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2. Plant Introduction - A Crucial Stage of Breeding

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Abstract:

Plant introduction is a crucial aspect of agriculture, facilitating the diversification of crops and enhancement of genetic resources. It involves the introduction of plant species or varieties from one geographic region to another for cultivation or research purposes. This process contributes to the development of resilient and high-yielding cultivars, aiding in food security and agricultural sustainability. Furthermore, plant introduction fosters genetic diversity, enabling adaptation to changing environmental conditions and the mitigation of pest and disease pressures. Effective plant introduction strategies rely on rigorous evaluation and selection criteria to ensure successful establishment and integration of new plant materials into existing agricultural systems.

Keywords:

Plant Introduction, Food Security, Genetic Diversity, Adaptation.

2.1 Introduction:

Plant introduction refers to collecting plant genetic resources from diverse locations and introducing them into plant breeding programs (FAO, 2020). It involves exploring new germplasm sources from within a country or across international borders and evaluating the introduced materials for their potential use in breeding new crop varieties (IPGRI, 1999). Plant introduction plays a crucial role in broadening the genetic base of crops. It provides breeders access to novel alleles, traits, and combinations that may not be present in existing breeding materials and gene pools (Acquaah, 2012). This helps overcome the limitations imposed by genetic bottlenecks and narrow genetic bases that often occur due to intensive selection over generations of plant breeding and cultivation (Frankel & Brown, 1984). Introducing new genetic diversity from unadapted germplasm facilitates the development of varieties with higher and more stable yields, wider adaptability, and improved resistance to biotic and abiotic stresses (Tanksley & McCouch, 1997).

2.1.1 Historical Context and Role of Plant Introduction in Genetic Diversity:

The role of plant introduction in augmenting genetic diversity has been evident since ancient times. Early civilizations engaged in plant exploration and germplasm exchange across regions to diversify their agricultural systems (Harlan, 1992). For instance, the Incas cultivated over 2000 varieties of potatoes across the Andean region of South America by selecting from wild relatives (Maxted et al., 1997).

In Mesoamerica, the Mayans and Aztecs cultivated various maize landraces adapted to agro-climatic conditions through plant introduction (van de Wouw et al., 2010). In Asia, China has a long history of moving cultivated plants and their wild relatives from one region to another (Harlan, 1992). For example, rice was introduced from India to China around 1100 BC, contributing to genetic gains in Chinese rice varieties (Borlaug, 2007).

In the 18th and 19th centuries, European colonial plant collectors like Banks, Solander, and Hooker made significant contributions through extensive plant exploration of Asia, Africa, and Americas (Banks, 1805; van de Wouw et al., 2010). Their collections laid the foundation for modern plant genetic resources in many countries. In 1793, Sir Joseph Banks established the Royal Botanic Gardens at Kew in London and initiated extensive plant collection missions around the British Empire (Banks, 1805). A breakthrough was the establishment of international agricultural research centers under the Consultative Group on International Agricultural Research (CGIAR) in the 1960s and 1970s. Centers like the International Maize and Wheat Improvement Center (CIMMYT) and the International Rice Research Institute (IRRI) facilitated the large-scale collection and exchange of genetic resources globally (Evenson & Gollin, 2003).

For example, CIMMYT's wheat introduction efforts in Mexico led to the development semi-dwarf, high-yielding varieties that were instrumental in the 'Green Revolution' (Borlaug, 2007).

Since the mid-20th century, over 7.4 million accessions of plant genetic resources have been collected and conserved ex-situ globally in genebanks (FAO, 2020). This has helped rescue numerous landraces and wild relatives from extinction due to modern agriculture (Maxted et al., 1997). Genetic analysis of these diverse accessions has revealed a wide range of beneficial alleles that can be utilized in breeding climate-resilient and nutritionally fortified varieties (van de Wouw et al., 2010).

The role of plant introduction gained further prominence during the Green Revolution of the 1960s when high-yielding semi-dwarf wheat and rice varieties developed by Borlaug were disseminated globally (Borlaug, 2007; Evenson & Gollin, 2003). These varieties helped avert widespread famine but were genetically narrow, developed from a limited set of parental lines. Subsequent plant exploration efforts broadened the genetic base by introducing diverse germplasm from centers of origin (Frankel & Brown, 1984). Plant introduction has played a vital historical role in augmenting the genetic diversity of crops since ancient times. It contributes significantly to global food security through targeted breeding efforts harnessing novel traits from diverse germplasm sources.

2.1.2 Global Relevance of Plant Introduction for Food Security Under Climatic Change:

Plant introduction is crucial in ensuring global food security in the face of climatic change. As temperatures rise and precipitation patterns become more erratic and extreme due to climate change, agricultural production is severely threatened (Lipper et al., 2014). Projections indicate that climate change could reduce global crop yields by over 10% by 2050 if no adaptation actions are taken (Nelson et al., 2014).

However, genetic diversity from plant introduction provides a rich source of novel traits and alleles to help breed climate-resilient crop varieties adapted to future conditions (Jarvis et al., 2008). Traits like drought tolerance, heat tolerance, submergence tolerance, and resistance to new diseases exacerbated by climate change can be introgressed into elite varieties from landraces and wild relatives through plant introduction (Abberton et al., 2016). For instance, the International Rice Research Institute (IRRI) has collected over 120,000 rice accessions from various countries, which are used to develop rice varieties tolerant to drought, flooding, and high temperatures (IRRI, 2020). Similarly, the International Center for Tropical Agriculture (CIAT) harnesses genetic diversity from its bean and cassava genebanks to breed varieties resilient to changing rainfall patterns in Central and South America (CIAT, 2019). Such efforts targeting climate change adaptation traits through plant introduction can help offset at least 30% of the losses projected due to climate impacts on crop yields by mid-century (Lipper et al., 2014).

International collaboration through gene banks and organizations like FAO and CGIAR is vital in facilitating global access to plant genetic resources and the exchange of climate-resilient germplasm (FAO, 2020).

For instance, the Svalbard Global Seed Vault provides a backup storage facility for seed samples from genebanks worldwide as insurance against long-term threats like climate change impacts on ex-situ conservation facilities (FAO, 2020).

Coordinated efforts are crucial to fully harness novel traits from diverse germplasm for developing climate-resilient crop varieties that can ensure food security even as climatic conditions change rapidly. With increasing threats from climate change, plant introduction assumes renewed importance for ensuring long-term global food security by broadening the genetic diversity available for crop improvement. Concerted international collaboration will be vital in facilitating comprehensive plant introduction programs targeting climate change adaptation.

2.1.3 Exploring Genetic Diversity for Plant Introduction:

The exchange in germplasm gives Genetic Diversity for Plant Introduction. Germplasm refers to the genetic resources for crop plants, which includes all the genetic materials that can be used for breeding new varieties. It comprises diverse plant genetic resources like landraces, wild crop relatives, breeding lines, cultivars, and gene bank accessions.

The main types of germplasm resources include:

Landraces - Indigenous cultivars developed by farmers through selection over generations that are genetically diverse and adapted to local growing conditions.

Wild crop relatives - Wild species related to crops that are valuable sources of genes/alleles for resistance to diseases, insects, and environmental stresses.

Advanced breeding lines - Genetically diverse breeding materials developed through hybridization and selection in breeding programs.

Genebank accessions - Germplasm accessions collected worldwide and conserved ex-situ in genebanks for long-term preservation and utilization. For example, over 7.4 million accessions are conserved globally in genebanks (FAO, 2020).

Harnessing diversity from these varied sources through plant introduction programs enables breeders to broaden the genetic base of crops and develop new varieties with enhanced yield, resilience, and nutritional quality suited for a changing climate.

2.2 Objectives and Purpose of Plant Introduction:

2.2.1 Chief Objectives of Plant Introduction:

a. Exploration and collection of new germplasm: Scouting centers of origin and diversity for novel traits.
b. Evaluation and characterization: Assessing traits of introduced materials through multi-location yield trials.
c. Utilization in breeding: Introgression of superior alleles into adapted cultivars using modern tools.
d. Conservation: Safely storing germplasm in gene banks for present and future use.

2.2.2 Purpose of Plant Introduction:

a. Germplasm exploration: Introducing new genetic material expands the gene pool breeders can draw from to develop superior varieties. Our crops need continuous infusions of novel traits to keep pace with future challenges.
b. Adaptation to new conditions: The changing climate is threatening agricultural productivity. The Introduction helps breed climate-smart crops by accessing traits from diverse ecological zones worldwide.
c. Utilizing crop wild relatives: These neglected plants hold a treasure trove of beneficial alleles we are only starting to tap. Introduction conserves them while harnessing resistance to stresses.
d. Addressing micronutrient deficiencies: We must breed biofortified staples rich in vitamins, zinc, and iron to overcome "hidden hunger."Exotic germplasm boosts such efforts.
e. Supporting underutilized crops: Many neglected but nutritious indigenous crops can be enhanced through Introduction to improve smallholder livelihoods.
f. Ensuring food security: Stable production gains from introduced germplasm will be vital to meeting the food demands of 9 billion people by 2050 sustainably.
g. Pest and disease resistance: Introduction arms us with durable resistance to evolving pathogen threats. Our green revolution was built on rust-resistant kinds of wheat from Mexico.
h. Supporting marginal environments: Harsh conditions limit yields, but introduced drought/heat tolerance helps farmers in dryland regions. CIMMYT helped India's rainfed areas.
i. Economic benefits: New varieties boost productivity and farmer incomes. IR8 tripled rice harvests across Asia, alleviating poverty for millions.

j. Regional collaboration: International centers like IRRI and ICRISAT are global hubs facilitating Introduction between nations. Strong regional networks accelerate progress.
k. Pre-breeding: Exotic traits are crossed into elite lines, generating progeny better adapted locally. This intermediate step before full variety development ensures efficient utilization.
l. Capacity building: Young breeders gain exposure touring collection missions. Developing country programs are strengthened through exchange visits, training programs, and joint projects.
m. Germplasm conservation: Well-curated gene banks safeguard invaluable genetic resources ex-situ for future use. The Svalbard Global Seed Vault provides a "fail safe" backup.

2.3 Types of Plant Introduction:

2.3.1 Based on The Type of Plant Material Introduced, The Plant Introduction They are:

***A. Seed Introduction*: -** It involves collecting seeds from diverse sources and introducing them into the target environment. Seeds can be easily stored and transported in large numbers. However, seed introduction has limitations, such as the unknown performance of introduced traits in new environments.

Drought-tolerant wheat lines developed at ICARDA were introduced into CIMMYT's global wheat breeding program through seed exchange in 2020.

B. Vegetative Introduction: **-** It involves introducing plant parts like roots, tubers, corms, bulbs, rhizomes, stem cuttings, etc. It allows for direct evaluation of plant performance. However, vegetative material has limited viability and cannot be stored or transported easily compared to seeds. Cassava mosaic virus-resistant varieties developed at IITA were introduced to African countries through the distribution of virus-tested stem cuttings in 2018.

C. Tissue culture-based Introduction: **-** Advanced techniques like anther/pollen culture and somatic embryogenesis are used to introduce genes from distantly related wild species that cannot be crossed conventionally. In vitro, regenerated plants are acclimatized and evaluated. Disease-resistant genes from wild relatives were introduced into bananas through protoplast fusion and somatic hybridization at BAPNET in India in 2015.

D. Pollen Introduction: **-** Collecting and transporting pollen from diverse sources to use in hybridization and breeding new varieties. For example, Drought tolerance traits were transferred from landraces to elite sorghum lines in ICRISAT's breeding program through pollen collection from global nurseries in 2017.

***E. Micropropagation-Based Introduction*: -** Using in vitro micropropagation techniques like meristem culture to introduce disease-free plant materials. For instance, meristem culture introduced banana varieties free of Fusarium wilt into African countries. Also, Virus-free coconut planting material was produced through meristem culture and distributed across Asia and Africa by Bioversity International in 2019.

F. Seedling Introduction: - Raising plants from introduced seeds in nurseries to directly evaluate plant traits and performance under field conditions before large-scale Introduction. Example: Cotton seedlings raised from introduced seeds were evaluated at research stations in India.

G. Molecular Marker-Assisted Introduction: - Introducing specific traits/genes tagged with molecular markers from unadapted germplasm into adapted breeding lines. For example, a drought tolerance QTL was introduced from wild soybeans into elite soybean varieties using molecular markers. For example, the Sub1 gene conferring submergence tolerance was introgressed from FR13A into high-yielding rice varieties in Bangladesh using molecular markers between 2010 and 2015.

H. Genome Introduction**:** - Introducing whole genome sequences/haplotypes from unadapted germplasm into adapted lines using modern breeding tools like genome editing for large-scale introgression of traits.

For instance, a disease resistance haplotype from a wild tomato species was introgressed into cultivated tomato varieties. For example, Disease resistance genes were precisely edited into tomato cultivars using CRISPR from a wild relative in China in 2020 to develop blight-resistant varieties.

2.3.2 Based on The Level of Introduction, Plant Introduction is of Mainly Two Types They Are:

A. Primary Introduction:

Primary Introduction refers to the initial Introduction of plant genetic resources collected directly from centers of diversity or crop wild relatives into a new target environment or country where they have not been previously evaluated (FAO, 2020). This involves completely new, unadapted germplasm requiring extensive characterization and evaluation. The critical steps in the primary Introduction are collecting plant genetic resources from diverse ecological regions and countries, quarantine inspection to ensure pest/disease freedom, Introduction into contained field evaluation sites, and multi-location yield trials over multiple seasons (Acquaah, 2012). Detailed characterization is done to record morphological, phenological, and agronomic traits. Adaptation to local abiotic and biotic stresses is rigorously tested. Promising accessions identified are then introduced into national breeding programs.

Primary Introduction plays a vital role in broadening the genetic base of crops and harnessing novel traits that may not be present in existing breeding materials. However, it is a long-drawn process requiring considerable resources due to the need for thorough adaptation testing (Tanksley & McCouch, 1997). Many accessions may fail to adapt, or their valuable traits may not be expressed in new target environments.

Exotic rice varieties like IR8, IR20, IR28, and IR36 were introduced by IRRI in the 1960s, contributing to the development of high-yielding dwarf varieties in India. Exotic Semi-dwarf, broad genetic bases wheat varieties like Lerma Rojo 64 and Sonora 64 were introduced from CIMMYT, Mexico, in the 1960s-1970s

B. Secondary Introduction:

Secondary Introduction refers to moving germplasm accessions that have already undergone primary Introduction and preliminary evaluation in one target environment or country to another new target environment or program (Camacho Villa et al., 2005). Since these accessions have a history of previous exposure and limited evaluation, less extensive characterization is required. The key steps involve obtaining well-documented germplasm from primary introduction sites or gene banks, testing them for a few seasons through multi-location yield trials, and identifying best-performing lines for breeding programs.

Since essential adaptation to local conditions has already been established, secondary Introduction allows for quicker utilization of pre-evaluated materials than the primary Introduction.

Submergence tolerant rice variety Swarna-Sub1 was introduced across flood-prone areas in eastern India in 2000s from the IRRI/Bangladesh program. High-yielding wheat lines like Sonalika, Kalyan from CIMMYT were introduced into Indian breeding programs during the 1970s-90s after initial evaluation in Mexico. In conclusion, both primary and secondary Introduction play critical complementary roles in broadening the genetic base of crops. While primary Introduction deals with completely new germplasm requiring thorough testing, secondary Introduction facilitates faster utilization of pre-evaluated materials in new target environments or programs.

2.4 National and International Agencies and Organizations Involved in Plant Introduction:

2.4.1 International Plant Introduction Agencies:

A. FAO (Food and Agriculture Organization of the United Nations): FAO works to improve agriculture, forestry, and fisheries practices and ensure good nutrition for all. In the area of plant genetic resources, FAO promotes international cooperation in the conservation and exchange of plant genetic resources. It facilitates germplasm exchange through agreements like the International Treaty on Plant Genetic Resources for Food and Agriculture (ITPGRFA). FAO also supports global networks like the European Association for Research on Plant Breeding (EAAP) and the European Search Catalogue (EURISCO) to facilitate germplasm exchange between countries and regions (FAO, 2020).

B. CGIAR (Consultative Group on International Agricultural Research): CGIAR is a global partnership that unites international organizations engaged in research for sustainable development. Several CGIAR centers like CIMMYT, IRRI, ICRISAT, and IITA maintain vast ex-situ gene banks of significant crops. They conduct extensive plant exploration, Introduction, and pre-breeding activities.

Introduced materials from CGIAR centers have significantly contributed to crop improvement globally. For example, IRRI introduced high-yielding rice varieties like IR8 and IR36 in the 1960s, accelerating the Green Revolution in Asia (CGIAR, 2022).

C. IPGRI (International Plant Genetic Resources Institute): IPGRI (now Bioversity International) is a research-for-development organization that works to diversify crops and farming systems. It promotes plant genetic diversity for food security through international agreements and networks. IPGRI has facilitated the Introduction of diverse crop germplasm between countries and regions (IPGRI, 1999).

D. EURISCO (European Internet Search Catalogue): EURISCO provides a single point of access to plant genetic resources data from gene banks across Europe. Researchers can search EURISCO to identify germplasm of interest, facilitating plant introduction within Europe (EURISCO, 2022).

2.4.2 National Plant Introduction Agencies:

In India, the need for establishing an organization to manage plant introduction and germplasm for crop improvement dates back to 1935 when the 'Crops and Soil Wing' of the 'Board of Agriculture and Animal Husbandry' recognized this need. In 1941, the Indian Society of Genetics and Plant Breeding discussed this further, emphasizing economic crops. Dr. B.P. Pal, at IARI, approached the Imperial Council of Agricultural Research (ICAR) to create a unit for global germplasm assembly under phytosanitary conditions, leading to the launch of the ICAR scheme for 'Plant Introduction' in 1946.

This initiative started in the Botany Division of IARI under Dr. Harbhajan Singh's leadership. *(Dr. Harbhajan Singh was the most renowned plant explorer. He was known as the "Indian Vavilov". In India, he gave the field of plant genetic resources a unique character. Large amounts of wheat and rice germplasm were brought by Dr. Singh, which aided India's Green Revolution. Several new species, including soybean, sunflower, low chilling, and temperate fruits (peaches, apples, West Indian cherry, and Chinese gooseberry), as well as a wide variety of ornamentals, were also introduced by him.*

The Pusa Sawani variety of okra is the best illustration of his excellent contributions to vegetable breeding). Later, the Botany Division of IARI expanded into the 'Plant Introduction and Exploration Organization' in 1956 and evolved into a distinct 'Division of Plant Introduction' in IARI in 1961. Following recommendations from a 'High-Level Committee' formed by the Government of India in 1970, the 'Division of Plant Introduction' gained autonomy, becoming the 'National Bureau of Plant Introduction' in August 1976, and later renamed as the 'National Bureau of Plant Genetic Resources' (NBPGR) in January 1977.

The bureau has five Divisions, three units, an experimental farm at its Headquarters in New Delhi, and 10 Regional Stations located in different phytogeographical zones of the country. Besides, an All India Coordinated Research Network Project on Under-utilized crops is located in the bureau.

A. Regional Stations of NBPGR:

- Shimla (Himachal Pradesh): Established in 1960 at Phagli, Shimla. The station's mandate is the collection, evaluation, characterization, and maintenance of temperate crops.
- Jodhpur (Rajasthan): Established in 1965, in the CAZRI Campus. Undertakes exploration, evaluation, and seed increase for agri-horticultural crops of arid and semi-arid zones.
- Thrissur (Kerala): Established in 1977. Responsible for the collection and evaluation of germplasm of southern peninsular region with particular emphasis on spices and plantation crops.
- Akola (Maharashtra): Established in 1977. Responsible for exploring Maharashtra, Karnataka, Goa, Daman, and Diu for germplasm collections. It also undertakes the evaluation and maintenance of crops suited to Central India and the Deccan Plateau.
- Shillong (Meghalaya): Established in 1978. Involved in the collection and evaluation of agri-horticultural germplasm of the north-eastern region, including Sikkim and parts of northern Bengal.
- Bhowali (Uttarakhand): Established in 1985. Responsible for exploration, characterization, evaluation, and multiplication of agri-horticultural crops of sub-tropical and sub-temperate regions.
- Cuttack (Orissa): Established in 1985 in CRRI Campus. The mandate is an exploration of agri-horticultural crops of eastern peninsular region with a primary emphasis on rice germplasm.
- Hyderabad (Andhra Pradesh): Established in 1985. Engaged in speedy repatriation of pest and pathogen-free material and quarantine clearance of germplasm. Undertakes exploration, evaluation, and seed increase for agri-horticultural crops of Andhra Pradesh and adjoining areas.
- Ranchi (Jharkhand): Established in 1988. A center for evaluating and maintaining germplasm of tropical fruits and other field crops of Bihar, eastern Uttar Pradesh, and West Bengal.
- Srinagar (Jammu & Kashmir): Established in 1988. Responsible for exploration, collection, and maintenance of agri-horticultural germplasm of temperate crops of Jammu and Kashmir region.

B. Activities of NBPGR

- Introduce supplements of required germplasm from other agencies in other countries.
- Exploration and collection of valuable germplasm.
- Inspection & quarantine.
- Testing, multiplication, and maintenance of germplasm.
- It is publishing its exchange and collection list.
- Setting up natural gene sanctuaries
- Maintenance of record of introduced plants.
- To supply on request germplasm of various scientists or institutions.
- Improvement of medicinal and aromatic plants.

In addition to the bureau, there are some other agencies, i) FRI, ii) Botanical Survey of India, iii) The National Research Institutes, All India coordinated research projects, Centarl institutes, e.g., Tea, Coffee. Sugarcane, Potato, Tobacco, etc.

2.4.3 Government Regulations and International Treaties for Germplasm Exchange in Plant Introduction:

Practical plant introduction relies on the open germplasm exchange between countries and regions. However, this is regulated by national laws and international agreements to ensure safety and equitable benefit-sharing. In India, the National Bureau of Plant Genetic Resources (NBPGR) regulates the import and export of germplasm under the Biological Diversity Act 2002. It oversees compliance with access and benefit-sharing per the Nagoya Protocol (FAO, 2020). Similarly, countries like the US have regulations under plant quarantine laws to prevent the entry of invasive pests during international germplasm exchange. At the international level, agreements like the International Treaty on Plant Genetic Resources for Food and Agriculture (ITPGRFA) facilitate germplasm exchange. The ITPGRFA recognizes the sovereign rights of nations over their plant resources and establishes a multilateral system to access a list of 64 crops and forages of primary economic importance (FAO, 2004). Countries must provide germplasm samples from these crops freely for research, breeding, and training on request. The treaty also aims to share non-monetary benefits from commercializing varieties improved using these resources. For example, countries introducing drought-tolerant rice varieties developed from germplasm from IRRI must acknowledge the contributing country in the resulting varieties. Such provisions balance open access with benefit-sharing, encouraging sustainable use of global plant diversity for food security under changing climatic conditions (Lipper et al., 2014). With growing transboundary threats, harmonized regulations and compliance with agreements like the ITPGRFA and Nagoya Protocol are crucial to support ongoing international plant introduction efforts.

2.5 Plant Introduction Procedure:

Plant introduction is one of the oldest and most effective plant breeding methods. The primary function of plant introduction is to make available the germplasm that can be utilized in plant breeding programs.

The introduction consists of various steps:

- ***A. Procurement.***
- ***B. Quarantine***
- ***C. Cataloging***
- ***D. Evaluation***
- ***E. Multiplication***

A. Procurement of Germplasm:

The procurement of germplasm in plants is regulated by several international treaties and agreements, including the International Code of Nomenclature for Cultivated Plants

(ICNCP) and the Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES). These regulations ensure that germplasm is collected, traded, and preserved in a way that is ethically sustainable and protects the genetic diversity of plant species. The procurement of new germplasm is facilitated through the National Bureau of Plant Genetic Resources (NBPGR) in New Delhi. In this process, scientists, individuals, and institutions can express their requirements to the Director of NBPGR at Pusa Complex, New Delhi-12. If the bureau's stock or known sources cannot meet these demands, it actively seeks germplasm from international counterparts. Typically, this material is acquired through correspondence, often in the form of gifts or exchanges of germplasm, acknowledging past contributions to the bureau, or in anticipation of future cooperation. The bureau's involvement in NBPGR activities emphasizes free germplasm exchange, facilitating the supply of required germplasm. Moreover, the specific plant parts needed, such as seeds, tubers, suckers, bulbs, or cuttings, depend on the crop species in question, ensuring a tailored approach to germplasm procurement and conservation

B. Quarantine:

Many diseases like Late blight infection caused the devastating Irish famine of 1845; powdery mildew and root-eating aphids, originally from Central America, are responsible for their respective infestations. In a relatively short timeframe during the mid-nineteenth century, French vineyards faced an onslaught of Plasmopara viticola and mildew. The coffee berry disease, commonly known as coffee rust, initially appeared in Sri Lanka in 1875 before spreading to India in 1876. These instances clearly show how quarantine pests can be introduced and establish themselves. Moreover, when new areas are opened up for crop production, it can bring about significant damage to communities and national economies. Importation of foreign pests, along with planting material, has led to sporadic yet substantial crop losses in India (et al., 2006).

For this, the first legislation for plant quarantine in India was the Destructive Insects and Pests Act (DIP Act) of 1914. This laid the foundation for the plant quarantine system. ICAR-NBPGR has been empowered under the Plant Quarantine (Regulation of Import into India) Order 2003 of the Government of India to conduct quarantine checks on the germplasm being exchanged for research purposes, including transgenics. The Directorate of Plant Protection, Quarantine and Storage (DPPQS) under the Ministry of Agriculture is the apex body for plant quarantine.DPPQS established a national network of 57 plant quarantine stations - 13 at airports, 34 at seaports, and 12 at land frontiers. ICAR-National Bureau of Plant Genetic Resources (NBPGR) is the nodal agency for quarantining plant genetic resources and transgenic materials.NBPGR has well-equipped quarantine facilities, including containment greenhouses and laboratories with advanced diagnostic capabilities.NBPGR's Regional Plant Quarantine Station at Hyderabad mainly processes the quarantine of materials for Southern India. Public-sector agricultural universities and private stakeholders are being strengthened with post-entry quarantine facilities. Strict quarantine protocols are followed to process imported materials and screen for quarantine pests/pathogens before release. The main aim of establishing a network of well-equipped quarantine centers is to effectively regulate the import of planting materials and prevent the Introduction and spread of harmful exotic pests associated pests (fungi, bacteria, viruses, insects, nematodes, weeds, etc.) into the country, thereby safeguarding India's biodiversity and agricultural economy.

Here is a detailed, step-by-step description of the plant quarantine process

i. *Exploration and Collection*: Explorers collect plant genetic resources from other countries or regions during exploration trips.
ii. *Submission of Import Permit Application*: An application is made to the Directorate of Plant Protection, Quarantine and Storage (DPPQS) for an import permit for the collected plant genetic resources.
iii. *Issuance of Import Permit*: After verifying all required documents and ensuring quarantine requirements are met, DPPQS issues an import permit.
iv. *Importation*: The plant genetic resources are imported and submitted to the nearest quarantine station. All imported materials must be accompanied by an official phytosanitary certificate, which is mandatory.
v. *Inspection and Diagnostics*: At the quarantine station, consignments are inspected visually and through microscopic examination for any quarantine pests or pathogens. Some of the tests are:
   a. Dry seed examination to remove shriveled, discolored, or deformed seeds which may carry seed-borne pathogens.
   b. Incubation tests to check for the presence of fungi or bacteria.
   c. ELISA (Enzyme-Linked Immunosorbent Assay) or other immunodiagnostic assays like DIBA (Dot-Immunobinding Assay) to detect pathogens.
   d. PCR (Polymerase Chain Reaction) to detect pathogens at the molecular level.
   e. They have specialized detection techniques for different categories of pests like nematodes, insects, etc.
   f. Taxonomic identification of intercepted pests using reference collections and identification keys.
vi. *Treatment*: If any pests are detected, appropriate treatments like fumigation or heat therapy are applied to eliminate them. Some of the treatments are:
   a. Fumigation with chemicals like methyl bromide to eliminate pests and pathogens.
   b. Heat therapy like hot water treatment (HWT) to eliminate pests.
   c. X-ray radiation to disinfest seeds from internal feeding insects.
   d. Pesticide treatments are tailored to specific pests or pathogens.
   e. Specialized treatments prescribed by IPPC for high-risk materials.
   f. Salvaging of infected materials through intensive treatments where possible
vii. *Post-Entry Quarantine*: High-risk materials are subjected to post-entry quarantine testing and containment in quarantine greenhouses or fields for at least one crop cycle for further observation.
viii. *Release from Quarantine*: If no pests are detected after post-entry quarantine, the plant genetic resources are released from quarantine.
ix. *Distribution*: The quarantine-cleared materials can then be safely distributed to breeders and researchers for utilization in crop improvement programs.

The plant material being imported or exported must adhere to specific quarantine rules, and NBPGR exercises quarantine control at several points of entry.

After a careful examination, the phytosanitary certificate is returned to the sender or owner.

C. Cataloging:

Cataloging involves the systematic documentation and organization of introduced plant materials. It includes recording important information such as the origin, characteristics, and traits of the introduced germplasm. This information is crucial for future reference and utilization in breeding programs. Cataloging helps maintain a comprehensive inventory of the introduced plant materials, facilitating easy retrieval and access for researchers and breeders. Plant material is classified into three categories 1) Exotic collection (EC), 2) Indigenous collection (IC), 3) Indigenous wild collection

D. Evaluation:

Evaluation is a critical step in the plant introduction procedure. It involves assessing the performance and characteristics of the introduced plant materials under specific growing conditions. The evaluation process includes measuring various agronomic traits, disease resistance, yield potential, and quality attributes by sending them to the various sub-stations of the bureau. Through rigorous evaluation, breeders can identify promising accessions with desirable traits for further utilization in breeding programs. This step helps select the most suitable plant materials for developing improved varieties.

E. Multiplication and Distribution:

Multiplication is increasing the quantity of selected plant materials through propagation techniques. This ensures a sufficient supply of the introduced germplasm for future research and breeding endeavors. Depending on the plant species, multiplication can be achieved through seed multiplication, vegetative propagation, tissue culture, or other suitable approaches. By multiplying the chosen plant materials, breeders can generate a larger population for further evaluation and utilization. Once the plant materials have been multiplied, the distribution comes into play. Distribution involves disseminating the multiplied plant materials to researchers, breeders, and farmers for further evaluation and use. Collaboration among research institutions, genebanks, and agricultural organizations is often necessary to ensure the plant materials reach the intended users. The distribution process is closely monitored, with proper documentation and tracking systems to keep records of the recipients and ensure efficient delivery.

2.6 Acclimatization and Adaptation:

When plants are introduced from one region to another, they have to undergo acclimatization to adapt to the new environmental conditions of the introduced region. Acclimatization is the process by which plants adjust to the new environmental conditions and develop tolerance. It involves genetic changes through natural selection and physiological and morphological changes in the plants. The introduced plants may have to adapt to differences in abiotic factors like climate, soil type, rainfall and biotic factors like new diseases, pests, and interactions with other species. Successful acclimatization leads to adapting the introduced plants to the new environment. The process of acclimatization starts from the time of the Introduction itself.

When plants are first introduced, they are exposed to mild selection pressures of the new environment, which allows some level of adjustment. During the evaluation phase, plants must demonstrate their ability to survive and perform reasonably well under the prevailing conditions. Plants that cannot acclimatize even at a basic level will be eliminated at this stage. The surviving plants are then multiplied and distributed on a limited scale for on-farm evaluation over several crop cycles. During on-farm evaluation and multiplication, the introduced plants come under more substantial selection pressures of the local conditions. They have to compete with local cultivars and cope with biotic and abiotic stresses without any human intervention. Plants that are not adapted may fail to establish, have meager yields, or may not produce viable offspring. Only the plants that show tolerance and ability to complete their life cycle will survive and propagate under these conditions.

Their progenies will be better acclimatized than the original introduced stock. Acclimatization may take several crop generations or years, depending on the degree of differences between the original environment and the new introduction zone. During this period, natural selection helps develop traits suitable for the new location. Plants also undergo physiological changes like better root development, altered leaf structure, chemical composition, etc., to adjust to the local soil and climate. Some introduced plants may only fully acclimatize if the environmental disparity is manageable. Even after acclimatization, further fine-tuning may be required for complete adaptation. When introduced plants are evaluated over multiple locations within similar agro-climatic zones, they encounter a more comprehensive range of local conditions. Some introduced lines may perform excellently in one location but fail or have reduced yields in other locations. Further selection helps retain only those lines that maintain stable performance across target environments. The genetic basis of adaptation also gets strengthened during this process. Desirable interactions may occur between introduced genes and local gene pools, generating new adapted varieties. Introducing essential adaptive genes from local cultivars into introduced genetic backgrounds can facilitate adaptation. Selection over generations enriches the gene frequency of locally adaptive alleles in the introduced germplasm.

The extent of acclimatization is determined by

a. The pollination mode: For example, when compared to self-pollination, cross-pollination results in more gene recombinations. Cross-pollination hence provides acclimation benefits over self-pollination.
b. The range of genetic variability present in the original population,
c. The duration of the life cycle of the crop and
d. Mutation

2.7 Utilization of Introduced Germplasm in Breeding Programs:

2.7.1 Strategies for incorporating introduced germplasm:

A. Hybridization and selection: Crossing elite lines with introduced donors exhibiting desirable traits and selecting progeny combining adaptation and novel alleles. For example, hybrids between Mexican dwarf and Indian bread wheat varieties.

B. Backcrossing: Repeatedly backcrossing an F1 hybrid with the recurrent parent and selecting for trait introgression at each generation. For instance, BC1 to BC6 generations were developed to transfer bacterial blight resistance from Oryza long staminate to cultivated rice.
C. Marker-assisted backcrossing: Incorporating molecular markers allows faster transfer of target traits/QTLs with minimal linkage drag. For example, marker-assisted backcrossing transferred drought QTL from wild soybeans to elite varieties.
D. Genomic selection: Harnessing genomic prediction models and high-throughput phenotyping to introgress traits/haplotypes from unadapted germplasm precisely. For instance, a disease resistance haplotype was introgressed from wild tomatoes into cultivars.
E. Wide hybridization and embryo rescue: Techniques like ovary/ovule culture enable crossing distant wild relatives, followed by selection and backcrossing. For example, wheat-rye hybrids were produced using these methods.

Here are some additional strategies that can be utilized for effectively incorporating introduced germplasm:

- Introgression libraries: Develop populations by backcrossing unadapted donors' multiple times to adapted recipients. Enables mining of population for various traits.
- Pre-breeding: Introgress traits into adapted, high-yielding breeding lines/varieties before direct use in variety development. Reduces linkage drag.
- Genetic mapping: Map traits from donors to identify best introgression lines retaining maximum recipient genome and minimizing linkage drag.
- Speed breeding: Use controlled environments to rapidly generate generations, aiding faster selection and recycling of elite traits/genes into adapted germplasm.
- Gene editing: Precisely introgress traits from unadapted donors into recipients using tools like CRISPR-Cas9 to overcome linkage issues.

2.7.2 Case Studies Highlighting Successful Utilization in Various Crops:

Here are some case studies highlighting the successful utilization of introduced germplasm in various crops through plant breeding:

- Rice: - IR36 - Developed in the 1970s at IRRI by crossing Peta and Dee-Geo-Woo-Gen, it contained genes for short stature and high yield. It was widely adopted across Asia, increasing yields.
- Wheat: - Kalyan Sona - An Indian variety developed in the 1980s by crossing Lerma Rojo 64 with Sonalika. It contained dwarfing genes and rust resistance from the CIMMYT introduction, along with good adaptation.
- Maize: - Shaktiman 1 - A quality protein maize variety released in 2000 in India. It contained the opaque2 gene from CIMMYT introductions, which increased lysine and tryptophan.
- Potato: - Kufri Jyoti - Bred in the 1970s at IIHR by crossing local cultivar with Diacol Capiro from CIP, it contained resistance to late blight and tuber yield, becoming the most popular variety.

- Cassava: - MCol 22 - Released in the 1970s in Nigeria, it contained high yield and mosaic disease resistance from Introduction. It was widely adopted across Africa.
- Sweet potato: - HPS-1 - A variety developed in India in the 1990s through an introduction from ICRISAT. It contained resistance to sweet potato weevil and scurf, boosting production.
- Chickpea: - JG 11 - An Indian variety from the 1970s containing wilt resistance from an ICRISAT introduction, it was widely grown due to higher, stable yields.
- Pigeonpea: - BSMR 736 - Released in the 1980s in India, it contained short-duration genes from ICRISAT material, suiting multiple cropping systems.
- Pearl millet: - HB 3 - A dual-purpose hybrid developed in the 1970s in India using introductions from ICRISAT and IITA. It contained downy mildew resistance and higher fodder and grain yield.

These case studies highlight how introduced traits were successfully integrated into adapted cultivars, boosting productivity.

Systematic evaluation and selection aided the utilization of exotic germplasm for tangible gains.

2.8 Merits and Demerits of Plant Introduction:

2.8.1 Merits of Plant Introduction:

- Augments genetic diversity - Introduction expands the gene pool for breeding programs by incorporating novel traits and alleles from diverse sources. This enhances the potential for crop improvement.
- Accelerates breeding progress - Novel traits from introductions help breeders develop varieties with higher yields, wider adaptability, and resistance to stresses faster than sole reliance on existing diversity.
- Broadens genetic base - Introduced germplasm from centers of origin and diversity broadens the narrow genetic base of crops resulting from domestication and modern breeding. This adds resilience against threats.
- Fulfills specific breeding objectives - Targeted introductions from diverse ecogeographic regions allow the incorporation of traits adapted to abiotic and biotic stresses of intended target environments.
- Facilitates development of hybrid varieties - Introduction aids hybrid breeding by providing diverse parental lines differing maximally in desired traits. Hybrids harness heterosis for increased yields.
- Enables genetic mapping and gene discovery - Introduced germplasm with significant trait variations helps map genes/QTLs underlying key traits through association mapping.
- Supports pre-breeding programs - Exotic germplasm serves as a source of novel traits and alleles that can be transferred to elite breeding lines through pre-breeding to expand trait diversity.
- Advances genetic gain - Continuous Introduction coupled with selection accelerates genetic gain per unit of time and area compared to sole reliance on existing diversity.

- Strengthens national genebank collections - Well-curated ex-situ collections safeguard introduced diversity and make it available for future breeding as needs change.
- Promotes international cooperation - Germplasm exchange fosters scientific cooperation, networking, and capacity building among countries and research institutions globally.
- Supports climate change adaptation - The introduction provides traits for developing stress-resilient varieties able to maintain production under climate change through broader adaptation.
- Conserves crop wild relatives - Collecting wild species aids their ex-situ conservation and provides traits like resistance that may become valuable.
- Contributes to food security - Varieties developed using introduced germplasm help boost production and ensure stable supplies to support the growing global population.
- Advances in crop production - Novel introductions have significantly contributed to past green revolutions and can support future production increases needed to meet rising demands.
- Inspires new crop development - The introduction of wild species leads to the development of new domesticated crops by broadening the plant kingdom available for agriculture and nutrition.
- Supports underutilized crop improvement - Targeted Introduction expands diversity available for enhancing underutilized nutritious crops of marginalized communities.
- Promotes sustainable intensification - Introduction coupled with breeding supports sustainable systems through stress-adapted varieties that ensure high yields with a lower environmental footprint.
- Inspires basic research - Introduced germplasm stimulates fundamental research in evolution, genetics, genomics, adaptation, and plant-environment interactions.
- Supports livelihoods - Varieties developed using introduced traits boost smallholder incomes and livelihood security through higher, more stable production.
- Conserves agrobiodiversity - Introduction expands the base of crop genetic resources maintained both on-farm and in gene banks, aiding global agricultural biodiversity conservation.

2.8.2 Demerits of Plant Introduction:

- Risk of introducing diseases/pests - Germplasm carries biosecurity risks of inadvertently introducing new pathogens, weeds, or insect pests that impact agriculture and natural ecosystems.
- Escaped introduced species become invasive - In some cases, introduced plants may escape cultivation and become invasive weeds, disrupting native biodiversity.
- Requires quarantine and testing - Strict quarantine evaluation and testing are needed to screen introductions for diseases, pests and weed potential, involving time and resources.
- Poor adaptation to new environments - Not all introductions may adapt to local growing conditions due to differences in abiotic and biotic stresses compared to source environments.
- May displace local landraces - High-yielding introduced varieties could replace locally adapted landraces, threatening agrobiodiversity.

- Genetic contamination can occur - Pollen/seed dispersal from introduced materials can genetically contaminate local landraces and wild relatives.
- Outbreeding depression - Crossing exotic germplasm with locals may lead to loss of hybrid vigor and local adaptation through outbreeding depression.
- May cause allergies in susceptible individuals - Rarely, some introductions cause new allergies in recipient regions.
- Requires long evaluation periods - It takes several crop generations and locations to evaluate introduced materials for adaptation before release fully.
- May cause genetic erosion - Widespread adoption of introduced varieties could undermine on-farm conservation of native landraces.
- Needs biosafety regulations - Strict laws are required to prevent the unintended spread of transgenic introductions to minimize biosafety and biopiracy risks.
- Requires capacity building - Developing countries need investment in human and infrastructural resources for practical Introduction, evaluation, and utilization.
- Demands international cooperation - Complex agreements govern germplasm exchange between countries to ensure safety, access, and benefit-sharing involving negotiations.
- May cause socio-economic impacts - Large-scale adoption of introductions could impact rural livelihoods dependent on native landraces.
- Requires long-term funding - Sustained long-term funding support is needed for continual Introduction, pre-breeding, and utilization given crop generation intervals.
- Needs adaptation research - Introduced materials may require additional research to develop agronomic practices and post-harvest technologies for local adaptation.
- May cause yield drag initially - First-generation hybrids or varieties involving exotic parents may have lower yields than locals until adapted through selection.
- Demands infrastructure - Well-equipped gene banks, screening facilities, laboratories, and human resources are essential but investment-intensive.
- Has biosafety monitoring costs - Introductions require long-term surveillance to prevent the spreading of diseases, weeds, or invasiveness even after release.
- Ethical concerns over wild species use - Germplasm collection and movement of some wild crop relatives across nations involve ethical considerations.

We know the potential and challenges associated with plant introduction initiatives. While there are biosecurity risks that must be addressed, it is essential to recognize the benefits that come with promoting variety and advancing society. With careful management and foresight, the advantages of plant introduction outweigh the drawbacks. It helps to strengthen the adaptability of current plant species while securing possibilities for addressing future issues that we may not yet anticipate.

Therefore, in order to support future generations, plant introduction should be conducted responsibly.

2.9 Future Directions and Innovations:

A. Leveraging Genetic Diversity: An area of utmost significance for future scientists is the exploration and utilization of genetic diversity in plant introduction. Our planet is home to an extraordinary array of plant species, each harboring unique genetic traits that can contribute to developing resilient and high-yielding crop varieties. Future scientists should prioritize the collection and preservation of diverse plant germplasm. Utilizing advanced techniques such as genomics, molecular markers, and high-throughput sequencing they can unlock the vast potential of these genetic resources.

B. Harnessing Genomics: However, new genomic technologies provide greater efficiency in adding essential traits. Using high-density marker maps and sequencing diverse germplasm, researchers can identify new alleles. Also, genomic selection indexes allow the selection of multiple traits at a time to speed up the pre-breeding process. In addition, using gene editing instruments such as CRISPR is effective in overcoming linkage drag and introducing traits from wild species more easily.

C. Leveraging Modern Breeding Methods: Doubled haploid production, speed breeding, and phenomics platforms are innovative techniques that can significantly accelerate the development of varieties involving introduced germplasm. These methods allow for the rapid generation of homozygous lines, faster plant growth, and efficient phenotypic characterization, respectively.

D. Additionally, molecular marker-assisted recurrent selection schemes enable the stacking of favorable alleles faster, enhancing the breeding process. To ensure the widespread adaptability of introduced varieties, it is crucial to conduct genotype x environment x management interaction studies that capture diverse agro-climatic zones. These studies help identify the most suitable varieties for different environments, optimizing their performance and impact.

E. Prioritizing Climate Resilience: Climate change poses daunting challenges to global agriculture, impacting crop productivity and geographical distribution. Future scientists must prioritize the development of climate-resilient crop varieties through plant introduction. This necessitates identifying and introducing genetic traits that tolerate drought, heat, salinity, and other environmental stresses. Cutting-edge technologies such as phenomics and remote sensing can aid in the screening and selecting promising plant materials for adaptation to changing climate conditions.

F. Fostering Collaboration and Knowledge Sharing: Collaboration and knowledge sharing are pivotal for advancing plant introduction. Future scientists should foster interdisciplinary collaborations, both within academia and with stakeholders in the agricultural sector. By pooling together expertise from diverse fields such as genetics, agronomy, biotechnology, and social sciences, we can accelerate innovation and address complex agricultural challenges. Additionally, promoting open-access publication platforms, conferences, and research networks will facilitate the dissemination of knowledge and exchange of ideas.

2.10 Conclusion:

The future of plant introduction rests with aspiring scientists and future generations. By embracing new directions and innovations, we can pave the way for sustainable and resilient agriculture.

Leveraging genetic diversity, embracing precision breeding, prioritizing climate resilience, promoting agroecological approaches, and fostering collaboration and knowledge sharing are essential steps for future scientists to undertake. Let us forge ahead with determination and a sense of responsibility, ensuring that our efforts contribute to a better future for agriculture and our planet.

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