# Ch 10 · Biotechnology & its Applications

## अध्याय 10 · जैव प्रौद्योगिकी एवं उसके उपयोग

Class 12 Biology · NCERT based · English + हिंदी · ✍️ revision notes

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### Applications of biotechnology · जैव प्रौद्योगिकी के उपयोग




Infographic: chapter map

## Introduction / परिचय

- Biotechnology mainly deals with **industrial scale production of biopharmaceuticals & biologicals** using genetically modified microbes, fungi, plants & animals.
- Applications: **therapeutics, diagnostics, genetically modified crops** for agriculture, **processed food, bioremediation, waste treatment & energy production**.

**Three critical research areas of biotechnology:**

1. Providing the **best catalyst** in the form of an improved organism, usually a microbe or pure enzyme.
2. Creating **optimal conditions** through engineering for a catalyst to act.
3. **Downstream processing** technologies to purify the protein/organic compound.

## I. Biotechnological Applications in Agriculture / कृषि में उपयोग

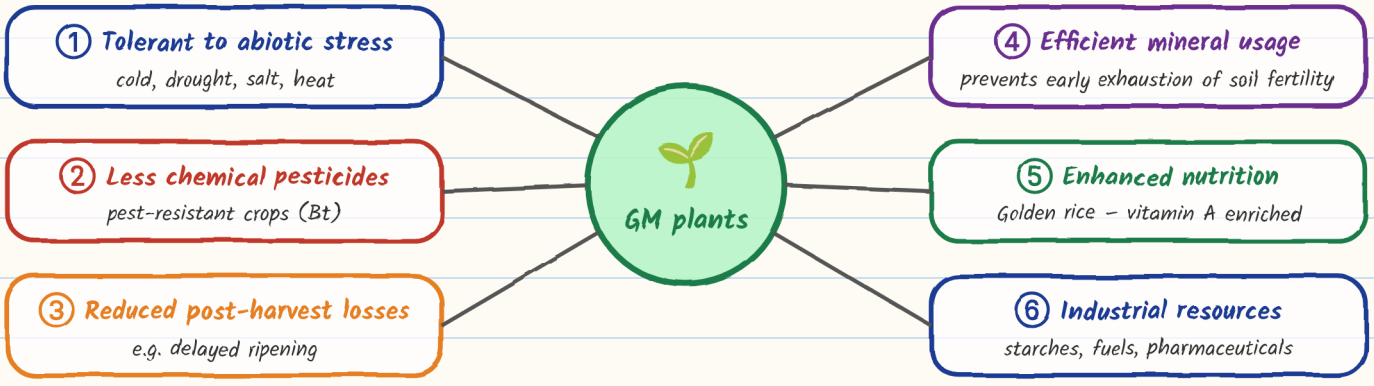
Three options to increase food production:

① **Agro-chemical** based agriculture ② **Organic** agriculture

③ **Genetically engineered crop**-based agriculture

- **Green Revolution** succeeded in tripling food supply, but yet not enough to feed the growing human population. Increased yields partly due to improved crop varieties, but mainly due to use of better management practices & use of **agrochemicals** (fertilisers & pesticides).
- For farmers in developing world, agrochemicals are often **too expensive**; further increase in yield with existing varieties not possible using conventional breeding.
- Use of genetically modified crops is a possible solution → minimum use of fertilisers & chemicals so that harmful effects on environment are reduced.
- GMO (Genetically Modified Organisms) (आनुवंशिकतः रूपांतरित जीव): plants, bacteria, fungi & animals whose **genes have been altered by manipulation**.

### Advantages of GM plants आनुवंशिकतः रूपांतरित पौधों के लाभ



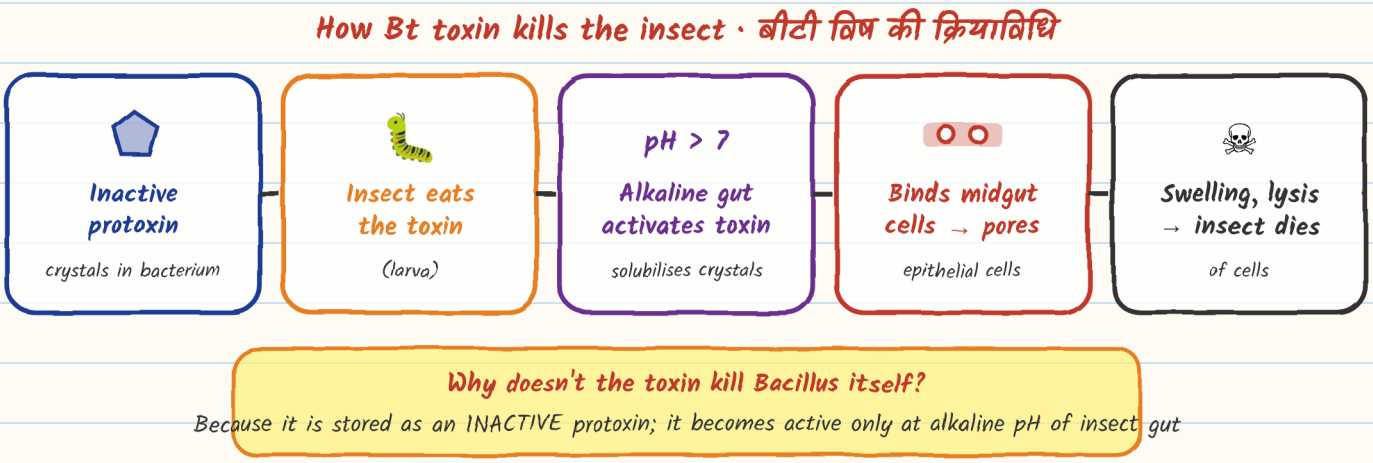

Infographic: Uses of genetically modified plants · GM पौधों के लाभ

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 fertility of soil).

5. **Enhanced nutritional value** of food, e.g. golden rice – **Vitamin 'A' enriched rice**.
6. GM used to create **tailor-made plants** to supply alternative resources to industries – starches, fuels & pharmaceuticals.

## 2. Pest Resistant Plants – Bt Cotton / बीटी कपास

- **Bt toxin** is produced by bacterium *Bacillus thuringiensis* (**Bt** for short).
- Bt toxin gene has been cloned from bacteria & expressed in plants to provide **resistance to insects** without the need for insecticides → in effect created a bio-pesticide.
- Examples: **Bt cotton, Bt corn, rice, tomato, potato & soyabean**.
- Some strains of *B. thuringiensis* produce proteins that kill certain insects:
  - **Lepidopterans** – tobacco budworm, armyworm
  - **Coleopterans** – beetles
  - **Dipterans** – flies, mosquitoes
- *B. thuringiensis* forms **protein crystals** during a particular phase of its growth. These crystals contain a **toxic insecticidal protein**.




Infographic: Mode of action of Bt toxin

- Bt toxin protein exists as inactive protoxins in the bacterium → does not kill *Bacillus*.
- Once an insect ingests the inactive toxin, it is converted into an active form of toxin due to the alkaline pH of the gut which solubilises the crystals.
- Activated toxin binds to the surface of **midgut epithelial cells** & creates **pores** → cell swelling & **lysis** → **death of the insect**.
- Specific Bt toxin genes were isolated from *B. thuringiensis* & incorporated into several crop plants such as cotton. Choice of genes depends upon crop & targeted pest, as most Bt toxins are **insect-group specific**.
- Toxin is coded by a gene named *cry*. There are a number of them.

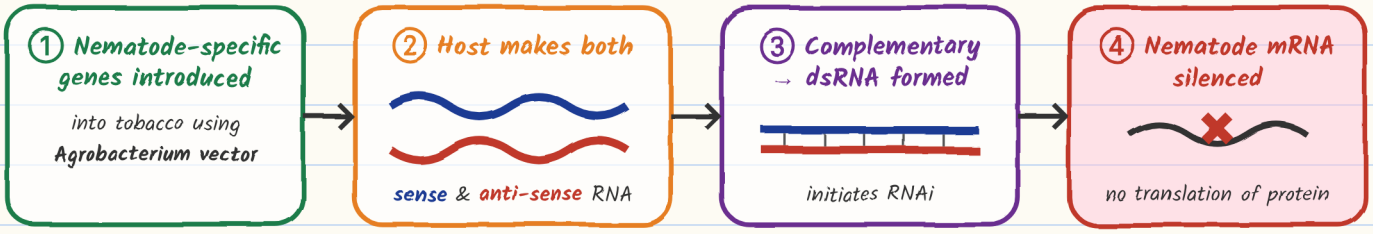
| Gene | Controls |
|---|---|
| ***cryIAc* & *cryIIAb*** | Cotton bollworms (कपास के मुकुल कृमि) |
| ***cryIAb*** | Corn borer (मक्का छेदक) |

📌 **Trick:** "**Ac** & **IIAb** → **Cotton**" (two genes for cotton) · "**IAb** alone → **Corn**". Gene names are written in *italics*; protein names (Cry) are not.

## 3. Pest Resistant Plants – RNA Interference / आरएनए अंतरक्षेप

- Several **nematodes** parasitise a wide variety of plants & animals including humans.
- A nematode *Meloidegyne incognitia* infects the **roots of tobacco plants** → great reduction in yield.
- A novel strategy based on *RNA interference (RNAi)* was adopted to prevent this infestation.
- **RNAi** takes place in **all eukaryotic organisms** as a method of **cellular defence**. Involves **silencing of a specific mRNA** due to a complementary **dsRNA** molecule that binds to & prevents translation of the mRNA (**silencing**).
- Source of this complementary RNA could be from an infection by **viruses having RNA genomes** or **mobile genetic elements (transposons)** that replicate via an RNA intermediate.

**RNAi – making tobacco resistant to nematode · आरएनए अंतरक्षेप**




**Result: parasite (Meloidegyne incognitia) cannot survive**
in transgenic host → tobacco protected from root infestation
परजीवी ट्रांसजेनिक पौधे में जीवित नहीं रह पाता

*Infographic: RNA interference for nematode resistance*

- Using ***Agrobacterium* vectors**, **nematode-specific genes** were introduced into the host plant.
- Introduction of DNA was such that it produced both **sense & anti-sense RNA** in host cells.
- These two RNAs, being complementary to each other, formed a **double-stranded RNA (dsRNA)** that initiated RNAi → **silenced the specific mRNA of the nematode**.
- Consequence: parasite **could not survive** in a transgenic host expressing specific interfering RNA → transgenic plant got itself protected from the parasite.

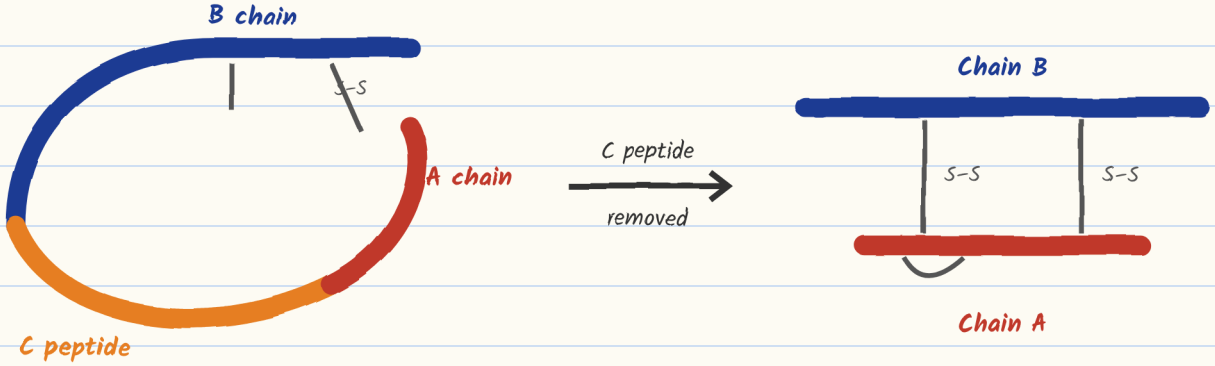
# 4. Biotechnological Applications in Medicine / औषधि में उपयोग

- rDNA technological processes have made immense impact in health care by enabling **mass production of safe & more effective therapeutic drugs**.
- Recombinant therapeutics **do not induce unwanted immunological responses** as is common with similar products isolated from non-human sources.
- At present, about 30 recombinant therapeutics have been approved for human use the world over. In India, 12 of these are presently being marketed.

## Genetically engineered insulin आनुवंशिकतः निर्मित इंसुलिन

- Management of **adult-onset diabetes** is possible by taking insulin at regular time intervals.
- Earlier, insulin used for diabetes was extracted from **pancreas of slaughtered cattle & pigs**. Insulin from an animal source caused some patients to develop **allergy** or other types of reactions to the foreign protein.
- Now possible to produce **human insulin using bacteria**.

### Maturation of pro-insulin into insulin · प्राक्-इंसुलिन से इंसुलिन




Pro-insulin (prohormone) — Mature insulin (A + B by disulphide bridges)

Infographic: Insulin structure & maturation · इंसुलिन की संरचना

- Insulin consists of **two short polypeptide chains: chain A & chain B**, linked together by disulphide bridges.
- In mammals, including humans, insulin is synthesised as a **prohormone** (like a pro-enzyme) which needs to be processed before it becomes fully mature & functional hormone.
- The prohormone (**pro-insulin**) contains an extra stretch called the C peptide. This C peptide is **not present in mature insulin** & is removed during maturation into insulin.
- Main challenge for production of insulin using rDNA techniques was **getting insulin assembled into a mature form**.

**1983 – Eli Lilly** (American company) →

Prepared **two DNA sequences** for A & B chains of human insulin →

Introduced into **plasmids of E. coli** → Chains A & B produced **separately**, extracted →

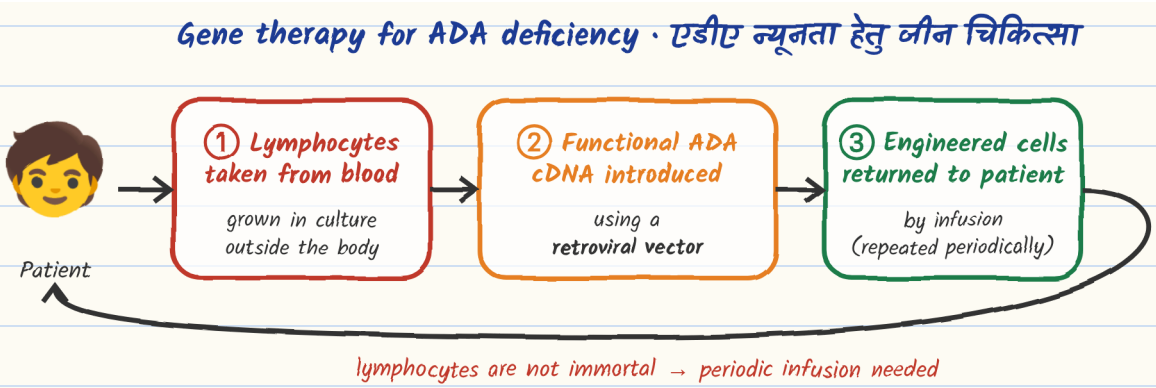
Combined by creating **disulphide bonds** → **Human insulin** (Humulin)

📌 **Exam Tip:** Recombinant human insulin is called **Humulin**. Advantage – identical to human insulin → **no allergy**; produced in large quantities; animal slaughter not needed.

## 5. Gene Therapy / जीन चिकित्सा

- **Gene therapy** = collection of methods that allows **correction of a gene defect** that has been diagnosed in a child/embryo.
- Genes are inserted into a person's cells & tissues to treat a disease. Correction of a genetic defect involves **delivery of a normal gene** into the individual or embryo to take over the function of & compensate for the non-functional gene.
- First clinical gene therapy was given in 1990 to a **4-year-old girl** with adenosine deaminase (ADA) deficiency.
- **ADA enzyme** is crucial for the **immune system** to function. The disorder is caused due to **deletion of the gene for ADA**.

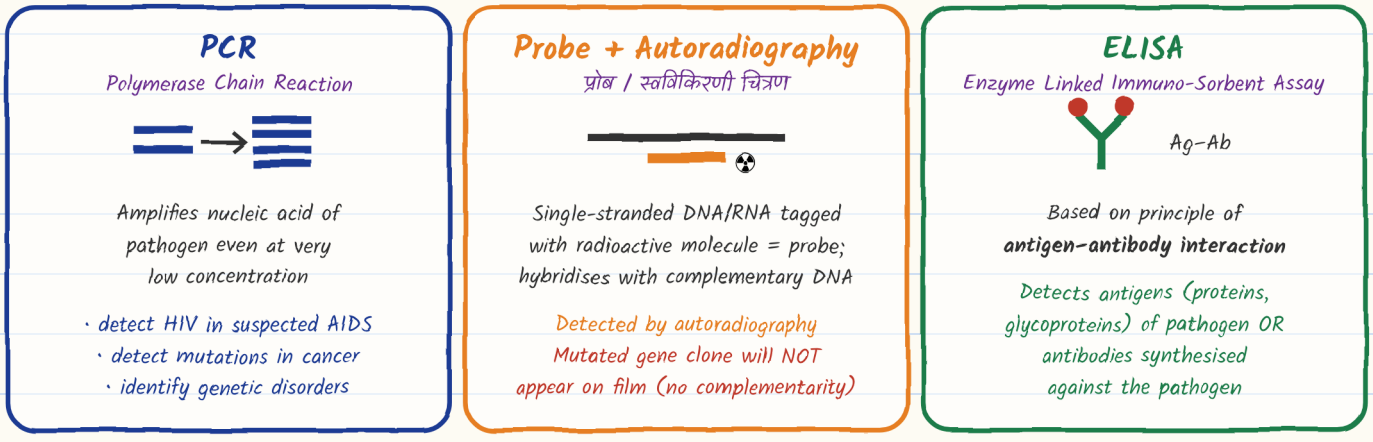
| Treatment for ADA deficiency | Limitation |
|---|---|
| **Bone marrow transplantation** | — |
| **Enzyme replacement therapy** – functional ADA given to patient by injection | Not completely curative |
| **Gene therapy** (lymphocytes) | Cells not immortal → **periodic infusion** needed |
| Gene introduced into cells at **early embryonic stage** | Could be a permanent cure |




Infographic: Steps of gene therapy for ADA deficiency

## 6. Molecular Diagnosis / आणविक निदान

- For effective treatment of a disease, **early diagnosis** & understanding its pathophysiology is very important.
- Using conventional methods of diagnosis (**serum & urine analysis**, etc.) early detection is not possible.
- Techniques serving purpose of early diagnosis: Recombinant DNA technology, PCR & ELISA.
- Presence of a pathogen (bacteria, viruses) is normally suspected only when the pathogen has produced a disease symptom. By this time, concentration of pathogen is already **very high** in the body.



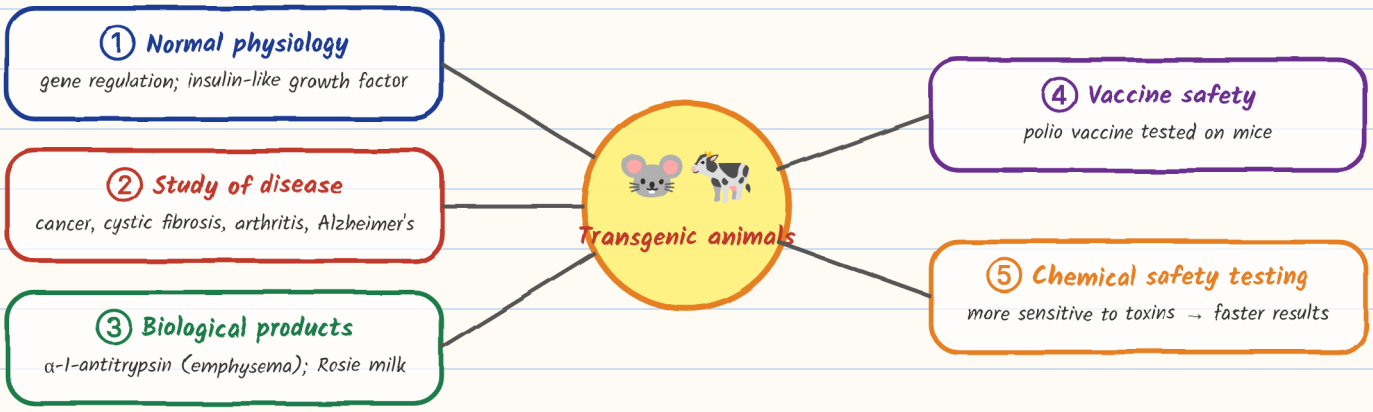

Infographic: Tools of molecular diagnosis · आणविक निदान के साधन

- **PCR**: very low concentration of bacteria or virus (at a time when symptoms of disease are not yet visible) can be detected by **amplification of their nucleic acid**. PCR is now routinely used to detect HIV in suspected AIDS patients, to detect **mutations in genes** in suspected **cancer** patients, & to identify many other **genetic disorders**.
- **Probe**: a single-stranded DNA or RNA, tagged with a **radioactive molecule**, is allowed to hybridise to its complementary DNA in a clone of cells, followed by detection using autoradiography. The clone having the **mutated gene will not appear** on the photographic film, because the probe will not have complementarity with the mutated gene.

- **ELISA**: based on principle of antigen–antibody interaction. Infection by pathogen can be detected by presence of antigens (proteins, glycoproteins, etc.) or by detecting antibodies synthesised against the pathogen.

## 7. Transgenic Animals / पारजीवी जंतु

- Animals that have had their DNA manipulated to possess & express an **extra (foreign) gene** = transgenic animals.
- Transgenic rats, rabbits, pigs, sheep, cows & fish have been produced, although over 95% of all existing transgenic animals are mice.




Infographic: Benefits of transgenic animals · पारजीवी जंतुओं के लाभ

| Use | Details |
|---|---|
| ① **Normal physiology & development** | Designed to study how genes are regulated & how they affect normal functions of body & its development, e.g. study of complex factors involved in growth such as **insulin-like growth factor**. By introducing genes from other species that alter formation of this factor & studying biological effects → information about biological role of the factor in the body. |
| ② **Study of disease** | Designed to increase our understanding of how genes contribute to development of disease. Serve as **models for human diseases** → investigation of new treatments. Transgenic models exist for **cancer, cystic fibrosis, rheumatoid arthritis & Alzheimer's**. |
| ③ **Biological products** | Medicines required to treat certain human diseases can contain biological products, often expensive to make. Transgenic animals that produce useful biological products can be created by introduction of portion of DNA (genes) which codes for a particular product, e.g. human protein α-1-antitrypsin used to treat **emphysema**. Similar attempts for treatment of **phenylketonuria (PKU) & cystic fibrosis**. |
| ④ **Vaccine safety** | Transgenic mice are being developed for use in testing the safety of vaccines before they are used on humans. **Polio vaccine** tested on mice. If successful, could replace use of monkeys to test safety of batches of vaccine. |
| ⑤ **Chemical safety testing** | Known as **toxicity/safety testing**. Same procedure as drug toxicity testing. Transgenic animals made that carry genes which make them **more sensitive to toxic substances** than non-transgenic animals → results obtained in less time. |

📌 **Rosie – the first transgenic cow (1997):** Produced **human protein-enriched milk** (2.4 grams per litre). The milk contained the human alpha-lactalbumin & was nutritionally a more balanced product for human babies than natural cow milk.

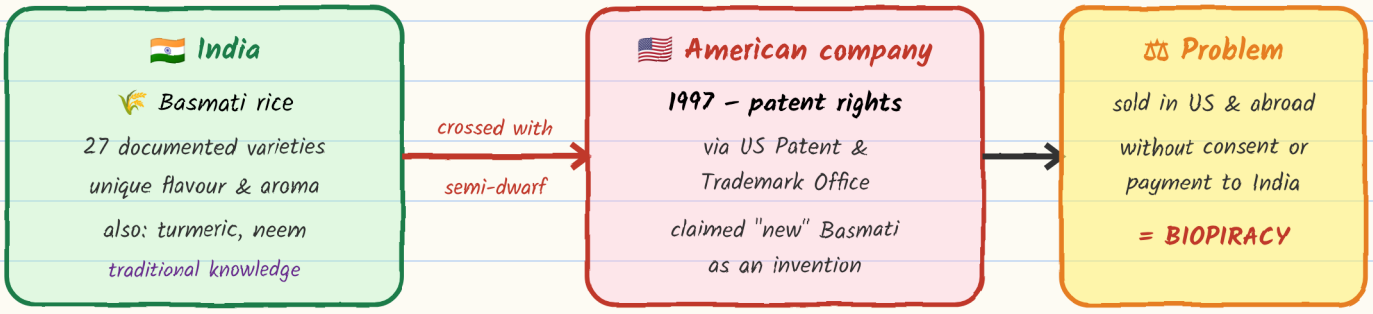
## 8. Ethical Issues / नैतिक मुद्दे

- Manipulation of living organisms by humans cannot go on any further without regulation. Some **ethical standards** are required to evaluate morality of all human activities that might help or harm living organisms.
- Genetic modification of organisms can have **unpredictable results** when such organisms are introduced into the ecosystem.
- Indian Government has set up organisations such as GEAC (Genetic Engineering Approval Committee) (आनुवंशिक इंजीनियरी अनुमोदन समिति), which will make decisions regarding the **validity of GM research** & the **safety of introducing GM-organisms** for public services.

- Modification/usage of living organisms for public services (as food & medicine sources) has also created problems with **patents** granted for the same.

## Biopiracy बायोपाइरेसी (जैव दस्युता)

> **Biopiracy** = term used to refer to the use of **bio-resources** by multinational companies & other organisations **without proper authorisation** from the countries & people concerned, **without compensatory payment**.




Infographic: Basmati rice – a case of biopiracy

- There are an estimated **2,00,000 varieties of rice** in India alone. **Basmati rice** is distinct for its unique aroma & flavour; **27 documented varieties** of Basmati are grown in India.
- In 1997, an **American company got patent rights on Basmati rice** through the US Patent & Trademark Office. This allowed the company to sell a 'new' variety of Basmati in the US & abroad.
- This 'new' variety had actually been derived from Indian farmers' varieties. Indian Basmati was crossed with **semi-dwarf varieties** & claimed as an invention or a novelty.
- Other people selling Basmati rice could be restricted by the patent. Several attempts have also been made to patent uses, products & processes based on Indian traditional herbal medicines, e.g. **turmeric, neem**.
- Industrialised nations are rich financially but **poor in biodiversity & traditional knowledge**. In contrast, developing & underdeveloped world is **rich in biodiversity & traditional knowledge** related to bio-resources.
- Traditional knowledge related to bio-resources can be exploited to develop modern applications & save time, effort & expenditure during commercialisation.
- There is a growing realisation of injustice, inadequate compensation & benefit sharing between developed & developing countries → some nations are developing **laws to prevent unauthorised exploitation** of their bio-resources & traditional knowledge.
- The **Indian Parliament** has recently cleared the second amendment of the Indian Patents Bill, which takes such issues into consideration, including patent terms, emergency provisions & research and development initiative.

## ⚡ Quick Revision / त्वरित पुनरावृत्ति

| Keyword | Remember |
|---|---|
| GMO | Organism with genes altered by manipulation |
| Golden rice | Vitamin A enriched |
| Bt | *Bacillus thuringiensis*; protoxin activated at alkaline gut pH |
| cryIAc, cryIIAb / cryIAb | Cotton bollworm / corn borer |
| *Meloidegyne incognitia* | Nematode infecting tobacco roots |
| RNAi | dsRNA silences specific mRNA; cellular defence in eukaryotes |
| Insulin | Chains A & B + disulphide bonds; C peptide removed |
| Eli Lilly (1983) | Recombinant human insulin in *E. coli* (Humulin) |
| First gene therapy (1990) | 4-year-old girl, ADA deficiency; retroviral vector |
| Recombinant therapeutics | ~30 approved worldwide; 12 in India |
| PCR / probe / ELISA | Nucleic acid amplification / autoradiography / Ag–Ab |
| Transgenic animals | > 95% are mice |
| Rosie (1997) | Transgenic cow; human α-lactalbumin; 2.4 g/L |
| α-1-antitrypsin | Treats emphysema |
| GEAC | Validity of GM research & safety of GMOs |
| Biopiracy | Basmati (1997), turmeric, neem |

## ⭐ Exam Corner / परीक्षा उपयोगी प्रश्न

### 1-Mark Questions (1M)

**Q1. Name the nematode that infects tobacco roots. / तंबाकू की जड़ों को संक्रमित करने वाला सूत्रकृमि?**

→ *Meloidegyne incognitia*.

**Q2. Which genes control cotton bollworms?**

→ cryIAc and cryIIAb.

**Q3. What is the full form of GEAC?**

→ Genetic Engineering Approval Committee.

**Q4. Name the enzyme deficient in the first patient of gene therapy.**

→ Adenosine deaminase (ADA).

**Q5. What is golden rice?**

→ Genetically modified rice enriched with vitamin A.

**Q6. Which peptide is removed from pro-insulin during maturation?**

→ C peptide.

**Q7. What percentage of transgenic animals are mice?**

→ Over 95%.

**Q8. Name the human protein produced in the milk of Rosie.**

→ Human alpha-lactalbumin.

## 2/3-Mark Questions 2-3M

**Q9. Why does the Bt toxin not kill the Bacillus that produces it?**

→ It exists as inactive protoxin; activated only in alkaline pH of insect gut.

**Q10. Explain how Bt toxin kills insects.**

→ Ingested protoxin → alkaline gut solubilises crystals → active toxin binds midgut epithelial cells → pores → swelling, lysis → death.

**Q11. List any four advantages of GM crops.**

→ Abiotic stress tolerance, less pesticides, reduced post-harvest losses, efficient mineral use, enhanced nutrition (golden rice).

**Q12. What is RNAi? What is the source of complementary RNA?**

→ Silencing of specific mRNA by complementary dsRNA; RNA viruses or transposons (RNA intermediate).

**Q13. Why is insulin from animal sources not preferred?**

→ Causes allergy/immune reactions to foreign protein in some patients.

**Q14. How is PCR useful in early diagnosis?**

→ Amplifies nucleic acid of pathogen at very low concentration before symptoms; used for HIV, cancer mutations, genetic disorders.

**Q15. What is biopiracy? Give an example.**

→ Use of bio-resources without authorisation & compensation; Basmati rice patent (1997), turmeric, neem.

**Q16. Why is gene therapy for ADA not a permanent cure? How can it be made permanent?**

→ Engineered lymphocytes not immortal → periodic infusion; introduce gene into early embryonic cells for permanent cure.

## 5-Mark Questions SM ★★★

**Q17. Explain how RNA interference has been used to make tobacco plants resistant to nematodes.**

→ *Meloidegyne; Agrobacterium vector; sense & anti-sense RNA → dsRNA → RNAi silences nematode mRNA → parasite dies.*

**Q18. Describe the structure of insulin and how Eli Lilly produced human insulin using rDNA technology.**

→ *Chains A & B, disulphide bonds, pro-insulin & C peptide; 1983, two DNA sequences into E. coli plasmids, separate chains combined.*

**Q19. What are transgenic animals? Explain five ways in which they are useful.**

→ *Definition; physiology, disease models, biological products (α-1-antitrypsin, Rosie), vaccine safety, chemical safety testing.*

**Q20. Describe gene therapy with reference to ADA deficiency.**

→ *Definition; 1990, 4-year-old girl; ADA role; bone marrow transplant, enzyme replacement; lymphocytes + retroviral vector + ADA cDNA; periodic infusion.*

🎯 **Last-minute tips:** Write gene names in *italics* (*cryIAc*) · Always link Bt toxin with "**inactive protoxin + alkaline pH**" · In RNAi answers use keywords: **sense, anti-sense, dsRNA, silencing** · Remember dates: **1983 (insulin), 1990 (gene therapy), 1997 (Rosie, Basmati patent)**.

~ All the best! / शुभकामनाएँ! ~