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Impact of Genetically Modified Crops on the Genetic Diversity of Cultivated and Wild Species of Plants

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Abstract – **Genetic engineering is the process of genetic modification of organisms through transferring genetic material from one organism to another organism in order to change an organism's characteristics to the desired traits. A genetically modified organism is an organism (plant, animal or microorganism) whose genetic material has been altered using gene or cell techniques of modern biotechnology. Genetic engineering is the improvement program which enhances the efficiency of crop improvement relative to conventional phenotypic selection by changing the focus from the paradigm of identifying superior varieties to a focus on identifying superior combinations of genetic regions and management systems. Biotechnology has the potential to address various problems in agriculture and society. GM strategies are being employed to minimize yield losses due to various stresses (biotic and abiotic) and are being used extensively for value addition in food crops by enrichment with quality proteins, vitamins, iron, zinc, carotenoids and anthocyanins. Other ongoing efforts include the enhancement of shelf life of fruits and vegetables so as significantly to reduce the post-harvest losses of perishable crops. Genetic modification produces genetically modified animals, plants and organisms. The introduced genetically modified crops into the environment can affect biodiversity. Genetic diversity is crucial for adapting to new environments, as more variation in genes leads to more individuals of a population having favorable traits to withstand harsh conditions. Low genetic diversity, on the other hand, can be very problematic during changing environments, as all individuals will react similarly. It is assumed that genetically engineered modifications may affect the genetic diversity of a population through crossbreeding or uncontrolled growth; therefore, many researchers are investigating whether this is true and how it might be prevented. The integration of conventional plant breeding with various biotechnological techniques advance crop genetic improvement and shortening the crop improvement cycle with desirable traits in order to satisfy the demand of people in both quantitative and qualitative ways.**

Keywords – **Genetically Modified Crops, Genetic Diversity, Conventional Breeding, Monoculture.**

I. Introduction

Genetic modification caused by human activity since around 12,000 BC, when humans first began to domesticate organisms. Genetic engineering as the direct transfer of DNA from one organism to another was first accomplished by Herbert Boyer and Stanley Cohen in 1972. In 1983 an antibiotic resistant gene was inserted into tobacco, leading to the first genetically engineered plant. Advances followed that allowed scientists to manipulate and add genes to a variety of different organisms and induce a range of different effects. Modern biotechnology has allowed the movement of genetic material across unrelated species, something impossible with the traditional breeding methods. This intentional transfer of genetic material has in turn brought biotechnology out from the laboratory to the field. The application of genetic modification allows genetic material to be transferred from any species into plants or other organisms. The introduction of a gene into different cells can result in different outcomes, and the overall pattern of gene expression can be altered by the introduction of a single gene. Genetically modified organisms (GMOs) are organisms whose genetic material has been artificially modified to change their characteristics in some way or another (James, 2006). Since genetically modified crops (GMOs) reinforce genetic homogeneity and promote large scale monocultures, they contribute to the decline in biodiversity and increase vulnerability of crops to climate change, pests and diseases.

Genetically modified crops grow in a dynamic environment and interact with other species of the agro-ecosystem and surrounding environment. As "biological novelties to the ecosystems," (Garcia, 2005) genetically modified crops may potentially affect the "fitness of other species, population dynamics, ecological roles, and interactions, promoting local extinctions, population explosions, and changes in community structure and function inside and outside agro-ecosystems." Independent scientists studying the effects of GMOs have also raised other concerns regarding the impact of GMOs on biodiversity. The spread of transgenes to wild or weedy relatives, the impact of GMOs on non-target organisms (especially weeds or local varieties) through the acquisition of transgenic traits via hybridization, the evolution of resistance to pests (in case of *Bt* crops), accumulation of *Bt* toxins, which remain active in the soil after the crop is plowed under and bind tightly to clays and humic acids and the unanticipated effects of the Bt toxin on non-target herbivorous insects, are areas of concern as are increasing concerns about the adverse impact of GMOs on insects (such as bees, for example), nematodes, and birds, all of whom either consume GMOs seeds or their by-products or are present in glyphosate saturated soils.

Genetically modified (GM) crops are becoming an increasingly common feature of agricultural landscapes. The total world's area planted to transgenic crops has increased dramatically, from 3 million hectares in 1996 to nearly 67.5 million hectares in 2003 (James, 2003). One of the biggest concerns expressed against transgenic crops is their potential to reduce species abundance or the levels of genetic diversity within cultivated varieties that include traditional land races as the focus will be on a small number of high value cultivars (Ammann, 2005). A major concern of genetically modified organisms is that they will cause reduced genetic diversity of plants and animals in the environment. What this means is that the DNA, which codes for proteins in an organism, will become more similar between individuals of a species. Genetic diversity is directly related to biodiversity, the variability in the traits of organisms that make up an ecosystem, because diversity in DNA will inform the characteristics of the organisms that make up a population. Maintaining genetic diversity is important for the environment and agriculture because increased variability in DNA will provide a better opportunity for organisms to adapt to a changing environment.

II. Impact of Genetically Modified Crops on Wild Species or Cultivated Species

2.1. *Gene Flow*

Just like conventional crops, GM crops have been shown to crossbreed with crops or native plants growing nearby. Gene flow in itself is not a risk and often plays a part in plant breeding and evolution, though this evolution can lead to plants that are more difficult to control and increases the extinction risk for rare species (Elsstrand, 2006). In short, some genetic modifications are more likely to increase invasiveness than others (McNeely, 2005). Gene flow from transgenic cultivars to native materials in centers of domestication has two potential consequences. First is a risk of accumulation of different transgenes in these native materials (called stacking), which may then serve as relays for the unwanted introduction of transgenes to other plant materials. Gene flow could cause individual plants to harbor multiple transgenes (a phenomenon known as gene stacking ;

Hall *et al.*, 2000).

Second, gene flow may affect the genetic diversity of the landraces and wild relatives in a number of situations. A genetically uniform source population (such as an improved or hybrid cultivar), high and recurrent levels of migration from the source to the recipient population (i.e., landraces), short distances (depending on the flowering biology of each crop), and/or a combination of these factors can lead to a potentially severe reduction in genetic diversity of the recipient populations and even genetic assimilation (defined as the displacement of the local diversity by the incoming diversity). The potential gene flow of GM crops to traditional varieties of crops such as maize and rice in particular has caused heated debates due to their potential impacts on both biological and cultural biodiversity (Soleri, Cleveland and Cuevas, 2006).

It is speculated that the random gene insertion, transgene instability, and genomic disruption due to gene transfer may result in unpredictable gene expression. Such a risk is, however, unlikely to be unique to GM plants or of any significance considering our current knowledge of genomic flux in plants. This gene flow is often a positive factor, because connections between populations will increase their effective population size, and consequently oppose the loss of genetic variation caused by genetic drift and bottlenecks. However, the gene flow can sometimes be too extensive or from populations too far apart, resulting in harmful effects on the recipient population, causing populations to loose important local adaptations or decreasing their production of viable and fertile offspring (outbreeding depression). An extreme variation of gene flow is hybridization, i.e. crossings between individuals so different that they are classified as different species or subspecies (Ellstrand & Elam, 1993; Levin *et al.* 1996). The spread of transgenes from a GM crop variety to non-GM traditional varieties through gene flow may change the integrity of the traditional varieties if the transgenes have a selective advantage.

2.2. *Promotion of Monoculture*

GM crops available so far encourage agricultural intensification, and as long as the use of these crops follows closely the high-input, pesticide paradigm, such biotechnological products will reinforce the “pesticide treadmill” usually associated with genetic uniformity and reduction of biodiversity in agro ecosystems. To the extent that transgenic crops further entrench the current monoculture system, they discourage farmers from using other ecologically based pest management methods (Altieri, 1996). Increasingly, evidence suggests that changes in landscape diversity due to monocultures have led to more insect outbreaks due to the removal of natural vegetation and decreasing habitat diversity (Altieri, 1994; Garcia, 2001). One of the main characteristics of the transgenic agricultural landscape is the large size and homogeneity of crop monocultures that fragment the natural landscape. This can directly affect abundance and diversity of herbivores and natural enemies as the larger the area under monoculture, the lower the viability of a given population of beneficial fauna. At the field level, decreased plant diversity in agro ecosystems allows greater chance for invasive species to colonize, subsequently leading to enhanced herbivorous insect abundance. Many experiments have shown fairly consistent results: Specialized herbivore species usually exhibit higher abundance in monoculture than in diversified crop systems (Andow, 1991). GM crops strongly encourage monoculture and increase vulnerability conflicts with sustainable agriculture. In the present agricultural scenario, the most direct negative impact on biodiversity is the conversion of natural ecosystems into agricultural land that has a tremendous environmental impact in terms of a significant loss of natural habitats. The extensive adoption of GM crops may lead to rapid losses of traditional crop varieties because of the continuous replacement of the traditional varieties by more co-

-mmercially advantageous GM varieties.

2.3. *Crop Genetic Diversity*

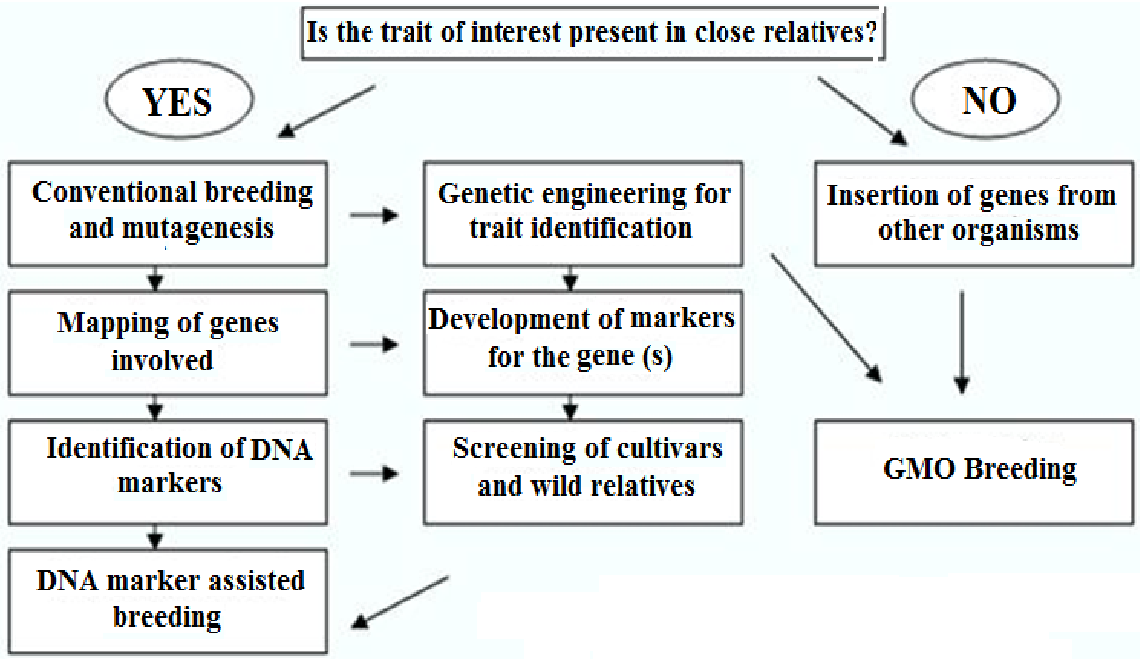
Genetic diversity includes the overall diversity of genes and genetic information contained in all individual species of plants. Over the past 50 years, there has been a major decline in two components of crop diversity; genetic diversity within each crop and the number of species commonly grown. The loss of biodiversity is considered one of today's most serious environmental concerns by the Food and Agriculture Organization (Cardinale *et al.,* 2012). Crop diversity loss threatens global food security, as the world's human population depends on a diminishing number of varieties of a diminishing number of crop species. Genetic diversity is usually thought of as the amount of genetic variability among individuals of a variety, or population of a species (Brown, 1983). The main perspective of genetic diversity may be a necessary condition to achieve high productivity and yield stability. From the other perspective, genetic diversity is the raw material used by plant breeders over the long term to develop improved plant varieties.

III. Comparing Conventional Breeding and Genetic Engineering

Classically-bred and genetically modified crops are the outcomes of genetic modifications created through different means of gene transfer technology. Both conventional breeding and genetically modified technology may involve changes in the genetic makeup of an organism with respect to DNA sequences and the order of genes. However, the amount of genetic changes brought about by the genetically modified technology is small and well defined as compared to classical breeding where thousands of uncharacterized genes of an organism may be involved. Furthermore, genetically modified crops are the outcome of very specific and targeted modification in the genome where the end products such as proteins, metabolites or the phenotype are well characterized. In traditional breeding the genomes of both the parents are mixed together and randomly re-assorted into the genome of the offspring. Thus, undesirable genes can be transferred along with the desirable genes and at the same time some genes may be lost in the offspring. To rectify these problems plant breeders carry out repeated back-crossing to the desirable parent. This is a time-consuming task and may not always be able to separate a tightly linked unsafe gene. For example, potato varieties developed using traditional breeding produce excessive amounts of naturally occurring glycoalkoloids (Hellenas KE *et al*., 1995). These glycoalkoloids cause alkaloid poisoning leading to gastrointestinal, circulatory, neurological and dermatological problems. Hybrids of *S. tuberosum* and *S. brevidens* produce a toxin demissidine, which is not produced in either parent (Laurila J *et al*., 1996). Another instance was the conventionally-bred insect-resistant high psoralens variety of celery which was found to produce skin rashes in farm workers who were involved in harvesting this crop (Berkley SF *et al*., 1986). Thus, classical (non-GM) breeding methods can have unintended effects and generate potentially hazardous new products. On the other hand, genetically modified technology employs a precise control on the timing and location of gene products resulting in tissue/ organ/ development/ stress-specific expression - an outcome not easy to accomplish with classical breeding. Moreover, genetically modified techniques allow introduction of new traits at one time without involving extensive cross-breeding as in the case of classical breeding. From the scientific point of view, foods developed either by conventional breeding or by genetically modified technology can impart the same effects on human health and the environment.

The term genetic engineering is used to describe the process by which the genetic makeup of an organism can be altered using "recombinant DNA technology". This involves the use of laboratory tools to insert, alter, or cut out pieces of DNA that contain one or more genes of interest. Developing plant varieties expressing good agronomic characteristics is the ultimate goal of plant breeders. With conventional plant breeding, however, there is little or no guarantee of obtaining any particular gene combination from the millions of crosses generated. Undesirable genes can be transferred along with desirable genes; or, while one desirable gene is gained, another is lost because the genes of both parents are mixed together and re-assorted more or less randomly in the offspring. These problems limit the improvements that plant breeders can achieve. In contrast, genetic engineering allows the direct transfer of one or just a few genes of interest, between either closely or distantly related organisms to obtain the desired agronomic trait.

Genetic engineering techniques are used only when all other techniques have been exhausted, i.e. when the trait to be introduced is not present in the germplasm of the crop; the trait is very difficult to improve by conventional breeding methods; and when it will take a very long time to introduce and improve such trait in the crop by conventional breeding methods. Crops developed through genetic engineering are commonly known as transgenic crops or genetically modified (GM) crops. Modern plant breeding is a multi-disciplinary and coordinated process where a large number of tools and elements of conventional breeding techniques, bioinformatics, molecular genetics, molecular biology, and genetic engineering are utilized and integrated.



Source: Danida, 2002.

Table 1. Comparisons of conventional breeding with genetic engineering in crop improvement.

Conventional Breeding	**Genetic Engineering**
Limited to exchanges between the same or very closely related species	Allows the direct transfer of one or just a few genes, between either closely or distantly related organisms
Little or no guarantee of any particular gene combination from the millions of crosses generated	Crop improvement can be achieved in a shorter time compared to conventional breeding
Undesirable genes can be transferred along with desirable genes	Allows plants to be modified by removing or switching off particular genes

Conventional Breeding	Genetic Engineering
Takes a long time to achieve desired results	Takes a short time to achieve desired results

Source: Agricultural Biotechnology (A Lot More than Just GM Crops).
http://www.isaaa.org/resources/publications/agricultural_biotechnology/download/.

There are five major steps in the development of a genetically engineered crop. But for every step, it is very important to know the biochemical and physiological mechanisms of action, regulation of gene expression, and safety of the gene and the gene product to be utilized. Even before a genetically engineered crop is made available for commercial use, it has to pass through rigorous safety and risk assessment procedures. The first step is the extraction of DNA from the organism known to have the trait of interest. The second step is gene cloning, which will isolate the gene of interest from the entire extracted DNA, followed by mass-production of the cloned gene in a host cell. Once it is cloned, the gene of interest is designed and packaged so that it can be controlled and properly expressed once inside the host plant. The modified gene will then be mass-produced in a host cell in order to make thousands of copies. When the gene package is ready, it can then be introduced into the cells of the plant being modified through a process called transformation. The most common methods used to introduce the gene package into plant cells include biolistic transformation (using a gene gun) or *Agrobacterium*-mediated transformation. Once the inserted gene is stable, inherited, and expressed in subsequent generations, then the plant is considered a transgenic. Backcross breeding is the final step in the genetic engineering process, where the transgenic crop is crossed with a variety that possesses important agronomic traits, and selected in order to obtain high quality plants that express the inserted gene in a desired manner. The length of time in developing transgenic plant depends upon the gene, crop species, available resources, and regulatory approval.

IV. Conclusion

Food insecurity and malnutrition are currently among the most serious concerns for human health, causing the loss of countless lives in developing countries. To be healthy, our daily diet must include ample high quality foods with all of the essential nutrients, in addition to foods that provide health benefits beyond basic nutrition. Agricultural biotechnology is proving to be a powerful complement to conventional methods for meeting worldwide demand for quality food. Genetically-modified (GM) crops can help us to meet the demand for high-yielding, nutritionally-balanced, biotic and abiotic stress tolerant crop varieties. To date, commercial GM crops have delivered benefits in crop production, but there are also a number of products in the pipeline which will make more direct contributions to food quality, environmental benefits, pharmaceutical production, and non-food crops.

With genetic engineering, more than one trait can be incorporated or stacked into a plant. Transgenic crops with combined traits are also available commercially. Genetically-modified (GM) crops can prove to be powerful complements to those produced by conventional methods for meeting the worldwide demand for quality foods. Crops developed by genetic engineering can not only be used to enhance yields and nutritional quality but also for increased tolerance to various biotic and abiotic stresses. Although there have been some expressions of concern about biosafety and health hazards associated with GM crops, there is no reason to hesitate in consuming genetically-engineered food crops that have been thoughtfully developed and carefully tested. Integration of modern biotechnology, with conventional agricultural practices in a sustainable manner, can fulfil the goal of attaining food security for present as well as future generations.

Transgenic plant research depends on the availability of procedures of plant transformation. Despite the fact that the genes being transferred occur naturally in other species, there are unknown consequences to altering the natural state of an organism through foreign gene expression. After all, such alterations can change the organism's metabolism, growth rate, and/or response to external environmental factors. These consequences influence not only the genetically modified organism itself, but also the natural environment in which that organism is allowed to proliferate.

Generally, the world population is increasing alarmingly, but productivity is reduced because of several production challenges. Hence, conventional plant breeding method alone cannot address the serious challenges that world facing. Therefore, in order to overcome the food security problems, conventional plant breeding should be assisted and integrated with various biotechnology developments to hasten the crop genetic improvements. To ensure the rapid and advanced agricultural developmental within short period of time, the incorporation of genetic engineering in plant breeding is very relevant in the future world. Genetic engineering is not about the replacement of conventional breeding rather than integrating with it in order to make further improvement. There are various challenges in relation to the application of genetic modifications because of its costs in large scale utilization especially in developing countries. The integration of genetic engineering into conventional breeding program is an optimistic strategy for crop improvement in the future.

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