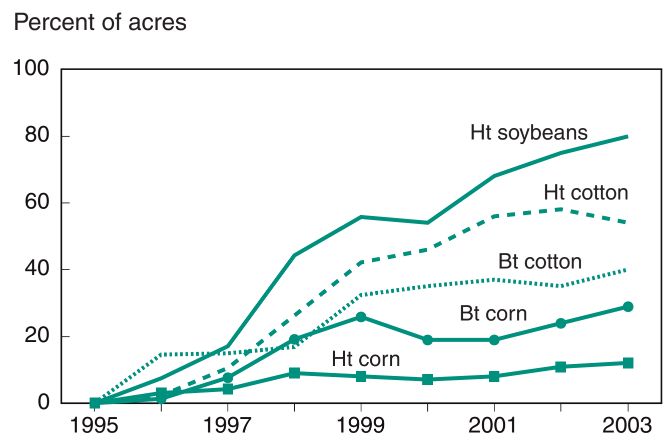
The commercial success of hybrid corn in the United States was followed by such plant breeding advances as hybrid sorghum and improved varieties of soybeans and cotton. The first commercial seed field of hybrid sorghum was planted in 1955; by 1960, 70 percent of the U.S. sorghum acreage was planted with hybrid seed (Airy et al., 1961, p. 145). Sorghum is now mostly grown from hybrid seed. Other vegetables, including onions, spinach, tomatoes, and cabbage, are also grown from hybrid seed (Emsweller, 1961).

The application of science to plant breeding also produced significant gains in crop yields in other countries. During the late 1960s and early 1970s, scientific breakthroughs in the breeding of key crops, such as rice and wheat, boosted production in many developing countries. When combined with the proper use of fertilizers, pesticides, and other inputs, these new varieties offered yield increases of 1 percent per year through the 1990s (Morris, 1998, pp. 3-4). The unprecedented growth in agricultural output in the developing world is often referred to as the "Green Revolution" and has played an important part in improving food security in such countries as India and China.

Despite its major role in plant breeding, the development of hybrids through interbreeding can require up to 12 years to develop market-ready seeds. Even then, those hybrids may still generate only limited desired traits or, possibly, unwanted characteristics (Gould, 1983; Ollinger and Fernandez-Cornejo, 1995, p. 17). Scientific discoveries in the field of genetics, beginning with Watson and Crick's postulate on the double helix model for DNA in 1953 and continuing through the creation of the first genetically engineered (GE) plant in 1982 (Shoemaker et al., 2001, p. 9), have significantly reduced the number of residual unwanted characteristics that often result from traditional plant breeding crosses, thus increasing the speed at which breeders can develop desirable new varieties.

GE crops are classified into one of three generations (Panos, 1998): crops with enhanced input traits, such as herbicide tolerance, insect resistance, and resistance to environmental stresses, such as drought; crops with added-value output traits, such as nutrient-enhanced seeds for feed; and crops that produce pharmaceuticals, bio-based fuels, and products beyond traditional food and fiber. At present, the adoption of GE crops is generally limited to those with first-generation traits. The most common herbicide-tolerant (HT) crops are characterized by resistance to the herbicide glyphosate. Commercially available HT crops include soybeans, corn, canola, and cotton and became available to a limited extent in 1996. The share of HT soybeans to total U.S. soybean acreage grew from 17 percent in 1997 to 68 percent in 2001 and 81 percent in 2003. HT cotton expanded from 10 percent of total U.S. cotton acreage in 1997 to 56 percent of cotton acreage in 2001 and 59 percent in 2003 (fig. 3). Insect-resistant GE crops in use today incorporate a gene from the soil bacterium *Bacillus thuringiensis* (Bt). The bacterium produces a protein toxic to lepidopteran insects. Plants produce the toxic protein throughout their life, providing them with long-term protection. The Bt gene has been incorporated in corn to protect the crop against the European corn borer, and in cotton to protect against the tobacco budworm, bollworm, and pink bollworm (Fernandez-Cornejo and McBride, 2000). Bt corn increased from 1 percent of total U.S. corn acreage in 1996 to 26 percent in 1999, fell to 19 percent in 2000 and 2001, and climbed back to 29 percent in 2002. Bt cotton increased from 15 percent of cotton acres in 1996 to 37 percent in 2001 and 41 percent in 2003.

Figure 3
Adoption of biotech crops in the United States



Source: Fernandez-Cornejo, 2003.