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Tree-Borne Oilseed Cultivation: Research Gaps and Future Perspective

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ABSTRACT: Tree-borne oilseeds (TBOs) are emerging as a pivotal resource for sustainable oil production, biodiesel, and industrial applications, offering a promising alternative to conventional sources. However, despite their potential, TBOs face significant challenges that hinder their widespread adoption, primarily related to seed quality and availability. With the rising domestic demand for edible oils and energy, India's reliance on imports has become increasingly pronounced, emphasizing the need to explore and enhance alternative domestic sources such as TBOs. TBOs are distributed across various ecological zones, yet their scattered distribution, suboptimal collection practices, and low-quality seeds present substantial barriers. Compounded by climate change, overexploitation, and inadequate infrastructure for storage and collection, these challenges restrict the effective utilization of TBOs. Expanding TBO cultivation beyond forested areas through agroforestry and reforestation is essential to meet the growing demand for oilseeds. However, the lack of high-quality planting material remains a critical impediment. This review provides a comprehensive analysis of the current state of TBOs, with a focus on technological insights and future perspective. It examines significant TBO species in India, highlights research efforts by various ICFRE institutes aimed at TBO improvement, and assesses the status of seed testing and certification both nationally and globally. The paper identifies key challenges and explores potential solutions, offering strategic recommendations for advancing TBO cultivation. By addressing these issues, the review aims to support policy advocacy efforts to enhance TBO production, reduce import dependency, and contribute to sustainable development in the sector.

Keywords: Tree- borne oil seeds, Seed Testing, TBO Research, Biodiesel, Edible oil

INTRODUCTION

India is one of the major growers and importers of oilseeds globally, ranking fourth in the vegetable oil economy after the USA, China, and Brazil. Oilseeds constitute approximately 13% of India's gross cropped area, contribute 3% to the Gross National Product, and account for 10% of the value of all agricultural commodities. Over the last decade (1999-2009), this sector has seen an annual growth rate of 2.44% in area, 5.47% in production, and 2.96% in yield. In recent years, domestic consumption of edible oils has significantly increased, reaching 18.90 million tonnes in 2011-12, with further growth expected. According to the OECD-FAO Agricultural Outlook (2021-2030), India's per capita vegetable oil consumption is projected to grow at 2.6% per annum, reaching 14 kg per capita by 2030. This rise, driven by urbanization and shifts toward highly processed foods rich in vegetable oils, necessitates an import growth rate of 3.4% per annum [1]. To ensure edible oil security, it is crucial to optimize domestic production.

India's growing demand for edible oils and energy sources, coupled with a heavy reliance on imports, highlights the need to utilize alternative domestic resources. Approximately 67% of India's vegetable oil consumption is met through imports. In addition, conventional petroleum energy presents challenges, including fluctuating global prices, depletion of reserves, import dependency, environmental degradation, and geopolitical conflicts like the Ukraine-Russia war. To bolster national energy and food security, it is essential to enhance domestic production of TBOs, which can be cultivated in various agro-climatic conditions, including wastelands, deserts, and hilly areas. TBOs are naturally shed by trees and typically collected by indigenous communities.

To address the country's edible oil demand, the Ministry of Agriculture, Cooperation, and Farmers' Welfare, Government of India, launched the National Mission on Oilseeds and Oil Palm (NMOOP) in April 2014. Under NMOOP, Mini Mission-III focuses on enhancing the area under TBOs, particularly in wastelands. This mission promotes interventions such as nursery development, plantation maintenance, intercropping incentives, research and development, equipment distribution for processing, support for TRIFED, training for farmers and extension workers, and local initiatives [2]. The objective is to increase TBO seed collection from 9 lakh tonnes to 14 lakh tonnes and supply elite planting materials to expand cultivation in wastelands across 28 states [2].

Tree-borne seed oils, defined as oils extracted from the seeds (endosperm) of certain trees rather than the fruit (pericarp), offer a significant source of vegetable oil [3, 4, 5]. Tree-borne oilseeds (TBOs), an essential non-timber forest product, are species-specific and vary across agro-climatic zones. In India, Sal (*Shorea robusta*), Mahua (*Madhuca longifolia*), Simarouba (*Simarouba glauca*), Kokum (*Garcinia indica*), Olive (*Olea europaea*), Karanja (*Pongamia pinnata*), Jatropha (*Jatropha curcas*), Neem (*Azadirachta indica*), Jojoba (*Simmondsia chinensis*), Cheura (*Diploknema butyracea*), Wild Apricot (*Prunus armeniaca*), Walnut (*Juglans regia*), Tung (*Aleurites fordii*) and many other minor TBOs are cultivated under diverse agro-climatic conditions, both in forest and non-forest areas, as well as in wastelands, deserts, and hilly regions. Some of these TBOs are utilized for edible oil production. In India, oilseeds of tree and forest origin, primarily found in tribal areas, are estimated to produce about 11-15 lakh tonnes of oil for edible and industrial purposes. Currently, around 5 lakh tonnes of TBO seeds are collected and processed, yielding approximately 1 lakh tonne of oil. According to a 2012 survey by the Indian Council of Forestry Research & Education (ICFRE), Dehradun, TBOs such as Neem, Karanja, Sal, Mahua, Cheura, Kokum, Simarouba, Jatropha, Jojoba, and Wild Apricot are cultivated across 14.7 lakh hectares of government or private lands, with only 7.5 to 10% of the potential being utilized [2].

TBOs serve both domestic and industrial purposes, including agriculture, cosmetics, pharmaceuticals, diesel substitutes, and cocoa-butter alternatives. National policies such as the National Biofuel Policy (2009) and the National Agroforestry Policy (2014) aim to replace fossil fuels with biofuels and promote integrated land use for livelihood, environmental, and energy security. While all oils can be used as biofuels, edible oils are primarily reserved for food, making non-edible oils the main raw material for biodiesel production in India. The country has significant potential, with over 100 tree species capable of producing seed oil suitable for biodiesel.

Despite their abundance, TBOs are often scattered and underutilized due to factors such as poor seed quality, lack of awareness, climate change, overexploitation, and unsustainable harvesting. Additional constraints include inadequate facilities for storage and seed collection, long gestation periods, harvesting during the rainy season, and limited availability of quality tree germplasm. To meet future demand, it is imperative to cultivate TBOs outside forest areas in plantations (agroforestry systems or Trees Outside Forests [TOF] plantations) while actively restoring natural forests to bridge the gap between oil production demand and supply in India.

IMPORTANT TBOS IN INDIA

India possesses significant potential for TBO cultivation, with species such as Mahua, Neem, Simarouba, Karanja, Ratanjyot, Jojoba, Cheura, Kokum, Wild Apricot, Wild Walnut, Kusum, and Tung, suitable for diverse agro-climatic conditions [6]. Screening of lesser-known TBO species from Northeast India, including *Cinnamomum impressinervium*, *Garcinia xanthochymus*, *Litsea coriacea*, *Croton joufra*, *Albizia procera*, *Cryptocaria andersoni*, and *Kayea assamica*, revealed their potential for edible oil production due to favorable omega-6/omega-3 and PUFA/SFA ratios [3]. These findings suggest that these lesser-known oilseeds could be valuable raw materials for various commercial applications, contributing to India's self-sufficiency in the vegetable oil sector. Below table provides a concise overview of each particularly focusing on the production of edible and non-edible oils and other valuable applications [3,6, 8-21].

RESEARCH STATUS OF TBOS IN INDIA

Various ICAR and ICFRE institutes in India are actively involved in the conservation, plantation, propagation, post-harvest seed handling, seed storage studies, longevity, and long-term storage using cryopreservation of Tree-Borne Oilseeds (TBOs). The National Oilseeds and Vegetable Oils Development (NOVOD) Board is particularly renowned for exploring and enhancing the potential of TBOs in India through activities such as nursery raising, plantation establishment, installation of processing facilities, and capacity building initiatives. NOVOD has launched research and development programs on Jatropha and Karanja for biodiesel production, involving a network of 25 institutions across the country to achieve these objectives. Additionally, national networks have been established for the promotion of other TBOs like Wild Apricot and Cheura in

Table 1. Details of important TBOs in India

Species	Scientific Name	Distribution	Characteristics	Uses
Cheura	*Diploknema butyracea*	Sub-Himalayan tracts, outer Himalayan ranges, tropical moist deciduous, semi-deciduous, and evergreen forests of Andaman Islands	Medium-sized hardy plant with economic age of 80-100 years. Fruits are large and fleshy.	Seed oil used as a substitute for ghee and butter in cooking, medicinal and cosmetic uses, defatted cake used as manure due to pesticide properties.
Simarouba (Paradise Tree)	*Simarouba glauca*	Tropical regions	Medium-sized evergreen tree. Polygamodioecious with staminate, pistillate, male, and some bisexual flowers. Grows well in tropical climates with varying rainfall levels.	Edible oil and biofuel, cocoa butter substitute, oil cake used as organic manure.
Mahua	*Madhuca indica*	Central India, warm regions	Fast-growing evergreen tree up to 20m in height. Produces abundant delicious flowers.	Edible fresh or dried flowers, seed oil used as vegetable butter, skin care products, fuel oil, biodiesel, seed cake used as manure, flowers used for alcoholic drink production.
Kokum	*Garcinia indica*	Western Ghats, Konkan, Goa, Southern Karnataka, Kerala	Slender evergreen tree with dropping branches. Grown in tropical rainforests.	Edible and non-edible oil, used in chocolates, confectioneries, soap, candle, ointment manufacturing, biodiesel source.
Olive	*Olea europaea*	Mediterranean region, Rajasthan (India)	Cultivated commercially in Mediterranean and in parts of India. Oil content from Indian cultivation ranges between 9-14%.	Used in culinary preparations, edible oil, biodiesel production.
Drumstick	*Moringa oleifera*	Sub-Himalayan tracts of Northern India	Fast-growing softwood tree. Contains up to 40% oil in seed kernels with high oleic acid.	Edible oil for cooking, biodiesel, cosmetics, lubricant for machinery, seed cake used in wastewater treatment and as fertilizer.
Wild Walnut	*Juglans regia*	Kashmir, Hills of Himachal Pradesh, Uttar Pradesh, Assam (India)	Most widespread tree nut globally. High protein and oil content in kernels (60-70% oil).	Consumed as fruit, oil rich in ω-3 and ω-6 fatty acids used for edible purposes, making soaps, inks, colors, and varnishes.
Silk Cotton	*Bombax ceiba*	Widely distributed throughout India, Ceylon, and Malaya	Tall tree with buttressed base. Used by various tribal communities for medicinal purposes.	Edible fatty oil from seeds, used for soap making and illumination.
Maulsari	*Mimusops elengi*	Central and South India	Evergreen tree with medicinal properties. Produces 16-25% fatty oil from seed kernels.	Edible oil, various medicinal uses.
Sal	*Shorea robusta*	Central India, Himalayan foothills in sub-temperate regions	Large tree used for timber and oil extraction from seeds.	Cooking oil, substitute for cocoa butter in chocolate industry, income source for rural and tribal areas.
Cocoa	*Theobroma cacao*	Kerala, Tamil Nadu, Orissa, Eastern India	Tropical tree used primarily for its seeds, which contain 50-57% oil.	Edible natural fat in chocolate, skin care products, pharmaceuticals, and medicinal uses.
Caper Berry	*Capparis decidua*	Rajasthan, Gujarat, Western Ghats (India)	Perennial woody plant adapted to dry climates.	Oil rich in oleic acid, used for edible and non-edible purposes.
Mango	*Mangifera indica*	Widely produced in tropical and subtropical regions	Kernel contains about 15% oil, comparable to soybean and cottonseed.	Edible oil as an alternative to cocoa butter, used in chocolates and confectioneries.
Palm	*Elaeis guineensis*	Tropics, widely cultivated in Malaysia and Indonesia	Evergreen palm tree. Produces high-quality oil.	Cooking oils, margarines, confectionery products, biodiesel, cocoa butter alternatives.
Kusum or Sagade	*Schleichera oleosa*	Eastern India, Sub-Himalayan forests	Tree of medicinal importance. Seeds contain 36% oil.	Edible oil, traditionally used for skin issues, rheumatism, hair care, soap making.

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Species	Scientific Name	Distribution	Characteristics	Uses
Dhupa	*Vateria indica*	Western Ghats, Kerala, Tamil Nadu (India)	Indigenous tree with seeds containing 20-22% oil.	Edible after refining, used in confectionery, soap, candle manufacturing, substitute for cocoa butter.
False Sandal-wood	*Ximenia americana*	Deccan Peninsula, Andaman Islands (India)	Valuable wild edible plant, seed kernels contain 49-60% oil.	Edible oil, suitable for soap making, lubrication, and other industrial uses.
Jojoba	*Simmondsia chinensis*	Rajasthan, Gujarat, Haryana, Andhra Pradesh (India)	Hardy desert shrub. Seeds contain about 50% oil.	Used in cosmetics, pharmaceuticals, lubricants, food, waxes for polishing, cake used as cattle feed.
Indian Jujube (Ber)	*Ziziphus mauritiana*	Yunnan (China) to Afghanistan, Malaysia, Queensland (Australia), India (commercially grown)	Medium-sized tree with varying height. Adapted to drought conditions.	Fruit eaten raw or pickled, seed oil used in biodiesel production, seeds used medicinally.
Tung	*Aleurites spp.*	Eastern Asia, Malaysia, Mizoram (India)	Deciduous tree known for its quick-drying oil.	Tung oil used for industrial purposes, including paint and varnish. Seeds used for biodiesel production.
Indian Tulip Tree	*Thespesia populnea*	Coastal regions, possibly indigenous to India and Hawaii	Small tree or shrub. Pan-tropical distribution.	Pharmaceutical applications, biodiesel production.
Indian Rose Chestnut	*Mesua ferrea*	Sri Lanka, Assam (India)	Tall tree with heavy, hard wood.	Timber used for railroad ties, medicinal uses, seed oil used in pharmaceuticals.
Neem	*Azadirachta indica*	Entire India, thrives in drier climates, wild in Deccan forests, scattered in Northern and Central India	Medium to large tree	Bio-pesticides, soap, cosmetics, manure, biodiesel, pesticide
Karanja	*Pongamia pinnata*	Throughout India, drought-resistant, salinity-tolerant, found along roadsides, railways, and watercourses	Medium to large tree	Soap making, leather dressing, lubrication, illumination, green manure, bio-diesel production
Jatropha	*Jatropha curcas*	Semi-arid regions, Andhra Pradesh, Gujarat, Rajasthan, Karnataka, Maharashtra	Shrub to small tree	Biodiesel, illumination, soap, candles, lubricant, hair oil, manure
Tamanu	*Calophyllum inophyllum*	Coastal areas, tropical regions	Large tree	Skin care, medicinal purposes, biodiesel, UV-absorption properties, wound healing, antibacterial properties
Tejpat	*Cinnamomum impressinervium*	Northeast India	Medium to large tree	Edible oil based on $\omega 6/\omega 3$ and PUFA/SFA ratio
Tapor Tenga	*Garcinia xanthochymus*	Northeast India	Medium to large tree	Edible oil based on $\omega 6/\omega 3$ and PUFA/SFA ratio
Bagh-nola	*Litsea coriacea*	Northeast India	Medium to large tree	Edible oil based on $\omega 6/\omega 3$ and PUFA/SFA ratio
Mahunda	*Croton joufra*	Northeast India	Medium to large tree	Edible oil based on $\omega 6/\omega 3$ and PUFA/SFA ratio
Koroi	*Albizia procera*	Northeast India	Medium to large tree	Edible oil based on $\omega 6/\omega 3$ and PUFA/SFA ratio
Sia-nahor	*Kayea assamica*	Northeast India	Medium to large tree	Edible oil based on $\omega 6/\omega 3$ and PUFA/SFA ratio

suitable states. Integrated efforts for TBO development are being facilitated through the exchange of planting materials and technical know-how among these institutions [7]. A summary of completed projects and significant findings on TBOs conducted by various ICFRE research institutes is provided in Table 2.

The germplasm of TBOs can be conserved through both in situ and ex situ conservation methods. Ex situ conservation involves plantations, gene banks, in vitro techniques, and cryopreservation to preserve diverse germplasm for varying durations. Several projects, including the All India Coordinated Research Projects and National Programs on the Conservation of Forest Genetic Resources, are ongoing in collaboration among various ICFRE institutes.

THE CHALLENGE OF QUALITY SEED AVAILABILITY FOR TBOs AND FORESTRY SPECIES: A KEY ISSUE

Challenges in seed quality for TBO (Tree-Borne Oilseed) cultivation include several key factors. Genetic variability within wild TBO populations often results in seeds with inconsistent size, oil content, and germination potential, further compounded by the lack of improved cultivars and standardized seed production techniques. Environmental conditions such as drought, high temperatures, and soil salinity can adversely affect seed development, leading to poor seed filling, reduced viability, and lower oil content. Improper seed handling and storage—exposed to high humidity and temperatures—can cause seed deterioration, while inadequate post-harvest processing and storage facilities exacerbate the issue. Additionally,

Table 2. Summary of Completed Projects and Significant Findings on Tree-Borne Oilseeds (TBOs) Conducted by Various ICFRE Research Institutes

S. No.	Institute	Project Name	Significant Findings
1	Tropical Forest Research Institute (TFRI), Jabalpur	Processing techniques of NWFPs in Chhattisgarh TBOs	Quality of oil seeds is affected by drying temperature, method, and storage containers. Jute bags are unsuitable due to increased moisture. Polyethylene bags and jars are recommended. Hot air drying at 60°C is better for maintaining seed quality.
2	Tropical Forest Research Institute (TFRI), Jabalpur	Integrated development of TBOs	Collaborated with local communities for planting Jatropha, Pongamia, and Madhuca on degraded lands. Provided technical training and raised awareness about TBOs' economic potential.
3	Arid Forest Research Institute (AFRI), Jodhpur	Development of a database on TBOs in India (Funded by NOVOD Board through ICFRE)	Compiled data on TBO cultivation in Gujarat and Rajasthan, focusing on species like Jatropha, Karanja, Neem, Mahua, Mango kernel, Jojoba, and Piloo.
4	Arid Forest Research Institute (AFRI), Jodhpur	Fatty oil studies of important oil-bearing plants of the arid region	High oil content was observed in Salvadora persica and S. oleoides from specific regions. Oil content varied across neem and Pongamia pinnata seeds from different locations, with some international provenances showing even higher oil content.
5	Institute of Wood Science and Technology (IWST), Bangalore	Fatty oil composition of lesser-known TBOs	Madhuca insignis seed oil identified as edible; Givotia oil showed antifungal activity; Hopea seed oil demonstrated antibacterial properties.
6	Institute of Forest Productivity (IFP), Ranchi	TBOs in community lands for improving livelihoods	Evaluated Pongamia pinnata clonal trials; significant growth observed in selected clones, indicating potential for community-based plantation initiatives.
7	Forest Research Institute (FRI), Dehradun	R&D on Jatropha under National Network Programme (Sponsored by NOVOD Board)	Conducted growth analysis, oil content studies, and pruning impact assessments on Jatropha.
8	Forest Research Institute (FRI), Dehradun	Studies on oilseeds of forest origin for oil and wetting agents	Five species, including Cedrela serata and Garuga pinnata, were identified with high fatty oil content. Sulphated oils were evaluated as substitutes for Turkey Red Oil.
9	Forest Research Institute (FRI), Dehradun	Studies on fungal infestation, mycotoxin elaboration, and biochemical changes in edible oilseeds	Aspergillus, Penicillium, and other fungi were found in stored samples, with aflatoxin presence varying by species. No fungal infestation in fresh samples of Prunus armeniaca.

seeds are vulnerable to pest and disease infestations both in the field and during storage, which can significantly impair seed quality and viability.

Tree-borne oilseeds (TBOs) from forest origins face many hurdles. One major problem is collecting seeds from scattered locations, which is time-consuming and inefficient. Additionally, high seed dormancy and difficulties in harvesting from avenue and forest plantations pose significant challenges. There is a notable lack of quality planting material and seeds, which are only available for limited periods. Marketing channels for TBOs are often unreliable and improper, which further complicates their distribution. Post-harvest technologies and processing methods are scarce, leading to poor handling and storage. As a result, prices are low, and there is a wide gap between potential and actual production. The absence of state incentives to promote biodiesel as a fuel adds to the economic challenges, making it hard to achieve a favorable cost-benefit ratio. Currently, TBOs contribute only a small portion of the country's vegetable oil production.

To address these issues, research and development efforts are needed. Focus areas should include germplasm resources, identifying elite planting material, developing propagation techniques, and establishing production technologies for large-scale plantations. Studies on how different TBO progenies perform under various agro-climatic conditions are essential. Additionally, effective pest and disease management strategies and quality assessment protocols are needed to improve overall productivity and sustainability.

In light of ongoing climate change and shrinking forest areas, it's crucial to restore TBO availability through forest restoration and cultivation outside forest areas using agroforestry models. Forest restoration involves bringing back degraded or damaged landscapes to their original state, helping to achieve climate mitigation, biodiversity conservation, and socio-economic benefits. Over the past few decades, emphasis has been placed on large-scale plantations under various schemes, which require a significant amount of seeds. Numerous national and international programs have committed to restoration, conservation, sustainability, and biodiversity.

Initiatives like social forestry, community forestry, and various national policies (e.g., National Forest Policy 1988, National Agroforestry Policy 2014) emphasize massive plantation efforts, especially in areas outside the forest. The Bonn Challenge, launched in 2011, aims to restore millions of hectares of degraded and deforested landscapes globally. India joined this initiative in 2015, pledging to restore 26 million hectares by 2030.

In India's Nationally Determined Contribution (NDC), a commitment was made to create an additional carbon sink of 2.5 to 3 billion tonnes of CO2 equivalent through forest and tree cover by 2030. The Indian government's 2022 Union budget highlights agroforestry and private forests as tools for decarbonizing the economy. With only 24.62% forest cover, far below the recommended 33%, there is little scope for increasing the area under natural forests. However, Trees Outside Forests (TOFs) offer tremendous opportunities for enhancing productivity and sustainability.

Certified Forest Reproductive Material (FRM) is vital for forestry and agroforestry functions, including timber production, food security, and climate change mitigation. FRM can significantly impact forest health, productivity, and resilience against climate changes, pests, and diseases. Promoting agroforestry through legislative changes and financial support is part of the government's broader goal of gradually moving towards a carbon-neutral economy.

However, one major constraint to scaling up agroforestry with tree components, including TBOs, is the unavailability of high-quality planting material. Ensuring the availability of quality planting material is essential before undertaking large-scale TBO plantations, as these species are perennial and can yield for 30-40 years once established.

The "Green Revolution" in agriculture was largely due to the use of quality seeds. The agricultural seed industry has well-established guidelines, rules, and protocols for testing seed quality. These are regulated by various bodies and legislation, such as the Seed Act of 1966 and Seed Control Order of 1983, and supported by organizations like the International Seed Testing Agency (ISTA) and the OECD. In contrast, the forestry sector lacks similar standards, policies, and infrastructure. Most genetic material in forestry, including TBOs, is obtained from unspecified sources, leading to poor seed quality and inconsistent results. A lack of control systems, such as minimum seed standards, testing protocols, and certification policies, further exacerbates the issue. Establishing uniform standards for tree seed testing and a "Seed Act" specific to forestry is essential to ensure the availability of high-quality seeds and planting material.

QUALITY CONTROL OF FORESTRY SEED INCLUDING TBOS

Quality control for seeds involves ensuring guaranteed germination rates and purity through a system of seed testing and certification [22-26]. Testing assesses physical purity, moisture, genetic purity, germination, vigor, and seed health. Recent advancements in non-destructive technologies, such as machine vision, spectroscopy, and thermal imaging, are enhancing seed quality assessment. Certification verifies the origin and quality of seeds, akin to a guarantee for manufactured goods, and is crucial for maintaining high-quality forest tree seeds and propagating materials. The OECD Scheme, established in 1967, sets international standards for forest reproductive material, categorizing them into four classes: source-identified, selected, qualified, and tested. This scheme promotes the production and use of forest seeds and plants in compliance with standards to ensure their trueness to name. The OECD's internationally recognized certification process, which 29 countries participate in, helps standardize and ensure quality across global seed exchanges and forestry functions. Many countries globally have established seed zone systems for their indigenous species and various schemes of seed certification have been designed (NWFTSCA- Forest Reproductive Material Certification Standards: Oregon-Washington Interagency, OECD- Control of Forest Reproductive Material Moving in International Trade, European Union (EU) - Council Directive 1999/105/EC, etc.) (Table 3).

This table compares the different forest reproductive materials certification schemes employed in the USA, OECD countries, the European Union, and India, highlighting their origin, general overview, and classification of forest reproductive materials.

In India, at present no legal framework exists. The first attempt to certify tree germplasm in India began in 1979 under an Indo-Danish project on seed procurement and tree improvement. Indian Council of Forest Research and Education (ICFRE) lobbied for the certification of tree germplasm and the Indian government reinitiated the process of developing a certification scheme for forest and agroforestry tree germplasm in 2008 but it is still

Table 3. Comparison of Forest Reproductive Materials Certification Schemes around the globe

Region	USA - Northwest Forest Tree Seed Certifiers Association (NWFTSCA)	OECD (Organization for Economic Cooperation and Development)	European Union (EU)	India
Name of Scheme	Forest Reproductive Material Certification Standards: Oregon-Washington Interagency	Control of Forest Reproductive Material Moving in International Trade	Council Directive 1999/ 105/EC (later EU 2000: Directive 199/105/CE)	No legal framework currently exists
General Overview	- Formed in 1966 - Provides certification for a wide range of forest reproductive materials (FRM) including seeds, scions, cuttings, seedlings, and pollen - Certification also covers FRM sources such as seed orchards, seed production areas, plantations, and evaluation tests - Recognizes four classes of reproductive material sources	- First published in 1967, amended in 1974 - Currently under revision - Approves reproductive material from seven types of "basic material": seed source, stand, seed plantation, seed orchard, parents of families, clonal mixtures, and clone - All materials tagged and accompanied by a certificate of provenance	- First enacted in 1966 - Substantially amended to incorporate advances in tree improvement	- First attempt to certify tree germplasm began in 1979 under an Indo-Danish project on seed procurement and tree improvement - Indian Council of Forest Research and Education (ICFRE) has lobbied for certification - Efforts to develop a certification scheme were reinitiated in 2008, but no national scheme has been established yet - Some states have their own testing and certification standards for commercially important species
Classes of FRM	1. Audit Class 2. Source-Identified Class 3. Selected Class 4. Tested Class	1. Source-Identified Material 2. Selected Material 3. Qualified Material (from untested seed orchards) 4. Tested Material	1. Source-Identified Material 2. Selected Material 3. Qualified Material (from untested seed orchards) 4. Tested Material	1. Source-Identified Material 2. Selected Material 3. Qualified Material (from untested seed orchards) 4. Tested Material

pending. Currently, few states in India have developed their own testing and certification standards for some commercially important tree species, but these are not up to mark to be used across the country.

OPPORTUNITIES FOR IMPROVEMENT

To tackle the challenges in TBO cultivation and enhance seed quality, a range of innovative strategies can be employed. Imagine a world where breeding programs are the heart of transformation, creating cultivars with not only higher genetic uniformity but also with enhanced oil content and resilience to environmental stresses. Advanced techniques like marker-assisted selection and biotechnology speed up the journey to developing superior TBO varieties. Pre-sowing treatments act as a protective shield, preparing seeds for the rigors of germination with methods such as priming and coating with bio-fertilizers. These treatments also guard against pests and diseases, ensuring robust seedling growth. The evolution of storage practices introduces modern techniques like controlled atmosphere storage and vacuum packing, which preserve seed vitality by preventing deterioration. Meanwhile, Integrated Pest and Disease Management (IPDM) strategies deploy biological control agents and resistant varieties to keep pests and diseases at bay. Looking ahead, the potential of oils and fats from tree-borne oilseeds as vital resources for food, fuel, and industrial applications drives ongoing research. Institutions like IICT are exploring new oil sources, while the development of bio-lubricants aims to reduce reliance on petroleum-based products. ICAR and ICFRE are at the forefront of improving collection and processing technologies, identifying valuable germplasm, and integrating TBOs into agroforestry systems. Additionally, the introduction of exotic species like the Shea butter tree and Argania spinosa offers new opportunities. Future efforts will focus on developing technologies and mechanisms to ensure that TBOs not only thrive but also contribute significantly to sustainable and profitable agroforestry systems.

CONCLUSION

In a world grappling with high oil prices, depleted fossil fuels, and environmental challenges, tree-borne oilseeds (TBOs) emerge as a promising solution. With the potential to provide sustainable energy and create rural jobs, TBOs like Sal, Neem, and Mahua are crucial for addressing these issues. To realize their full potential, we need to implement robust seed handling and certification processes, strengthen supply systems, and adhere to international standards. By overcoming current obstacles and drawing on successful local initiatives, TBOs can reduce India's reliance on imported oils and contribute to a more sustainable and resilient agricultural sector.

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REFERENCES

1. ECONOMIC SURVEY (2021-22). Government of India. Retrieved from https://static.pib.gov.in/WriteReadData/specificdocs/documents/2022/jan/doc202213111201.pdf#:~:text=GOVERNMENT%20OF%20INDIA.%20Economic%20Survey%202021%2D2022
2. NMOOP (2018). Retrieved from https://www.nfsm.gov.in/StatusPaper/NMOOP2018.pdf
3. CHALIHA B, L LAHKAR, A DOLEY, R KOTOKY, SP SAIKIA AND SC NATH (2017). Screening of some lesser known tree-borne oilseed plants from North-East India for their oil content and major fatty acid components. *Prostaglandins, Leukotrienes and Essential Fatty Acids, **126**: 9-19. doi: 10.1016/j.plefa.2017.08.014. Epub 2017 Aug 24. PMID: 29031401
4. MUKTA N AND KS VARAPRASAD (2018). Tree borne oilseeds for Agroforestry. In: *Agroforestry Opportunities for Enhancing Resilience to Climate Change in Rainfed Areas* (p. 43)
5. CHALIHA B, D SAIKIA AND SP SAIKIA (2019). Tree-Borne Edible Oilseeds as Sources of Essential Omega Fatty Acids for Human Health. In: *The Health Benefits of Foods-Current Knowledge and Further Development*. IntechOpen
6. DHYANI SK, S VIMALA DEVI AND AK HANDA (2015). Tree Borne Oilseeds for Oil and Biofuel. Technical Bulletin 2/2015. ICAR-CAFRI, Jhansi. pp: 50
7. NOVOD (2008). 3rd R&D report on tree borne oilseeds, NOVOD Board India. Retrieved from http://www.novodboard.com/3rd%20R&D-Report.pdf
8. THEOBROMA CACAO OIL (n.d.). Medicines FAQ. Retrieved from https://www.medicinesfaq.com/brand/theobroma-cacao-oil
9. KUKRETI I (2018). Down to Earth is a fortnightly magazine focused on politics of environment and development, published in New Delhi, India. The Centre for Science and Environment assists in the production of the magazine. *Down to Earth*. Retrieved from https://www.downtoearth.org.in/news/forests/oil-grows-on-trees-60255
10. LEONE A, A SPADA, A BATTEZZATI, A SCHIRALDI, J ARISTIL AND S BERTOLI (2016). *Moringa oleifera* seeds and oil: Characteristics and uses for human health. *International Journal of Molecular Sciences*, **17**(12): 2141.
11. NAEL AT AND AAAW MOHAMMED (2011). Utility and importance of *walnut*, *Juglans regia* Linn: A review. *African Journal of Microbiology Research*, **5**(32): 5796-5805.

12. POGGETTI L, C FERFUIA, C CHIABA, R TESTOLIN, & M BALDINI (2018). Kernel oil content and oil composition in *walnut* (*Juglans regia* L.) accessions from north-eastern Italy. *Journal of the Science of Food and Agriculture*, **98**(3): 955-962.

13. CHAUHAN S, A SONI, CHINU AND S CAHUDHARY (2015). A review on ethnobotanical and pharmacological uses of *Bombax ceiba*. *Asian Pacific Journal of Pharmaceutical and Applied Sciences*, **1**(1): 12-18.

14. RANI S AND K RAHMAN (2017). *Molsari* (*Mimusops elengi* Linn.): A boon drug of traditional medicine. *International Journal of Pharmaceutical Sciences and Research*, **8**(1): 17.

15. GAMI B, S PATHAK AND M PARABIA (2012). Ethnobotanical, phytochemical and pharmacological review of *Mimusops elengi* Linn. *Asian Pacific Journal of Tropical Biomedicine*, **2**(9): 743-748.

16. KUMAR S, RC PRADHAN AND S MISHRA (2016). Exploration of *Shorea robusta* (Sal) seeds, kernels and its oil. *Cogent Food & Agriculture*, **2**(1): 1186140.

17. SINGH P, G MISHRA, S SRIVASTAVA, KK JHA AND RL KHOSA (2011). Traditional uses, phytochemistry and pharmacological properties of *Capparis decidua*: An overview. *Der Pharmacia Lettre,* **3**(2): 71-82.

18. DEVKI G AND S RASHMI (2020). Screening of the potential phytochemicals from the *Capparis decidua* fruit extract using GC-MS. *OAJBS*.ID.000235, **2**(6).

19. NADEEM M, M IMRAN AND A KHALIQUE (2016). Promising features of *mango* (*Mangifera indica* L.) kernel oil: a review. *Journal of Food Science and Technology*, **53**(5): 2185-2195.

20. PALM OIL WORLD (n.d.). Retrieved from http://www.palmoilworld.org/about_malaysian-industry.html

21. HASSIM NAM & LNHM DIAN (2017). Usage of palm oil, palm kernel oil and their fractions as confectionery fats. *Journal of Oil Palm Research*, **29**(3): 301-310.

22. ACKZELL L (2002). On the doorstop to new legislation on forest reproductive material: policy framework and legislation on trade with forest reproductive material. *Genet Resour*, **30**: 52–53.

23. LAL P, AS DOGRA AND SL DABRAL (2008). Need for an institutional and regulatory mechanism for certification of forest reproductive material. Study commissioned by the Indian Council of Forestry Research and Education (ICFRE).

24. OECD (n.d.). OECD - Forest. Retrieved from https://www.oecd.org/agriculture/forest/

25. INTERNATIONAL RULES FOR SEED TESTING (n.d.). Retrieved from https://www.seedtest.org/en/publications/international-rules-seed-testing-1168.html

26. INDIAN SEED SECTOR (n.d.). Retrieved from https://seednet.gov.in/Material/IndianSeedSector.aspx