

# Overview and Agricultural Applications of Biotechnology

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Biotechnology is the use of microorganisms, plants, animals, their parts or their products to make materials such as food, medicine, and chemicals that are useful to man. We have been using products of biotechnology for a long time. Vinegar, soy sauce, and *patis* (fish sauce) are products of biotechnology, as well as beer, wine, and cheese, pandesal and nata de coco.

Yeast for instance is a microorganism that was first used to make beer and wine for as early as 6,000 BC. Cheese made using bacteria has been produced for hundreds of years. Centuries ago, people were not aware that the useful materials were products of microbial processes. The processes were accidentally optimized to make large quantities of products by trial and error.

Biotechnology, in general, is the use of living organisms to produce products useful to man. Modern biotechnology, on the other hand, attempts to make the living organisms perform a specific product in a predictable and controllable way. To be able to do this, there was a need by scientists to focus their research on the genetic information of the living cell contained in chemical messages called genes. What a cell contains, how it appears and functions, and what processes it could perform, depend on the genetic information contained in the genes. One to several genes in each cell contains the information that will determine if a cell is capable of performing a process to make a useful product. The science of transferring portions of the genes from one cell to another in order to improve the quality and/or quantity of cell products is genetic engineering, an important technique in modern biotechnology.

Through extensive research, scientists now understand the chemical components of the genes, the molecules that encode an organism's genetic information. Genes were discovered to be made up of a substance called deoxyribonucleic acid or DNA. DNA is made up of four types of nucleotides, each type containing a different nitrogenous base: an adenine, thymine, cytosine, or a guanine. DNA of different organisms are made up of exactly the same nucleotides. What is different among different types of organisms is how the four types of nucleotides are arranged or ordered in their genes. These differences result to their variation.

Some genes are now well studied and scientists have also developed ways to change, delete, or add some messages they contain. Moreover, they have also discovered the techniques to change certain regions of the gene before introducing it to another cell of a different organism. This procedure of changing some messages in genes and transferring them

to another cell is genetic engineering. The objective of the genetic engineering procedure is to make an improved cell that could produce a needed chemical, carry out other useful processes, or give an organism a desirable characteristic that it did not possess originally.

### **The genetic engineering process**

Genetic engineering or genetic manipulation describes the techniques of (a) taking a gene from the cell, inserting the gene into another fragment of DNA called cloning vector DNA, and transferring the vector plus insert into another cell through a process called transformation or (b) taking a gene from one cell, making some changes in the genes, and putting the altered genes back into the original cell. The objective of the genetic engineering procedure is to possibly produce an improved cell that could synthesize a needed chemical, carry out other useful processes, or give the cell a desirable characteristic that it did not possess originally.

### **Benefits from genetic engineering technology**

Each living cell contains genes that determine what useful products the cell can synthesize. Scientists can take a specific gene responsible for the synthesis of a known protein product from a plant or animal cell and transfer them to a microorganism such as bacterium and yeast. Since these microorganisms grow easily in large quantities, there will be a lot of cells to produce the new protein product and, consequently, a lot of the product.

Another benefit from genetic engineering is useful to plant and animal breeders. Scientists can take a desirable gene from one plant, animal or microorganisms. The gene could then be incorporated into an unrelated species which is usually not possible in normal breeding. This technique could allow a wider range of traits to be incorporated more quickly and more reliably into target species, not possible with conventional methods.

### **Products of Modern Biotechnology**

The products of modern biotechnology may be grouped into 4 categories, namely agricultural products, bioremediation products, diagnostic products and therapeutic products.

#### **Agricultural Products**

The most popular products of modern biotechnology fall into the category of agricultural products, which usually come in the form of transgenic plants. Using recombinant

DNA technology, we are able to give plants characteristics they do not normally possess but will improve the plant in terms of its usefulness to the human race. Some examples:

- FlavrSavr™ tomato has been modified to produce fruits having a longer shelf life.
- The most recent GMO is named golden rice. These rice grains are fortified with vitamin A, helping prevent blindness from Vitamin A deficiency.
- Typhoon-resistant rice, having longer stalks, can survive even in floods, so that extensive loss is prevented during the rainy season
- Pest-resistant crops reduce the need for chemical pesticides that damage the environment and are toxic to humans. These crops are usually resistant to specific types of pests, so that other insects in the environment are not harmed.

### **Diagnostic Products**

The first step towards curing a disease is to recognize the disease. Traditionally, this was done by asking the patient to describe what he or she is feeling and by taking the vital signs of the disease. Although this procedure provides the physician with a lot of information, this method of diagnosis is inconclusive and very open to speculation and human error. With biotechnology, we can refine science.

A new technique called PCR (polymerase chain reaction) detects genes that are unique to an organism. The presence of these genes would act as a "positive ill" for the presence of the disease-causing organism

### **Bioremediation Products**

Because of man's past and present disregard for the environment, many of the bodies of water and even the land have been heavily polluted by non-biodegradable and toxic wastes. To address this problem, biotechnologists have harnessed the power of microbes and certain plants to clean up the mess we humans have left behind

Certain microorganisms and plants are now being used to clean up toxic wastes such as oil spills in the ocean. These "clean-up organisms" are able to break down these toxic chemicals into harmless ones which occur normally in the environment. Because they are able to clean up the polluted water or land, they rehabilitate these environments to their former state so that they may once again support life.

Another thing that these organisms can do is recycle agricultural waste. For example, certain bacteria can be used to help process agricultural waste products to make organic fertilizer, biofuels, animal feed supplements and other important industrial products.

## **Therapeutic Products**

Many human diseases result from deficiency in certain proteins. For example, diabetics are deficient in the protein insulin, so their bodies can't process sugar very well. To help them live more normal lives, they take in supplementary insulin that is produced by bacteria, which are using the human gene as the recipe.

- This technique can be applied to many other substances needed for humans afflicted with deficiencies that result in disease.
- As previously mentioned, recombinant DNA technology can also be used to produce harmless parts of disease-causing viruses and bacteria. These can then be injected into a person as a vaccine, thereby preventing disease.

## **SUSTAINABLE AGRICULTURE THROUGH BIOTECHNOLOGY**

The unabated increase in world population in the last millennium brought with it problems of poverty, hunger, malnutrition, and environmental degradation. In addition, the frequent climatic and extreme temperature changes aggravated the insufficiency of our land and water resources to provide sufficient food and nutrition. World population has doubled since 1960 to 6.1B and is expected to increase by 50% to 9.3B by 2050. All of the projected growth will take place in today's developing countries. Already 2B people lack food security, and water supplies and agriculture lands are under increasing pressure. In addition, poverty is projected to increase with 10M more people condemned to poverty after the September 11 incident. Water use has risen six-fold over the past 70 years. A UN report shows the close link between population trends and environmental conditions.

Since the beginning of modern times, development in domestication of plants and animals – the so-called "agriculture" – has affected very much the condition of our environment. In order to feed our increasing number of people, our forefathers opted to do drastic damages to our environment by destroying large areas of lands and mountains to conduct massive cultivation. Currently, 1/8 of the earth's land area is cultivated to crops that are slowly being reduced to provide shelter and recreation to the increasing population.

As research in agriculture progresses, modern agriculture employs scientific crop improvement methods and new technologies such as hybridization, wide hybridization, tissue culture, heterosis breeding, and cell culture. To expedite intensive agriculture, machines were invented that can be used for land preparation, seeding, weed control, and harvesting. Application of irrigation, water, fertilizer, and pesticides becomes a requirement for increased production.

Over-dependence of our farmers on these requisites results to more damage to our environment. Excessive chemical fertilization and pesticide application have been associated with dying of lakes and contamination of soil and underground water. There are also accompanying problems on the decrease in wildlife populations, loss of beneficial organisms and impairment of farm workers' health. Intensive cultivation with mechanized tools leads to

erosion of topsoil and reduced soil fertility. Continuous nitrogen fertilization of rice paddies is associated with increased soil acidity accompanied by reduced crop productivity.

On top of this, modern agriculture has also narrowed the plant and animal biodiversity. Of the 400 or so crop species that are known to be edible, only 22 species are cultivated for human consumption. Modern agriculture therefore needs to be improved to make it more productive but sustainable and protective of our environment, and of our natural and human resources.

Biotechnology is one of the tools in solving these problems. Modern biotechnology that involves plant tissue and cell culture, recombinant diagnostics, recombinant microorganisms, and genetically engineered plants and animals are the new alternatives in modern agriculture.

## **1. Recombinant Diagnostics**

Molecular markers and monoclonal antibodies are tools in recombinant diagnostics to detect genomic changes in response to the change in environment, in the onset of diseases and pests, and in other physiological status of the plant. A DNA micro array, which is a technology that expedites the detection of these changes, is now extensively employed in studying cultural management methods in growing crops, in response to pests, and other extreme environmental changes. Molecular marker-assisted breeding makes use of the candidate genes or specific DNA sequences to expedite the selection of desirable recombinants at a short time and small space. These technologies are currently being used in rice breeding at IRRI and PhilRice, especially in wide hybridization and in the development of introgression lines with tungro, bacterial blight, and stemborer resistance. In the Philippines, molecular marker technology is also being employed to search for pest resistance genes in coconut, cotton, abaca, mungbean, and potato.

## **2. Recombinant microorganisms**

### Bioremediation

Plants can also be made to contain genes and become agents for bioremediation. Scientists have succeeded in cultivating mustard plants that have the ability to take up mercury and convert it into a compound less toxic to the environment (EAB, 2000). Rapeseed, cotton, and *Arabidopsis* are now modified to produce plastic precursors that are highly biodegradable (EAB, 2000). Corn has also been modified to contain enzyme phytase that reduces the pollutant phytate-phosphate complex.

### Herbicide resistance

One of the most successful genetically modified plants is the herbicide tolerant crop that includes soybean, cotton, corn, and oilseed rape. Surveys done by the American Soybean

Association and the US National Center for Food and Agricultural Policy prove that using herbicide-tolerant soybeans are benefiting American farmers. Improved weed control through herbicide-tolerant soybeans has more than doubled the amount of soybean areas in conservation tillage. Almost 50% of soybean growers eliminated tillage. Additional 34% soybean areas were managed with reduced tillage system. Reduction in tillage not only benefited the farmers but wildlife as well. The ecosystems within the fields are conserved and the topsoil remains instead of being washed off into streams, thereby preserving soil fertility. (Crop Biotech News, January 18, 2002). In addition, a savings of 19M dollars was achieved due to fewer herbicide applications since 1995. Reduced tillage practices also saved 247 M tons of irreplaceable topsoil in 2000, and reduced the number of times a farmer had to run equipment over the field, saving 234 M gallons of fuel (Crop Biotech News, Nov. 16, 2001). Currently, the areas planted to herbicide resistant soybeans went up by 14% from 54% in 2000 to 68% in 2001 (Crop Biotech News Aug 9,2001).

### Pest Resistant Crops

Pest and disease resistant crops such as soybean, cotton, corn, rapeseed, rice, and other crops were devoted in order to minimize pesticide use that damages the human health and the environment.

Mexican scientists developed white potatoes that would resist potato virus X (PVX), potato virus Y (PVY) and potato leaf roll virus (PLRV). These modified potatoes will increase yield by 5-22%. This productivity increase will raise income levels among potato farmers, while they lower the cost of food (Crop Biotech News, May 2001). Bt cotton and corn consistently outperformed non-Bt plants in the USA, China, Indonesia, Mexico, Australia, and India. In China, Bt cotton was not sprayed compared to the 12 times spraying per season in the conventional cotton, and an increase from 825 kg to 1,125 kg cotton lint / ha (Crop biotech News, June 2001). In Mexico, around US\$2.7 M in economic benefits was generated annually using Bt cotton. Of this, about 85% accrued to farmers and 15% to seed suppliers (Crop Biotech News, Aug. 17, 2001). In Indonesia, 60% of the area planted to Bt cotton reached three to four times higher productivity than conventional cotton. Frequency of spraying was also reduced from 7 to 12 times per season to 0 to 3 times per season (CropBiotech News, June 15,2001). In Australia, around 3AM bale of crop can now be harvested from fields planted with 30% GM cotton resistant to some types of insects. A 50% reduction of chemical sprays was also observed in areas planted with Bt cotton. In the Philippines, result of a multi-locational testing for Bt corn by Monsanto yielded 50-70% increase in yield, with no spraying application. Bt corn was found to be highly resistant to the Asiatic corn borer (Crop Biotech News November 16,2001).

Non-target organisms are also protected when cultivating pest resistant crops. In the field trials conducted in the Philippines, natural enemies such as spiders, bugs, and others were found to be in abundance in the GM corn and not in the sprayed non-GM com. This shows how organism-specific the action of the Bt toxin is.

### Plants with improved nutritional quality

Improvement of our existing food crops to make them more nutritious is also possible through biotechnology. These include fruits and vegetables with reduced allergens, increased vitamins, and amino acids in legumes, tomato, pepper, and rice.

### Improvement in biodiversity

Using genetic engineering, the reduction in biodiversity will be minimized and slowly regained. There are now studies to improve our traditional varieties so that we can cultivate them again in existing environmental conditions. For example, our traditional *Wagwag* variety has been improved through biotechnology making it photoperiodic insensitive, with shorter height, and resistant to disease without altering its high eating quality. IR 64, which was very resistant to all kinds of disease, and somehow lost all of it through time, is now being improved to incorporate disease resistance genes. As we generate new lines through biotechnology, the number of varieties that the farmers can choose from is increased. We also have a germplasm bank where we store these variabilities for use in future breeding work.

### **3. Genetically-engineered animals**

Research in animal biotechnology has always been ahead of plant biotechnology. Most of the recent advances in plant biotechnology especially in the field of pharmaceuticals have always been patterned from animal work. Livestock and fishery improvement always look into the incorporation of disease resistance genes. Livestock are also improved so that they produce less fat, improved flavor and meat tenderness. A new transgenic pig now contains the gene for phytase, so that whatever non-phytase containing feed it ingests will reduce the non-degradable phytate-phosphate complex and come out as a non-pollutant in its dung.

In conclusion, biotechnology can help us recover the already devastated environment that we have. Through biotechnology, we have more sustainable and resource-efficient crop management practices that require less energy/fuel and conserve natural resources, more effective control of pests and disease that are hazardous to human health, soil texture and fertility conserved, conserved quality of ground and surface water, higher yield and reduced cost of production = the requisites of a sustainable farming system.