Chapter 10: Biotechnology and Its Applications

Comprehensive Study Notes

Class 12 Biology - NCERT Based

EXAM SPRINT - Complete Coverage for NEET and Board Examinations

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Introduction

Biotechnology: Industrial scale production of biopharmaceuticals and biologicals using genetically modified microbes, fungi, plants and animals.

Applications of Biotechnology:

- Therapeutics
- Diagnostics
- Genetically modified crops for agriculture
- Processed food
- Bioremediation
- Waste treatment
- Energy production

Three Critical Research Areas:

1. **Best Catalyst**: Improved organism (microbe) or pure enzyme
2. **Optimal Conditions**: Engineering for catalyst to act
3. **Downstream Processing**: Technologies to purify protein/organic compound

10.1 BIOTECHNOLOGICAL APPLICATIONS IN AGRICULTURE

Three Options for Increasing Food Production:

1. **Agro-chemical based agriculture**
2. **Organic agriculture**
3. **Genetically engineered crop-based agriculture**

Historical Context:

- Green Revolution: Tripled food supply but insufficient for growing population
- Increased yields due to:
  - Improved crop varieties
  - Better management practices
  - Use of agrochemicals (fertilizers and pesticides)
- **Problem**: Agrochemicals too expensive for developing world farmers

10.1.1 Tissue Culture Technology

Definition: Whole plants regenerated from explants (any plant part) grown in test tube under sterile conditions in special nutrient media.

Key Concepts:

- **Totipotency**: Capacity to generate whole plant from any cell/explant
- **Micro-propagation**: Production of thousands of plants through tissue culture
- **Somaclones**: Plants genetically identical to original plant

Nutrient Medium Requirements:

- Carbon source (sucrose)
- Inorganic salts
- Vitamins
- Amino acids
- Growth regulators (auxins, cytokinins)

Commercial Applications:

- Tomato, banana, apple production
- **Disease Recovery**: Virus-free plants from diseased plants using meristem culture
- Meristem (apical and axillary) is virus-free even in infected plants

10.1.2 Somatic Hybridization

Process:

1. Isolate single cells from plants
2. Digest cell walls to obtain protoplasts (naked, surrounded by plasma membrane)
3. Fuse protoplasts from two different varieties
4. Grow hybrid protoplasts to form new plant

Example: Pomato (tomato + potato protoplast fusion)

- **Result**: Not commercially successful due to undesired characteristics

10.1.3 Genetically Modified Organisms (GMO)

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

Benefits of GM Plants:

1. **Abiotic Stress Tolerance**: Cold, drought, salt, heat resistance

2. **Reduced Chemical Pesticide Reliance**: Pest-resistant crops
3. **Reduced Post-harvest Losses**
4. **Increased Mineral Usage Efficiency**: Prevents soil fertility exhaustion
5. **Enhanced Nutritional Value**: Golden rice (Vitamin A enriched)
6. **Industrial Applications**: Tailor-made plants for starches, fuels, pharmaceuticals

10.1.4 Bt Cotton (Pest Resistant Plants)

Bt Toxin Source: *Bacillus thuringiensis* bacteria

Mechanism:

1. Bt bacteria produces protein crystals during growth phase
2. Crystals contain toxic insecticidal protein
3. **In Bacillus**: Toxin exists as inactive protoxin
4. **In Insect**: Alkaline gut pH solubilizes crystals → active toxin
5. Active toxin binds to midgut epithelial cells
6. Creates pores → cell swelling and lysis → insect death

Target Insects:

- **Lepidopterans**: Tobacco budworm, armyworm
- **Coleopterans**: Beetles
- **Dipterans**: Flies, mosquitoes

Specific Bt Genes:

- **cryIAc and cryIIAb**: Control cotton bollworms
- **cryIAb**: Controls corn borer

- Gene choice depends on crop and targeted pest

Bt Crops: Cotton, corn, rice, tomato, potato, soybean

10.1.5 RNAi Technology (RNA Interference)

Target Problem: Nematode *Meloidegyne incognitia* infects tobacco plant roots

RNAi Process:

1. Natural cellular defense mechanism in eukaryotes
2. **Mechanism**: Complementary dsRNA binds to specific mRNA
3. **Result**: Prevents mRNA translation (gene silencing)

Application Strategy:

1. Use Agrobacterium vectors
2. Introduce nematode-specific genes into host plant
3. DNA produces both sense and anti-sense RNA
4. Complementary RNAs form double-stranded RNA (dsRNA)
5. dsRNA initiates RNAi → silences nematode mRNA
6. **Result**: Parasite cannot survive in transgenic host

10.2 BIOTECHNOLOGICAL APPLICATIONS IN MEDICINE

Impact of Recombinant DNA Technology:

- Mass production of safe and effective therapeutic drugs
- **Advantage**: No unwanted immunological responses (identical to human proteins)
- **Global Status**: ~30 recombinant therapeutics approved worldwide

- **India Status**: 12 recombinant therapeutics marketed

10.2.1 Genetically Engineered Insulin

Historical Problem:

- Insulin extracted from cattle and pig pancreas
- **Issues**: Allergic reactions to foreign protein

Insulin Structure:

- Two short polypeptide chains: A and B
- Linked by disulfide bridges
- **In mammals**: Synthesized as pro-hormone with C-peptide
- C-peptide removed during maturation

rDNA Production Method (1983 - Eli Lilly):

1. Prepare two DNA sequences for A and B chains
2. Introduce sequences in E. coli plasmids
3. Produce chains A and B separately
4. Extract and combine chains using disulfide bonds
5. **Result**: Functional human insulin

Oral Administration: Not possible - insulin is protein, gets digested by proteases

10.2.2 Gene Therapy

Definition: Collection of methods for correcting gene defects; involves inserting genes into person's cells and tissues to treat disease.

Principle: Deliver normal gene to compensate for non-functional gene

First Clinical Gene Therapy (1990):

Patient: 4-year-old girl with Adenosine Deaminase (ADA) deficiency

ADA Deficiency:

- **Cause**: Deletion of ADA gene
- **Effect**: Immune system dysfunction
- **Enzyme Role**: Crucial for immune system function

Treatment Approaches:

1. **Bone Marrow Transplantation**: Limited success
2. **Enzyme Replacement Therapy**: Inject functional ADA - not completely curative
3. **Gene Therapy Approach**:
   - Extract patient's lymphocytes
   - Grow in culture outside body
   - Introduce functional ADA cDNA using retroviral vector
   - Return genetically engineered lymphocytes to patient
   - **Limitation**: Requires periodic infusion (cells not immortal)

Permanent Cure Strategy: Introduce ADA gene into bone marrow cells at early embryonic stages

10.2.3 Molecular Diagnosis

Importance: Early diagnosis crucial for effective treatment

Conventional Methods Limitation: Early detection not possible with serum and urine analysis

Modern Techniques:

1. Polymerase Chain Reaction (PCR)

- **Application**: Detect very low concentrations of pathogens
- **Principle**: Amplify nucleic acid of pathogen
- **Usage**:
  - HIV detection in suspected AIDS patients
  - Detect mutations in suspected cancer patients
  - Identify genetic disorders

2. Probe Hybridization

- **Method**: Single-stranded DNA/RNA tagged with radioactive molecule
- **Process**: Probe hybridizes to complementary DNA in cell clone
- **Detection**: Autoradiography
- **Result**: Clone with mutated gene won't appear on photographic film

3. ELISA (Enzyme Linked Immunosorbent Assay)

- **Principle**: Antigen-antibody interaction
- **Detection Methods**:
  - Detect pathogen antigens (proteins, glycoproteins)
  - Detect antibodies synthesized against pathogen

10.3 TRANSGENIC ANIMALS

Definition: Animals with manipulated DNA to possess and express extra (foreign) gene

Statistics: Over 95% of transgenic animals are mice

Purposes of Transgenic Animals:

1. Normal Physiology and Development Study

- **Purpose**: Study gene regulation and effects on body functions
- **Example**: Insulin-like growth factor studies
- **Method**: Introduce genes from other species that alter factor formation

2. Disease Study

- **Purpose**: Understand gene contribution to disease development
- **Application**: Models for human diseases
- **Examples**: Cancer, cystic fibrosis, rheumatoid arthritis, Alzheimer's

3. Biological Products

- **Purpose**: Produce medicines for human diseases
- **Advantage**: Cost-effective production of expensive biological products
- **Examples**:
  - α-1-antitrypsin for emphysema treatment
  - Treatments for phenylketonuria (PKU) and cystic fibrosis
- **Success Story**: Transgenic cow "Rosie" (1997)
  - Produced human protein-enriched milk (2.4 g/L)
  - Contained human alpha-lactalbumin
  - More nutritionally balanced for human babies

4. Vaccine Safety Testing

- **Application**: Test vaccine safety before human use

- **Example**: Transgenic mice for polio vaccine safety testing
- **Advantage**: Could replace monkey testing for vaccine batches

5. Chemical Safety Testing (Toxicity Testing)

- **Process**: Create animals more sensitive to toxic substances
- **Method**: Introduce genes making animals more sensitive than normal
- **Advantage**: Faster results for toxicity studies

10.4 ETHICAL ISSUES

Regulatory Framework:

GEAC (Genetic Engineering Approval Committee):

- Evaluates validity of GM research
- Ensures safety of GM organisms for public services
- Makes decisions on introducing GM organisms

Key Ethical Concerns:

1. Unpredictable Environmental Effects

- Genetic modification can have unforeseen consequences
- Risk when GM organisms introduced into ecosystem
- Need for careful evaluation before release

2. Patent Issues and Biopiracy

Biopiracy Definition: Use of bio-resources by multinational companies without proper authorization and compensatory payment

Global Disparity:

- **Industrialized Nations**: Rich financially, poor in biodiversity
- **Developing Nations**: Rich in biodiversity and traditional knowledge

Case Study - Basmati Rice Patent (1997):

- **Background**: 200,000 rice varieties in India; 27 documented Basmati varieties
- **Issue**: US company got patent rights on Basmati rice
- **Problem**: "New" variety derived from Indian farmer's varieties
- **Impact**: Could restrict other Basmati rice sellers

Other Examples:

- Patent attempts on turmeric and neem uses
- Based on Indian traditional herbal medicine knowledge

3. Legal Responses:

- **Indian Patent Bill**: Second amendment to address bio-resource exploitation
- **International Awareness**: Growing realization of inadequate compensation
- **National Laws**: Countries developing laws to prevent unauthorized exploitation

Benefits vs Risks Balance:

- **Benefits**: Medical advances, agricultural improvements, industrial applications
- **Risks**: Environmental impact, ethical concerns, economic exploitation
- **Need**: Proper regulation and international cooperation

NEET-Specific Important Points

High-Yield Topics:

1. **Bt Cotton mechanism** - Detailed understanding of toxin activation
2. **Insulin production** - rDNA technology application
3. **Gene therapy** - ADA deficiency case study
4. **RNAi technology** - Mechanism and applications
5. **Transgenic animals** - Purposes and examples
6. **Molecular diagnosis** - PCR, ELISA principles
7. **Ethical issues** - Biopiracy and patent problems

Common NEET Question Patterns:

1. Mechanism-based Questions:

- How Bt toxin works in insects but not bacteria
- RNAi process steps
- PCR amplification principle

2. Application Questions:

- Uses of transgenic animals
- Gene therapy applications
- Biotechnology in agriculture

3. Comparative Questions:

- Traditional vs modern diagnosis methods
- Different types of transgenic organisms

- Ethical vs scientific considerations

Memory Aids and Mnemonics

Bt Toxin Mechanism:

"PIGAS" - Protoxin → Insect gut → Alkaline pH → Gene silencing

Three Critical Research Areas:

"COD" - Catalyst, Optimal conditions, Downstream processing

Transgenic Animal Uses:

"PDVCS" - Physiology, Disease study, Vaccine safety, Chemical testing, biological productS

Gene Therapy Steps:

"EICR" - Extract, Introduce, Culture, Return

Practice Questions for NEET

Multiple Choice Questions:

1. **Bt toxin is not toxic to Bacillus because:** a) Bacteria are resistant to toxin b) Toxin is immature c) Toxin is inactive d) Bacteria enclose toxin in special sac
2. **First clinical gene therapy was given for:** a) Cystic fibrosis b) ADA deficiency c) Hemophilia d) Sickle cell anemia
3. **Golden rice is enriched with:** a) Protein b) Vitamin A c) Iron d) Vitamin C

Short Answer Questions:

1. What is totipotency? Give its application.
2. Distinguish between somaclones and somatic hybrids.
3. Why is insulin not given orally to diabetic patients?

Long Answer Questions:

1. Describe the mechanism of Bt toxin action in detail.
2. Explain the process of producing genetically engineered insulin.
3. Discuss the applications of transgenic animals with examples.

Summary Tables

Biotechnology Applications Comparison:

Field	Technology	Example	Benefit
Agriculture	Bt crops	Cotton, corn	Pest resistance
Agriculture	Golden rice	Vitamin A rice	Nutrition enhancement
Medicine	rDNA insulin	Human insulin	No immune response
Medicine	Gene therapy	ADA treatment	Genetic disorder cure
Medicine	PCR diagnosis	HIV detection	Early detection

Transgenic Organisms Classification:

Type	Purpose	Example	Application
Plants	Pest resistance	Bt cotton	Agriculture
Animals	Disease models	Transgenic mice	Medical research

Type	Purpose	Example	Application
Animals	Product synthesis	Rosie cow	Pharmaceutical production
Microbes	Protein production	E. coli insulin	Medicine manufacturing

Ethical Issues Framework:

Issue	Concern	Example	Solution Approach
Environmental	Ecosystem disruption	GM crop release	GEAC regulation
Economic	Biopiracy	Basmati patent	Patent law amendments
Social	Benefit sharing	Traditional knowledge	International cooperation

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EXAM SPRINT - Master biotechnology applications with focus on mechanisms, ethical considerations, and real-world examples. Practice application-based questions for NEET success!