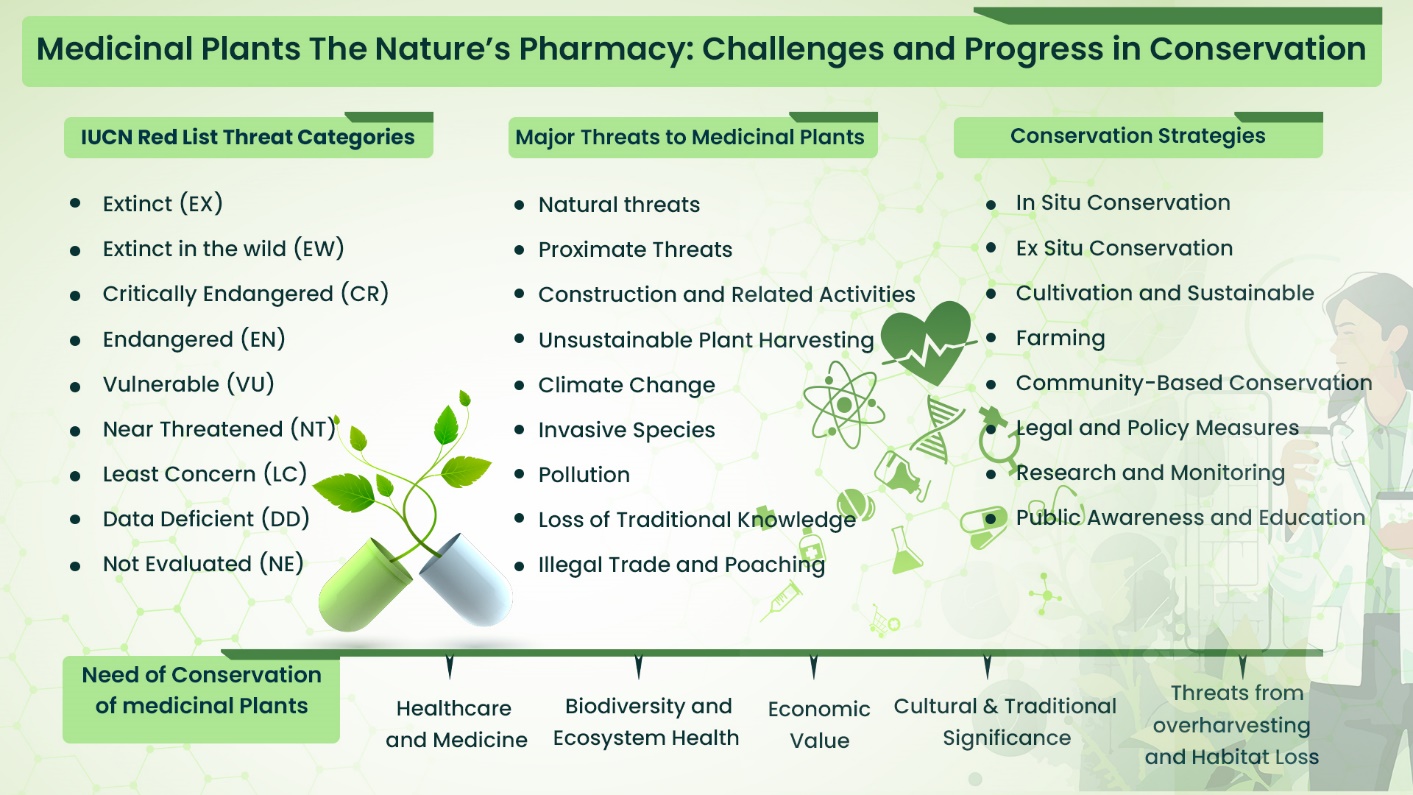
**Medicinal Plants the Nature’s Pharmacy:** **Challenges and Progress in Conservation**

**Abstract**

Nature enriched us with abundant resources and their benefits. Plants are one of them to benefit the human population in all the aspects. Conserving medicinal plants is essential and crucial for several reasons e.g. for supporting healthcare, sustaining biodiversity, stability of the environment, preserving cultural practices, and protecting economic livelihoods. Losing them can disrupt ecological balance. Moreover, medicinal plants are the source of numerous modern pharmaceuticals. They provide chemical compounds essential for developing new medicines to treat various health conditions. Conserving them ensures a continuous supply of raw materials for drug research and development. Some plants have important nutritional constituents so they are recommended for their therapeutic values. Needless to say, that conservation will provide income through harvesting, cultivation, and trade. Thus, protecting these plants will help sustaining the livelihoods of people who depend on them. Medicinal plants have evolved unique properties to survive in different environments. Studying and conserving them can provide insights into developing more resilient crops and natural solutions to health challenges. Many plant species remain unexplored for their medicinal properties. The extinction of these plants could mean the loss of potential cures for diseases that we have yet to discover.

Plants /Botanical resources share a very strong and reciprocal relationship with humans. Plants have diversified potential to fulfill the human demands. Nature has provided us lots of medicinal plants and they are considered as a rich resource of phytochemicals which serve as raw material in drug development industries. Science is also hopeful for the development of biofuels as a future replacement to fossil fuels, such as coal, oil and gas. Plants provide many byproducts of commercial importance as well as they are necessary for healthy functioning of biosphere. Apart from these uses, plant resources can be considered as integral part of a large inter-dependent ecosystem that encompasses the abiotic and the biotic components of life. Due to ever-increasing population, over exploitation of plant resources had been started leading to the loss or extinction of plant resources in nature. Hence, it is very important and need of time to develop suitable conservation strategies for sustainable use of these important plant resources.

**Key Words-** Botanical resources, Phytochemicals, Therapeutic-values, Biofuels, Conservation

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**Graphical Abstract**

**1.0 Introduction**

All the materials and substances that are available naturally and can be exploited for human use are referred as natural resources. Their conservation and sustainable use are essential to ensure their ongoing access and availability for future generations. Increasing human interactions lead to the loss of plant resources by causing their habitat loss, species loss, degradation and fragmentation. Nature has bestowed India with an enormous wealth of medicinal plants, due to which the country is often referred as ‘Medicinal Garden’ or ‘Botanical Garden’ of the world (1)**.** Comment given by Wood ‘The race to save biodiversity is being lost, and it is being lost because the factors contributing to its degradation are more complex and powerful than those forces working to protect it.’ (2)The conservation of plant diversity has received considerably less attention than the conservation of animals, perhaps because plants lack the popular appeal of many animal groups (3). As a result, plant conservation is greatly under-resourced in comparison with animal conservation (4).

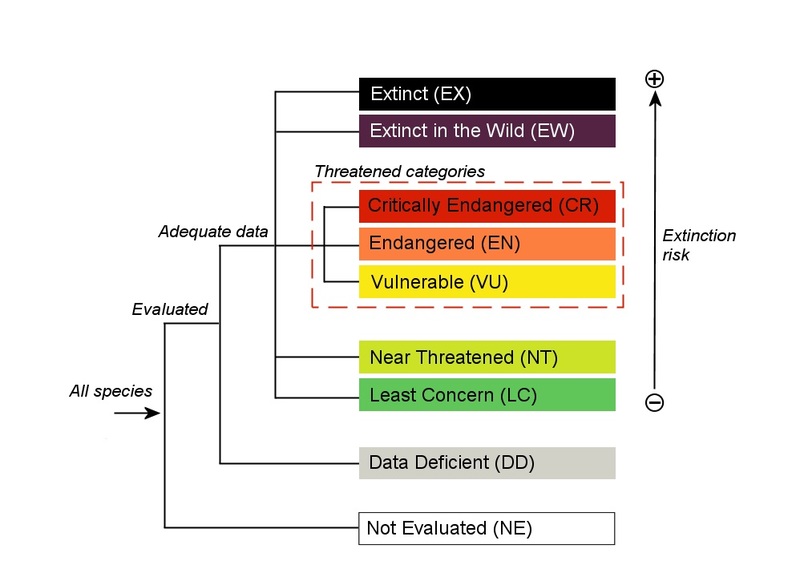


Fig. 1 IUCN Red List threat categories and their risk level

(Source: IUCN 2022)

With an increasing sense of urgency, resources conservation is required and needful steps have to be taken to conserve the resources for future generations and proper functioning of our ecosystem.

India is floristically rich and is globally recognized as one of the 12 megadiversity countries (5) accompanied by 10 biogeographic regions (6) along with more than 40 sites that are well-known for their genetic diversity and high endemism, in their updated list of Earth’s biodiversity hotspots, involved 2 from India.

In this review emphasis is given for conserving the medicinal plants, because they are the foundation of traditional and modern medicine. [Many pharmaceuticals are derived from plant compounds, and preserving these plants ensures we continue to have access to potential new treatments and cures](https://www.mdpi.com/2071-1050/16/14/5841) (Zusiphe et al 2024) (7). Moreover, Medicinal plants contribute to the overall biodiversity of ecosystems. Protecting them helps maintain ecological balance and supports the health of other species within the ecosystem. Thus, there arises a need for healthy populations of medicinal plants that will contribute to the stability of ecosystems, which in turn supports soil health, water quality, and climate regulation. One of the most important aspect of conserving medicinal plants is that it will assist in economic stability as medicinal plants can be a source of income for local communities through sustainable harvesting and cultivation. This economic benefit can incentivize conservation efforts (Wani et al 2021) (8). Conserving these plants helps preserve cultural knowledge and practices that have been passed down through generations and medicinal plants will also play a role in food security and nutrition, providing essential nutrients and health benefits to communities

**2.0** **Major Threats to Plant Resources-**

Our planet has different types of climatic and altitudinal variations along with undulating topography and various kind of ecological habitats. These conditions attributed in development of rich flora of different kind of medicinal plants which serve as raw material for pharmaceutical industries and traditional medicine systems. With the growing pressure for medicinal plants, most of which is still experienced by wild collection, consistent pressure is generated on the existing resources which finally leads to the reduction of some forest species and also at the same time the forest land suffers the loss of its natural fora at an alarming rate (9).

In order to control this situation, various steps have been taken such as commercial cultivation and habitat conservation, to set up the natural reserves and to implement the laws for exporting the plants which should be kept under control (10). With increasing awareness people became more aware regarding health and medications they use. Now a day’s people rely on herbal medicines. The use of medicinal plants is growing speedily globally with the growing pressure for natural health products, herbal drugs, and secondary metabolites of medicinal plants (11,12). Loss of habitat, degradation, fragmentation, invasive species, pollution, overexploitation for byproducts and adverse climatic changes are some major threats to plant diversity. Now a days many plant species are on the urge of extinction. On global scale plant conservation is a tedious task.it can be managed by proper awareness, knowledge, planning, implementation and back-up for filling the gaps. Due to habitat destruction and overharvesting, approximately 15,000 species are at risk of extinction, and with the growing human population and plant utilization, around 20% of the wild resources have almost already been depleted (13,14).With the rapid loss of biodiversity and habitat destruction, the threat of vanishing of medicinal plants has been increased globally, and this menace has been well-known for decades particularly in India, Nepal, Tanzania, Uganda, and China (11,15,16).Top of FormBottom of Form

Major threats to plant resources, especially medicinal plants, include the following:

**Natural Threats** – Many types of natural threats like land slide, volcanic eruptions, hurricanes, climatic changes cause loss of plant species growing in that particular area. In last few decades due to increase in temperature and other factors there has been increase in forest fires that is destroying large areas of vegetation, leading to the loss of plant resources. Climate change and land-use changes have made some areas more prone to frequent and intense wildfires.

**Proximate Threats** – Loss of habitat is very important proximate threat for plant extinction. There are some other threats also exist like land use in various ways also cause loss of plant diversity. Expansion of agriculture, intensification of agriculture, degradation of cultivated land, inappropriate way of grazing, burning, hunting, afforestation with exotic species. The conversion of diverse ecosystems into agricultural lands, especially for monoculture crops, reduces plant diversity and contributes to habitat loss. Monocultures also increase vulnerability to pests, diseases, and climate fluctuations.

**Construction and related activities** – urban expansion and other construction, mining and quarrying. Moreover, Deforestation, urbanization, logging, and infrastructure development has lead to the loss of natural habitats, which threatens plant populations. Forests, wetlands, and grasslands, which harbor diverse plant species, are particularly vulnerable to Habitat Destruction. Rapid road construction, mining, and industrial development lead to habitat fragmentation, reducing plant populations and disrupting ecosystems.

**Unsustainable Plant Harvesting** – Harvesting of trees for timber, wood for furniture and other purposes and harvesting for their products also causing their depletion because harvesting rates are greater than recovery rates. Over-harvesting and unsustainable harvesting of medicinal plants, often driven by high demand in local and global markets, has also lead to a rapid decline in plant populations, making it difficult for them to regenerate

**Climate Change**: Changes in temperature, rainfall patterns, and extreme weather events impact plant growth, flowering, and seed production. Climate change also alters ecosystems, making it harder for plants to adapt and survive in their native habitats.

**Invasive Species** – There are many invasive species which do not allow other important plants to grow and they disappear from their habitat. Non-native plant species can invade and outcompete native plants for resources such as water, nutrients, and sunlight. This competition can lead to the decline or extinction of indigenous plant species.

**Pollution**: Industrial activities, agricultural runoff, and the use of pesticides and herbicides can contaminate soil and water, affecting plant health and growth. Air pollution can also impact photosynthesis and overall plant vitality.

**Loss of Traditional Knowledge**: As indigenous communities face displacement or adopt modern lifestyles, traditional knowledge about medicinal plants and their conservation is at risk of being lost, leading to a decline in the sustainable use of these resources.

**Illegal Trade and Poaching**: The black-market trade in rare and endangered plants, often driven by the high value placed on certain species for medicinal, ornamental, or culinary purposes, poses a significant threat to plant conservation.

Addressing these threats requires a combination of Conservation-Efforts, sustainable harvesting practices, policy regulations, community involvement, and the integration of traditional knowledge with modern conservation strategies.

**3.0 Conservation of Medicinal Plants**

A natural resource is one that is offered by nature without any human involvement. The soil, minerals, forests, water, etc. are examples of a county’s natural resources. Complexity and costs of managing sustainable use of wild populations increase markedly with an increasing number of uses and resource users. The conservation of biodiversity is a global issue, often predicated by governments and communities on the intrinsic value of biodiversity (17). There is also awareness that biodiversity can provide financial returns (18). These values were traditionally tied to ethnobotanical uses of biodiversity for food, fiber, medicines and cultural reasons (19). The present-day cry of environmental degeneration, fragmentation, ecological genocide, genetic erosion, and extinction as well as destruction of our biological heritage is the result of inaction (20). Medicinal plants and their natural habitats are threatened due to overexploitation. The conservation of the endangered medicinal plant species in their natural habitats and to achieve their sustainable exploitation in less vulnerable areas is our utmost goal (21).

As per Ayurvedic Pharmacopoeia of India, around 396 plant species are used in different Ayurvedic formulations. Out of these, 30 species have been included in the Red Data Books of Indian Plants published by the BSI to prioritize them for conservation (Annexure 1).  
Conservation of medicinal plants is today’s utmost requirement because of their multipurpose use in herbal medicines, pharmaceuticals and cosmetics. Many of them are on the urge of extinction or already extincted.

Conserving medicinal plants is vital to preserve biodiversity, support traditional knowledge, and ensure sustainable use. Here are some effective conservation strategies:

1. **In Situ Conservation**:
   * **Protected Areas**: Establishing and managing national parks, wildlife reserves, and botanical sanctuaries to conserve medicinal plants in their natural habitats.
   * **Sacred Groves**: Preserving areas with cultural or religious significance where medicinal plants naturally thrive, often managed by local communities.
   * **Sustainable Harvesting**: Implementing guidelines and regulations to ensure that harvesting practices do not deplete plant populations, allowing plants to regenerate.
2. **Ex Situ Conservation**:
   * **Botanical Gardens and Arboreta**: Growing and maintaining medicinal plants outside their natural habitat in botanical gardens, where they can be studied and propagated.
   * **Seed Banks and Gene Banks**: Collecting and storing seeds, plant tissues, or genetic material for future use, research, or reintroduction into the wild.
   * **Plant Tissue Culture**: Using laboratory techniques to propagate medicinal plants, especially those that are rare, endangered, or difficult to cultivate.
3. **Cultivation and Sustainable Farming**:
   * **Cultivating Medicinal Plants**: Encouraging the cultivation of medicinal plants on farms to reduce pressure on wild populations and provide a sustainable source of raw materials.
   * **Agroforestry Systems**: Integrating medicinal plant cultivation with other crops or trees to create sustainable, diverse farming systems that mimic natural ecosystems.
   * **Organic and Sustainable Farming Practices**: Promoting farming methods that avoid harmful chemicals, ensuring the health of both the plants and the environment.
4. **Community-Based Conservation**:
   * **Empowering Local Communities**: Involving local communities in conservation efforts by providing them with training, resources, and economic incentives to protect medicinal plants.
   * **Traditional Knowledge Integration**: Encouraging the use of indigenous knowledge about medicinal plants, which can guide sustainable harvesting and conservation practices.
   * **Benefit-Sharing Programs**: Establishing mechanisms to share the benefits derived from medicinal plants, such as profits from sales or royalties, with the communities that protect and cultivate them.
5. **Legal and Policy Measures**:
   * **Legislation and Regulations**: Implementing laws to protect endangered medicinal plants, regulate harvesting, and prevent illegal trade.
   * **CITES (Convention on International Trade in Endangered Species)**: Ensuring that international trade in medicinal plants is monitored and controlled to prevent over-exploitation.
   * **Intellectual Property Rights**: Protecting the traditional knowledge of indigenous communities through intellectual property rights, ensuring they benefit from the use of their knowledge.
6. **Research and Monitoring**:
   * **Research on Medicinal Plant Biology**: Studying the growth, reproduction, and ecological requirements of medicinal plants to inform conservation strategies.
   * **Ethnobotanical Research**: Documenting traditional uses of medicinal plants to preserve knowledge and identify valuable species.
   * **Monitoring Populations and Habitats**: Regularly assessing the status of medicinal plant populations and habitats to identify threats and adapt conservation strategies.
7. **Public Awareness and Education**:
   * **Raising Awareness**: Educating the public, policymakers, and stakeholders about the importance of medicinal plants and the need for their conservation.
   * **Training Programs**: Providing training for farmers, harvesters, and local communities on sustainable harvesting and cultivation practices.
   * **Promoting Sustainable Use**: Encouraging consumers to use sustainably sourced medicinal plant products and supporting businesses that adhere to ethical practices.

By combining these strategies, we can create a comprehensive approach to conserving medicinal plants, ensuring their availability for future generations while supporting biodiversity and the well-being of communities that rely on them.

**Conservation Strategies used for medicinal plants**

For conservation of plants especially medicinal plants effective strategies should be implemented. Integrated methods of conservation as well as sustainable harvesting methods, developing local awareness are also required for conservation of medicinal plants. The conservation of medicinal plants can be approached by implementation of scientific techniques along with social awareness and actions.

There are three scientific techniques of conservation of medicinal plants.

1. Legislation
2. In-situ conservation
3. Ex-situ conservation

**Legislation – Conservation of medicinal plants is covered under existing laws pertaining to forestry.** No separate policies or regulations are there for conservation of medicinal plants growing in forests in India. The Government has taken a number of steps for the conservation of medicinal plants. Following are the laws formulated by government of India for conservation of forests which directly or indirectly protects the wild flora of medicinal plants.

1. Forest Act, 1927
2. Wildlife (Protection) Act 1972
3. Forest (Conservation) Act, 1980
4. Environment Protection Act, 1986
5. National forest policy, 1988
6. National biodiversity act, 2002
7. The scheduled tribes and other traditional forest dwellers act, 2006

Export of 29 species of medicinal plants is regulated under the EXIM policy. A Wildlife Crime Bureau has since been established to check illegal trade and smuggling in wildlife including medicinal plants.

**In-situ conservation –**

Conservation of a given species in its natural habitat or in the area where it grows naturally is known as in-situ conservation. ii. It includes Gene bank/Gene sanction, Biosphere reserves, national parks, sacred sites, Sacred grooves etc. iii. It is only in nature that plant diversity at the genetic, species and eco-system level can be conserved on long-term basis. It is necessary to conserve in distinct, representative biogeographic zones inter and intra-specific genetic variation. (22). Indigenous plants and natural communities can be preserved by in -situ conservation. In addition, in situ conservation increases the amount of diversity that can be conserved (23) and also strengthens the link between resource conservation and sustainable use (24). Establishment of biosphere reserves, national parks, wild life sanctuaries, sacred groves and other protected areas forms examples of ‘in-situ’ methods of conservation (22). Most medicinal plants are endemic species, and their medicinal properties are mainly because of the presence of secondary metabolites that respond to stimuli in natural environments, and that may not be expressed under culture conditions (25,26). In situ conservation of whole communities allows us to protect indigenous plants and maintain natural communities, along with their intricate network of relationships (27). In-situ conservation efforts worldwide have focused on establishing protected areas and taking an approach that is ecosystem-oriented, rather than species-oriented (28). Successful in -situ conservation depends on rules, regulations, and potential compliance of medicinal plants within growth habitats (29) (30). Throughout the globe in situ conservation has concentrated on building protected areas and adopting an ecosystem-based approach, rather than on species (31).

**Natural reserves** - The degradation and destruction of habitats is a major cause of the loss of medicinal plant resources (32). Natural reserves are protected areas of important wild resources created to preserve and restore biodiversity (33). Conserving medicinal plants by protecting key natural habitats requires assessing the contributions and ecosystem functions of individual habitats (34).

**Wild Nurseries-** A wild nursery is established for species-oriented cultivating and domesticating of endangered medicinal plants in a protected area, natural habitat, or a place that is only a short distance from where the plants naturally grow (35,36,37)Although the populations of many wild species are under heavy pressure because of overexploitation, habitat degradation and invasive species, wild nurseries can provide an effective approach for in situ conservation of medicinal plants that are endemic, endangered, and in-demand (38,39).Some complementary methods of in-situ conservation are also in practice-

1. **On-farm conservation**: On-farm conservation involves the maintenance of traditional varieties by farmers in agroecosystems. A major focus for the conservationist or development practitioner will be to encourage the farmer to continue cultivation of traditional varieties and this may be achieved by niche marketing, seed shows, participatory traditional variety improvement or even financial incentives (40).
2. **Home gardens** are found in both rural and urban areas in predominantly small-scale subsistence agricultural systems (41). Relying on research and observations on home gardens in developing and developed countries in five continents, Ninez formulated the following definition (42). The household garden is a small-scale production system supplying plant and animal consumption and utilitarian items either not obtainable, affordable, or readily available through retail markets, field cultivation, hunting, gathering, fishing, and wage earning.
3. **Zero energy input-based** concept of Para frost conservation is existing in the Himalayan region naturally. This area is covered with snow.

**Ex- situ conservation-** This is the conservation outside the native habitat. It gives protection to populations in danger of destruction, replacement or deterioration. Ex situ conservation is not always sharply separated from in situ conservation, but it is an effective complement to it, especially for those overexploited and endangered medicinal plants with slow growth, low abundance, and high susceptibility to replanting diseases (43,44,45). Ex situ conservation aims to cultivate and naturalize threatened species to ensure their continued survival and sometimes to produce large quantities of planting material used in the creation of drugs, and it is often an immediate action taken to sustain medicinal plant resources (46,47). Approaches to ex situ conservation include methods like seed storage, DNA storage, pollen storage, in vitro conservation, field gene banks and botanical gardens (48). Field gene banks provide easy access to conserved material for use, they run the risk of destruction by strategies using the tools of biotechnology are increasingly being applied towards conservation of plant genetic resources. These include (a) in vitro conservation (b) in vitro propagation and re- introduction of plants to their natural habitats, and (c) molecular marker technology. Several in vitro techniques have been developed for storage of vegetatively propagated and recalcitrant seed producing species (49). In general, they fall under two categories: (i) slow growth procedures, where germplasm accessions are kept as sterile plant tissues or plantlets on nutrient gels; and (ii) cryopreservation, where plant material is stored in liquid nitrogen. Slow growth procedures provide short- and medium-term storage options, while cryopreservation enables long- term storage of the plant material (50).

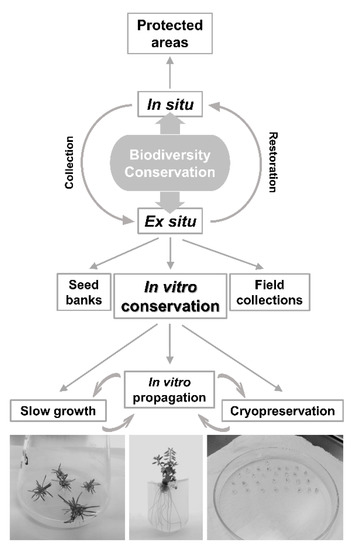


Fig. 2  Schematic representation of different conservation strategies

Source- (51)

**Field gene bank (field repository/clonal repository)**

1. (Gene Bank: Storage in the form of seed (Base collection at -20°C; Active collection at +4°C to l0°C). The three national gene banks have been established in India for ex situ conservation of medicinal and aromatic plants.
2. National Bureau of Plants Genetic Resources (NBPGR), New Delhi, under ICAR.
3. Central Institute of Medicinal and Aromatic Plants (CIMAP), Lucknow, Uttar Pradesh, under the Council of Scientific Industrial Research (CSIR), Ministry of Science and Technology, Government of India.
4. Tropical Botanical Gardens Research Institute, (TBGRI), Palode, Thiruvananthapuram (Kerala).
5. The conservation of genetic variability of cultivated plants and their wild relatives is the sole responsibility of the National Bureau of Plant Genetic Resources (NBPGR) that operates under the Indian Council of Agricultural Research (ICAR), Department of Agricultural Research and Education (DARE) (22).



Fig.- 3 Field Gene bank

**National active germplasm sites** - The national active germplasm sites (NAGS) are the integral component of the network. There are presently 40 NAGS, which are based at ICAR institutes, (crop-based institutes for a specific crop or a group of crops) and SAUs. These are integral part of national plant biodiversity conservation network. The NAGS are entrusted with the responsibility of multiplication, evaluation, maintenance and the conservation of active collection and their distribution to bonafide users both at the national and international levels. These active/ working collections are stored in modules maintained at +4°C and 35- 40 per cent relative humidity (RH). Under these temperatures, seeds are expected to remain viable for 15 to 50years. For medium term storage, seed moisture content is brought down to 8 to 10 per cent. The NBPGR has a network of II regional stations located in different agroclimatic zones of the country to support the active germplasm conservation activities of the regions.

**Cryopreservation- “**Cryopreservation” is defined as the viable freezing of biological material and their subsequent storage at ultra-low temperatures (- 196C)” using liquid nitrogen.

**Seed preservation:** The seeds have been grouped broadly into two categories, based on their response to dehydration (52). A majority of them are desiccation tolerant, called ‘Orthodox’ and hence can be stored for longer durations. The second group of plant species are called ‘Recalcitrant’, whose seeds suffer injury on their drying and therefore cannot be stored at subzero temperatures (22).

**Pollen preservation:** Pollen storage was mainly developed as a tool for controlled pollination of synchronous flowering in plants, especially in fruit tree species. In addition, pollen storage has also been considered as an emerging technology for genetic conservation (53,54,55). Pollen can easily be collected and cryo-preserved in large quantities in relatively small spaces.

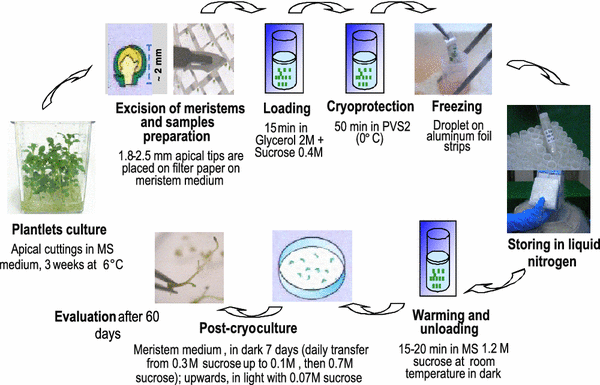


Fig. 4 Showing different steps of cryopreservation

Source: (56)

**In-vitro conservation and future prospects** - The essential prerequisites for an in vitro conservation programme are creation of special. facilities (culture rooms with controlled environment, artificial lights, laminar airflow cabinets, autoclave, etc. and trained scientists and technicians. (22) Any in vitro conservation programme primarily comprises two stages, first is in-vitro multiplication to make large number of plants, and second is in vitro storage. The material can be stored in the form of meristems, shoot tips, axillary buds, embryos, callus and cell suspension. In vitro gene banks are easy to maintain and often inexpensive provided effective storage systems are developed.

**DNA storage (Conservation at -20°C)-** Storage of DNA is widely applicable simple to carry out as well as the storage of DNA seems to be relatively easy and cheap. With the help of genetic engineering, it became possible to break down the barriers of transferring genes among species and genus. The development of genetic engineering has led to the feasibility of large-scale biosynthesis of natural products, and advancements in tissue culture and fermentation of medicinal plants have opened new avenues for the large scale and highly efficient production of desirable bioactive compounds. Tissue culture (including plant cell and transgenic hairy root culture) is a promising alternative for the production of rare and high-value secondary metabolites of medical importance (57). Micropropagation via tissue encapsulation of propagules can not only facilitate storage and transportation, but also promotes higher regeneration rates (58). When the amounts of normal seeds are insufficient for propagation, synthetic seed technology, defined as artificially encapsulated somatic embryos (or other tissues) could be used for cultivate in vitro or ex vitro, is a feasible alternative (59,60). Furthermore, breeding improvements can be carried out using molecular marker-based approaches applied at the genetic level, and the time required for breeding may be significantly shortened (57,58,59).

**Conclusion**

Different type of conservation strategies, management and sustainable utilization of medicinal plants are in practice, only a small portion of success has been achieved. Scientists and policymakers have to focus on new procedures and policies to protect our remaining wild medicinal plants to ensure their availability for future generations.

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