Application of Biotechnology in Agriculture

Application of Biotechnology in Agriculture involves scientific techniques such as Genetically Modified Organisms, Bt Cotton, Pest Resistant Plants. It helps in modifying plants, animals, and microorganisms and improve their agricultural productivity. Techniques like vaccines, tissue culture, genetic engineering are also used.

Before Agricultural Biotechnology

Between the 1930s and 1960s, there was a tremendous increase in food production worldwide, due to the Green Revolution. This revolution basically involved the use of high-yielding crop varieties, increased use of fertilizers and better irrigation methods. Although the green revolution tripled the food supply worldwide, it was still not enough for the growing population.

Farmers have also used agrochemicals (pesticides and fertilizers) to increase crop yield. However, agrochemicals are too expensive for farmers in developing countries. The use of these chemicals also adds to environmental pollution. Moreover, it is difficult to further increase crop yield using existing varieties and conventional breeding.

Is there a way to use our knowledge of plant genetics to produce new varieties and increase yield? Can we minimize the use of pesticides and fertilizers and use a more environment-friendly approach? Yes, agricultural biotechnology has given rise to genetically modified crops that solve all the above problems.

Genetically Modified Organisms

You must have heard the term 'GMO' used by people around you or in the news every now and then. What does this mean? GMO stands for 'Genetically Modified Organisms'. GMOs are plants, animals, bacteria or fungi whose genes have been modified by genetic manipulation. Genetically modified crops or GM crops are used in the following ways:

- They are more tolerant to stresses such as drought, cold, heat etc.
- They are pest-resistant and therefore less dependent on chemical pesticides.
- Genetically Modified crops help to reduce post-harvest losses.

- They help to increase the mineral usage by plants, thereby preventing early exhaustion of soil fertility.
- Genetically modified crops have enhanced nutritional value. Example – Vitamin A enriched rice.

Genetic modifications also help to create tailor-made plants to provide alternative resources to industries, such as fuels, starches, and pharmaceuticals. Let's look at some examples of GM crops and how they are useful.

Bt Cotton

This is a genetically modified version of cotton. 'Bt' stands for the microbe *Bacillus thuringiensis.* This microbe produces an insecticidal protein or toxin that kills other insects such as tobacco budworm, flies, mosquitoes, beetles etc. Why is this protein not toxic to the *Bacillus* itself?

This is because it stays inactive (as protoxin) in the *Bacillus.* It gets activated only once it comes in contact with the alkaline pH in the insect gut when the insect ingests it. The activated toxin then binds to the surface of epithelial cells and creates pores in it. This causes the cells to swell and lyse, eventually leading to the death of the insect.

Scientists isolated the Bt toxin genes from *Bacillus thuringiensis* and incorporated it into various crop plants such as cotton. This variety is ‘Bt cotton’. Since most Bt toxins are insect-group specific, the choice of genes to be incorporated depends on the crop and the targeted pest. A gene named *cry* codes for the toxin protein and there a number of these genes. For example, the genes *cryIAc* and *cryIIAb* encode toxins that control cotton bollworms whereas the gene *cryIAb* controls the insect ‘corn borer’.

Bt cotton plant (Source: Flickr)

Pest Resistant Plants

Several nematodes live as parasites on multiple hosts like plants, animals, and even human beings. A specific nematode '*Meloidegyne incognitia*' infects the roots of tobacco plants and causes a great decrease in yield. To prevent this infestation, a novel strategy was adopted which is based on the process of RNA interference (RNAi).

RNAi is a method of cellular defence in all eukaryotes. It involves the silencing of a specific mRNA by a complementary double-stranded (ds) RNA that binds and inhibits the translation of this mRNA. The complementary RNA can come from an infection by viruses that have RNA genomes or genetic elements called 'transposons'.

Scientists took advantage of this process and introduced nematode-specific genes into host plants using *Agrobacterium* vectors. The introduced DNA produces both sense and anti-sense strands in the host cells. These complementary strands then produce dsRNA and initiate RNAi and thus silence the specific RNA of the nematode. Consequently, the parasite cannot survive in the host that expresses this RNA, leading to resistance against that parasite.

(Source: biologypt2012)

Solved Example For You

Q: Why is the toxin produced by *Bacillus thuringiensis* (Bt) toxic to other insects but not to itself?

a. Bt has an enzyme that cleaves the toxin.
b. The toxin is enclosed in a capsule.
c. The toxin is inactive in Bt.
d. Bt is resistant to the toxin.

Solution: The answer is ‘c’. The toxin is inactive in Bt which is why it does not produce any effect on it.

Application of Biotechnology in Medicine

Have you ever come across a diabetic who needs regular insulin injections? Where do you think this artificial insulin comes from? It is a product of biotechnology applications in the field of medicine. Let's learn about these biotechnology applications in detail.

Biotechnology Applications In Medicine

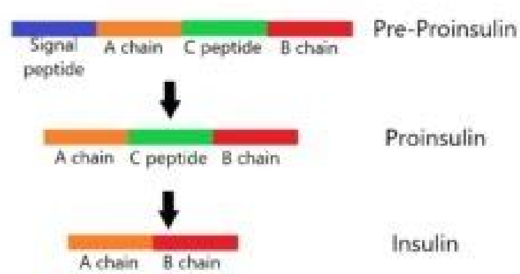
You may have already learnt about Recombinant DNA (rDNA) technology. This biotechnology application is very important in healthcare because it allows for the mass production of safe and more effective medicines. It also prevents undesirable immune responses which are common with medical products from non-human sources.

Currently, about 30 recombinant therapeutics have been approved for human use worldwide, and 12 of these are presently being marketed in India. Let's take a look at some of the applications.

1) Genetically Engineered Insulin

Earlier, diabetes was treated using insulin from the pancreas of slaughtered pigs and cattle. Do you think this insulin causes any side-effects in humans? Yes! Insulin from animal sources induces allergies and other unwanted immune reactions in humans. This is why there was a need to isolate human insulin. Is there a way to do this? What if we can use bacteria to produce human insulin? Not only can we grow bacteria in large amounts, but we can also mass-produce human insulin!

Insulin consists of two short, polypeptide chains – chain A and B, linked via disulfide bridges. Insulin is produced as a 'prohormone' in mammals (including humans). This prohormone has an extra peptide, the C peptide, which needs to be removed to give rise to mature insulin.



Maturation of Insulin.

The major challenge while generating human insulin is to assemble insulin into its mature form. An American company called 'Eli Lilly' overcame this hurdle in 1983. They prepared two DNA sequences that correspond to the A and B chains of human insulin. They then incorporated these sequences into plasmids of *E.* Coli to generate insulin chains. Further, they produced the chains separately, extracted and combined them by creating disulfide bonds to give rise to human insulin.

2) Gene Therapy

If a child is born with a genetic defect, is there a way to correct that defect? Yes, there is, with gene therapy! Gene therapy is a biotechnology application involving a collection of methods that can correct a gene defect in a child or an embryo. It involves inserting a normal gene into the person's cells or tissues to compensate for the non-functional gene. Let's understand how this works.

In 1990, the first clinical gene therapy was applied to treat a 4-year old girl with a deficiency in the enzyme adenosine deaminase (ADA). This disorder is due to the lack of the gene for ADA, which is an enzyme important for the function of the immune system. Bone marrow transplantation helps cure this disorder in some cases. Enzyme replacement therapy, which involves injecting the patient with functional ADA, is also effective in some cases. However, both these procedures are not completely curative.

In gene therapy, blood lymphocytes of the patient are grown in a culture outside the body. Subsequently, a functional ADA cDNA is incorporated into these lymphocytes and re-introduced into the patient. This alleviates the symptoms of the disorder. However, the patient requires periodic infusions of these genetically-engineered lymphocytes, since these cells are not immortal. A permanent cure for this could be to introduce the gene producing ADA from marrow cells into cells at early embryonic stages of life.

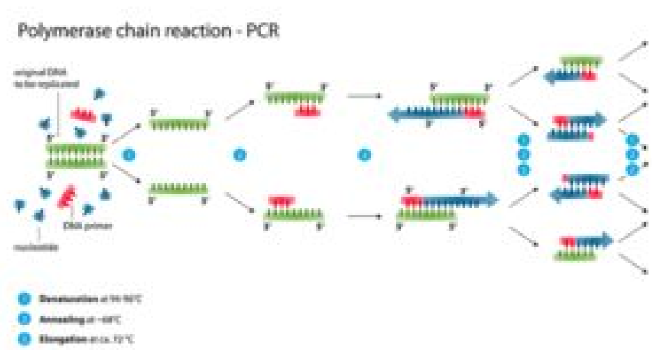
3) Molecular Diagnosis

We all know that early diagnosis of a disease is important to effectively treat the disease. Early detection is not possible using conventional methods like serum and urine analysis. Let’s look at some biotechnology applications that help in early diagnosis of diseases.

i) Polymerase Chain Reaction (PCR)

Normally, we can detect a pathogen (bacteria, virus etc.) only when the disease symptoms start to appear. However, by this time, the pathogen concentration in the body is very high! Is there a way to detect pathogens at initial stages of the disease when their concentrations are low?

Yes, using a technique called PCR. PCR involves amplification of the nucleic acid in the pathogen allowing us to detect the pathogen at very low concentration. Today, we use PCR routinely to detect HIV in suspected AIDS patients and to detect gene mutations in suspected cancer patients.



Steps in Polymerase Chain Reaction (PCR) [Source: thebalance]

ii) Enzyme-Linked Immunosorbent Assay (ELISA)

The basic principle of ELISA is antigen-antibody reactions. ELISA can diagnose infections by detecting the presence of antigens (proteins of the pathogen) in the patient serum or by detecting the antibodies produced against the pathogen.

iii) In Situ Hybridisation

This technique involves tagging a single-stranded DNA or RNA with a radioactive molecule (probe). This then hybridizes with its complementary DNA in a clone of cells. On detection using autoradiography, the clone with the mutated gene will not appear on the photographic film because the probe is not complementary to the mutated gene.

Solved Example For You

Q: Which of the following techniques is based on antigen-antibody reactions?

a. rDNA technology
b. ELISA
c. PCR
d. Gene therapy

Solution: The answer is ‘b’. ELISA is based on antigen-antibody reactions.

Transgenic Animals and Ethical Issues

You may have heard of scientists using mice or rats to do their research. Are these the same mice or rats we find around us commonly? No! Scientists use genetically modified mice or rats for their research. These are ‘Transgenic animals’. Let’s learn more about these animals.

Transgenic Animals

These are animals that have had their DNA manipulated to express an additional (foreign) gene. Although more than 95% of transgenic animals are mice; there also exist transgenic rats, sheep, rabbits, pigs, cow, and fish. What is the need to generate these animals and how do we benefit from these modifications? Let’s look at some common reasons.

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Normal Physiology and Development

Transgenic animals allow us to study how genes affect the normal functions of the body and its development. In addition, they also help us understand how genes are regulated in the body.

For example, by introducing genes from other species, that alter the formation of a particular factor and by studying its biological effects, we can gain knowledge about the biological role of the factor in our body.

Study of Disease

Transgenic animals also serve as models for human diseases and increase our understanding of how genes contribute to disease development. They also make it possible to investigate new treatment methods for diseases. Currently, transgenic models exist for many human diseases such as Alzheimer's, cancer, rheumatoid arthritis, cystic fibrosis etc.

Biological Products

Treatment of certain human diseases requires medicines that contain biological products, which are usually expensive to make. Transgenic animals can be used to make these biological products too. Incorporation of genes of a particular product into transgenics will result in the production of that biological product.

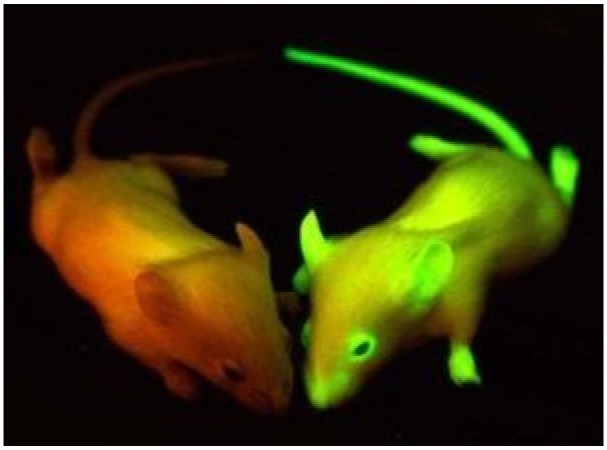
An example is human α-1-antitrypsin which is used to treat emphysema. The most noteworthy example is Rosie – the first transgenic cow, generated in 1997. The milk from this cow contained human α-lactalbumin and had a higher nutritional value for human babies, compared to natural cow milk.

Vaccine Safety

Before using vaccines on humans, they are first tested for safety on transgenic mice. Transgenic mice are currently in use to test the safety of polio vaccines. If the test is successful and reliable, transgenic mice will replace the use of monkeys to test the safety of these vaccines.

Chemical Safety Testing

The toxicity or safety of substances is also tested using transgenics. For this, transgenic animals are created with genes that make them more sensitive to the toxic substance under study. Subsequently, they are exposed to the toxic substance and the effects are studied. Using transgenics for toxicity testing gives results in a short time.



Transgenic mice [Source: Wikimedia Commons]

Ethical Issues

What do you think will happen if the genetic manipulation of living organisms by humans goes unregulated?! It will not only lead to exploitation of the organisms but will also have harmful impacts on our ecosystem. It is wrong at the moral and biological level! This is why we need ethical standards to regulate the human manipulation of organisms.

GEAC

In terms of genetically modified organisms (GMOs), the Indian Government has set up the Genetic Engineering Approval Committee (GEAC). This organization makes decisions regarding the validity of research involving GMOs and addresses the safety of GMOs introduced for public use.

Patents And Rights

Recently, certain companies were granted patents for products and technologies that involve genetic material or other resources developed and used by people of a specific region over many years. This has angered a lot of people.

A recent example is Basmati rice, which was developed by Indian farmers over hundreds of years. An American company, in 1997, obtained the patent rights for Basmati rice from the US Patent and Trademark Office. This patent not only allows this company to sell new variations of Basmati rice and make a profit but also restricts other people from selling it.

Similar attempts have been made to patent Indian herbal medicines too. Therefore, people and countries need to be vigilant and counter patent applications that exploit products and techniques native to their land.

Basmati rice field in Punjab, India [Source: Wikimedia Commons]

Biopiracy

Biopiracy refers to the use of bio-resources by multinational companies without proper authorization or compensation to the people or country concerned. Most developed, financially rich nations are poor in biodiversity or traditional know-how; while it is the other way around for developing nations. This leads to exploitation of the traditional knowledge to develop modern, commercial applications that save the makers time, money and effort.

People are now more aware of the injustice and inadequacy in compensation and sharing of benefits between the developing and developed nations. As a result, several nations now have laws that prevent other nations from exploiting their bio-resources and traditional knowledge. The Indian Parliament recently cleared the second amendment of the Indian Patents Bill, that takes the issue of biopiracy into consideration.

Solved Example For You

Q: State True or False. Transgenic animals generated in laboratories can be released into the ecosystem after use.

Solution: False. Transgenic animals, if released can spread in a natural population and cause an imbalance in the ecosystem.