CHAPTER **25**

Transgenic Pesticides—
A Case of Altered Heredity

Gregor Mendel
1822 — 1884

Founder of the science of genetics published his "Experiments with Plant Hybrids" in 1866. His work was ignored until 1900.

"This genie can't be pushed back into the bottle".

David N. Leff
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The deciphering of the genetic code a half-century ago was a watershed event for human biology. Although the technology leap has taken decades to be manifest it is not only changing the face of medicine but also preordains an agricultural revolution. Traditional plant breeding, on which agriculture has long relied to bring crop improvements, has made steady but slow advances with most crop and ornamental plants. *Genetic engineering* (the ability to move genes that code for desirable traits across phylogenic boundaries—also called *recombinant* or *r-DNA* techniques) has granted agriculture the capacity to speed the introduction of desirable traits by direct genetic intervention.

Traditional plant breeding is limited largely to reshuffling genes among closely related traits, usually within a species. The tools of genetic engineering and the creation of *genomics* (the study of the structural and functional nature of genes) though pioneered in medicine has quickly spread to agriculture and now offers enormous potential to invest plants and livestock with desirable traits that, heretofore, were unimaginable.

Transgenic organisms are genetically altered by artificial introduction of DNA from another organism. The artificial gene sequence is referred to as a *transgene*. Plants with such transgenes are also referred to as being *genetically modified* (GM). The two major categories of transgenic organisms cogent to the study of pesticides are those altered to induce *insect-resistance* (also called *plant pesticides* or *plant incorporated protectants*) and/or *herbicide-tolerance*. Since 1995, many examples from these categories have become commercial successes and are now so closely linked to the pesticide industry that they are considered an intrinsic part of it.

In this chapter, we address several aspects concerning transgenics: origins, current status of major products, how the products of agricultural biotechnology are regulated and finally some concerns about and the potential future for this rapidly advancing technology.

Products of Biotechnology

The traditional path. Mankind has artificially altered the genetic makeup of his crops and domestic animals for thousands of years. The search for faster growth, sweeter fruit, better yields and similar traits were enhanced by planned selection and crossbreeding of varieties having characteristics valued by growers and consumers. Plants and animals naturally change over time as a result of an intrinsic and normally slow gene mutation rate. Such rates vary by species and are normally not dramatic, but nonetheless have been capitalized upon since mankind's early attempts at agriculture.

Between the 1920s and '50s, irradiation and chemical mutagenesis techniques were developed that allowed breeders to dramatically increase the induction of new traits which then could be winnowed to select the most desirable for introduction into various crops. Such techniques are still used today. Progress in other areas important to breeding (tissue culture, haploid breeding, etc.) also made contributions to breeding progress in recent decades (http://www.colostate.edu/programs/lifesciences/TransgenicCrops/).

The leap to genetic engineering was made possible only because sustained research over the past five decades has disclosed many of the secrets of gene structure and function. Biotechnology is only the most recent of a continuum of scientific advancement that is contributing its solutions to agriculture. One can anticipate that biotechnology will incrementally be enhanced and then supplanted by other presently unknown technologies.

Biotechnology: An agricultural revolution. The concept that organisms and crops could be engineered to augment pest control was well known by a few people in the 1970's. Many companies and the federal government were interested in the concept. The Monsanto Company was one of the earliest heavy investors in biotechnology and believed it could offer alternative solutions to crop protection. By the mid 1980s, Monsanto had committed to a research program designed to create crop protection products through the application of biotechnology. Other companies were also investing, some more seriously than others. In 1994, Genentech's FlavrSavr® tomato, supposedly endowed with better shelf life and flavor, was introduced as the first transgenic crop. Commercially unsuccessful, it was followed soon afterwards by introductions of genetically modified crops that would quickly alter the agricultural *status quo*. A very well written review of the history of pesticide-related transgenic crops was recently published and is recommended to those who want to understand how this new technology unfolded (Charles, 2001).

A summary of the many tools essential to artificially transplanting genes from one organism to another is available at http://www.colostate.edu/programs/lifesciences/TransgenicCrops/. We will mention a few of these important tools below.

The discovery of special enzymes capable of specifically cutting or joining gene segments allowed scientists, for the first time, to deliberately manipulate genes. *Restriction enzymes* recognize and cut DNA at specific locations along the gene, while *ligases* are equally specific in catalyzing the reattachment of the ends of two DNA fragments. These and other enzymes give genetic engineers important tools with which gene fragments can be manipulated to advantage. Among the most challenging steps is defining and matching gene sequences to their corresponding traits. Not only must researchers find the key sequence of interest and its functional relationship to a particular trait, but must also find essential gene fragments that regulate the gene's expression and operation. Two important such entities are *promoters* (sequences of DNA that turn a gene on so that it is properly expressed) or *terminators* (gene fragments that signal the end of a functional DNA sequence). It is common for researchers to use *marker genes* to identify important DNA regions since the marker can easily be traced after being inserted into the new chromosomal/genomic DNA of an organism.

There were two advancements that greatly facilitated the transfer of foreign genes into targeted crop cells. The first was the discovery that a modified *Agrobacterium tumefaciens*, a natural gall-forming bacterium capable of naturally splicing elements of its genetic material into plants, could be adapted to carry discrete DNA pieces from select organisms into crops. This approach only worked for a few, mainly broadleaf, crops and therefore, the development by Cornell University's John Stafford of the *gene gun*, a device, though originally laughable, was successful in projecting DNA coated particles carrying a desired trait into receptor cells, some of which could then be viably propagated (Charles, 2001). *Biolistics* refers to the process by which selected DNA pieces are introduced into cells using the gene gun.

The ability to move a gene coding for a trait from any organism to a crop cell, then obtaining a viable plant or plants by regenerating it through tissue culture eventually allowed production of new transgenic varieties from backcrossing the traits into elite seed lines. Conceptually, the process is the same whether used to introduce a gene into cotton plants from *Bacillus thuringiensis* (*Bt*) coding for one of its insecticidal natural proteins, or transferring a gene from a glyphosate-digesting bacterium into a soybean plant.

Although insect resistant crops made a sizable initial impact when first widely marketed in 1995, most shocking to row-crop herbicide producers was the rapid and deep market penetration of Monsanto's Roundup Ready® soybeans, starting in 1996. Simple in conception and challenging in execution the creation of this and other transgenic crops seemed improbable nearly until they were released for general use.

Plant pesticides and herbicide-tolerant crops. *Plant pesticides* are defined by EPA as plants that have been genetically engineered to contain the delta-endotoxin genes from *B. thuringiensis*. This definition will expand as genes from additional sources are incorporated into plants.

In 1995, EPA registered the first plant pesticide, Monsanto's *Bt*-cotton containing *Bt Cry1Ac* delta-endotoxin, following ten years of intensive research. This novel form of cotton was introduced experimentally in 1995, as Bollgard® cotton, resistant to tobacco budworm, cotton bollworm and pink bollworm with activity on other minor lepidopteran pests. *Bt*-enhanced cotton, corn and other insect-resistant crops produce one or more crystalline