CUET (UG) Biology Notes: Biotechnology and its Applications

1. Application of Biotechnology in Agriculture

Biotechnology offers the integration of Genetically Engineered (GE) crop-based agriculture as an alternative to conventional agrochemical-based or organic farming.

Genetically Modified Organisms (GMOs)

Plants, bacteria, fungi, and animals whose genes have been altered by manipulation.

Key benefits of GM plants for agriculture:

1. Made crops more tolerant to abiotic stresses (cold, drought, salt, heat).
2. Reduced reliance on chemical pesticides (pest-resistant crops).
3. Helped to reduce post-harvest losses.
4. Increased efficiency of mineral usage by plants (prevents early exhaustion of soil fertility).
5. Enhanced nutritional value of food (e.g., Golden Rice is enriched with Vitamin A).

Bt Cotton (Pest Resistance)

- Source: A soil bacterium called Bacillus thuringiensis (Bt) produces proteins that kill certain insects (lepidopterans, coleopterans, and dipterans).
- Mechanism: The bacterium forms protein crystals containing a toxic insecticidal protein. It exists as an inactive protoxin.
- Activation: Once ingested by an insect, the alkaline pH of the gut solubilizes the crystals, converting the protoxin into an active form.
- Action: The active toxin binds to the surface of midgut epithelial cells and creates pores that cause cell swelling and lysis, leading to the death of the insect.
- Specific Genes (cry genes): The toxin is coded by a gene named cry.
    - cryIAc and cryIIAb control the cotton bollworms.
    - cryIAb controls the corn borer.

RNA Interference (RNAi) in Tobacco Plants

- The Problem: A nematode, Meloidogyne incognita, infects the roots of tobacco plants, causing a great reduction in yield.
- The Solution (RNAi): A cellular defense mechanism present in all eukaryotic organisms. It involves the silencing of a specific mRNA due to a complementary double-stranded RNA (dsRNA) molecule that binds to and prevents translation of the mRNA (silencing).
- Process: Using Agrobacterium vectors, nematode-specific genes were introduced into the host plant. The introduction produced both sense and antisense RNA in the host cells. These two RNAs being complementary formed a dsRNA that initiated RNAi and silenced the specific mRNA of the nematode, preventing it from surviving in the transgenic host.

Tissue Culture

- Totipotency: The capacity to generate a whole plant from any cell/explant.
- Micropropagation: Producing thousands of plants through tissue culture. These plants are genetically identical to the original plant (somaclones).
- Disease-Free Plants: Even if a plant is infected with a virus, the meristem (apical and axillary) is free of viruses. Meristems can be removed and grown in vitro to obtain virus-free plants (e.g., banana, sugarcane, potato).

2. Application of Biotechnology in Medicine

Recombinant DNA technological processes have made immense impacts by enabling mass production of safe and more effective therapeutic drugs.

Medical Application	NCERT Details & Key Processes

Genetically Engineered Insulin	• Past: Insulin was extracted from the pancreas of slaughtered cattle and pigs (caused allergies). • Structure: Consists of two short polypeptide chains: Chain A and Chain B, linked together by disulphide bridges. • Pro-insulin: Mammalian insulin is synthesized as a pro-hormone which contains an extra stretch called the C peptide. This C peptide is removed during maturation. • The Breakthrough (1983): An American company, Eli Lilly, prepared two DNA sequences corresponding to A and B chains of human insulin and introduced them in plasmids of E. coli to produce insulin chains separately, then combined them by creating disulphide bonds.

Medical Application	NCERT Details & Key Processes
Gene Therapy	A collection of methods that allows correction of a gene defect. Involves delivery of a normal gene into the individual or embryo to take over the function of and compensate for the non-functional gene. • First Clinical Case (1990): Given to a 4-year-old girl with ADA (Adenosine deaminase) deficiency, which causes Severe Combined Immunodeficiency (SCID). • Process: Lymphocytes from the patient's blood are grown in culture. A functional ADA cDNA (using a retroviral vector) is introduced into these lymphocytes, which are returned to the patient. • Limitation: As cells are not immortal, the patient requires periodic infusions. A permanent cure is possible if the gene is introduced into cells at early embryonic stages.
Molecular Diagnosis	Traditional methods (serum and urine analysis) cannot provide early detection. Early detection techniques include: 1. PCR (Polymerase Chain Reaction): Amplifies nucleic acids. Used to detect HIV in suspected AIDS patients and mutations in genes in suspected cancer patients. 2. ELISA (Enzyme-Linked Immunosorbent Assay): Based on the principle of antigen-antibody interaction. Detects infection by the presence of antigens (proteins, glycoproteins) or antibodies synthesized against the pathogen. 3. Autoradiography: A single-stranded DNA or RNA tagged with a radioactive molecule (probe) is allowed to hybridize to its complementary DNA in a clone of cells, followed by detection using photographic film. Mutated genes will not appear on the film because the probe will not have complementarity.

3. Transgenic Animals

Animals that have had their DNA manipulated to possess and express an extra (foreign) gene. Over 95% of all existing transgenic animals are mice.

Reasons for developing transgenic animals:

1. Normal Physiology and Development: Designed to allow the study of how genes are regulated and how they affect the normal functions of the body.
2. Study of Disease: Serve as models for human diseases so that investigation of new treatments is possible. Models exist for Cancer, Cystic fibrosis, Rheumatoid arthritis, and Alzheimer's.
3. Biological Products: Transgenic animals can produce useful biological products created by

the introduction of the portion of DNA (gene) which codes for a particular product.
    - Rosie (1997): The first transgenic cow. Produced human protein-enriched milk (2.4 grams per liter). The milk contained the human alpha-lactalbumin, making it nutritionally more balanced for human babies than natural cow-milk.
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    - α-1-antitrypsin: A human protein used to treat emphysema.
4. Vaccine Safety: Transgenic mice are being developed for use in testing the safety of vaccines before they are used on humans (e.g., polio vaccine).
5. Chemical Safety Testing: Transgenic animals are made that carry genes making them more sensitive to toxic substances than non-transgenic animals.

4. Ethical Issues

The manipulation of living organisms requires regulation to assess the morality and safety of such actions.

- GEAC (Genetic Engineering Appraisal Committee): The Indian Government has set up this organization to make decisions regarding the validity of GM research and the safety of introducing GM organisms for public services.

Biopiracy and Patents

- Biopiracy: The term used to refer to the use of bio-resources by multinational companies and other organizations without proper authorization from the countries and people concerned without compensatory payment.
- The Patent Controversy: Industrialized nations are financially rich but poor in biodiversity and traditional knowledge, whereas developing nations are rich in biodiversity. Patents have been heavily contested.
    - Basmati Rice Case: In 1997, an American company got patent rights on Basmati rice through the US Patent and Trademark Office. This allowed them to sell a "new" variety of Basmati in the US and abroad, which was actually derived from Indian farmers' varieties (by crossing Indian Basmati with semi-dwarf varieties).
    - Other Examples: Attempts have also been made to patent Neem and Turmeric for their traditional medicinal uses.