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Evolutionary History and Existing Diversity of Commercially Important *Eucalyptus* Species

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Abstract: ***Eucalyptus, a genus of flowering trees and shrubs from the Myrtaceae family, has a significant evolutionary history and pivotal role in India's biodiversity and commercial forestry. This review paper provides a comprehensive overview of the evolutionary journey, diversity, and commercial importance of Eucalyptus species in India. Originating from the Gondwanan supercontinent, Eucalyptus has adapted to various global environments over millions of years, including diverse Indian climates. India hosts a rich diversity of Eucalyptus species like Eucalyptus globulus and Eucalyptus tereticornis, which have become integral to the country's ecological and economic landscapes. The species' rapid growth, high wood density, and versatility make them commercially vital for timber, pulpwood, and essential oil production. Eucalyptus wood is highly valued in construction, furniture, and the pulp and paper industries, while its aromatic oils are utilized in pharmaceuticals, perfumes, and aromatherapy. Despite their economic benefits, Eucalyptus plantations pose ecological concerns, highlighting the need for sustainable management practices and careful species selection to balance commercial exploitation with conservation. This review underscores the necessity for ongoing research and conservation efforts to sustainably harness and preserve the valuable resources offered by Eucalyptus species, ensuring their continued contribution to India's forest ecosystems and economy for future generations.***

Keywords: Evolutionary history, Biodiversity, Commercial forestry, Sustainable management practices

1.History and origin

Eucalyptus is a tree native to Australia and surrounding regions. They were brought to the UK in seed form in 1774 to Kew. The seeds and specimens collected at this time were from the coastal areas where tolerance to frost was low. This meant that many collected plants did not survive the cold UK winters. Only in the mid-1800s, when seed from Tasmania was collected (from higher altitudes, colder regions), *Eucalyptus* plants started to survive here. It was then that they began to be grown as plantation trees, and it was only after WWII did an interest in Eucalyptus as an ornamental and foliage tree began. Since then, the importance of seed provenance to increase the hardiness of Gum Trees (collecting wild seeds from the coldest areas) has been recognized, and the selection of species available has improved. Many trials, hybridizations, and species selections later have left us with the knowledge of the trees that will best survive UK temperatures. *Eucalyptus* Trees are now a common sight in the UK as ornamental trees and plantation trees grown for firewood and biomass.

The evolutionary history of *Eucalyptus*, a genus of flowering trees and shrubs, spans millions of years and is intricately tied to the geological and climatic changes that have shaped the Earth's ecosystems.

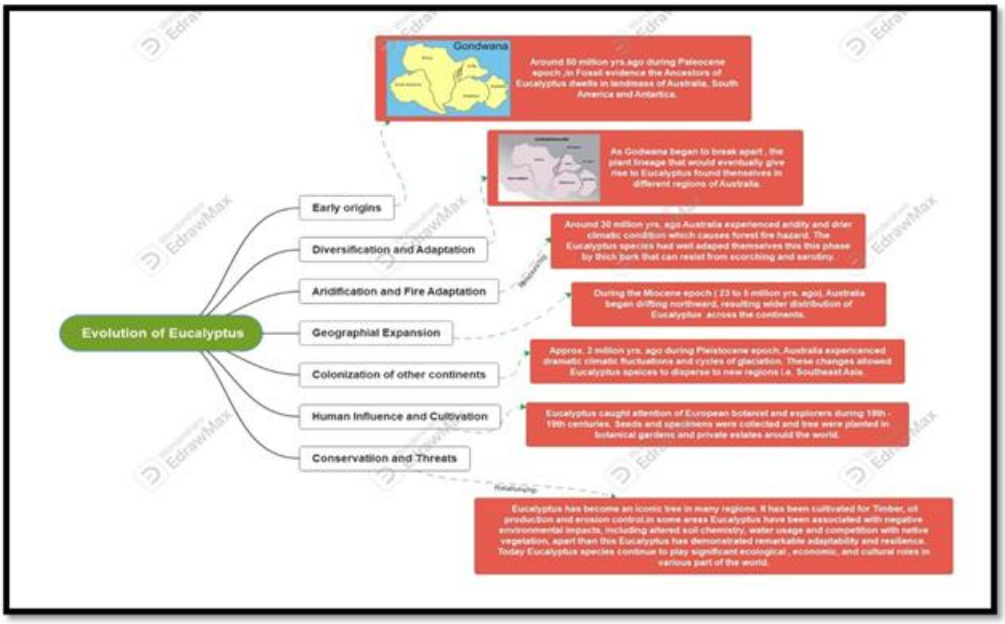

Figure 1: Evolution of Eucalyptus species (made by author) using *Wondershare Edrawma*

1.1Evolutionary history of Eucalyptus in the world:

Here is a detailed account of the evolutionary journey of Eucalyptus in the world:

a) Australia:

Australia is Eucalyptus's primary centre of diversity, with over 800 recognized species. They are found in diverse habitats, ranging from rainforests to deserts. Some well-known Australian species include *Eucalyptus regnans* (Mountain Ash), *Eucalyptus globulus* (Tasmanian Blue Gum), and *Eucalyptus camaldulensis* (River Red Gum).

b) Southeast Asia:

Eucalyptus species have naturalized and become widely cultivated in Southeast Asian countries such as Indonesia, Thailand, and Vietnam. They are often used for timber production, pulpwood, and reforestation efforts. Notable species include *Eucalyptus deglupta* (Rainbow Eucalyptus) and *Eucalyptus urophylla*.

c) South America:

Eucalyptus was introduced to South America in the mid-19th century, primarily in Brazil. Today, Brazil has the largest area of *Eucalyptus* plantations outside of Australia. Brazil's most common species cultivated for timber include *Eucalyptus grandis*, *Eucalyptus urophylla*, and *Eucalyptus dunnii*. Other South American countries, such as Chile, Argentina, and Uruguay, also have significant *Eucalyptus* plantations.

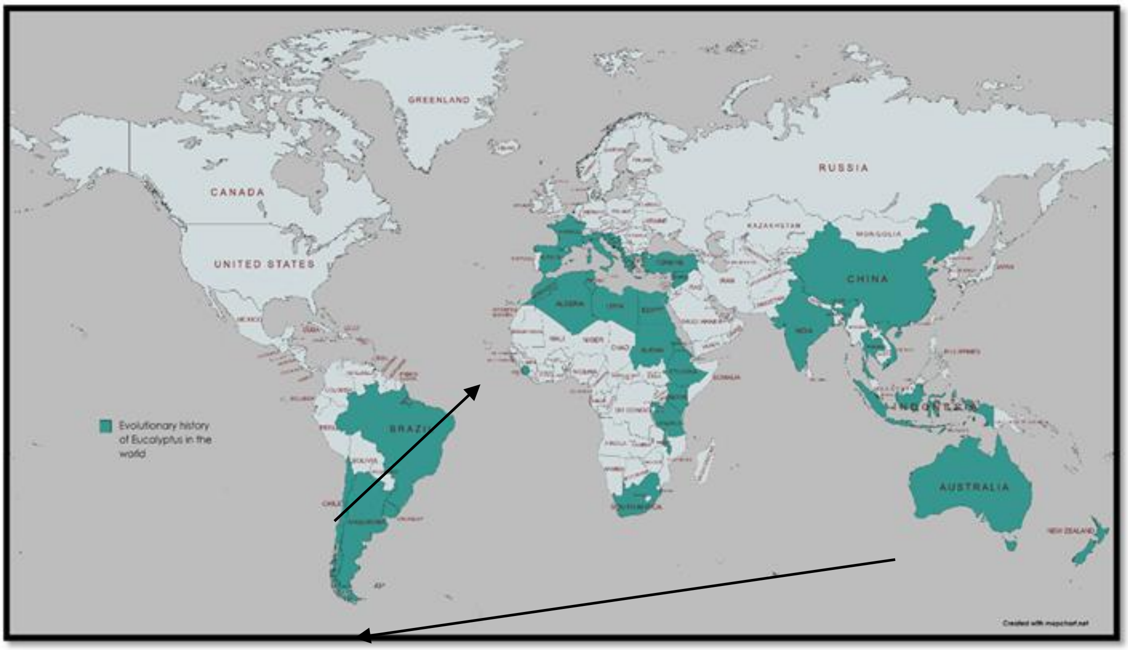

Figure 2: Evolutionary history of Eucalyptus in the world (made by Author) https://www.mapchart.net/world.html

d) Africa:

Eucalyptus species have been introduced and widely cultivated in several African countries for economic and environmental benefits. South Africa is a significant producer of *Eucalyptus* timber, with species like *Eucalyptus grandis*, *Eucalyptus saligna*, and *Eucalyptus nitens* commonly grown. Other African countries, including Kenya, Tanzania, and Ethiopia, cultivate *Eucalyptus* for timber, fuelwood, and agroforestry purposes.

e) Mediterranean Region:

Eucalyptus species have been introduced to Mediterranean countries, such as Spain, Portugal, Italy, and Greece, where they have adapted well to the climate. *Eucalyptus globulus* is commonly cultivated for timber, essential oil production, and erosion control in these regions.

f) North America:

In North America, *Eucalyptus* species have been planted in various regions with suitable climates, primarily in California, Florida, and parts of the southern United States. The most well-known species is the *Eucalyptus globulus*, the Blue Gum, which has become naturalized in some areas.

g) Other Regions:

Eucalyptus species have been introduced to other parts of the world, including India, China, New Zealand, Hawaii, and the Pacific Islands. These introductions have been primarily for timber production, erosion control, and ornamental purposes.

It's important to note that the exact number and distribution of *Eucalyptus* species worldwide may vary as taxonomic revisions and discoveries continue to occur. Nonetheless, *Eucalyptus* remains one of the most diverse and globally distributed genera of flowering plants.

2.Existing diversity and commercial Eucalyptus

The evolutionary history of the existing diversity and commercially important *Eucalyptus* species in India is intertwined with their introduction and subsequent cultivation in the country. Here is an overview of the evolutionary journey of these species:

a) Introduction and Early Cultivation:

Eucalyptus species were first introduced to India during the colonial era in the late 18th century. British botanists and foresters recognized the potential of these species for timber production and afforestation efforts. The initial plantings focused on species like *Eucalyptus terticornis* and *Eucalyptus grandis*, which adapted well to the Indian climate and soil conditions.

b)Naturalization and Adaptation:

The introduced Eucalyptus species gradually naturalized and adapted to various regions of India. They demonstrated a remarkable ability to thrive in diverse environments, including the Western Ghats, Eastern Ghats, Nilgiri Hills, Deccan Plateau, and parts of northern and northeastern India. This adaptability contributed to their widespread cultivation and subsequent diversification.

c) Species Diversification:

As Eucalyptus plantations expanded in India, efforts were made to diversify the species cultivated. Several commercially important *Eucalyptus* species were introduced to cater to specific purposes and market demands. Some notable species include:

i. ***Eucalyptus camaldulensis*** (River Red Gum): This species is known for its adaptability to waterlogged conditions and is commercially significant for timber production, fuelwood, and agroforestry.
ii. ***Eucalyptus tereticornis*** (Forest Red Gum): Widely cultivated for its fast growth rate, high-quality timber, and potential for pulpwood and agroforestry.
iii. ***Eucalyptus citriodora*** (Lemon-scented Gum): This species is valued for its lemon-scented leaves, which are used in essential oil production for perfumes, insect repellents, and aromatherapy.
iv. ***Eucalyptus globulus*** (Tasmanian Blue Gum): Introduced for its timber and pulpwood, it has become naturalized in some regions and is cultivated in parts of India.

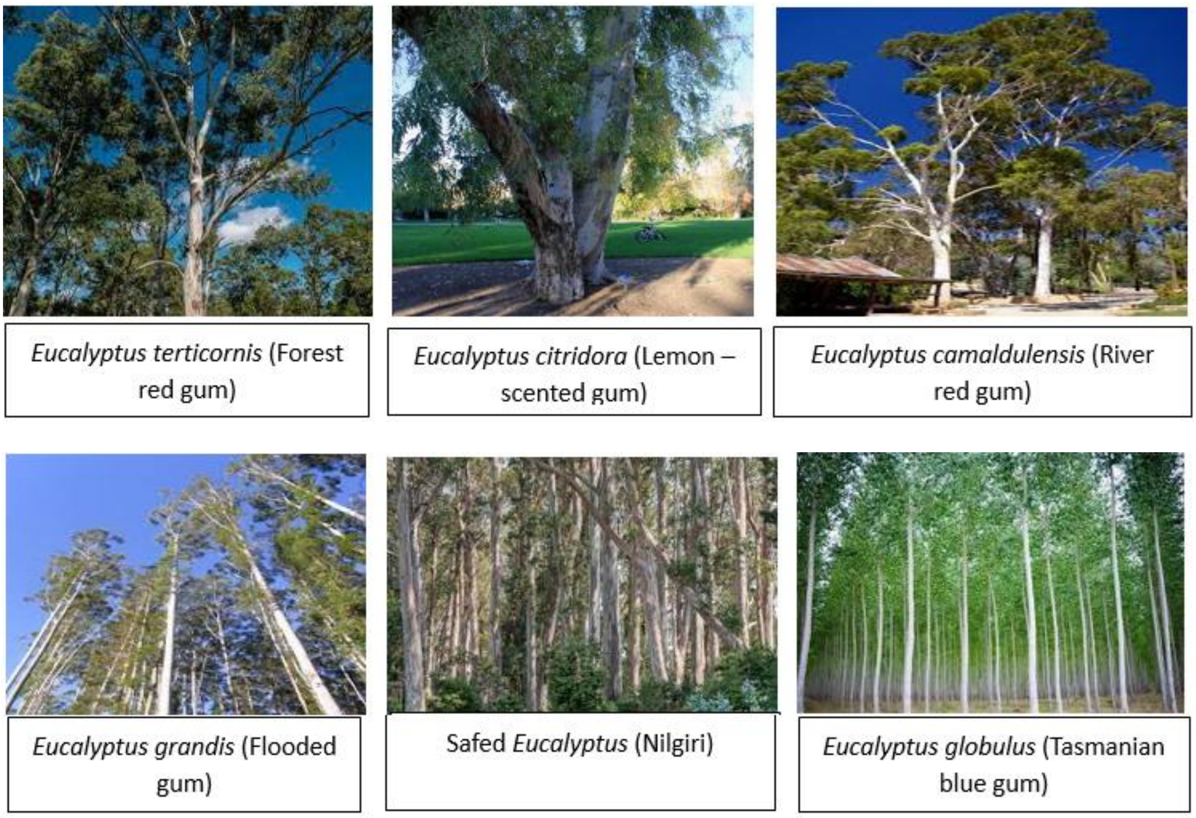

Figure 3: Commercial important Eucalyptus species grown in India. (source -Google Pictures)

d)Economic Significance:

India's commercially important Eucalyptus species have played a significant role in the country's forestry and economic sectors. They are valued for their fast growth, high-quality timber, and various other uses. *Eucalyptus* plantations have provided timber for construction, furniture, plywood, and paper industries. Additionally, *Eucalyptus* oil extracted from the leaves of certain species is sought after for medicinal, cosmetic, and industrial purposes.

e) Conservation and Native Species Focus:

In recent years, there has been an increased emphasis on the conservation and restoration of native tree species in India. While the commercially important *Eucalyptus* species have been cultivated extensively, efforts are being made to promote native tree species for afforestation and agroforestry purposes. The focus has shifted towards utilizing indigenous species that are better adapted to local ecosystems and can support biodiversity conservation.

The evolutionary history of commercially important *Eucalyptus* species in India showcases their introduction, successful adaptation, and economic significance. While their cultivation has faced criticism and concerns over their ecological impacts, they have contributed to India's forestry sector and provided socio-economic benefits to many communities. The ongoing shift towards promoting native tree species aims to balance commercial interests and conservation priorities.

3.Market Overview of Eucalyptus in India

In recent years, various central and eastern Uttar Pradesh regions have become interested in commercialising Eucalyptus and Poplar plantations in western Uttar Pradesh. The socio-economic level of farmers and various agroclimatic conditions influence plantation practices in Eastern UP. The distribution of trees during planting revealed that, on average, 23% were distributed throughout fields, 36% were planted in blocks or orchards, 24% were planted on bunds, and 17% were planted around homesteads, etc. Significant demand-supply gaps continue due to the high need for these two species in the plywood/veneer and other wood-based sectors. After 6-7 years of planting, the market value of Eucalyptus and Poplar trees is nearly identical, with gains of Rs. 2000 to 2500 per tree from 3.0 to 3.5 qt of wood**.**

Eucalyptus is mainly utilized in Balli and Phanti for building materials and the boxing industry. In (2004), Muthoo looked at the supply and demand for wood on the Indian market and the market prospects for the tropical timber industries. The demand for tropical timber is anticipated to increase over the coming decade and might exceed 10 million m3 by the end of the decade. He asserts that India's rising demand for timber results from the country's revival, which is expected to develop at over 6% annually, and the quickening growth of the middle and upper-income classes**.**

According to research by Gangadharapp *et al.* (2004), just 17% of farmers harvested trees older than 40. Most agroforestry growers felled trees between the ages of 20 and 30. They also discovered that 27% of sawmill proprietors, 62% of forest contractors, and 11% of farmers sold their products directly to consumers. Finally, they found that 58% of farmers were unaware of the going rate for their goods**.** Therefore, commercial strategies for creating successful, ecologically sound, and socioeconomically viable plantation models of these species may further pave a new route for farmers' economic growth and expand the area's green cover. (https://www.360marketupdates.com) Through 2032, the therapeutics & cosmetics application category is expected to account for a large portion of the global eucalyptus oil market share.

One of the significant factors, particularly in the European market, is the rising consumer knowledge of natural ingredients and the desire to swap out synthetic components for natural alternatives. Eucalyptus helps treat burnt skin because of its healing and anti-inflammatory characteristics. Eucalyptus oils' capacity to hold onto skin moisture will also aid their development as cosmetic ingredients. Due to the increasing pharmaceutical industry, the Asia Pacific is expected to have a significant revenue share in the eucalyptus oil market throughout the forecast period.

Asia has recently taken centre stage in the world's pharmaceutical market, spurring innovation and expansion. Exports of processed foods have also accelerated in the area. According to the Directorate General of Commercial Intelligence and Statistics, the export of APEDA (Agricultural and Processed Food Products Export Development Authority) products increased to USD 7,408 million in April–June 2022 from USD 5,663 million a year earlier. These elements will encourage the area food and beverage industry to employ eucalyptus oil as a food preservative.

Figure 4: Services and goods from *Eucalyptus* species (Kaur et al. 2021)

3.1. Utilization of Eucalyptus:

a) Eucalyptus oil

The oil of Eucalyptus provides a growing understanding of the significance of eucalyptus essential oils in aromatherapy applications; market value is anticipated to increase at a noticeable rate by 2023–2032. Due to its immunoregulatory, anti-inflammatory, analgesic, and antioxidant characteristics, lemon eucalyptus oil can aid in treating cough, bronchitis, and other ailments. Essential oils in aromatherapy techniques are expanding dramatically as customers become more open to alternative old-fashioned cures and health treatments.

The oil is mainly extracted from *Eucalyptus polybractea*, *Eucalyptus kochii*, *Eucalyptus globulus*, and other species of these leaves. The oil, famous for its earthy aroma, has several medicinal uses, including air purification and reducing brain fog. These characteristics are driving up demand for products containing eucalyptus oil. One of the critical elements affecting eucalyptus oil market trends is the rising demand for plant-based skin care products. Personal care product producers have prioritised developing digital channels to reach more consumers after the COVID-19 outbreak.

Given the product's capability to stop cellular breakdown and skin inflammation brought on by UV exposure, these trends will help increase the production of eucalyptus oil for skin care applications. Additionally, the expanding food processing industry will open up new growth opportunities for product developers since it has the potential to be used as a food preservative**.** According to a WHO report, By 2032, the market for pharmaceutical-grade eucalyptus oil will grow significantly due to the government's increased emphasis on treating diabetes. For instance, the World Health Assembly adopted a Resolution in May 2021 to expand access to insulin and other medications to prevent and treat diabetes. The use of pharmaceutical-grade eucalyptus oils to regulate blood sugar levels will increase due to this campaign. This oil is widely used in healthcare since it may help treat wounds and ease joint discomfort.

b) Veneers

In many studies, it is mentioned that there are nine different *eucalyptus* species for veneer sheets and multi-laminated plywood panels, according to Iwakiri S. *et al*. (2013). A prototype laminating lathe cut veneers to a nominal thickness of 2.0 mm. The analysis determined the values of total yield and yield for the nine pertinent species according to three quality classifications. Five 2.0 mm veneer sheets were joined with phenol-formaldehyde glue at a weight of 360 g/m² to create the plywood panels produced in a lab (double line).

A prototype laminating lathe cut veneers to a nominal thickness of 2.0 mm. The analysis determined the values of total yield and yield for the nine pertinent species according to three quality classifications. The panels were squeezed for ten minutes at a temperature of 140°C, with a specific pressure of 10 kg/cm². Results indicated that, except for *E. phaeotricha* and *E. pellita*, all other *Eucalyptus* species had above 50% average veneer yield after lamination. Within the confines of this study the species *Eucalyptus grandis*, *Eucalyptus saligna*, *Eucalyptus dunnii*, *Eucalyptus globulus*, *Eucalyptus viminalis*, *Eucalyptus robusta*, and *Eucalyptus pellita* have great potential for use in the production of veneer sheets and plywood panels intended for outdoor use, according to the results of glue line shear testing and static bending parallel and perpendicular.

c) Paper and pulp industry

Portugal, Brazil, Indonesia, and China are among the nations that have switched to using eucalyptus as a raw material for the manufacturing of paper (Branco et al., 2018; Kuru et al., 2018). As a result, eucalyptus became the most widely utilized species for pulp and paper manufacturing on a commercial basis, and additional planting areas were created across the countries. Worldwide, eucalyptus plantations have grown to about 20 million hm2, accounting for 33% of all plantations in existence (Ferreira et al., 2019).

Over time, eucalyptus diminishes soil fertility and uses a lot of water. This affects the surrounding water quality and may decrease land production. By keeping the leftovers from logging, soil fertility may be preserved. When the leftovers are absorbed back into the soil, their rich organic content may enhance the development of eucalyptus. In 2019, Ferreira et al. Increasing the salt tolerance of eucalyptus seedlings is one way to increase eucalyptus yield. Benefits of this technology include less deforestation, limited and reduced saline effect, and raw material for pulp and paper mills. Luksungnoen & associates (2019)

d) Firewood, charcoal, and Building material

Regarding social impact, the eucalypt genus has been most helpful in underdeveloped nations in providing fuel and building materials for hut construction. The first eucalypt plantation in India to provide firewood was established in 1843 at Ootacamund, where the trees were grown in grassland gaps amidst evergreen woods. It became apparent that the valleys' stunted woods would otherwise be destroyed. These early *Eucalyptus globulus* plantings are primarily responsible for the survival of these valley forests today.

According to Ranjan (1987), the plantations of Eucalyptus spp. on Ethiopia's high plateaus, which provide Addis Ababa with charcoal and fuel, are of comparable historical significance. More than 60 years ago, ANON (1947& 1948) and Nyasaland (1946) recognized the rapid expansion of eucalypts for firewood production. These nations included Malawi, Botswana, Ecuador, Nigeria, Uganda, and Mozambique. Currently, Argentina, Bangladesh, Bolivia, Brazil, Colombia, Ecuador, Ethiopia, Guatemala, India, Iran, Israel, Ivory Coast, Lesotho, Madagascar, Nepal, Pakistan, Paraguay, Portugal, Senegal, Somalia, Sri Lanka, Swaziland, Tanzania, Thailand, Turkey, Uruguay, and Venezuela are among the countries that plant extensively with eucalypt species for firewood, charcoal, and poles. Harmand (1988), Nkaonja (1985),

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Rajan (1987), Tiwari (1992), ANON (1980 & 1987), and Vivekanandan (1989). A few nations have reported a decrease in charcoal and firewood costs due to eucalypt plants.

If producers have been disincentive, this proves that consumers have benefited. For the impoverished, fuelwood is a free good in rural tropical areas. As a plantation product, firewood is an expense. However, bark, lops, tips, and fallen leaves are free or inexpensively accessible. All emerging nations share this characteristic. According to West Bengal research, families in lower socio-economic classes can save two hours daily by gathering fallen debris from plantations. The availability of eucalyptus poles for hut construction and repair has shown to be quite advantageous.

For this reason, 27 million poles are employed in Gujarat's rural areas Tiwari, (1992). The material was previously purchased at very high costs from the trees. According to Aziz Abdul (1991), Prajapathi et al. (1991), and Venugopal (1988), the availability of sticks made from the branches of downed eucalypt trees for use as supports for hybrid tomato and pea plants has encouraged the development of these crops in some places.

e) Timber

In Bangladesh, China, India, Pakistan, and a few other nations, using eucalyptus as tiny timber is new. The lack of native timber has brought about this trend. Brazil, Chile, Colombia, Ecuador, Israel, Madagascar, Portugal, Senegal, South Africa, Spain, Turkey, the USA, the former USSR, and Uruguay have all planted eucalyptus trees to produce lumber. Rajan (1987), Tiwari (1992) and ANON (1981). The species and climate have an impact on the quality of eucalypt wood. With a value of 100 for teak, *E. tereticornis's* comparative strength is weight 100; shock-resistance ability 115; shear 90; hardness 115; strength as a beam 75; stiffness as a beam 70. Its economic and social relevance stems from the fact that eucalypt wood only costs Rs. 1,100 per m3.

4. Identification and classification of Eucalyptus through morphological characterization

The genus Eucalyptus is an aromatic tree in the Myrtle Family (Myrtaceae) that can grow to be 150-180 feet tall and 4-7 feet wide. It has a straight trunk that extends for two-thirds of its height and a well-developed crown. Many lateral branches and roots surround the core trunk and tap roots. The tap root is rarely longer than 10 feet. (Hall et al.,2021). The bark is pale yellow-brown and deciduous. The older branches' leaves are narrowly lanceolate, typically curled, alternating, and hang vertically. They have a glossy, dark green, thick, leathery appearance. They range in length from 1.5 to 2 dm. The immature sprouts' leaves are oval, opposite, sessile, and horizontal. They have a greyish-waxy bloom that is attractive. (Munz et al., 1973) White blooms grow singly in the axils of flattened stalks. They measure about 4-5.5 cm broad. The sepals and petals fuse to form a warty lid that appears on the bud and falls off at the anthesis. The flower features a lot of stamens. The ovary has four chambers and many ovules. From December through May, flowers are at their peak. The fruit is a hard, woody capsule with a large, flat disc that is broadly top-shaped or globose. It has four valves that are loculicidal dehiscent at the top. The fruit is 2-2.5 centimetres in diameter. The many seeds are about 2 x 1 mm in size (relatively tiny compared to other woody plant species)—dark brown seeds with brownish-red chaff. (Krugmen et al.,1974). The juvenile leaves of E. globulus are oblong, opposite, sessile, and glaucous and occur on squared stems, as are the large, solitary fruits (2-2.5 cm), which are warty, glaucous, and four-ribbed. (Hall et al., 2021)

The eucalyptus tree arose in Tasmania, Australia, and other Indo-Malayan islands. There are roughly 700 eucalypt species, all of which possess significant environmental importance; 37 of those varieties are of interest to the forest industry, whereas just 15 are employed commercially. The only two species not growing in Australia are *Eucalyptus deglupta* and *E. urophylla.*

Tipu Sultan, the ruler of Mysore, planted the first eucalyptus in India around 1790 in his palace garden on Nandi hills near Bangalore. According to a single narrative, he imported seed from Australia and introduced perhaps 16 species (Shyam Sundar, 1984). The second notable introduction of Eucalyptus occurred in the Nilgiri hills of Tamil Nadu in 1843, and subsequently (1856), regular plantations of *E. globulus* were established to supply firewood demands (Wilson, 1973).

The most extensively planted eucalypts in India are *E. tereticornis* and a variant of *E. tereticornis* known as Mysore gum (considered to be a hybrid). This Eucalyptus hybrid accounts for over half of the eucalypts planted in several parts of India (Jacobs, 1981) and is thought to have originated from a tiny stand of *E. tereticornis* introduced in the Nandi hills (Pryor, 1966; Chaturvedi, 1976). Because of the inaccessibility and difficulties in collecting seeds, the early introductions of *E. camaldulensis* and *E. tereticornis* to India came from southern temperate locations in Australia rather than northern tropical regions where the climatic conditions closely resembled those available in India (Boland, 1981).

5. Need for commercial Eucalyptus plantation

An option to increase the number of plants in deforested regions would be to propagate plants in large numbers using biotechnological methods. Scientific literature has outlined protocols for propagating many forest plant species in a semi-solid culture medium (Vidal and Sánchez 2019; Suwal et al. 2020). However, it is generally recognized that tissue culture is a standard method for bulk plant reproduction. It is expensive and labour-intensive to use a traditional semi-solid medium. Gelling agents significantly raise the price of in vitro production and restrict the automation of mass production for commercial purposes.

6. Conservation methods adopted for Eucalyptus plantation

A notable benefit of tissue culture is that it's possible to store germplasm in vitro for long periods without the substantial investments in land, employment, water, fertilizer, and pesticides required for plantation- or nursery-based germplasm archives. (Trueman.2006, Benson.2008, Sharma et al.2013 and Gomes et al.2017). In vitro storage can also cause valuable clones to mature later, particularly if their shoots or callus are stored under minimal-growth or nil-growth circumstances (McMohan et al., 2013 & 2014; Park et al., 1998 & Bonge, 2015).

In addition to propagation, tissue culture allows for the in vitro preservation of genetically superior Eucalyptus germplasm for extended periods while avoiding the large-scale land investment, fertilizer, pesticide, labour, and water required for silviculture-based germplasm banks (Watt et al. 2000 a; b; Ipekei and Gozukirmizi 2003). Various approaches, including synthetic seeds and cryopreservation, have been used to conserve important Eucalyptus genotypes in vitro (Padayachee et al., 2009; Reddy et al., 2012).

Plantation trees had more substantial adventitious rooting capacity, stem growth, internode length, and developmental commitment to vegetative growth when propagated from juvenile explants or cuttings rather than beyond explants or cuttings (Wendling et al.2014, Mitchell et al.2004, Rasmussen et al.2010, Pijut et al.2011 & McCown, 2016). Shoot tips, nodes, or axillary buds from nursery stock plants or adult trees were the initial explant source in 46% of the eucalypt tissue-culture techniques that specified an explant source. This comprises explants from nursery stock plants in 24% of the steps, explants from the canopy of adult trees in 18% of the techniques, and explants from coppice shoots or epicormic shoots at the base of adult trees in 4% of the methods. Cool storage, synthetic seed preservation, and cryopreservation are tissue culture procedures that may keep juvenile tissue in vitro with little or no growth.

As a result, these strategies offer a high potential to boost nursery efficiency and tree output in forestry plantation programs. Notwithstanding this, there have only been a few reports of eucalypt germplasm being maintained under growth-limiting circumstances. Synthetic seed preservation for *E. grandis* and *C. tortellini C. citriodora* was additionally attempted.

Plant germplasm can be kept as synthetic seeds in most cases by encapsulating tiny explants such as shoot tips, nodes, or axillary buds in calcium alginate (Sharma et al.2013, Rai et al. 2009, & Rihan et al.2017). Encapsulation can limit the emergence of the shoots, exceptionally when the synthetic seeds have been preserved under minimal-growth conditions such as low temperature, low irradiance, or low nutrition availability (Hung et al. 2012, Nunes et al.2003; Watt et al.2000). Cryopreservation of *E. globulus, E. grandis, E. grandis E. camaldulensis, E. grandis E. urophylla, E. gunnii, and E. gunnii E. dalrympleana* Maiden has been attempted.

Because of the drying vulnerability of eucalypt buds, cryopreservation has been problematic (Padayachec et al.,2008,2009). However, axillary buds of *E. grandis* and *E. camaldulensis* have been successfully cryopreserved with 49% regrowth by placing encapsulated tissue samples on semi-solid MS media with progressively higher sucrose and glycerol concentrations (each 0.4, 0.7, then 1.0 M), drying them in empty Petri dishes to a moisture content of 25% before freezing, and reintroducing them on media with progressively decreasing sucrose and as well as glycerol concentrations (Blakesley et al.2001).

Shoot-tip and axillary-bud cryopreservation has proven tricky for some eucalypts. Still, it can potentially maintain plant germplasm for many years without needing periodic subcultures for recovery and re-storage over cool storage and synthetic seed preservation.

Cryopreservation has been used successfully to store embryogenic callus of other tree species (Ruedell et al.2015 & Khimaszewska et al. 2016), but no reports of eucalypt cryopreservation have been identified. Tissue culture, in addition to propagation, provides a way to store genetically superior *Eucalyptus* germplasm in vitro for lengthy periods while obviating the need for large-scale land investments, fertilizer, pesticides, labour, and water required for silviculture-based germplasm banks (Watt et al. 2000a, 2000b; Ipekei and Gozukirmizi 2003). Cryopreservation and artificial seeds have been used to maintain essential *Eucalyptus* genotypes in vitro (Padayachee et al. 2009; Reddy et al. 2012).

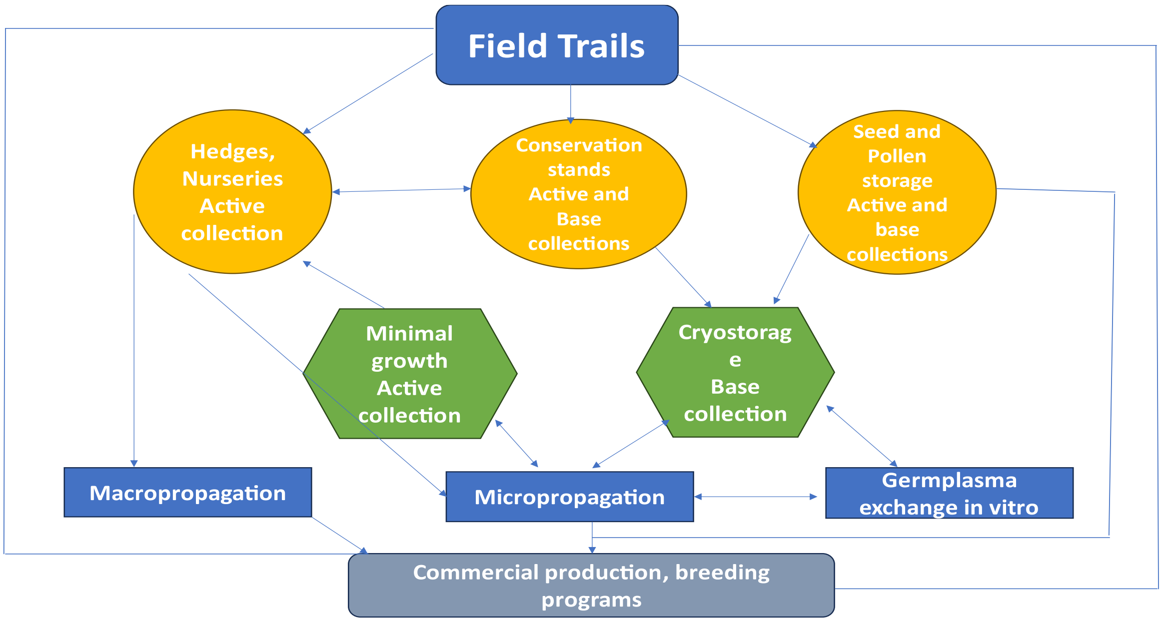

Figure 5: The link between in vitro conservation methods and those commonly employed (watt et al., 2000)

7.Method of propagation in the Eucalypts species

Several propagation methods, including girdling (Hartmann et al., 2011), cutting (Trueman et al., 2013), mini-cutting (Brondani et al., 2012a), coppicing (Xavier et al., 2013), epicormic shoot induction (Wendling et al., 2013), and micropropagation (Brondani et al., 2012b). Selected trees can be saved and cloned using these procedures (Baccarin et al., 2015). Some of these methods are rendered impossible since killing or girding the mother plants for species, and provenance examinations are impossible.

To acquire juvenile shoots, it is, therefore, possible to induce epicormic shoots from trimmed branches of certain mother plants (Wendling et al., 2013; Baccarin et al., 2015; Oliveira et al., 2015). These buds, which are known as epicormic buds and come from latent axillary buds, are utilized to recreate the plant crown (Wendling et al., 2013) and can aid in the proliferation and expansion of particular trees.

a) Conventional method:

A notable benefit of tissue culture is that it's possible to store germplasm in vitro for long periods without the substantial investments in land, employment, water, fertilizer, and pesticides required for plantation- or nursery-based germplasm archives. (Trueman.2006, Benson.2008, Sharma et al.2013 and Gomes et al.2017). In vitro storage can also cause valuable clones to mature later, particularly if their shoots or callus are stored under minimal-growth or nil-growth circumstances (McMohan et al., 2013 & 2014; Park et al., 1998 & Bonge, 2015).

In addition to propagation, tissue culture allows for the in vitro preservation of genetically superior Eucalyptus germplasm for extended periods while avoiding the large-scale land investment, fertilizer, pesticide, labour, and water required for silviculture-based germplasm banks (Watt et al. 2000 a; b; Ipekei and Gozukirmizi 2003). Various approaches, including synthetic seeds and cryopreservation, have been used to conserve important Eucalyptus genotypes in vitro (Padayachee et al., 2009; Reddy et al., 2012). Plantation trees had more robust adventitious rooting capacity, stem growth, internode length, and developmental commitment to vegetative growth when propagated from juvenile explants or cuttings rather than beyond explants or cuttings (Wendling et al.2014; Mitchell et al.2004; Rasmussen et al.2010, Pijut et al.2011 & McCown, 2016).

Shoot tips, nodes, or axillary buds from nursery stock plants or adult trees were the initial explant source in 46% of the eucalypt tissue-culture techniques that specified an explant source. This comprises explants from nursery stock plants in 24% of the steps, explants from the canopy of adult trees in 18% of the techniques, and explants from coppice shoots or epicormic shoots at the base of adult trees in 4% of the methods. Cool storage, synthetic seed preservation, and cryopreservation are tissue culture procedures that may keep juvenile tissue in vitro with little or no growth. As a result, these strategies offer a high potential to boost nursery efficiency and tree output in forestry plantation programs. Notwithstanding this, there have only been a few reports of eucalypt germplasm being maintained under growth-limiting circumstances. Synthetic seed preservation for *E. grandis* and *C. tortellini C. citriodora* was additionally attempted.

Figure 6: Nursery-raised seedlings from the forest department using conventional methods.

Plant germplasm can be kept as synthetic seeds in most cases by encapsulating tiny explants such as shoot tips, nodes, or axillary buds in calcium alginate (Sharma et al.2013, Rai et al. 2009, & Rihan et al.2017). Encapsulation can limit the emergence of the shoots, exceptionally when the synthetic seeds have been preserved under minimal-growth conditions such as low temperature, low irradiance, or low nutrition availability (Hung et al. 2012, Nunes et al.2003; Watt et al.2000). Cryopreservation of *E. globulus, E. grandis, E. grandis E. camaldulensis, E. grandis E. urophylla, E. gunnii, and E. gunnii E. dalrympleana* Maiden has been attempted. Because of the drying vulnerability of eucalypt buds, cryopreservation has been problematic (Padayachec et al.,2008,2009).

However, axillary buds of *E. grandis* and *E. camaldulensis* have been successfully cryopreserved with 49% regrowth by placing encapsulated tissue samples on semi-solid MS media with progressively higher sucrose and glycerol concentrations (each 0.4, 0.7, then 1.0 M), drying them in empty Petri dishes to a moisture content of 25% before freezing, and reintroducing them on media with progressively decreasing sucrose and as well as glycerol concentrations (Blakesley et al.2001). Shoot-tip and axillary-bud cryopreservation has proven tricky for some eucalypts. Still, it can potentially maintain plant germplasm for many years without needing periodic subcultures for recovery and re-storage over cool storage and synthetic seed preservation. Cryopreservation has been used successfully to store embryogenic callus of other tree species (Ruedell et al.2015 & Khimaszewska et al. 2016), but no reports of eucalypt cryopreservation have been identified.

b) Non- conventional method:

In vitro propagation Tissue culture is a system that emphasises maintaining exact axenic conditions within culture containers to enable the optimal growth of complete plants, tissues, or cells (Phillips and Garda 2019). The culture vessel contains a basal medium containing all the water, vitamins, and energy vital to growing plants that thrive (George et al. 2008 b). Furthermore, the growth conditions for the plants are optimized beyond the culture vessel, as these vessels are often incubated in growth chambers to provide optimum illumination and temperature.

Plant growth regulators (PGRs) are generally supplemented into the medium at different stages to trigger plant development, depending on the purpose of the culture stage. Microorganisms such as bacteria, fungi, and yeast take advantage of the high nutrient conditions in the culture medium and compete with the explants, resulting in contamination and, in most cases, the death of the plant cultures (Watt et al. 2003; Brondani et al. 2011).

Various aseptic procedures, nutritional medium, and controlled environmental conditions are used in micropropagation strategies to regenerate complete plants in vitro from cells, tissues, or organs (Debergh and Read 1991; George 2008 b). This strategy is frequently used to rapidly multiply a large number of plants while preserving juvenility and beneficial genetic traits, which in commercial eucalypt forests refer to cultivars with complicated wood traits, shorter rotational periods, cold or drought-resistant, pest resistance, and a buildup of biomass in the trunk rather than the leaves (Nakhooda and Jain 2016).

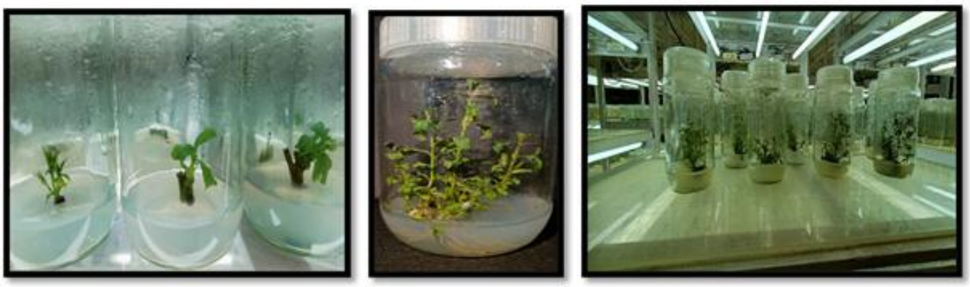

Figure 7: Tissue culture techniques for mass production

During micropropagation, various organs such as roots, shoots, and buds can be induced through dictated supplementation of growth regulators, carbohydrates, minerals, vitamins, and temperature (Fehér et al. 2003). Furthermore, micropropagation necessitates far fewer nutrients than macropropagatory strategies (Davey and Anthony 2010).

The first in vitro propagation was reported in *Eucalyptus* through callus cultures from seedling tissues. (Jacquiot, C.1964) derived callus from cambial tissues of *E. cladocalyx, E. Gomphocephala, E. gunni, E. tereticornis, and E. camaldulensis* (Sussex L.M. 1965) was able to produce callus and suspension cultures of *E.camaldulensis*. The early work of de Fossard and co-workers was on callus cultures of *E.bancroftii, E.melliodora, and E.nicholii*(De Fossard et al.,1976, 1977); as research progressed, media became more defined, and new culture techniques were applied to *Eucalyptus* species for a variety of purpose

Several articles have examined *E. grandis* in vitro propagation (McComb and Bennett, 1986; Lakshmi-Sita and Rani, 1985; Muralidharan and Mascarenhas, 1987; Le Roux and van Staden, 1991; Watt et al., 1991; Watt, Duncan, Blakeway, and Hermant, 1995). The pathways of propagation in that species consist of direct organ culture from young plants and developmental substances (Cresswell and De Fossard, 1974; Cresswell and Nitsch, 1975; Warrag, Ortega, Lesney and Rockwood, 1987; MacRae, 1991; Watt, Gauntlett and Blakeway, 1996) and inducing shoots from nodal meridians (axillary buds) (De Fossard, Barker and Bourne, 1977; Durand-Cresswell and Nitsch, 1977; Gupta et al., 1981; Furze and Cresswell, 1985; Warrag, Lesney and Rockwood, 1990). E. camaldulensis (Muralidharan and Mascarenhas, 1989) and E. citriodora (Lakshmi-Sita, 1979) have both been shown to produce spontaneous shoots via callus.

Of these propagation techniques, micropropagation via axillary bud production is the most useful for germplasm preservation since this method ensures that the characteristics of the source plant remain unchanged, and thus, there is a high likelihood of producing biologically consistent and inherited stable plants. Several studies on axillary bud propagation have been reviewed (Durand-Cresswell, Boulay, and Franclet, 1982).

Eucalyptus micropropagation may be accomplished by both direct and indirect organogenesis (Nakhooda and Jain 2016; Trueman et al. 2018). These strategies have been used to establish cultures for common eucalypt forestry species such as Eucalyptus grandis (Watt et al. 1991), E. camaldulensis (Girijashankar 2012), E. citriodora (Muralidharan and Mascarenhas 1987), E. polybractea (Fernando et al. 2016), and E. globulus (Nugent et al .2001). Organogenesis is the formation of adventitious buds in tissues that would not usually produce buds. The formation of adventitious eucalypt shoots appears to go through an intermediary callus phase (i.e., via indirect organogenesis), even though the anatomical origin and development of the new shoots are typically understudied. Organogenesis is a process that uses the totipotent characteristic of plant cells to guide the differentiation of vegetative plant tissue into adventitious shoots or roots without the need for an intermediary callus stage (Dibax et al., 2010). Incorporating one or more PGRs, which regulate every phase of plant physiological development, controls and characterizes the various stages of development in vitro (Gaspar et al. 1996).

8.Conclusion

The evolutionary history, existing diversity, and commercial importance of Eucalyptus species in India highlight the significance of this genus in both ecological and economic contexts. Eucalyptus has a remarkable evolutionary lineage, originating from ancient times and adapting to diverse environments over millions of years. The presence of various Eucalyptus species in India showcases their successful acclimatization to the country's diverse climatic conditions. The rich diversity of Eucalyptus species in India contributes to the ecological resilience of the country's forests. Each species possesses unique characteristics, growth habits, and environmental preferences, enhancing the overall biodiversity and functioning of Indian ecosystems. Understanding and conserving this diversity is essential for maintaining the long-term sustainability of India's forest ecosystems.

Moreover, Eucalyptus species hold significant commercial value in India. Their rapid growth, high wood density, and versatile applications make them valuable industry resources. Eucalyptus plantations have been established nationwide to meet the demand for timber, pulpwood, and essential oils. The utilization of Eucalyptus wood in construction, furniture, pulp, and paper industries, as well as the extraction of essential oils for pharmaceuticals and aromatherapy, contribute to India's economic growth. However, it is necessary to approach the cultivation and utilization of Eucalyptus species sustainable. Careful selection of species, coupled with sustainable management practices, is crucial for minimizing potential ecological impacts and ensuring the conservation of native species. Balancing commercial interests with environmental considerations will promote the long-term viability and responsible utilization of Eucalyptus resources in India. By appreciating and conserving their evolutionary heritage and embracing sustainable practices, India can harness the benefits of Eucalyptus species while safeguarding its natural ecosystems for future generate.

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