The Idea of an Essay

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A Survey of Plant Breeding and Genetic Engineering

Makayla Gwinn
Cedarville University, makaylargwinn@cedarville.edu

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About 30% of people living in developing countries suffer from protein-energy malnutrition (PEM), a condition that imparts a heightened risk for diseases and slow or retarded development, but plant breeders believe they have the technology needed to mitigate the prevalence of this harmful condition. PEM is caused by a deficiency of certain essential amino acids, the building blocks of protein. Without these necessary components, the body is unable to manufacture the proteins it needs, thus resulting in the aforementioned symptoms. Instead of looking to doctors for the cure, plant breeders dug to the root of the problem and proposed a solution: genetic engineering (Galili & Amir, 2013).

Genetic engineering is the process by which geneticists shift, delete, add, or rotate genes—the part of an organism's DNA that determines its characteristics—to change the genetic makeup of an organism to produce a transformation that results in a positive outcome. Specifically, plant breeders often seek to produce in plants a resistance to pests, a more succulent taste, larger or more nutritious fruit, and resistance to disease (Singh & Prasad, 2016). This process results in organisms commonly referred to as "genetically modified" or "genetically engineered." Using the process of genetic engineering to add certain amino acids to the genetic makeup of particular food crops, scientists have been able to produce plants that contain the amino acids needed to prevent PEM, thus opening doors that could potentially lead to a decrease in the number of cases of PEM.

From mitigating disease in developing countries to showing up in food products found in your local grocery store, genetically engineered products are becoming a common part of many peoples' lives. It is important for consumers to know the history as well as the current trends in the industry of plant breeding in order to better understand the significance, challenges, and health concerns stemming from genetically engineered plants. This essay examines the techniques used in traditional plant breeding, describes the current methods of genetic engineering, and touches on the prevalence of genetically modified foods found on the market today.

The idea of plant breeding is not novel to today; throughout the ages, farmers have continually sought to produce superior crops. The difference between past and present crop improvements lies in the methods and extent of the genetic transformation. Agriculturists of the past were limited to the transfer of genes specific to the crop they were dealing with, whereas today, plant breeders can incorporate genes from other organisms (Ali, Bang, Chung, & Staub, 2015). Traditional methods of plant breeding include mass selection (Symkal, et.al., 2016), pollen transfer (Molinar) or cross-pollination, and hybridization (DeJohn).

Mass selection is a process in which farmers decide which individual plants they want to breed in order to pass on desirable characteristics to the next generation (Symkal, et. al., 2016). The farmers select seeds from plants expressing beneficial traits and use those seeds during the next sowing season. This simple method of saving and planting seeds from favored plants exhibits the continual process of modifying the frequency of the appearance of certain genes in a population of plants. Despite its simplistic nature, mass selection results in the development of different strains of a plant that are better adapted to their environment. For example, farmers growing corn in regions with a long growing season will chose to grow the corn variety best suited for warm weather, while farmers harvesting in areas with a short growing season will select breeds best suited for cooler conditions (DeJohn).

Another traditional method of plant breeding is pollen transfer (Molinar, 2012), also referred to as cross-pollination (DeJohn). In an effort to recreate natural pollination, or fertilization, and produce offspring with specific character traits, plant breeders transfer the pollen from one plant to another. The pollen from the first plant fertilizes the eggs in the second plant and, ideally, produces a seed exhibiting positive qualities from both of the parents.

To illustrate the process of pollen transfer, Richard Molinar (2012), previously a Farm Advisor for the University of California's Cooperative Extension, wrote concerning his own experience with this method. He states, "One of my jobs in the late 1960s was to take a small piece of 200 grit sandpaper folded into a small pointed trough and collect the pollen (male flower part) from certain alfalfa plants. I then transferred this pollen to the pistil (female plant part) of another alfalfa plant." The seed resulting from this fertilization was then tested for a particular kind of pest resistance, and, if successful, finally cultivated on a larger scale. As Molinar illustrates, pollen transfer is a long process, but it is a viable means of producing new varieties of plants.

In addition to mass selection and pollen transfer, hybridization is another technique used by plant breeders to cultivate certain character traits in crops. Hybridization can have a number of results; one particular benefit is an increase in crop yield (Symkal, et. al., 2016) or an early harvest, as in the case of the Early Girl tomato variety (DeJohn). Hybridization involves the cross-pollination of two purebred plants, each of which bears a desired characteristic. The resulting offspring are called F1 hybrids. These hybrids can only be used for one growing season because, due to the principles of genetics, their offspring will not consistently exemplify the desired characteristics. Therefore, this method is useful, but it cannot be used to develop a strain of plants that will continually produce the desired results.

Farmers have long struggled against limited growing seasons, temperature fluxes, and natural disturbances as they sought to cultivate their crops and utilize these traditional methods of plant breeding. Only recently did technology provide farmers with more modern tools for improving crops. Commonly found today, inventions such as the greenhouse allow for year-round growing and a shorter time between each generation of plants. Advancements in farm machinery and an improvement in the ability to control diseases, weeds, and pests also led to progress in the plant breeding industry. Technologies such as these along with advancements in genetics led to today's use of genetic engineering.

In contrast to the traditional methods of plant breeding, modern genetic engineering utilizes more involved techniques and procedures. Such methods include *Agrobacterium tumefaciens*-mediated gene transformation (Singh & Prasad, 2016) and pollen tube-mediated gene transfer (Ali, Bang, Chung, & Staub, 2015). These intricate procedures can be used to introduce new genes into the genetic makeup of a plant.

First, *Agrobacterium tumefaciens*-mediated genetic transformation, or more simply *Agrobacterium*¬-mediated transformation, is commonly used to transform a plant's DNA. The *Agrobacterium* is a strain of bacteria that plant breeders use as a means of moving new genes into the DNA of developing plant tissues. The breeders then use "marker genes" to monitor the success of their transformation (Singh & Prasad, 2016). This method of transformation requires the preparation of plant cells to receive the new genes and a period of time to allow the plant to successfully incorporate the new gene. Expensive equipment and highly trained professionals are also vital for producing successful results (Ali, Bang, Chung, & Staub, 2015). Overall, *Agrobacterium*-mediated transformation is usually an effective method for introducing new genes into plants.

Second, the pollen tube-mediated gene transfer method involves transforming a newly formed zygote, or fertilized egg, rather than introducing new genes into the already-developing cells of a plant. Thus, pollen tube-mediated gene transfer results in a transformed seed that is immediately ready to grow and exhibit the new characteristic that has been incorporated into its genetic makeup. The process of this method involves accessing the plant's pollen tube, which leads to the ovary of the plant, and introducing the foreign genes. These genes travel to the ovary where they are incorporated into the zygote(s), therefore producing a transformed seed (see Figure 1). This method of gene transfer has proved successful in cotton, but researchers say more studies need to be done to optimize the use of pollen tube-mediated gene transfer (Ali, Bang, Chung, & Staub).

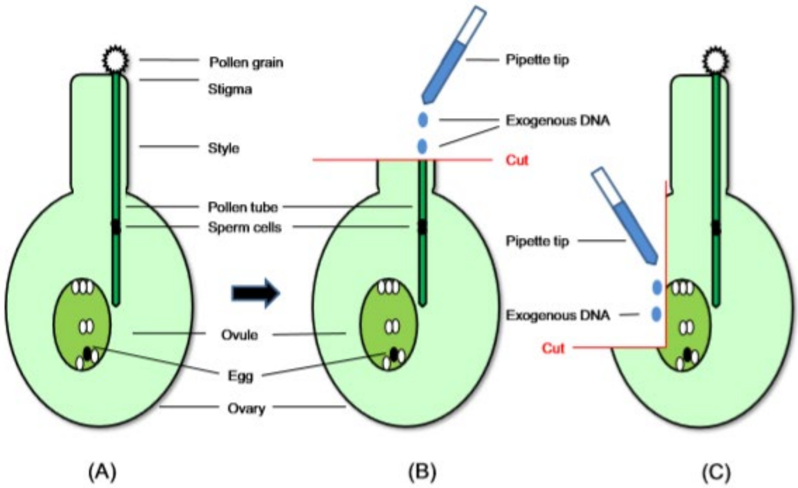

Figure 1. *Illustration (B) shows the process of pollen tube-mediated gene transfer. Illustration (A) represents natural pollination, and (C) illustrates the ovary drip method (Ali, Bang, Chung, & Staub, 2015).*

These techniques represent only two of the many methods of genetic engineering. However, both types illustrate two of the general techniques of gene transfer. ¬*Agrobacterium*-mediated transformation represents the family of methods that introduce change into developing plant cells; such methods include electroporation, biolistic bombardment, and protoplast fusion. On the other hand, pollen tube-mediated gene transfer is an example of creating zygotes that contain transformed DNA; the floral dip and ovary drip methods utilize the same principle (Ali, Bang, Chung, & Staub).

Using such methods, genetic engineering has taken over the industry of crop improvement. Singh and Prasad (2016) state that "genetic engineering has become the most extensively practiced method in crop improvement." From cereal grains to alfalfa to canola oil, agriculturists are constantly turning to genetically engineered plants as a means of improving their products, crop yields, and ultimately their profit. Due to these benefits, genetically engineered crops are extremely prevalent within the United States.

The popularity of genetically modified crops is displayed clearly in reports concerning America's agriculture. Fernandez-Cornejo, Wechsler, and Milkove (2016) report that "more than 90 percent of U.S. corn, soybean, and cotton acreage is planted with genetically engineered (GE) seeds with herbicide-tolerant and/or insect-resistance traits." Further dividing the distribution of genetically modified crops, it is evident that genetically engineered alfalfa, a crop primary fed to dairy cattle, was planted on 1.87 million acres of land making up 11 percent of the total U.S. alfalfa acreage in 2013. Also in 2013, genetically modified canola seeds accounted for 95 percent of the total number of canola acres in the U.S. However, the highest percentage of genetically modified plants is found in sugarbeet crops. Approximately 99.9 percent of the U.S.'s sugarbeet acres were sown with genetically modified seed (see Figure 2) (Fernandez-Cornejo, Wechsler, & Milkove, 2016).

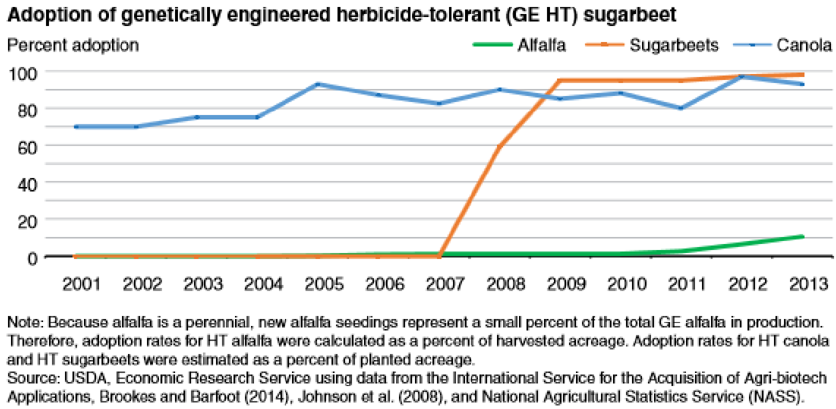

Figure 2. *This graph shows the percent of alfalfa, canola, and sugarbeet crops being genetically modified from 2001-2013 (Fernandez-Cornejo, Wechsler, & Milkove, 2016).*

In addition to the above-mentioned crops, genetically modified grains such as rice, wheat, and barley have also been cultivated. Rice genes have been transformed for a number of reasons, including “tolerance to drought and salinity” and “enhanced plant growth” (Singh & Prasad, 2016). Similarly, different varieties of wheat have been modified to cope with drought, and some strains of barley have been changed to better withstand cold temperatures. Researchers continue to study these and other crops to better understand the process of gene transfer and its outcomes (Singh & Prasad, 2016).

In sum, genetic engineering dominates the agricultural world as a means of improving food crops. Though farmers have always bred specific traits into their crops through traditional methods, modern technology such as *Agrobacterium*-mediated transformation and pollen tube-mediated gene transfer open new doors of possibility. The ability to change the genetic makeup of plants led to a revolution in the way crops are grown in the U.S; as illustrated, food crops such as sugarbeets and canola are grown almost exclusively from genetically engineered seeds. In addition, genetic engineering changes the way problems such as protein-energy malnutrition are dealt with in developing countries as it offers previously unheard-of solutions. Clearly, genetic engineering has completely transformed the agriculture industry.

Annotated Bibliography

Ali, A., Bang, S., Chung, S., & Staub, J. (2015). Plant transformation via pollen tube-mediated gene transfer. *Plant Molecular Biology Reporter, 33*(3), 742-747. https://doi.org/10.1007/s11105-014-0839-5

The four authors of this article report on the usefulness of pollen tube-mediated gene transfer (PTT) and compare this method of plant gene transformation with other popular methods such as biolistic bombardment and protoplasmic fusion. They begin by presenting a brief overview of traditional methods of genetic improvement in crops and the purpose of this genetic improvement. Then, they explain the process of pollen tube-mediated gene transfer and outline the history and development of this method. The authors conclude that this method, if researched and improved upon, could become a very beneficial method of gene transformation.

I use the information found in this essay to describe the process of pollen tube-mediated gene transfer as a method of genetic engineering. This article also serves as a good source of information concerning alternative methods of genetic engineering, and as a result, I used it to discover more research articles on this topic.

DeJohn, S. (n.d.). *How genetic engineering differs from traditional plant breeding*. Retrieved from https://www.gardeners.com/how-to/gmo-vs-traditional-plant-breeding/7926.html

Suzanne DeJohn, an experienced gardener who previously worked as a research technician at a plant pathology lab, gives a brief but thorough description of basic methods of plant breeding. She explains the process of select traditional and modern techniques. She also includes a section on the "Benefits and Risks Associated with Genetic Modification." Her information is relevant and understandable, and I use her material to help explain the processes of the traditional plant breeding methods of mass selection, cross-pollination, and hybridization.

Fernandez-Cornejo, J., Wechsler, S., & Milkove, D. (2016). The adoption of genetically engineered alfalfa, canola, and sugarbeets in the United States. *Economic Information Bulletin, (EIB-163)*. Retrieved from https://www.ers.usda.gov/webdocs/publications/81176/eib-163.pdf?v=42697

These three researchers constructed a report concerning the use of genetically modified alfalfa, canola, and sugarbeets in the U.S. The body of their report details the history, the deregulation, and the current trends regarding these crops. Supplemented by numerous charts and graphs that illustrate their data, the authors present a thorough overview of these crops. In my essay, I primarily utilize their data concerning current use of genetically modified crops to present readers with statistics regarding the distribution and use of such crops.

Galili, G., & Amir, R. (2013). Fortifying plants with the essential amino acids lysine and methionine to improve nutritional quality. *Plant Biotechnology Journal, 11*(2), 211-222. https://doi.org/10.1111/pbi.12025

This study examines various efforts that have been made to incorporate the amino acids lysine (Lys) and methionine (Met) into mass produced commercial crops that lack or have a deficiency in these amino acids. The authors touch on six different methods that have been used to increase the amount of Lys and Met in crops such as corn and soybeans. They explain the procedures and examine the final products to evaluate the effectiveness of the six methods. In the end, they conclude that more research must be done enhancing Lys and Met content in plants before this becomes a common practice.

I use this information to illustrate a specific situation in which genetic engineering has proved beneficial. With this example, I aim to bring to light the importance of this issue and its far-reaching implications.

Molinar, R. (Oct 2012). *Traditional plant breeding vs. genetic engineering – a primer*. Retrieved from www.westernfarmpress.com/management/traditional-plant-breeding-vs-genetic-engineering-primer

In this article, the author first notes that plant breeding has been pursued throughout the centuries as a means to increase crop yields, create disease- and insect-resistant plants, and lengthen shelf-life. Second, he reviews different methods of traditional plant breeding techniques, some of which he has used himself. Third, he records a brief history of genetic engineering and its popularity with the masses; then he lists some of the most common genetically engineered plants. Fourth, he touches on the process of incorporating new genes into plants and writes about two specific genetic engineering projects dealing with sweet corn, squash, and papaya. The author concludes his short article by showing the prevalence of genetically modified crops on today's market.

This article provides me with a basic overview of the history and current trends of plant breeding. Not only do I use the author's experiences as an illustration of someone who has firsthand experience with the traditional method of plant breeding, but I also use his article as a source of information concerning the process of pollen transfer.

Singh, R., & Prasad, M. (2016). Advances in Agrobacterium tumefaciens-mediated genetic transformation of graminaceous crops. *Protoplasma, 253*(3), 691-707. https://doi.org/10.1007/s00709-015-0905-3

This report details the use of *Agrobacterium tumefaciens*-mediated genetic transformation in different cereal and grass crops. It looks specifically at the effectiveness of this method of genetic engineering in rice, wheat, corn, barley, sorghum, sugarcane, rye, *Brachypodium*, and different types of millets and grasses. The authors examine the benefits and challenges of *Agrobacterium*-mediated transfer. I use this article to explain the process of *Agrobacterium*-mediated gene transfer and to show the purpose of plant breeding.

Smykal, P., Varshney, R.K., Singh, V.K., Coyne, C.J., Domoney, C., Kejnovsky, E., & Warkentin, T. (2016). From Mendel's discovery on pea to today's plant genetics and breeding: Commemorating the 150th anniversary of the reading of Mendel's discovery. *Theoretical and Applied Genetics, 129*(12), 2267-2280. http://doi.org/10.1007/s00122-016-2803-2

In this collaborative research article, seven authors from around the globe write about the history of genetics in celebration of the 150th anniversary of Gregor Johann Mendel's landmark research in the field of genetics using pea plants to examine heredity. To start off, the authors relate that modern geneticists are indebted to Mendel. Throughout the article, they explore the history of genetics and briefly look at how it is used today in plant breeding.

Though some of the information presented is irrelevant to my research, I use the parts of this article that enhance my understanding of the use of genetics in plant breeding today. The section entitled "Impact of Mendelian genetics on plant breeding and food security" is especially helpful in understanding the past technologies associated with plant breeding. I use the information presented in that section to help explain mass selection and hybridization.