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Distance Learning Programme

UPSC Prelims

Science & Technology

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SCIENCE & TECHNOLOGY

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CHAPTER 5

BIOTECHNOLOGY

Convention on Biological Diversity (CBD) defines biotechnology as: "Any technological application that uses biological systems, living organisms, or derivatives thereof, to make or modify products or processes for specific use."

Branches of Biotechnology

Green/ Agricultural Biotechnology

Green Biotechnology is the application of biotechnology for preparation of Transgenic or Genetically Modified plants and animals as an alternative to traditional agriculture to produce environmentally friendly farming solutions.

Genetically Modified Organisms (GMO)

Genetically Modified Organisms are the organisms whose genes have been altered by using methods, other than natural methods, generally using techniques such as recombinant DNA technology. They include plants, bacteria, fungi and animals. As a result, their DNA contains one or more genes which are not normally found in their DNA.

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Bt Toxin

The Bt toxin is produced by Bacillus thuringiensis (or BT), a soil-dwelling bacterium which has been extensively used in modifying a variety of crops as it is a biological pesticide. Bt toxin gene has been cloned from the bacteria and has been expressed in plants to provide resistance against pest and insects, thus eliminating the need for chemical pesticides.

Genetically Modified Crops

- **Bt Cotton:**
  - Some strains of Bacillus thuringiensis produce proteins that kill certain insects such as tobacco budworm, armyworm, beetles, flies, and mosquitoes. Bt forms protein crystals during a particular phase of their growth. These crystals contain a toxic insecticidal protein. This toxin does not kill the Bacillus because the Bt toxin protein exists as inactive protoxins but 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 solubilise the crystals.
  - It eventually causes death of the insect. The toxin is coded by a gene named cry gene. The foreign gene Cry1Ac is incorporated in the cotton crop to make it pest resistant.
  - Cotton is a crop of significant economic importance in India, but damage by insect and pests reduces its yields by 50%. Bt Cotton is the first and the only transgenic crop approved by the Genetic Engineering Approval Committee (GEAC) for commercial cultivation in India.
- **Limitation:** Bt cotton has been shown to be effective against the tobacco budworm and the pink bollworm, but less effective in controlling cotton bollworms. There are

also other cotton insect pests for which Bt cotton offers no control. These secondary pests can cause significant crop damage. This is why farmers growing Bt cotton continue to use pesticides against bollworms and other pests. Also Bt gene does not provide permanent solution against its target. In America and other places, growing resistance against Bt cotton in bollworm has been noticed, destroying cotton crops again.

- **Bt Brinjal:**
  - Bt Brinjal is a transgenic brinjal created by inserting a gene cry1Ac from the soil bacterium Bacillus thuringiensis into Brinjal. This is said to give the Brinjal plant resistance against insects like the shoot borer and fruit borer.
  - Bt Brinjal is the first Genetically Modified food crop in India. It is developed by Maharashtra Hybrid Seed Company Ltd. (Mahyco), a leading Indian seed company.
  - Bt Brinjal has generated much debate in India. The promoters say that Bt Brinjal will be beneficial to small farmers because it is insect resistant, increases yields, is more cost-effective and will have minimal environmental impact. The Cry1Ac endo-toxin is a protein which breaks down when cooked. It is active only in an alkaline medium and since humans consume brinjal only when cooked it will not interfere with digestion. Additionally, as the stomach is acidic the digestive process will not be affected by the introduction of the Cry1Ac toxin.
  - While the Genetic Engineering Appraisal Committee (GEAC) cleared the Bt Brinjal for commercial cultivation, the Ministry of Environment, Forest and Climate Change has put a moratorium on its release, waiting for more public consultations across the country.
- **Limitation:** On the other hand, concerns about Bt Brinjal relate to its possible adverse impact on human health and bio-safety, livelihoods and biodiversity. The transgene transfer to local and hybrid varieties of brinjal through cross pollination is likely to adversely impact the Indegenousness of Indian brinjal.

Golden Rice

Golden Rice is genetically engineered rice made by splicing a gene from the daffodil plant and a bacterium which is expected to produce beta-carotene, a rich source of provitamin A. When ingested, provitamin A is converted to Vitamin A. A campaign has been launched in India to allow golden rice for tackling Vitamin A deficiency in children. Since Golden Rice is also a genetically modified crop, there exists a threat of contamination of other rice varieties. The Genetic Engineering Approval Committee (GEAC) in 2014 gave the green signal for field trials of genetically modified (GM) rice.

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Biosafety

Bio-related research activities may involve manipulation of microbial, animal or plant cells. The risks associated with these activities arise from the samples and / or the procedural requirements. Adherence to standard microbiological techniques and using facilities suitable to the risk level of the pathogen helps to protect both personnel involved and environment from laboratory-acquired infections.

The risk from the pathogen handled depends on the following factors.

- Capability to cause infection in the host and the severity of the same.
- Preventive measures and treatment available.

- Route of entry
- Infective dose level
- Stability in the environment
- The range of cells/strains that can act as a host.

Containment of Biological Hazards

Physical containment helps to confine the pathogenic organisms being handled and prevent exposure to personnel. The containment facilities become more complex and secure (to cater to the increasing nature of the risks involved in handling pathogens) with rising biosafety levels which are determined depending upon the nature of biohazard.

Recently, some batches of privately manufacture oral polio vaccine were found to be contaminated with polio type-2 virus, which has been eradicated worldwide, including in India. Such hazards may lead to vaccine-derived polio virus (VDPV) which is a rare strain of polio viruses that have genetically mutated from the strain contained in the OPV.

At least 50 cases of UDPV have been found in the last 6 years, according to the Indian Pediatrics journal.

Biosafety Level

It consists of a combination of laboratory practices, equipment and facilities suitable to the procedures being performed and hazards of the pathogen. There are four biosafety levels, which correspond to four risk groups:

(1) Biosafety level I; (2) Biosafety Level II; (3) Biosafety level III; (4) Biosafety level IV

Potential Negative Effects of GMOs

- **On the Environment**
  - **Genetic Pollution:** Genes introduced in GMOs can pass on to other members of the same species and perhaps other species through 'gene escape' thereby leading to their genetic contamination. Genes might interact at gene, cell, plant and ecosystem level. For instance, herbicide resistance into weeds, and the development of "super weeds".
  - **Outcrossing:** It is the migration of genes from GM plants into conventional crops or related species in the wild, as well as the mixing of crops derived from conventional seeds with GM crops. This may have an indirect effect on food safety and food security.
  - **'Sleeper' Genes could be Accidentally Switched on and Active Genes could become 'Silent':** Organisms contain genes that are activated under certain conditions, for example, under attack from pathogens or severe weather. When a new gene is inserted, a "promoter" gene is also inserted to switch it on. This could activate a "sleeper" gene in inappropriate circumstances. Sometimes the expression of genes is even "silenced" as a result of unknown interactions with the inserted gene.
  - **Interaction with Wild and Native Populations:** GMOs could compete or breed with wild species. GM crops could pose a threat to crop biodiversity, especially if grown in areas that are centres of origin of that crop. In addition, GM crops could compete with and substitute traditional farmers' varieties and wild relatives that have been bred, or evolved, to cope with local stresses.
  - **Impact on Birds, Insects and Soil Biota:** Widespread use of GM crops could lead to the development of resistance in biota, insect and bird populations exposed to the GM crops.

- **On Human Health**
  - **Allergenic Genes:** These could be accidentally transferred to other species, causing dangerous reactions in people with allergies.
  - **Food Chain:** Unrecognised and maybe harmful GM products may appear in the food chain.
  - **Antibiotic Resistance:** Genes that confer antibiotic resistance are inserted into GMOs as "markers" to indicate that the process of gene transfer has succeeded. Concerns have been expressed about the possibility that these "marker genes" could confer resistance to antibiotics. This approach is now being replaced with the use of marker genes that avoid medical or environmental hazards.
- **Potential Socio-Economic Effects**
  - **Loss of farmers' access to plant material:** GM crops can be grown only with GM seeds whose monopoly is, with few multi-national companies – creating undue advantage for them at the cost of poor farmers. As opposed to normal crops, whose seeds can be used by the farmers year after year, GM seeds have to be bought for every crop from the market only.

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Terminator Seed

Terminator seed technology is the genetic modification of plants to make them produce sterile seeds. They are also known as suicide seeds. Terminator's official name, used by the UN and scientists is Genetic Use Restriction Technologies (GURTs).

  - **Intellectual property rights could slow down research:** The proprietary nature of biotechnology products and processes may prevent their access for public-sector research. This might have a strong negative impact on developing countries where negligible private research initiatives are in place.

Potential Benefits of GMOs

- **Agricultural Productivity**
  - **Tolerance of crops to abiotic stresses:** If crops can be made more resistant to cold, drought, salt, heat, etc. it would reduce the danger of crop failure and increase production in agriculture. And would be a step towards mitigating risks of increasing global warming. The first transgenic crop with abiotic stress-tolerance was the drought-tolerant maize (Zea mays) developed by Monsanto.

Trait	Advantages	Sample Product
Pest-Resistance	Less damage by insect. virus, bacteria, etc.	Corn
Herbicide-Resistance	Herbicides will kill only weeds, not crops	Cotton
Delayed Ripening	Can be shipped with less damage	Tomato
Miniature Size	Improved quality and taste	Watermelon
Improved Sweetness	Better taste	Sweet peas
Cold-Resistance	Withstand freezing and thawing	Strawberries
High Starch	Absorbs less oil when fried	Potato
Polyester Gene Added	Better tensile properties	Cotton
Growth Hormone Added	Faster Growth	Salmon
Hepatitis B Virus Protection Added	May provide immunity to Hepatitis	Banana

- **Enhanced nutritional value of food:** By inserting genes into crops such as rice and wheat, we can increase their nutritional value, e.g., Golden Rice. Many other similar products aimed at bio-fortification are in the pipeline.

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Bio-fortification

It is the process by which the nutritional quality of food crops is improved through agronomic practices, conventional plant breeding, or modern biotechnology. Biofortification differs from conventional fortification in that biofortification aims to increase nutrient levels in crops during plant growth rather than through manual means during processing of the crops. Biofortification may therefore present a way to reach populations where supplementation and conventional fortification activities may be difficult to implement and/or limited.

- Examples of biofortification projects include:
- Iron-biofortification of rice, beans, sweet potato, cassava and legumes;
- Zinc-biofortification of wheat, rice, beans, sweet potato and maize;
- Provitamin A carotenoid-biofortification of sweet potato, maize and cassava; and
- Amino acid and protein-biofortification of sorghum and cassava.

Zero Hunger Programme

Programme consists of setting up of genetic gardens for biofortified plants/crops that help supplement micro-nutrient deficiencies, including iron, iodine, vitamin A and zinc among others.

The FSSAI has released new standards for the fortification of food. The guidelines are meant to regulate the fortification of food, especially packaged food with essential micronutrients to counter rising malnutrition in the country.

- **More productive farm animals:** Genes might be inserted into cattle to raise their milk yield, fertility, and resistance to disease.

- **Protection of Environment**
  - **More food from less land:** Improved productivity from GMOs might mean that farmers in the future won't have to bring much of marginal land into cultivation. This could assist in food security in current times when the pressure on land usage is increasing.
  - **Reduced reliance on chemical pesticides:** Genetically engineered resistance to pests and diseases in crops could greatly reduce the chemicals needed for crop protection and could also improve the health of farm and industrial workers.
  - **Rehabilitation of damaged or less-fertile land:** Large areas of cropland in the developing world have become saline by unsustainable irrigation practices. Genetic modification could produce salt-tolerant varieties.
  - **Bioremediation:** Rehabilitation of damaged land may also become possible through organisms bred to restore nutrients and soil structure.

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Bioremediation

It is the use of microbes to clean up contamination in the environment, especially soil and groundwater. It uses small organisms like bacteria, that are present naturally in the environment. Bioremediation stimulates the growth of certain microbes that use contaminants as a source of food and energy eventually converting harmful pollutants into simple and harmless substances. Contaminants treated using bioremediation include oil and other petroleum products, solvents, and pesticides.

- **Longer shelf lives:** The genetic modification of fruits and vegetables can make them less likely to get spoiled during storage or on the way to market. This could expand trade opportunities as well as reduce massive wastage incurred during transportation.

Biofuel from Coconut Oil

- Biogas obtained by anaerobic digestion of cattle dung and other loose and leafy organic matters/wastes can be used as an energy source for cooking, lighting and other applications like refrigeration, electricity generation and transport applications.
- Recent experiments have explored the possibility of using a mixture of biofuel derived from coconut oil and diesel for running automobile engines. The advantages of using coconut biofuel were more mileage and less pollution. The emission levels are lower than other forms of biodiesel. It can be used without making modifications to the engine of a diesel vehicle.
- Solidification of coconut oil at temperatures below 24 degrees centigrade, leading to clogging of fuel lines is a major hurdle in making use of coconut oil. The problem could be overcome by blending coconut oil with about 20% diesel. Biodiesel is produced through a process called trans-esterification in which coconut oil is made to react with alcohol, forming an ester-coconut methyl ester or coconut biodiesel. Having the least share of free fatty acids, its physiochemical properties and increased level of saturation due to the high percentage of lauric acid, make coconut oil a possible fuel.
- It has five other by-products including husk, coconut shells, coconut water, cake (that can be used as cattle feed) and glycerol. Each of these has a market value which also makes it viable for commercial supply at present.

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Genetic Use Restriction Technology

- Terminator seeds: Terminator technology is the genetic modification of plants to make them produce sterile seeds. They are also known as suicide seeds.
- Terminator seeds trouble farmers in the developing world because they would no longer be able to save seeds to re-use from one harvest to the next forcing them to buy new seeds before every sowing phase.
- Many poor farmers cannot afford to buy seeds each year. Instead, they save, swap and share seeds that have been developed over generations.
- However, biotech companies argue that Terminator technology will prevent the contamination of non-GM crops with GM-crops. They say that if all GM varieties had the terminator trait they would not be able to spread into the environment, and so biosafety would be ensured.
- However, like any other GM genes, Terminator genes could spread to other crops by cross-fertilisation and by accidental mixing. So the GM Terminator genes would themselves contaminate non GM-crops, meaning that these non-GM crops would produce sterile seeds and would no longer be GM-free.
- It is dangerous to keep in the hands of private companies, such technologies which may affect the future of food security.

GM Crops in India

- India is following a policy of case by case approval of transgenic crops.
  - The GEAC in 2014 gave the green signal for field trials of genetically modified (GM) rice, mustard, cotton, chickpea and brinjal. While the GEAC has approved the commercial release of Bt brinjal it has been stayed by the Ministry of Environment, Forest and Climate Change.

- The only genetically modified crop approved for release in India is Bt cotton.
- So far about 20 GM crops are under trial at various stages. An indefinite moratorium was placed on the commercial release of GM brinjal in 2010-the first GM food crop.
- Attempts to bring GM mustard were rejected by regulators in 2002 after concerns from farmers and consumers.
- The Technical Expert Committee (TEC) constituted by the Supreme Court in 2012 to advise it on issues related to GM crops field trials and bio-safety assessment called for strengthening the existing regulatory system before granting permission for conducting more field trials.

Red/Medical Biotechnology

Red biotechnology refers to the use of biotechnology in the improvement of medical processes and development of pharmaceutical products like antibiotics, vaccines, etc.

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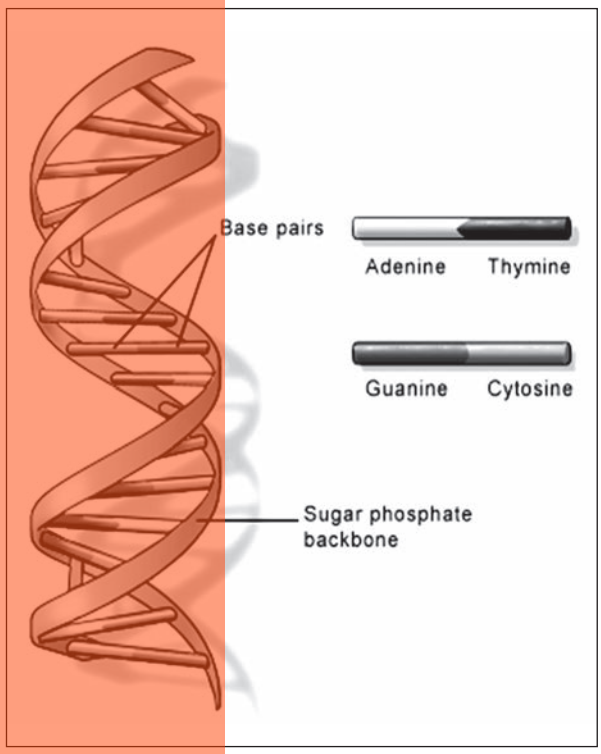
Genetic Material

Genetic material is the medium which is responsible for the transfer of hereditary characteristics from one generation to another. For a molecule to act as a genetic material, it must fulfil the following criteria:

- It should be able to generate its replica (Replication).
- It should be chemically and structurally stable.
- It should provide the scope for slow changes (mutation) that are required for evolution.

Nucleic acids are polynucleotides for which the building block is a nucleotide. A nucleotide has three chemically distinct components. One is a nitrogenous base from among Adenine, Guanine, Thymine, Cytosine and Uracil, the second is a monosaccharide either ribose or deoxyribose (a nucleic acid containing deoxyribose is called deoxyribonucleic acid-DNA while that which contains ribose is called ribonucleic acid-RNA) and the third is phosphate.



DNA & RNA are the two types of nucleic acids found in living systems. DNA acts as the genetic material in most of the organisms. RNA, though also acts as a genetic material in some viruses, mostly functions as a messenger.

DNA is referred to as universal genetic material. It is a long polymer of deoxyribonucleotides. The length of DNA is usually defined as the number of base pairs (pairs of nucleotides) present in it. DNA has a Double Helical structure.