BT Corn: A Solution to a Growing Problem

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Writer's Comment: As a biotechnology major, the majority of my classes completely disregard the value of writing experience. In most cases, my Monday through Friday workload revolves entirely around some variant of biology or chemistry. When I enrolled in Agricultural Biotechnology and Public Policy, I was provided with the unique experience to actually draft a paper that focused entirely on the genetic engineering of widely used crops, such as corn. As much as I love writing, this paper was a bit of a challenge given the extremely technical nature of the subject matter. I always found my writing style to be more suited for creative or persuasive writing, so delving into a more scientific style was daunting. After extensively researching the topic of genetically modified corn, I was able to accurately present the most crucial pieces of information regarding the production and sales of these foods in a way that would be useful to the average consumer. The professor for this course, Dr. Doug Cook, was a great resource throughout this writing experience. Dr. Cook provided a lot of useful insight during class in regards to both the scientific practices behind genetic modification, as well as the major ethical and policy related issues that surround this topic.

Instructor's Comment: Anooj Desai's essay, "Bt Corn: A Solution to a Growing Problem," introduces the reader to one of marvels of modern technology, namely genetically engineered corn plants that resist otherwise highly damaging insect pests. Scientists engineered these corn plants with a highly specific protein that protects the plants from herbivory by insects. As surprising as it may be, the transfer of DNA between distantly related species, such as bacteria and plants, is a long-standing natural phenomenon. The best understood vector of DNA transfer is a soil bacterium, known as Agrobacterium tumefaciens. Decades ago, scientists began to harness this natural process to shuttle pre-selected genes into plants with the goals of increasing their resistance to insect pests and weeds, enhancing their nutritional value, and improving agronomic performance, among others. The subject of Mr. Desai's essay is a "transgene" derived from another common bacterium, Bacillus thuringiensis (Bt). The "Bt" gene encodes a biologically active protein that organic farmers

have used as a topically applied pesticide for the better part of the past century. Despite its widespread use in organic production systems, and the fact that the gene transfer is itself a natural phenomenon, insect resistant "Bt Corn" is the subject of vigorous public debate. Should we be manipulating the genomes of our food supply? Are there risks and if so how do they compare to those of non-engineered crops? What can we learn from two decades of use of such plants in agricultural systems and our food supply? What is the underlying biology of the transferred genes and their mode of action? How much does scientific fact enter into the public debate, versus biased advocacy and personal values? These and other topics are among those covered in Agricultural Biotechnology and Public Policy, taught every spring quarter through the Department of Plant Pathology.

– Douglas Cook, Department of Plant Pathology

Abstract

Bt toxin (Bt), a protein produced by the environmental bacterium Bacillus thuringiensis (Bt), has become the predominant tool to control insect pests of cultivated Zea mays (corn). Incorporating the bacterial Cry protein into the genome of corn has dramatically reduced the incidence of damage from otherwise devastating pests, such as the European corn borer, while also decreasing the use of chemical pesticides. Despite the widespread use of Bt in organic production, transgenic Bt corn has met with significant opposition due to the perceived negative effects of genetic modification. The popularity of transgenic maize among farmers has given increased market share, which has raised alarms among those groups who fear corporate control of the agricultural system. Corporations like Monsanto and Syngenta, in conjunction with governmental agencies, are responsible for ensuring that products are safe for consumption by humans and livestock, and that negative environmental impacts do not accrue. The complexity of such issues, combined with often-visceral resistance to genetically engineered crops, has complicated the public's ability to identify a balanced perspective of the risks and benefits of the Bt transgenic maize.

Eating through over two billion dollars annually (Major Crops Grown in the United States, 2013), insects are a major threat to global maize crop production. Although chemical insecticides are available, their high toxicity and non-target impacts make them an unattractive solution to this two billion dollar problem. With the discovery of the Bt toxin, a new means of creating insect resistance in plants became a reality. Different Bt toxins have been engineered to combat two major insect pests of corn, namely the European corn borer and corn rootworms. The European corn borer, more formally known as *Ostrinia nubilalis*, is commonly found in Canada, the United States, and Africa where it poses a major risk to the efficient growth of corn. The European corn borer is present in multiple strains due to the introduction of the insect from various parts of Europe, resulting in regions where three to four different generations coexist, such as in Virginia. Since evolutionary variances occur in this species, creating an effective, universal resistance against the European corn borer is challenging. Although the corn borer has a large range of host plants, western strains of the insect primarily feed on corn (Wolfenbarger et al., 2008). Many non-transgenic techniques are used to manage the spread of corn borers, such as the destruction of the corn stalks that house most of the insect larvae or tilling to reduce corn plant residues on the surface. Still, one of the most effective means of prevention comes from incorporating specific genes that allow host plants, such as corn, to independently fend off these pests.

The other major antagonist to the United States corn industry is the corn rootworm (*Diabrotica*). The corn rootworm is the most problematic pest in major corn-growing regions of the American Midwest, such as Iowa. The western, southern, and northern corn rootworms are the most detrimental species to the corn industry as they cause a large majority of the crop damage (Abel et al., 2000). The various species of corn rootworms have differences in life cycles, so understanding the time frames during which larvae hatch is important in preventing their growth while they are most the abundant (Gassman et al., 2011). Distribution of the insect can differ within a single region. For example, although the western corn rootworm dominates most of Pennsylvania, the northern rootworm is found in greater numbers in the cooler, northern portion of the state. Both the larvae and adult corn rootworms damage the root tissues, preventing proper nutrient and water uptake. Since the insects pose the threat of major root damage, no-till fields often exacerbate the situation by restricting corn rooting networks to the top six inches of soil where rootworms are most abundant (Ribbens, 2002).

As European corn borers and corn rootworms are the largest obstacles in the corn farming industry, advances in insect resistance are being explored to reduce the level of negative byproducts while maximizing growth efficiency. With over eighty million acres of corn harvested in the United States alone, ensuring that pests do not eat away too much of the yield is a major concern for farmers and consumers alike. In fact,

the impact these insects have on corn growth has been known for a long time. European corn borers were first found in America in 1917 near Massachusetts, and the insects have since spread west past the Rocky Mountains and south to the Gulf Coast (Smith & Khan, 1994). The corn rootworm was initially discovered in North America in 1824, but it was contained in the northern central region of the United States until 1950, when species of the insect began to spread to Pennsylvania (Smith & Khan, 1994). Given the enormous economic impact these insects had on the farming industry, prevention of their proliferation became a major focus for scientists who hoped to provide a means of resistance for crops without damaging the environment or harming consumers (whether humans or farm animals). Although initial methods relied more on environmental manipulators such as pesticides or tilling, genetic engineering has become a new outlet for producing corn strains resistant to insect pests.

Current science and advances in Bt corn

Genetic modification can introduce resistance directly into the corn genome. One of the most successful means of resistance was derived from the toxin produced by the soil dwelling bacterium Bacillus thuringiensis. By 1996, scientists were able to introduce the Cry protein from this bacterium into the maize genome, thereby creating an effective resistance to previously devastating pests (Peairs, 2014). Incorporation of Bt Cry proteins would be the solution to many problems, including the adverse effects of chemical pesticides, the need for equipment to spread the pesticides, and the potential for beneficial insects to be adversely affected along with malicious ones.

The Bt toxin has a very specific mechanism for attacking insects: once the toxin is consumed by the target organism, it attacks the insect gut by forming pores in the lining (Meissle et al., 2014). Bt crystals from the toxin bind to receptors in the insect gut, which cause the insect to stop eating. Soon, these crystals begin to pierce the gut lining, causing it to break down and allowing the spores and gut bacteria to invade the body of the insect. By incorporating this Bt toxin mechanism into genetically modified corn plants, farmers are able to grow corn resistant to the European corn borer and the corn rootworm, while at the same time producing a plant that is entirely safe for consumption with full nutritional value (Haro von Mogel, 2014).

Use of Bt toxin also allows scientists to create corn strains that are resistant specifically to some insects without killing off potentially beneficial ones. The effectiveness of the Bt delta endotoxin depends on three important factors: the insect's susceptibility to the toxin, the strain-related origin of the toxin, and the solubility of the Bt crystals in the insect gut juice (Jaquet et al., 1987). For this reason, a key to effective genetic modification is ensuring that the Bt toxin being incorporated into the genome is derived from the correct subspecies of Bacillus thuringiensis. The major difference between the toxin attack mechanisms involves how the Bt crystals solubilize within the insect gut. If the incorrect strain of Bt is selected for genetic incorporation, the Bt crystals will be less effective in creating the pores in the gut required to kill the insect. To actually introduce these Bt toxin-producing genes into corn crops, the Bt gene must be isolated from the bacterium and then joined to an antibiotic resistance marker gene. The Bt gene along with the marker is inserted into the plant cells and then grown in the presence of resistance genes for antibiotics or herbicides. These modified cells are then tested for their ability to resist the specific antibiotic or herbicide originally selected, and if the resistance is present in the cell, the Bt gene inserted alongside the resistance gene will be confirmed as being incorporated as well (Webber, 1995). The genetically modified corn can now produce the lethal Bt proteins and directly deliver them to insects that feed on them.

Bt corn in the marketplace: producers and consumers

Following the successful genetic modification of corn, Bt corn seeds began to be introduced into the marketplace. Major biotechnology companies like Monsanto, DuPont, and Syngenta began producing corn seeds that had various Cry genes incorporated within the genome (Gonzalez-Cabrera et al., 2006). Since there is large variation in the effectiveness of Bt proteins produced by the various subspecies of Bacillus thuringiensis, companies began introducing strains of Bt corn that would be more resistant to specific insect pests.

Still, this variation in Bt corn strains has had some negative repercussions on the regulation end. One of the most significant instances of these problems was seen in Plant Genetic Systems creation of StarLink, a corn strain genetically engineered using the novel Cry9C gene (Romeis et al., 2008). Controversy arose when the Cry9C protein was found to remain in the digestive systems of human consumers much longer

than the other Bt proteins already on the market. Although no adverse health effects were recorded, the presence of the Bt proteins in taco shells resulted in a major recall of the product due to the lack of approval for human consumption. Faced with these controversies, Bt corn producers like Monsanto began targeting the genetically modified corn market towards animal feed, which had less stringent regulations on the presence of transgenic protein in food products. Still, this obstacle has not reduced the value of these GM corn plants. The economic value of these corn crops was highlighted in a 2013 case of foreign espionage, where a number of Chinese citizens were arrested and charged in the United States for attempting to steal genetically modified seeds from major companies like Monsanto and DuPont. These multi-million dollars seeds were targeted by the Beijing company DBN Group which planned to steal trade secrets directly from the cornfields themselves (McCauley, 2015).

In response to this increasing demand for genetically modified organisms, several US regulations were implemented to ensure safe practice and distribution. The Environmental Protection Agency (EPA) regulates all genetically modified crops under the FIFRA standards, wherein any crop containing Bt toxin-producing genes must be verified as safe for the environment before it can be introduced. The Food and Drug Administration (FDA) regulates safety of GM crop consumption by both humans and animals, with the FDA closely monitoring the production and sale of any plants modified using genes or proteins significantly foreign from what they would produce naturally. The U.S. Department of Agriculture (USDA) handles GM plant regulation on the end of field trials, where the Animal and Plant Health Inspection Service (APHIS) subdivision creates specific guidelines and rules for the import, interstate movement, and environmental release of various genetically engineered organisms (U.S. Regulation of Genetically Modified Crops, 2011).

Challenges and opposition to Bt corn

Although Bt corn use has shown to provide a number of advantages over non-GMO alternatives, the genetically modified crop faces obstacles to becoming a globally accepted product. Opposition ranges from untrusting consumers to environmental organizations; some foresee negative ecological impacts while others view genetic engineering as unethical or unnatural. Disputants often cite the potential negative impact of Bt corn on the environment, the surrounding biodiversity, and even the potential health risks involved if humans or animals consume this transgenic corn (Carpenter, 2011). On the other end, farmers also strongly oppose the economic impact genetic engineering might have, especially when considering the proprietary nature of GMO seeds and the potential for corporations to patent food sources depending on how they have been cultivated (Venneria et al., 2008). Much of the opposition stems from consumers viewing GMO products as unnatural due to the genomic modification required to produce them (Saxena & Stotzky, 2001). Unfortunately, some of this opposition may stem from semantics: genetic engineering has often been accomplished by traditional breeding yet genetic engineering is still deemed an unnatural process.

The opposition or support for Bt corn is in many ways subjective, and the genetically modified crop still has many other, more immediate obstacles to overcome before it can become a global solution to the yield losses affecting all parts of the world. As exemplified by StarLink, producers of Bt corn must ensure the absence of the protein in products released on the market, due to the negative stigma of consuming these byproducts. Pharmacokinetic studies of the human body can help determine how these proteins move through the body, ensuring that they are not present for too long or are expelled before causing harm to the consumer.

To date, at least twenty-six countries have placed bans on GMO foods (U.S Regulation of Genetically Modified Crops, 2011). This opposition causes problems for regions that do plant Bt corn, especially when considering the gene flow associated with these crop fields. In many cases, close by fields of crops may be subject to cross contamination of genes, causing unforeseen consequences or giving GM qualities or traits to plants believed to be non-GMO. Potentiality the biggest hurdle for Bt corn is the increasing resistance against the Bt toxin found in insects that feed on these crops. Evolution has rapidly increased the fitness levels of European corn borers and corn rootworms, the two major antagonists to cornfields. Syngenta recorded an increase in sales of its main soil insecticide in the last three years, a potential result of genetic adaptations or mutations accumulating slowly in these insects. Although it is unlikely one permanent solution to these insect pests will be created, especially when considering the rapidly acquired resistances and immunities these bugs have begun to display, the current struggle is to ensure crop yields remain fairly average every season.

Conclusions

Major GMO producers like Monsanto or DuPont need to overcome the immediate problems these crops are facing. While consensus on the ethics of global use of these genetically engineered food products is unlikely, companies will attempt to find transgenic solutions to problems associated with growing corn. The introduction of these crops in regions of the U.S. has already provided some benefits to GMO fields as well as neighboring non-GMO fields, as seen by the area-wide suppression of insect pests. The rapid evolution of corn-feeding insects requires innovation. For example, refuge methods of farming can make Bt toxin resistance harder to acquire by forcing resistance-inducing genes to be passed down recessively; this makes it significantly harder for Bt-resistant insects to pass down these advantageous traits to their offspring (Mann et al., 2002).

Greater public awareness of what genetic engineering is and how it functions needs to be achieved. A strong argument in support of GMOs can only be formed if individuals understand all aspects of these techniques, including any negative ones. Bt corn has proven to combat some major obstacles that farmers encounter, but the rapid evolution of the insect pests has put pressure on GMO producers to find solutions that will last longer than a few seasons. Still, pesticide use has begun to increase as the bugs are becoming more resistant to the Bt producing corn plants, meaning Bt corn use is being overshadowed by the re-emergence of these chemicals. To gain the widespread acceptance that will usher it into the mainstream market, Bt corn needs to prove itself a more valuable product than the non-GMO alternative, while at the same time proving that it has no adverse effects.

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