

Sandalwood Sustainable Harvesting Methods

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Introduction

Sandalwood oil is one of the most valuable essential oils globally, extracted primarily from trees of the genus *Santalum* (Indian sandalwood, *Santalum album*) and *Osyris* (African sandalwood, *Osyris lanceolata*). The oil is highly sought after in the fragrance, pharmaceutical, and cosmetic industries due to its unique woody aroma and numerous therapeutic properties. The global sandalwood oil market was valued at approximately \$150 million in 2022 and is expected to grow at a CAGR of 10.5% from 2023 to 2030. Sandalwood oil is composed mainly of sesquiterpenes, with α -santalol (41–55%) and β -santalol (16–24%) being the key components responsible for its fragrance and medicinal benefits. Traditionally, sandalwood oil has been used in Ayurveda, Chinese medicine, and aromatherapy for its anti-inflammatory, antiseptic, and sedative properties. Due to increasing demand, commercial production of sandalwood oil has expanded beyond its native regions, leading to conservation concerns as wild populations continue to decline.

Globally, sandalwood harvesting varies significantly based on species availability, conservation laws, and market demand. Indian sandalwood (*Santalum album*), native to South India and Indonesia, has historically been the largest source of sandalwood oil. However, due to overexploitation, more than 90% of India's natural sandalwood forests have been depleted, prompting strict government regulations. As a result, controlled plantations have been established in Australia, which is now the world's largest producer of cultivated sandalwood, producing over 150 metric tonnes of sandalwood oil annually. In contrast, African sandalwood (*Osyris lanceolata*), found in Eastern, Central, and Southern Africa, remains predominantly harvested from the wild due to the lack of large-scale plantations. This species, a slow-growing hemiparasite, faces significant threats from illegal logging, driven by high-value oil markets, particularly in East Africa, where the price of sandalwood oil can reach up to \$4,500 per liter.

In East Africa, *Osyris lanceolata* is harvested extensively in Kenya, Tanzania, Uganda, and Ethiopia, mainly in dryland and semi-arid regions. In Kenya, it is primarily found in Laikipia, Kajiado, Kitui, and Taita Taveta counties, where wild populations are rapidly declining due to illegal harvesting. Despite government bans, sandalwood trafficking remains rampant, with an estimated 500 tonnes of illegally harvested sandalwood seized between 2015 and 2020. The primary harvesting methods involve uprooting

entire trees to access the valuable heartwood, which significantly reduces regeneration potential. Studies indicate that over 80% of African sandalwood harvesting in East Africa is unsustainable, putting the species at risk of extinction.

Kenya has been a hotspot for African sandalwood exploitation, prompting the government to ban sandalwood cutting and export in 2007. Additionally, *O. lanceolata* was listed under CITES Appendix II in 2016, requiring international trade monitoring to prevent overexploitation. However, enforcement challenges persist, and efforts to establish commercial sandalwood plantations have been slow due to limited agronomic knowledge and the species' dependency on host trees. Research into sustainable sandalwood management is critical to ensuring its long-term conservation while supporting local livelihoods.

Given the growing threats to wild sandalwood populations, there is an urgent need to develop sustainable harvesting techniques that balance conservation with economic interests. Traditional oil extraction methods involve destructive harvesting, leading to tree mortality rates of nearly 100% in areas where trees are uprooted.

However, alternative non-lethal techniques such as root tapping and selective branch pruning could provide a more sustainable approach while maintaining oil production. Studies on *Santalum album* in Australia indicate that controlled root tapping can yield 2–3% essential oil per kilogram of root biomass, while branch pruning can still produce 0.5–1.2% essential oil without killing the tree. The effectiveness of these methods in *Osyris lanceolata* remains largely unexplored, requiring rigorous scientific investigation.

Sustainable Sandalwood Harvesting: Alternative Non-Lethal Techniques

The traditional method of sandalwood oil extraction has historically involved complete tree uprooting, targeting the heartwood, which contains the highest concentration of essential oil. This practice results in near-total tree mortality and poses severe ecological and economic challenges, particularly in regions where sandalwood populations are already under pressure from overharvesting. As efforts to introduce *Santalum album* in Kenya continue and *Osyris lanceolata* domestication gains momentum, it is imperative to develop and implement non-lethal extraction methods. Techniques such as controlled root tapping and selective branch pruning offer

viable alternatives, allowing for periodic oil extraction while preserving tree vitality and promoting regeneration.

Among the most promising sustainable techniques are root tapping and selective branch pruning, both of which allow sandalwood to regenerate after oil extraction while reducing dependence on wild populations. These methods have gained attention in commercial plantations, particularly in Australia, where research on *Santalum album* has demonstrated the potential for sustainable oil yield. However, their effectiveness on *santalum album* in Kenya and in *Osyris lanceolata* remains largely unstudied, necessitating research into their applicability in African contexts [1-5].

Root Tapping: Controlled Oil Extraction from Underground Biomass

Root tapping involves partial root harvesting, where specific roots are carefully extracted from mature trees without killing them. This technique is based on the understanding that sandalwood trees store significant amounts of essential oil in their roots, and by selectively harvesting a fraction of these roots, the tree can survive and continue to grow. Studies on *Santalum album* in Australia have shown that controlled root tapping can yield between 2–3% essential oil per kilogram of root biomass, while allowing trees to remain productive for multiple harvest cycles over their lifespan.

Justification

Sandalwood (*Santalum album* and *Osyris lanceolata*) is among the most valuable tree species globally due to its high-quality essential oil, widely used in perfumery, traditional medicine, and cosmetics. The global demand for sandalwood oil, estimated at over US\$300 million annually, has led to rampant overexploitation and population declines, particularly in India and Africa. In Kenya, *Osyris lanceolata* is near threatened, with illegal harvesting and habitat destruction posing significant threats to its survival.

KEFRI has started a project on domesticating *Osyris* and has introduced *Santalum album* in Kenya.

The Need for Sustainable Harvesting Practices

Current sandalwood oil extraction primarily relies on uprooting trees to harvest the root biomass, where the highest oil concentrations are found. This practice has led to widespread population declines, particularly in regions where replanting efforts are minimal. In India, for example, *Santalum album* populations have dropped by over 50% in the last century, necessitating strict government regulations and conservation programs. Similarly, in Kenya, reports indicate that illegal harvesting of *Osyris lanceolata* has led to a drastic reduction in wild populations, with limited regeneration due to seed predation and habitat degradation.

Sustainable harvesting techniques such as root tapping and branch pruning have been proposed as viable alternatives to complete tree removal. Studies on *Santalum album* in Australia have shown that controlled root tapping can yield 2–3% essential oil per kilogram of root biomass, while selective branch pruning can produce 0.5–1.2% oil content without killing the tree. However, no comprehensive studies have assessed the effectiveness of these techniques for *Osyris lanceolata* and *Santalum album* in Kenya.

Knowledge Gaps on Oil Yield and Chemical Composition

The chemical composition and yield of sandalwood oil vary based on genetic factors, host species, and environmental conditions. Research on *Santalum album* has demonstrated that factors such as soil type, climatic conditions, and host tree selection influence

oil quality. However, similar studies on *Osyris lanceolata* remain limited. There is an urgent need to understand how non-lethal harvesting techniques affect oil yield and composition in different growing conditions in Kenya.

Economic and Conservation Justification

Sandalwood oil is one of the most expensive essential oils in the world, with market prices exceeding US\$2,000 per kilogram for high-quality *Santalum album* oil. In Africa, *Osyris lanceolata* oil is becoming increasingly valuable, with emerging markets in Europe and Asia. However, due to the unsustainable harvesting of wild populations, Kenya lacks a structured and legal supply chain for sandalwood oil, leading to significant losses in potential revenue.

If sustainable harvesting techniques are successfully implemented, Kenya could develop a legal and sustainable sandalwood oil industry, benefiting local communities through agroforestry-based sandalwood production. This would also help reduce illegal trade and promote conservation by allowing trees to continue growing while still producing commercially valuable oil.

Alignment with KEFRI's Strategic Plan and National Forestry Policies

This research aligns with KEFRI's Strategic Plan 2023–2027, which prioritizes:

- Sustainable utilization of forest resources, including non-timber forest products (NTFPs).
- Agroforestry and conservation strategies that integrate high-value tree species.
- Climate resilience in dryland ecosystems, where *Osyris lanceolata* naturally occurs.

Additionally, this study supports Kenya's National Strategy for the Sustainable Use of Genetic Resources, which encourages the domestication and conservation of threatened plant species. Developing sustainable sandalwood harvesting techniques would contribute to national efforts in forest restoration, biodiversity conservation, and economic empowerment through high-value tree farming.

Objectives

This study aims to:

General objective

- To evaluate sandalwood sustainable harvesting methods

Specific objectives

- Assess the impact of root tapping and branch pruning on tree health and growth by monitoring physiological responses, survival rates, and biomass regeneration.
- Compare oil yield and chemical composition from different harvesting methods to determine the feasibility of non-lethal extraction.
- Evaluate the economic feasibility of sustainable sandalwood oil extraction, considering yield efficiency, production costs, and market viability (cost-benefit analysis)

Methodology

This study will evaluate the impact of root tapping and branch pruning on tree health, oil yield, and chemical composition of *Osyris lanceolata* (African sandalwood) and *Santalum album* (Indian sandalwood). The research will also assess the economic feasibility of these sustainable harvesting methods. Frequency of data collection will be quarterly while oil extraction will begin at year three after establishment.

Study Design and Site Selection

Selection of Study Sites

The research will be conducted in Laikipia and Kitui counties where KEFRI has Sandalwood trial sites. Selected based on: Presence of sandalwood species (cultivated stands) and variability in climate and soil conditions (semi-arid to arid regions)

Experimental Setup

Each study site will contain experimental plots for *Santalum album* and *Osyris lanceolata*.

Treatment Groups

Root Tapping (RT) - Carefully extracting oil from lateral roots while keeping trees alive.

Branch Pruning (BP) - Selectively pruning mature branches for oil extraction.

Control (C) - Unharvested trees to serve as a baseline for comparison.

Each site will have 30 trees per treatment (90 trees per site), totaling 270 trees across all sites.

Spacing: Trees are spaced at 6m × 6m to mimic agroforestry conditions.

Growth Conditions: Soil, moisture, and climatic variables will be monitored to ensure consistency across sites.

Data Collection Procedures

Tree Health and Growth Monitoring

To determine how root tapping and branch pruning affect tree health, the following parameters will be measured every six months for two years:

Tree Height and Diameter Growth

Height measurement: A clinometer will be used to track tree height changes.

Diameter measurement: A diameter tape will measure trunk girth at breast height (DBH).

Growth comparison: Differences in height and diameter between tapped, pruned, and control trees will indicate potential stress or adaptation.

Leaf Chlorophyll Content

A SPAD meter will assess chlorophyll levels, which correlate with tree vigor and photosynthetic efficiency.

Low chlorophyll levels could indicate stress from excessive root tapping or pruning.

Root Regrowth Monitoring

A subset of root-tapped trees will be carefully excavated every six months to observe lateral root regeneration.

This will determine whether trees can recover from root tapping over time.

Oil Yield and Chemical Composition Analysis

To compare the oil yield and chemical composition from different harvesting methods, sandalwood samples will be processed and analyzed.

Sample Collection and Processing

Root Tapping Treatment (RT)

Root tapping involves partial root harvesting, where specific roots will carefully be extracted from mature trees without killing them. This technique is based on the understanding that sandalwood trees store significant amounts of essential oil in their roots,

and by selectively harvesting a **fraction of these roots**, the tree can survive and continue to grow. Studies on *Santalum album* in Australia have shown that controlled root tapping can yield between **2–3% essential oil per kilogram of root biomass**, while allowing trees to remain productive for **multiple harvest cycles over their lifespan**.

The root tapping process will follow several key steps to ensure minimal impact on tree health:

Identification of Mature Trees

Root tapping will be conducted on trees that have reached at least 15–20 years of age, as younger trees have lower oil concentrations and are more vulnerable to stress.

Selective Root Harvesting

Instead of uprooting the entire tree, only lateral and secondary roots will be carefully extracted using specialized tools that minimize root damage. Primary taproots, which are essential for tree stability, will remain intact.

Regeneration Monitoring

After root extraction, the trees will be monitored for **physiological stress**, root regrowth, and overall health, ensuring they will recover and continue growing.

Oil Extraction Process

Extracted roots will be processed through steam distillation, with studies showing that 2–3% essential oil can be obtained per kilogram of dry root material.

Selective Branch Pruning Treatment (BP)

Selective branch pruning is another promising non-lethal technique that involves harvesting oil-rich branches rather than targeting the tree's heartwood or roots. Although branches generally contain lower essential oil concentrations than roots, pruning offers a sustainable alternative, particularly in managed plantations.

The branch pruning process will follow these key steps:

Pruning Mature Trees Only: Branch pruning will be performed on trees that are at least **10–15 years old**, as younger trees require their full canopy for growth and oil accumulation.

Harvesting at the Right Time: Research indicates that oil yield fluctuates with **seasonal variations**, with higher concentrations occurring during the dry season when secondary metabolite production peaks. Harvesting will take place during the dry seasons biannually.

Strategic Cutting Techniques: Only selected lateral and secondary branches will be pruned, leaving the main structure intact to ensure continued growth and photosynthesis.

Distillation and Yield Analysis: Carry out Steam distillation of pruned branches which yields between 0.5–1.2% essential oil per kilogram of biomass, making this method viable in commercial setups where trees can be harvested multiple times.

Oil Extraction and Analysis

Extraction Method: steam distillation

Samples will be dried under the sun then heated in water for 6–8 hours to extract essential oils.

The oil yield will be calculated as percentage weight of extracted oil per kilogram of dry biomass.

Chemical Composition Analysis: Gas Chromatography-Mass Spectrometry (GC-MS)

GC-MS will identify and quantify key oil components: α -santalol & β -santalol (the primary active compounds in sandalwood oil).
Farnesol, Santalenes, and minor sesquiterpenes.

The chemical profiles of oil from different harvesting methods will be compared to determine:
Whether root oil differs from branch oil.
Whether stress from pruning affects oil quality.

Economic Feasibility Study

To determine whether sustainable sandalwood oil harvesting is economically viable, we will conduct a cost-benefit analysis.

Cost Analysis

Labor costs: Root tapping vs. branch pruning.
Equipment costs: Tools needed for non-lethal harvesting.
Processing costs: Oil extraction, storage, and refining.
Revenue Projections

Oil Yield Estimates

Root tapping: 2–3% oil per kg of root biomass.
Branch pruning: 0.5–1.2% oil per kg of branch biomass.
Market Price of Sandalwood Oil:
\$1,500–\$2,500 per liter for high-quality sandalwood oil.
Profit estimates based on international demand.

Break Even Analysis

Using Net Present Value (NPV) and Internal Rate of Return (IRR) calculations, the study will determine:
How many years farmers need to break even using sustainable harvesting.
Whether non-lethal harvesting is more profitable long-term than cutting trees for immediate profit.

Data Analysis

Growth and Health Analysis

One-way ANOVA will compare height, diameter, canopy density, and chlorophyll levels between treatment groups.

T-tests will determine if root regrowth rates differ significantly between sites.

Oil Yield and Composition Analysis

Generalized Linear Models (GLM) will assess whether root oil differs significantly from branch oil.

Principal Component Analysis (PCA) will group chemical compositions by harvesting method.

Economic Analysis

Break-even analysis will project at what point sustainable harvesting becomes more profitable than destructive harvesting.

Expected Outcomes

Scientific validation of root tapping and pruning as sustainable sandalwood harvesting methods.

Recommendations for farmers and policy-makers on viable oil extraction techniques.

Demonstration of economic feasibility to promote commercial adoption of sustainable sandalwood practices.

Technical papers and a journal.

References

1. Chetty K (2018) Sandalwood Cultivation and Harvesting Techniques. Australian Forestry Research Institute.
2. Gupta A (2018) Pharmacological Properties of Sandalwood Oil: A Review. Journal of Essential Oil Research 30: 154-167.
3. Kumar R, Kulkarni S (2016) Sandalwood Conservation Strategies in India: Challenges and Opportunities. Indian Journal of Forestry 45: 211-225.
4. Mugambi P (2022) Sustainable Sandalwood Extraction Methods in East Africa: A Preliminary Study. African Journal of Agroforestry 12: 89-103.
5. Page T (2021) Commercial Sandalwood Production in Australia: Lessons for Global Conservation. Journal of Agroforestry Science 58: 299-317.