APPLICATIONS OF BIOTECHNOLOGY IN AGRICULTURE

What is biotechnology and agricultural biotechnology?

“Biotechnology is the application of scientific techniques with organisms (animals, plants, microorganisms etc.) to produce new products or new forms of organisms and eliminating the existing products”. While “Agricultural biotechnology is the area of biotechnology involving a collection of scientific techniques used to improve plants, animals and microorganisms having applications in agriculture.”

Agricultural biotechnology has been practiced for a long time, as people have sought to improve agriculturally important organisms by selection and breeding. Based on an understanding of DNA, scientists have developed solutions to increase agricultural productivity. Starting from the ability to identify genes that may confer advantages on certain crops, and the ability to work with such characteristics very precisely, Biotechnology enhances breeder’s ability to make improvements in crops and livestock. Biotechnology enables improvements that are not possible with traditional crossing of related species alone.

In the 1970s, advances in the field of molecular biology provided scientists with the ability to manipulate DNA at the molecular level. This technology is called genetic engineering. It also allows transfer of DNA between more distantly related organisms that was not possible with traditional breeding techniques. Today, this technology has reached a stage where scientists can take one or more specific genes from nearly any organism including plants, animals, bacteria or viruses, and introduce those genes into another organism. “An organism that has been transformed using genetic engineering techniques is referred to as a transgenic organism or a genetically engineered organism”.

Many other terms are in popular use to describe these aspects of today’s biotechnology. The term “genetically modified organism” or “GMO” is widely used, although genetic modification has been around for hundreds if not thousands of years, since deliberate crosses of one variety or breed with another result in offspring that are genetically modified compared to the parents. Similarly, foods derived from transgenic plants have been called “GMO foods,” or “GMPs” (genetically modified products), and “biotech foods.” While some refer to foods developed from genetic engineering technology as “biotechnology-enhanced foods,” others call them “franken foods.”

Application of biotechnology in Agriculture:

The three options for increased food production are

i. Agrochemical – based agriculture.

ii. Organic agriculture
iii. Genetically engineered crop-based agriculture.

The Green Revolution succeeded in increasing the yield of crops mainly due to

i. Use of improved varieties of crops and

ii. Use of agrochemicals (fertilizers and pesticides).

Further increases in the yield with the existing varieties of crops are not possible using conventional methods of breeding. Agrochemicals cause pollution of soil and water and too expensive for the framers.

Advantages of genetically modified plants:

The use of genetically modified plants has been useful in the following ways:

(i) Genetic modification has made the crops more tolerant to abiotic stresses like cold, heat, drought, salinity, etc.

(ii) It has reduced the dependence of crops on chemical pesticides as they are made pest-resistant.

(iii) Post – harvest losses are much reduced.

(iv) As the efficiency of mineral usage of plants is increased, so the early exhaustion of soil fertility is prevented.

(v) Food produced from GM (Genetically Modified) crops has enhanced nutritional value.

(vi) Genetic modification has been used to create tailor-made plants to supply resources to industries such as starch, fuel, pharmaceuticals, etc.

HOW IS AGRICULTURAL BIOTECHNOLOGY USED?

1-Genetic engineering:

Scientists have learned how to move genes from one organism to another. This has been called genetic modification (GM), genetic engineering (GE) or genetic improvement (GI). Regardless of the name, the process allows the transfer of useful characteristics (such as resistance to a disease) into a plant, animal or microorganism by inserting genes (DNA) from another organism. Virtually all crops improved with transferred DNA (often called GM crops or GMOs) to date have been developed to aid farmers to increase productivity by reducing crop damage from weeds, diseases or insects.

2-Molecular markers:

Traditional breeding involves selection of individual plants or animals based on visible or measurable traits. By examining the DNA of an organism, scientists can use molecular markers to select plants or
animals that possess a desirable gene, even in the absence of a visible trait. Thus, breeding is more precise and efficient. For example, molecular markers are used to obtain cowpea resistant to a beetle, disease-resistant white yam and cassava resistant to Cassava Mosaic Disease. Another use of molecular markers is to identify undesirable genes that can be eliminated in future generations.

3-Molecular diagnostics:

   Molecular diagnostics are methods to detect genes or gene products that are very precise and specific. Molecular diagnostics are used in agriculture to more accurately diagnose crop/livestock diseases.

4-Vaccines:

   Biotechnology-derived vaccines are used in livestock and humans. They may be cheaper, better and/or safer than traditional vaccines. They are also stable at room temperature, and do not need refrigerated storage; this is an important advantage in tropical and developing countries. Some are new vaccines, which offer protection for the first time against some infectious illnesses. For example, in the Philippines, biotechnology has been used to develop an improved vaccine to protect cattle and buffalo against hemorrhagic septicemia, a leading cause of death for both species.

5-Tissue culture:

   Tissue culture is the regeneration of plants in the laboratory from disease-free plant parts. This technique allows for the reproduction of disease-free planting material for crops. Examples of crops produced using tissue culture include citrus, pineapples, avocados, mangoes, bananas, coffee and papaya etc.

**How does genetic engineering differ from traditional biotechnology?**

   In traditional breeding, crosses are made in a relatively uncontrolled manner. The breeder chooses the parents to cross, but at the genetic level, the results are unpredictable. DNA from the parents recombines randomly, and desirable traits such as pest resistance are bundled with undesirable traits, such as lower yield or poor quality.

   Traditional breeding programs are time-consuming and labor-intensive. A great deal of effort is required to separate undesirable from desirable traits, and this is not always economically practical. For example, plants must be back-crossed again and again over many growing seasons to breed out undesirable characteristics produced by random mixing of genomes.

   Current genetic engineering techniques allow segments of DNA that code genes for a specific characteristic to be selected and individually recombined in the new organism. Once the code of the gene
that determines the desirable trait is identified, it can be selected and transferred. Similarly, genes that code for unwanted traits can be removed. Through this technology, changes in a desirable variety may be achieved more rapidly than with traditional breeding techniques. The presence of the desired gene controlling the trait can be tested for at any stage of growth, such as in small seedlings in a greenhouse tray. The precision and versatility of today’s biotechnology enables improvements in food quality and production to take place more rapidly than when using traditional breeding.

Benefits of genetic engineering in agriculture:

Everything in life has its benefits and risks, and genetic engineering is no exception. Much has been said about potential risks of genetic engineering technology, but so far there is little evidence from scientific studies that these risks are real. Transgenic organisms can offer a range of benefits above and beyond those that emerged from innovations in traditional agricultural biotechnology. Following are a few examples of benefits resulting from applying currently available genetic engineering techniques to agricultural biotechnology.

1-Transgenic crops

Although genetically engineered organisms in agriculture have been available for only 10 years, their commercial use has expanded rapidly. Recent estimates are that more than 60–70 % of the food products on store shelves may contain at least a small quantity of crops produced with these new techniques. Since 1995, farmers have been growing genetically engineered crops. In 2003, 7 million farmers in 18 countries were planting biotech crops. Almost one third of the global biotech crop area was grown in developing countries. In the United States, these transgenic varieties are largely undifferentiated and fully integrated into commodity markets. In 2005, 52% of corn, 87% of soybeans and 79% of cotton planted in the United States was genetically engineered. In addition, in 2005 transgenic crops were planted globally on about 222 million acres. Transgenic varieties in the marketplace have been beneficial to farmers and the environment.

Major crop plants produced by genetic engineering techniques have been so welcomed by farmers that currently one third (1/3) of the corn and about three-quarters (3/4) of the soybean and cotton grown in the USA are varieties developed through genetic engineering. Twelve transgenic crops (corn, tomato, soybean, cotton, potato, rapeseed [canola], squash, beets, papaya, rice, flax, and chicory) have been approved for commercial production. The most widely grown are “Bi” cotton, corn and glyphosate-resistant soybeans.
1.1- Insect resistance:

The soil bacterium *Bacillus thuringiensis* (*Bt*) produces crystal proteins called Cry proteins that are toxic to larvae of insects like Tobacco budworm, army worm, beetles and mosquitoes but not harmful to animals or humans. The Cry proteins exist as inactive protoxins and get converted into active toxin when ingested by the insect, as the alkaline \( pH \) of gut solubilizes the crystals. The activated toxin binds to the surface of epithelial cells of midgut and creates pores. This causes swelling and lysis of cells leading to the death of the insect (Larva). The genes (cry genes) encoding this protein are isolated from the bacterium and incorporated into several crop plants like cotton, tomato, corn, rice, soybean, etc.

In the last few years, several crops have been genetically engineered to produce their own Bt proteins, making them resistant to specific groups of insects. Applications of Bt bacteria have been used to control insects for many years, before the advent of the current Bt crops made using biotechnology. Varieties of Bt insect-resistant corn and cotton are now in commercial production. Other crops being investigated include cowpeas, sunflower, soybeans, tomatoes, tobacco, walnut, sugar cane, and rice.

1.2- Herbicide tolerance:

Chemical herbicides are frequently used to control weeds. Weeds growing in the same field with crop plants can significantly reduce crop yields because the weeds compete for soil nutrients, water, and sunlight. Many farmers now control weeds by spraying herbicides directly onto the crop plants. Because these herbicides generally kill only a narrow spectrum of plants (if they didn’t, they would kill the crop plants, too), farmers apply mixtures of multiple herbicides to control weeds after the crop has started to grow. Researchers realized that if a crop plant is genetically engineered to be resistant to a broad-spectrum herbicide, weed management could be simplified and safer chemicals could be used. It is often argued that such GE varieties reduce soil erosion, because they make adoption of soil-conserving practices such as “no-till” easier. Resistance to synthetic herbicides has been genetically engineered into corn, soybeans, cotton, canola, sugar beets, rice, and flax. Some of these varieties are commercialized in several countries. Research is ongoing on many other crops. One application of this technology is that herbicide could be coated on seed from a herbicide resistant variety (for example, maize) and while the maize would germinate and thrive, weeds and parasites would be killed.

1.3- Virus resistance:

Many plants are susceptible to diseases caused by viruses, which are often spread by insects (such as aphids) from plant to plant across a field. The spread of viral diseases can be very difficult to control and crop damage can be severe. Insecticides are sometimes applied to control populations of transmitting insects,
but often have little impact on the spread of the disease. Often the most effective methods against viral diseases are cultural controls (such as removing diseased plants) or plant varieties bred to be resistant (or tolerant) to the virus, but such strategies may not always be practical or available.

Scientists have discovered new genetic engineering methods that provide resistance to viral disease where options were limited before.

- In the US, several varieties of squash and zucchini resistant to three important viral diseases have been developed and commercialized.

- Beginning in 1992, a devastating outbreak of Papaya Ring Spot Virus (PRSV) swept through the papaya plantations of Hawaii—papaya production dropped 40% in the course of 5 years. Researchers in Hawaii and at Cornell University developed two GE varieties of papaya resistant to PRSV. Papaya growers in Hawaii have been able to grow GE virus resistant papaya since 1998.

- Scientists are currently developing virus-resistant crops for Africa, including cassava, maize and sweet potato.

2- Increased crop productivity

Biotechnology has helped to increase crop productivity by introducing such qualities as disease resistance and increased drought tolerance to the crops. Now, researchers can select genes for disease resistance from other species and transfer them to important crops. For example, researchers have developed two varieties of papaya resistant to papaya ringspot virus by transferring one of the virus’ genes to papaya to create resistance in the plants. Seeds of the two varieties, named ‘SunUp’ and ‘Rainbow’, have been distributed under licensing agreements to papaya growers since 1998. Further examples come from dry climates, where crops must use water as efficiently as possible. Genes from naturally drought-resistant plants can be used to increase drought tolerance in many crop varieties.

3- Enhanced crop protection

Farmers use crop-protection technologies because they provide cost-effective solutions to pest problems which, if left uncontrolled, would severely lower yields. As mentioned above, crops such as corn, cotton, and potato have been successfully transformed through genetic engineering to make a protein that kills certain insects when they feed on the plants. The protein is from the soil bacterium *Bacillus thuringiensis*, which has been used for decades as the active ingredient of some “natural” insecticides.

In some cases, an effective transgenic crop-protection technology can control pests better and more cheaply than existing technologies. For example, with *Bt* engineered into a corn crop, the entire crop is
resistant to certain pests, not just the part of the plant to which Bt insecticide has been applied. In these cases, yields increase as the new technology provides more effective control. In other cases, a new technology is adopted because it is less expensive than a current technology with equivalent control.

There are cases in which new technology is not adopted because for one reason or another it is not competitive with the existing technology. For example, organic farmers apply Bt as an insecticide to control insect pests in their crops, yet they may consider transgenic Bt crops to be unacceptable.

4- Improvements in food processing

The first food product resulting from genetic engineering technology to receive regulatory approval, in 1990, was chymosin, an enzyme produced by genetically engineered bacteria. It replaces calf rennet in cheese-making and is now used in 60 percent of all cheese manufactured. Its benefits include increased purity, a reliable supply, a 50 percent cost reduction and high cheese yield efficiency.

5- Improved nutritional value

Genetic engineering has allowed new options for improving the nutritional value, flavor and texture of foods. Transgenic crops in development include soybeans with higher protein content, potatoes with more nutritionally available starch and an improved amino acid content, beans with more essential amino acids, and rice with the ability produce beta-carotene, a precursor of vitamin A, to help prevent blindness in people who have nutritionally inadequate diets.

6- Better flavor

Flavor can be altered by enhancing the activity of plant enzymes that transform aroma precursors into flavoring compounds. Transgenic peppers and melons with improved flavor are currently in field trials.

7- Fresher produce

Genetic engineering can result in improved keeping properties to make transport of fresh produce easier, giving consumers access to nutritionally valuable whole foods and preventing decay, damage, and loss of nutrients. Transgenic tomatoes with delayed softening can be vine-ripened and still be shipped without bruising. Research is under way to make similar modifications to broccoli, celery, carrots, melons, and raspberry. The shelf life of some processed foods such as peanuts has also been improved by using ingredients that have had their fatty acid profile modified.
8- Environmental benefits

When genetic engineering results in reduced pesticide dependence, we have less pesticide residues on foods, we reduce pesticide leaching into groundwater, and we minimize farm worker exposure to hazardous products. With Bt cotton’s resistance to three major pests, the transgenic variety now represents half of the U.S. cotton crop and has thereby reduced total world insecticide use by 15 percent! Also, “increases in adoption of herbicide-tolerant soybeans were associated with small increases in yields and variable profits but significant decreases in herbicide use”.

9- Benefits for developing countries

Genetic engineering technologies can help to improve health conditions in less developed countries. Researchers produced “golden rice,” which has sufficient beta-carotene to meet total vitamin A requirements in developing countries with rice-based diets. This crop has potential to significantly improve vitamin uptake in poverty-stricken areas where vitamin supplements are costly and difficult to distribute and vitamin A deficiency leads to blindness in children.

Possible risks associated with using transgenic crops in agriculture

A safe and sufficient food supply is essential for humanity. Like any technology, agricultural biotechnology will have economic and social impacts. Since their introduction, crops improved using biotechnology have been used safely, with benefits such as the reduction of pesticide use. Agricultural biotechnology is only one factor among many influencing the health and welfare of farmers and other citizens in the developing world. As biotechnology continues to evolve, factual and open public discourse is vital to define the role it should play in society.

Some consumers and environmentalists feel that inadequate efforts have been made to understand the dangers in the use of transgenic crops, including their potential long-term impacts. Some consumer-advocate and environmental groups have demanded the abandonment of genetic engineering research and development. Many individuals, when confronted with conflicting and confusing statements about the effect of genetic engineering on our environment and food supply, experience a “dread fear” that inspires great anxiety. These issues and fears can be divided into three groups:

1- Health,
2- Environmental,
3- Social.