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Genetically Modified Crops: An Overview

Genetically modified (GM) crops are plants that have had genes from other plants, animals, or microorganisms incorporated into their genome through genetic engineering techniques. These transgenic plants, when used in agriculture, are referred to as GM crops. The resulting food products from these crops are known as GM food. The inception of GM crops dates back to 1982 with the development of an antibiotic-resistant tobacco plant. Notably, China became the first country to commercialise a transgenic plant by introducing a virus-resistant tobacco in 1992. GM crops have applications spanning agriculture, industry, medicine, and environmental cleanup.

Characteristics and Advancements

GM crops possess a wide array of engineered traits, enhancing their value and utility in various domains:

1. **Disease Resistance:** Incorporation of genes to make crops resilient against diseases.
2. **Extended Shelf Life:** Delaying the ripening of fruits to prolong their freshness.
3. **Herbicide Tolerance:** Enabling crops to withstand specific herbicides, aiding weed control.
4. **Insect Pest Resistance:** Genetically enhancing crops to resist insect pest infestations.
5. **Drought and Stress Tolerance:** Modifying crops to endure adverse environmental conditions.
6. **Enhanced Nutrient Profiles:**
 - Improvement in vitamin A and iron content, especially in staple crops like rice.
 - Modification in the content and composition of edible oils in oilseed crops like rapeseeds, focusing on fatty acid composition.
7. **Production of Secondary Metabolites and High-Value Products:**
 - Cultivation of transgenic plants for secondary metabolite production.

- Expression of high-value proteins in seeds.

8. Medical Applications:

- Development of transgenic plants capable of producing edible vaccines.

9. Agricultural Efficiency:

- Enhancements in photosynthesis efficiency.

10. Aesthetics and Commercial Value in Floriculture:

- Improvement in architecture, colour, fragrance, and vase life of commercially valuable flowers.

Methods for Plant Transformation

Agrobacterium Mediated Transformation

- **Genus Characteristics:** *Agrobacterium* is a genus of soil-borne, Gram-negative bacteria.
- **Species and Disease:** *Agrobacterium tumefaciens*, a commonly studied species, causes crown-gall disease in plants.
- **DNA Transfer Capability:** Notable for its ability to transfer T-DNA part of Ti plasmid to plants, making it a valuable tool for plant genetic engineering.
- **Plant Host Specificity:** Primarily infects dicot species and is less effective on monocots.
- **Application in GM Food Plants:** Used to genetically modify various food plants, including Soybean, Cotton, Sugar Beet, Alfalfa, Rapeseed Oil (Canola), Creeping Bentgrass, Potato, Tobacco, Tomato, and Brinjal.

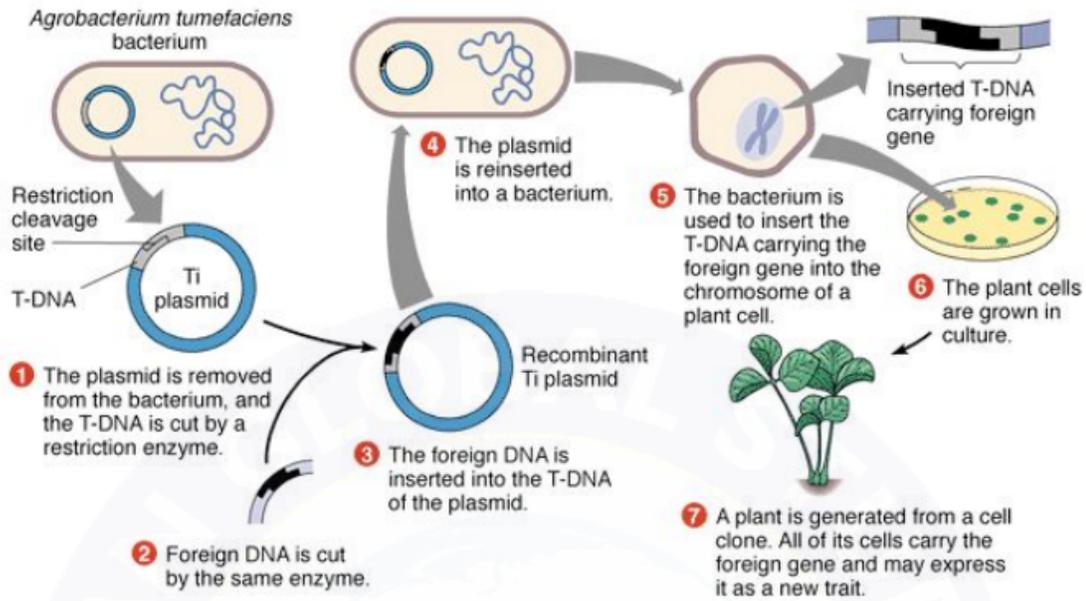


Figure.1. Agrobacterium based gene transfer method

Particle Bombardment (Biolistics)

- **Importance in Cereal Crops:** Essential for transforming cereal crops like rice and most wheat varieties.
- **Mechanism:** Involves propelling tungsten or gold particles coated with DNA into target plant material at high velocity.
- **DNA Integration:** Upon impact, the DNA is released into plant cells and can integrate into the plant genome.

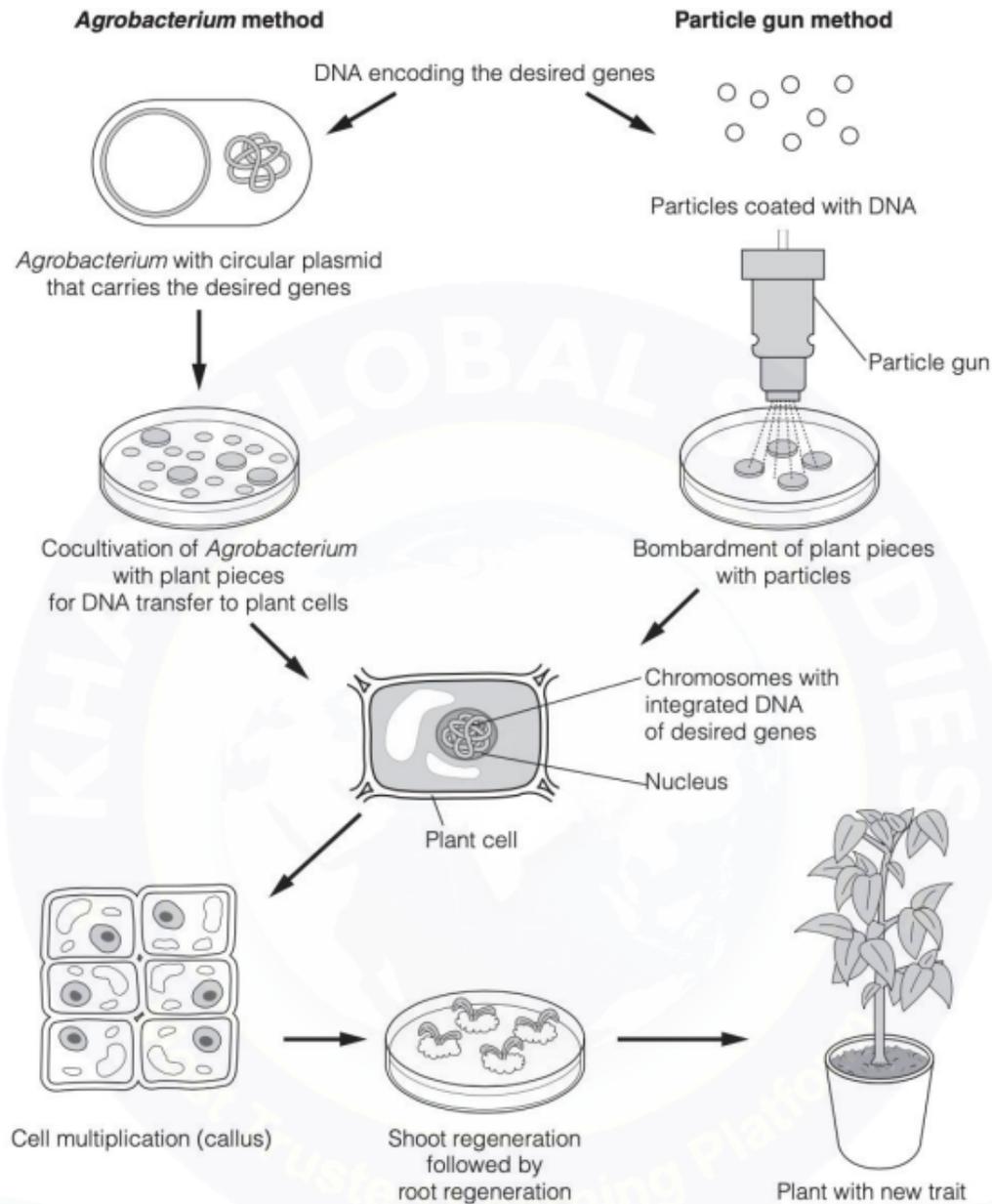


Figure.2. Plant material transformed by an *Agrobacterium* based system and by DNA from particle gun

Virus Mediated Gene Transfer

- **Process Overview:** This method utilises modified viruses as vectors to transfer genetic material into plant cells.
- **Vector Modification:** The viruses are engineered to carry desired genes instead of their own pathogenic genes.

- **Host Range:** Effective for a wide range of plant species, leveraging the natural infection capability of viruses.
- **Applications:** Widely used for both research and development of genetically modified plants, particularly for traits difficult to introduce through other methods.
- **Commonly used viruses:**

Virus Vector	Utilisation	Target Plant Species
Tobacco Mosaic Virus (TMV)	Used in genetic modification of tobacco plants	Broad range of plant tissues, especially tobacco
Cauliflower Mosaic Virus (CaMV)	Employed for gene transfer in dicotyledonous plants	Commonly used in canola and other dicots
Gemini Virus	Serves as a vector for a variety of crops	Broad range of plant species
Potato Virus X (PVX)	Utilised for gene transfer in potatoes and related species	Solanaceae family, including potatoes

Applications of Genetically Engineered Crops

Goal	Use	Typical Method	Examples of Crops Transformed
Herbicide Tolerance	Use of herbicides post emergence of seedlings at lower doses than required before seedling emergence	Introduce bacterial gene for enzyme which degrades the herbicide or which bypasses the point of plant metabolism inhibited	Soybean, canola, corn and cotton
Insect Resistance	Reduce losses without pesticide spraying	Insertion of gene from the bacterium <i>Bacillus thuringiensis</i> gives resistance to a range of insect pests	Corn (against European corn borer); cotton (against bollworm); potato (against Colorado beetle)
Post-harvest quality	Increasing shelf-life and reduces losses in transport and harvest	Modified activity of polygalacturonase or other ripening enzymes	Tomato

Virus resistance	Reduced losses due to viral diseases	Insertion of viral coat protein gene into plant	Tobacco (tobacco mosaic virus); potato (potato viruses X and Y)
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Near future possibilities of genetically engineered crops

Goal	Application
Salinity tolerance	Increased crop yield in areas affected by salinity (e.g. in long-term irrigation)
Drought tolerance	Increased crop yield in marginal, semi-arid zones
Waterlogging tolerance	Improved survival in temporary flooding
Enhanced flavour, storage and properties	Improved consumer acceptance; decreased losses; decreased energy inputs to processing or storage; enhanced product value or usefulness
Enhanced amino acid content	Dietary improvement and health
Antibody and pharmaceutical production	Less energy input and cost than use of animal cell culture
Improved disease resistance	Reduced pesticide inputs; increased yields mean population can be fed using smaller land area

Areas of Concern in Genetically Modified Foods

Unintended Biological and Environmental Impacts

- **Biological Interference:** Concerns about unnecessary interference with biological states or processes that have evolved naturally over time.
- **Science Limitations:** Modern science's limitations in fully understanding the potential negative ramifications of genetic manipulation.
- **Ecosystem Threats:** The risk of GMOs acting as invasive species, threatening ecosystem diversity due to their enhanced adaptability and stress and disease tolerance.
- **Cross-Pollination:** The potential for conventionally-bred crop plants to be cross-pollinated by pollen from modified plants.

Safety Concerns

- **Allergenicity and Toxicity:** Fears that GMOs could introduce new allergens into foods, or contribute to the spread of antibiotic resistance.
- **Food Quality:** Questions regarding the impact of GMOs on the nutritional value, cariogenicity, and food intolerance.

Herbicide-Tolerant Transgenics: Environmental and Agricultural Concerns

- **Herbicide Resistance:** Transfer of herbicide-tolerant genes to wild relatives or weeds, posing a significant environmental threat.
- **Creation of "Superweeds":** The possibility that transgenic crops can lead to the emergence of weeds resistant to herbicides.
- **Increased Herbicide Dependence:** Contrary to the aim of reducing herbicide usage, the use of herbicide-tolerant crops may increase reliance on a few herbicides.
- **Weed Control Problems:** The potential for increased weed control issues if weeds develop resistance to herbicides through gene flow from transgenic crops.
- **Use of Older, Toxic Herbicides:** The pursuit of herbicide tolerance for older, more toxic, and persistent products.
- **Alternative Weed Control:** Preference for non-chemical means of weed control, such as crop rotation, dense plantings, cover cropping, ridge tillage, despite being labour-intensive for farmers, over any herbicide use.
- **Gene Flow Risk:** Acknowledgment that gene flow is the primary risk in releasing transgenic plants.

Socioeconomic and Ethical Concerns

- **Patent and Monopoly Issues:** The control of seed patents by a few large corporations, raising concerns about farmer dependency and loss of seed diversity.
- **Impact on Small Farmers:** The economic impact on small-scale farmers, particularly in developing countries, who may not afford the high costs of GM seeds and associated technologies.

- **Consumer Choice and Labeling:** The debate over the labeling of GM foods and the right of consumers to be informed and choose non-GM products.
- **Ethical Considerations:** Ethical dilemmas regarding the modification of living organisms and the potential consequences on natural biodiversity.

Global Regulatory and Health Perspectives

- **Inconsistent Regulations:** Variations in GMO regulations globally, leading to challenges in international trade and concerns about the rigor of safety assessments.
- **Long-Term Health Effects:** Uncertainties about the long-term health effects of consuming GM foods, due to the lack of extensive, long-term studies.
- **Impact on Beneficial Insects and Soil Health:** Potential negative effects of GM crops on non-target organisms, including beneficial insects and soil microbiota.
- **Resistance in Pests and Pathogens:** The potential for pests and pathogens to develop resistance to the traits engineered into GM crops, leading to new agricultural challenges.

Global GM Crop Cultivation

- **Top GM Growing Countries:** The USA, Brazil, Argentina, India, and Canada are the leading countries in GM crop cultivation, collectively accounting for approximately 90% of the global GM cultivation area.
- **Major GM Crops:** The primary GM crops grown worldwide include Soybean, maize, cotton, and canola. The key traits for these crops are herbicide tolerance and insect resistance.

Cultivation of GM Crops in India

- **Sole Approval:** *Bt* cotton is the only GM crop approved for commercial cultivation in India since 2002.
- **Impact Studies:** ICAR conducted long-term studies on *Bt* cotton showing no adverse effect on soil, microflora, and animal health.

- **Parliamentary Report:** A report on 'Genetically modified crops and its impact on environment' was submitted to the Parliament on August 25, 2017, emphasizing critical scientific evaluation and regulatory restructuring for GM crops.

Bt Cotton

- **Approval:** In 2002, GEAC approved the commercial release of *Bt* cotton hybrids/varieties resistant to cotton bollworm.
- **Introduction and Expansion:** Indian farmers began cultivating Bt cotton in the 2002-03 season. By 2014, the cultivation area expanded to 11.6 million hectares.
- **Prevalence:** Approximately 96% of India's cotton area was covered by Bt cotton as of 2014. It is estimated to be 99% in 2021.

Development of Bt Cotton

- **Origins and Genetic Modification:** Bt cotton was developed by introducing a gene coding for Bt toxin, derived from the bacterium *Bacillus thuringiensis*, into the cotton genome. This genetic modification enables the cotton plant to produce an insecticide internally to combat pests, particularly bollworm.

Characteristics and Mechanism

- **Pest Resistance:** The primary function of Bt cotton is to resist lepidopteran larvae, the main pests in commercial cotton cultivation.
- **Insecticide Production:** The inserted Bt toxin gene allows the plant to produce the Bt protein, a natural insecticide, in its tissues.
- **Reduced Insecticide Usage:** The genetic modification significantly decreases the need for applying broad-spectrum insecticides, especially against pests that have developed resistance to pyrethroids.

Global Standing

- **Ranking:** India is the second-largest producer of cotton in the world.
- **Production Statistics:** In the 2022-23 cotton season, India produced an estimated 343.47 lakh bales, equivalent to 5.84 million metric tonnes.

- **Global Production Share:** This production accounts for approximately 23.83% of the world's total cotton production.
- **Cultivation Area:** India has a larger area available for cotton cultivation compared to China.

Limitations and Secondary Effects

- **Specificity of Action:** While effective against lepidopteran pests, Bt cotton is not effective against other common pests such as plant bugs, stink bugs, and aphids.
- **Potential for Additional Insecticide Use:** In some cases, the use of other insecticides may still be necessary to manage pests not affected by the Bt toxin.
- **Impact on Secondary Pests:** A study conducted in 2006 by Cornell University, the Center for Chinese Agricultural Policy, and the Chinese Academy of Science revealed that in China, secondary pests not targeted by Bt toxin increased over seven years in Bt cotton fields. This led to the resurgence of pesticide use at levels similar to non-Bt cotton, thereby diminishing the economic advantage of Bt cotton due to the higher cost of GM seeds.

Bt Brinjal

- **Genetic Modification:** Bt brinjal is a genetically engineered version of brinjal (eggplant or aubergine), modified to resist pests.
- **Gene Insertion:** The modification involves inserting the Cry1Ac gene from the soil bacterium *Bacillus thuringiensis* into the brinjal's genome. This gene produces a protein toxic to certain insects, particularly the Brinjal Fruit and Shoot Borer (*Leucinodes orbonalis*).

Development and Function

- **Developer:** The Bt brinjal was developed by Maharashtra Hybrid Seeds Company (Mahyco), an Indian seed company.
- **Gene Expression:** The Cry1Ac gene is expressed in all brinjal tissues throughout its life cycle.
- **Mechanism of Action:** When the Brinjal Fruit and Shoot Borer larvae feed on Bt brinjal plants, they ingest the Cry1Ac protein, which disrupts their digestive process, causing paralysis and death.

Commercialization and Adoption

- **Approval in India:** Bt brinjal was approved for commercialization in India in 2009, but faced a moratorium due to public outcry and debates.
- **Approval in Bangladesh:** In 2013, Bt brinjal was approved for commercial release in Bangladesh.
- **Adoption in Bangladesh:** By 2021, approximately 65,000 farmers in Bangladesh cultivated Bt brinjal, with around 20% using seeds from previous seasons.
- **Recent Developments:** In 2020, GEAC allowed biosafety research field trials for two indigenous *Bt* Brinjal varieties, Janak and BSS-793, in eight states.

Dhara Mustard Hybrid-11 (DMH-11)

Development

- **Cross Varieties:** DMH-11 is a hybrid developed by crossing Varuna and Early Heera-2.
- **Genetic Incorporation:** It incorporates genes from the barnase and barstar soil bacterium.

Traits and Fertility

- **Yield and Fertility:** The hybrid is designed to be fertile with a better yield, achieved by overcoming the temporary sterility in Varuna through cross-pollination with Early Heera-2.

Advantages of Hybrid Mustard Varieties

- **Increased Yield:** Trials by the Indian Council of Agricultural Research (ICAR) suggest DMH-11 yields are 28% higher than Varuna and 37% better than local varieties.
- **Potential in Hybrid Development:** The barnase-barstar system used in DMH-11 demonstrates the potential to develop new hybrids, potentially reducing India's edible oil import bill.

Controversies and Concerns

- **Introduction of Foreign Genes:** There are concerns regarding the introduction of foreign genes into the species.
- **Herbicide Tolerance:** DMH-11 requires the bar gene for development, which confers tolerance to the herbicide glufosinate-ammonium.
- **Impact on Pollination:** There are fears that GM mustard, like DMH-11, may negatively affect bee pollination.

GEAC Approval

- **Environmental Release:** In 2022, the Genetic Engineering Appraisal Committee (GEAC) approved the environmental release of DMH-11, marking it as potentially the first genetically modified (GM) food crop for Indian farmers.
- **Purpose of Approval:** This approval was specifically for seed production and testing in accordance with existing Indian Council of Agricultural Research (ICAR) guidelines, GEAC-imposed conditions for the environmental release, and other extant rules and regulations.
- **Conditional Cultivation:** Currently, GEAC's approval allows for the cultivation of DMH-11 under ICAR supervision, with its commercial availability dependent on further evaluation over three growing seasons.
- **Legal Proceedings:** The issue of the environmental release of GM Mustard is currently under adjudication before the Hon'ble Supreme Court of India.

Biosafety Aspects of GM Crops in India

Statutory bodies on GM crop regulation

Statutory Body	Role and Responsibilities
Recombinant DNA Advisory Committee (RDAC)	Monitors developments in biotechnology at national and international levels.
Institutional Biosafety Committee (IBSC)	Approves low-risk experiments and ensures adherence to safety guidelines. Recommends high-risk experiments to RCGM.
Review Committee on Genetic Manipulation (RCGM)	Reviews ongoing high-risk and controlled field experiments. Approves applications for research on GM plants.

Genetic Engineering Appraisal Committee (GEAC)	Approves activities involving large-scale use of GMOs in research and production.
State Biotechnology Coordination Committee (SBCC)	Reviews safety and control measures for GMO handling. Acts as a state-level agency to assess damage from GMO release and implement control measures.
District Level Committee (DLC)	Inspects and reports on compliance with regulatory guidelines. Acts at district level to assess damage from GMO release and take control measures.

Genetic Engineering Appraisal Committee (GEAC)

- **Role in Biosafety:** The GEAC, operating under the Ministry of Environment, Forests and Climate Change (MoEFCC), is primarily responsible for ensuring biosafety.
- **Statutory Body:** Functions as a statutory body for the approval of activities involving hazardous living microorganisms and recombinants.
- **Approval Responsibilities:** Responsible for the approval of genetically engineered organisms and products' release into the environment, including experimental field trials.
- **Regulation of LMOs:** Oversees the use of living modified organisms (LMOs) in high-risk categories in the manufacture/import of recombinant pharmaceutical products.

Main Functions of GEAC

- **Commercial Use of GMOs:** Permits the use of genetically modified organisms (GMOs) for commercial purposes.
- **Regulatory Measures:** Adopts procedures for restriction or prohibition under the Environment Protection Act (EPA), 1986.
- **Field Trial Oversight:** Approves large-scale field trials and evaluates data for transgenic crops.
- **Large Scale GMO Release:** Authorises the large-scale production and environmental release of GMOs and related products.

- **Enforcement Authority:** Authorises agencies or persons to take punitive actions under the EPA.

Rules 1989

- **Regulatory Framework:** The Government of India notified “Rules for the Manufacture/Use/Import/Export and Storage of Hazardous Microorganisms, Genetically Engineered Organisms or Cells” in 1989 under the Environment (Protection) Act, 1986.
- **Implemented by Multiple Bodies:** Implemented by MoEFCC, the Department of Biotechnology (DBT), and State Governments.
- **Competent Authorities:** Enforced through six competent authorities: Recombinant DNA Advisory Committee (RDAC), Institutional Biosafety Committee (IBSC), Review Committee on Genetic Manipulation (RCGM), GEAC, State Biotechnology Coordination Committee (SBCC), and District Level Committee (DLC).

Cartagena Protocol on Biosafety

- **Nature and Purpose:** A legally binding international agreement, supplemental to the Convention on Biological Diversity (CBD), focusing on the safe transfer, handling, and use of LMOs.
- **Adoption and Ratification:** Adopted on 29 January 2000 and entered into force on 11 September 2003. India ratified the Protocol on 23 January 2003.
- **Objectives:** Aims to ensure protection of biological diversity and consider risks to human health, focusing on transboundary movements of LMOs.

Functions of the Biosafety Protocol

- **Advance Informed Agreement:** Establishes a procedure for countries to receive necessary information before agreeing to import LMOs.
- **Precautionary Approach:** Incorporates the precautionary approach from the Rio Declaration on Environment and Development.
- **Safety Requirements:** Sets practical requirements for the safe movement of LMOs.
- **Biosafety Clearing-House:** Establishes a platform for information exchange on LMOs and assists countries in implementing the Protocol.