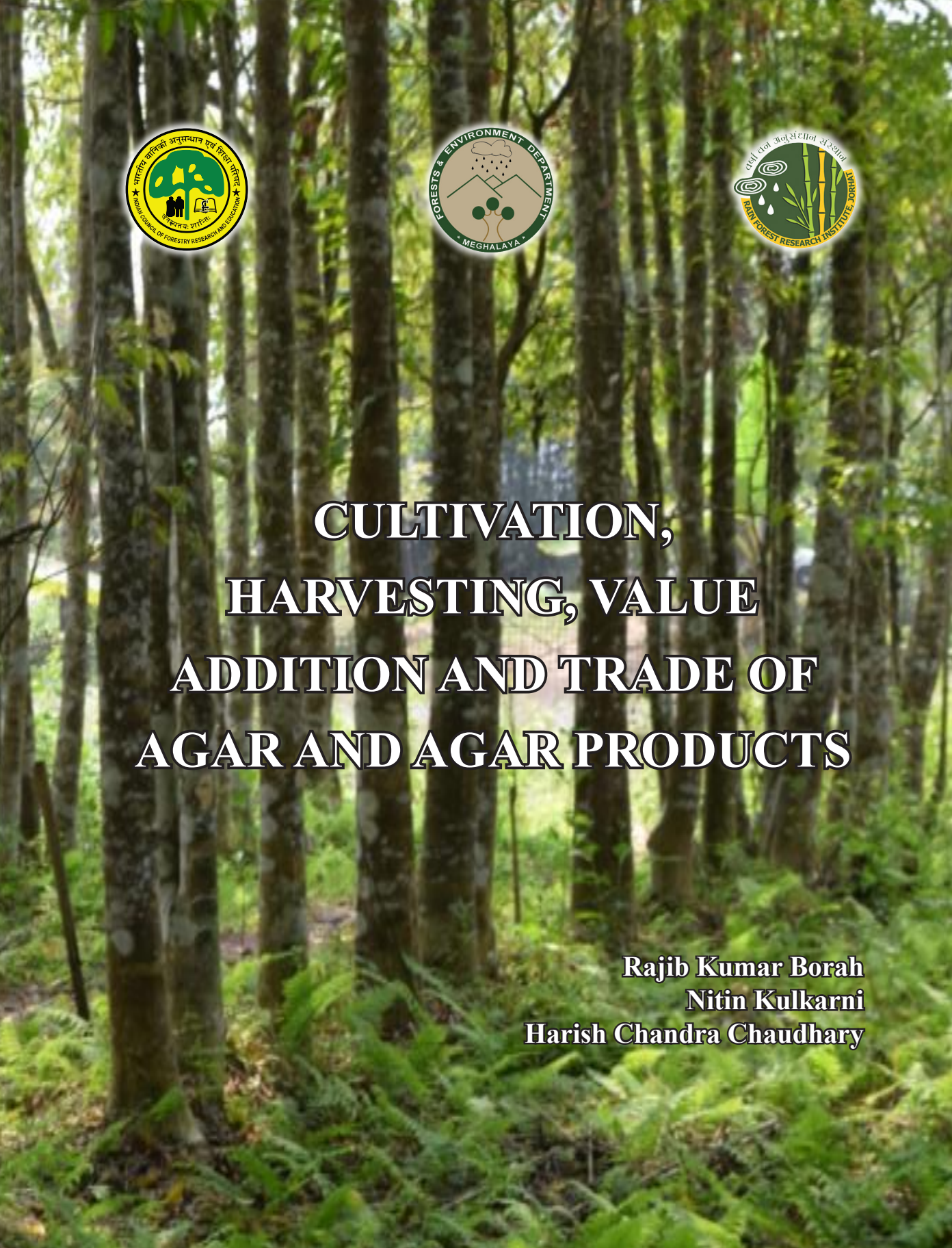


CULTIVATION, HARVESTING, VALUE ADDITION AND TRADE OF AGAR AND AGAR PRODUCTS

Rajib Kumar Borah
Nitin Kulkarni
Harish Chandra Chaudhary

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Chapter 1: INTRODUCTION

1.1 Brief Overview of Agar

Agarwood, a resin-infused fragrant wood, is derived from tropical evergreen trees of the genera *Aquilaria*, *Gyrinops*, *Aetoxylon*, and *Gonystylis*, belonging to the family Thymelaeaceae. It is also known by various names such as '*agaru'*, '*aloeswood'*, '*eaglewood'*, '*gaharu'*, '*oud'*, '*chén xiāng'*, and '*jinkoh'*. These species are distributed from India to the island of New Guinea and from tropical China to the Lesser Sunda Islands. Among these, *Aquilaria* species have been the primary source of agarwood.

In India, agar trees are found in Arunachal Pradesh, Assam, Manipur, Meghalaya, Tripura, Mizoram, Nagaland, Sikkim, and Northern West Bengal, as well as in some southern states like Karnataka, Kerala, and Goa. Agar trees naturally grow in all parts of Meghalaya except the Shillong Plateau. Besides *Aquilaria malaccensis*, the primary source of agarwood in India, the rare *A. khasiana* is also found in Meghalaya.

The resin-embedded agarwood is valued for its distinctive fragrance and healing properties. Agarwood has been used for over 2,000 years for medicinal, aromatic and religious purposes. The resin is widely used for production of incense, perfume, cosmetics and medicines. The resin develops and accumulates in stem and branches of agar tree as an immune response to biological, physical and chemical stress. Natural formation of resin, as an immune response to fungal infection or borer attack occurs in 10-15 percent trees in wild populations. Resin formation can also be triggered by artificial injury, microbial infection, and chemical treatment. Most common among these is artificial inoculation of some fungal inoculants. Development of cost-effective techniques to ensure assured formation of resin is still in progress.

The quality of agarwood depends on various factors, including the species, geographic location, part of the tree from which it has been extracted, cause of resin formation, duration since infection, and methods of harvesting and processing. Agarwood can retain its fragrance for long periods when properly handled, allowing for its storage and long-distance trade as a high-value commodity akin to precious stones and metals. Fine-grade agarwood, often called "**liquid gold**," ranks among the world's most expensive natural raw materials. Agar trees are non-palatable. Hence, they are not susceptible to browsing and grazing by livestock and can withstand various soil, climatic, and topographic conditions. Properly managed agar trees can be harvested in ten to fifteen

years to produce agarwood chips, oil, and other value-added products. Low gestation period, low input requirements, and absence of adverse allelopathy effects make agar one of the promising agroforestry species.

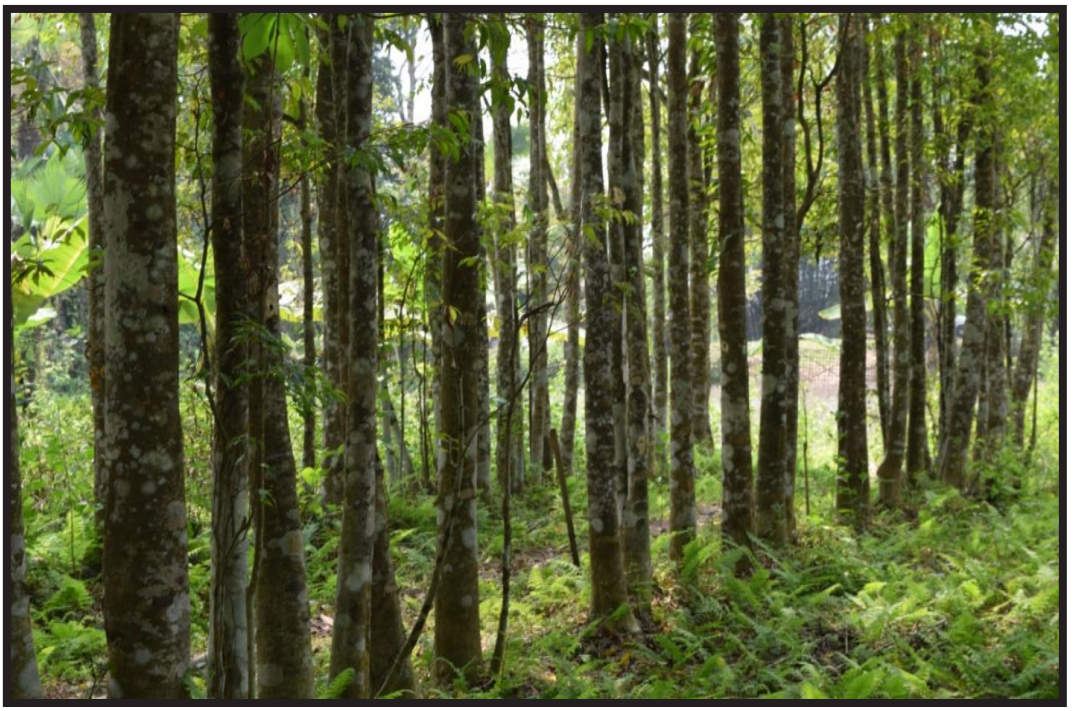


Figure 1: *Aquilaria malaccensis* Trees

Processing agarwood, especially extracting resin-embedded portions as agarwood chips, is labor-intensive. Similarly, raising agar plants in nurseries and creating and maintaining agar plantations can generate significant wage employment for tribal residents in rural areas. Plantation, maintenance, harvesting, value addition, marketing, and trade of agarwood and its products hold immense potential to generate income and employment for the state's residents.

Due to a limited resource base and high demand, *Aquilaria malaccensis*, the primary source of agarwood in India, has been listed in Appendix II of the Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES) as a "potentially threatened species" to ensure that the legal trade does not become a direct cause leading towards its extinction. The export of agarwood requires an Export Permit from designated CITES Authorities. Such a permit can be issued on the basis of a Certificate of Legal Procurement (CLP) issued by an officer not below the rank of Assistant Conservator of Forests.

1.2 Botanical Description of *Aquilaria malaccensis* Lam.



Figure 2: *Aquilaria malaccensis*

The generic name *Aquilaria* originates from the Latin word 'aquila,' meaning 'eagle,' or from the Akkadian word 'eklu,' meaning 'dark' or 'ekelu,' meaning 'to be dark'. The specific epithet "*malaccensis*" refers to its probable type locality, Malacca, a costal state of Malaysia.

Aquilaria malaccensis Lam. is a shade-tolerant tree that is medium to large in size and can reach heights of 20 to 40 meters. The tree typically has a straight, occasionally fluted trunk with thick buttresses up to 2 meters high and a diameter of up to 60 cm. The bark is thin, smooth, ash-colored, and tough, while the wood is light, soft, and porous. The branchlets are slender, pale brown, and initially pubescent but turn glabrescent over time.



Figure 3: Leaves of *Aquilaria malaccensis*

The leaves of *Aquilaria malaccensis* are simple and alternate in arrangement. Each leaf has a petiole that is 4 to 6 mm long. The leaf blade is elliptical-oblong to oblong-lanceolate in shape, measuring 7.5 to 12 cm in length and 2.5 to 5.5 cm in width. The leaves are chartaceous to sub-coriaceous, glabrous, and sometimes pubescent and glabrescent beneath, with both surfaces appearing shiny. The base of the leaf is acute, attenuate, or obtuse, while the apex is acuminate with an acumen up to 2 cm long. The veins are irregular, often branched, elevated, and distinct beneath, curving upward to the margin and plane or obscure above, forming 12 to 16 pairs of secondary veins.



Figure 4: Flowers of *Aquilaria malaccensis*

The inflorescence of *Aquilaria malaccensis* can be terminal, axillary, or supra-axillary, sometimes appearing as internodal umbels. These inflorescences are usually branched into 2 to 3 umbels,

each bearing about 10 flowers. The peduncle is 5 to 15 mm long, and the pedicel is slender, measuring 3 to 6 mm. The flowers are pentamerous and campanulate, with a length of 5 to 6 mm, and are green or dirty-yellow in color with scattered puberulous outside. The floral tube is nearly glabrous inside, distinctly 10-ribbed, and persistent in fruit. The calyx lobes are 5 in number, ovate-oblong, 2 to 3 mm long, nearly as long as the tube, and reflexed with a densely puberulous interior. There are 10 petaloid appendages inserted at the throat of the tube, oblong or slightly ovate-oblong, about 1 mm long, somewhat incurved, and densely pilose. There are 10 free stamens that emerge from the tube's throat, with filaments 1.2 to 2 mm long. The episepalous stamens are longer than the others. The anthers are linear and obtuse. The pistil is included within the flower, with an ovoid ovary measuring 1 to 1.5 mm long, 2-celled, and densely pubescent. The style is obscure and the stigma is capitate.



Figure 5*:* Fruit capsule of *Aquilaria malaccensis*



Figure 6: Capsule with seeds

The fruit is a loculicidal capsule, obovoid or obovoid-cylindrical, measuring 3 to 4 cm in length and 2.5 cm in width. It is usually compressed, pubescent, and becomes glabrescent with age, having a cuneate base and a rounded apex with a woody pericarp. The seed is ovoid, 10 × 6 mm, including a beak 4 mm long, densely red-haired, and bearing from the base a twisted, tail-like, pubescent appendage as long as the seed itself.

1.3 Habitat and Ecology

Aquilaria malaccensis is a large evergreen tree found in various habitats, including rocky, sandy, or calcareous soils, well-drained slopes, ridges, and areas near swamps. It is mainly found in foothills and undulating slopes of evergreen and semi-evergreen forests. The preferred soil type for agar cultivation is well-drained, deep, sandy loam or loam soil rich in organic matter with an acidic pH. It is generally found at altitudes between 0 to 1000 meters above sea level. The annual rainfall ranges from 1800 to 3500 mm,

with temperatures between 20 and 28 degrees Celsius and a relative humidity of 80%. *Aquilaria sp*. has been observed to have low natural regeneration and slow growth.

1.4 Distribution of Aquilaria malaccensis

1.4.1 Global

Aquilaria malaccensis is distributed across several Asian countries, including India, Bangladesh, Bhutan, Indonesia, Laos, Malaysia, Myanmar, Philippines, Singapore, and Thailand. Although the World List of Threatened Trees initially listed Iran as one of the countries with a population of *A. malaccensis*, an exploratory review by CITES in 2002 confirmed no presence of the species in Iran.



Figure 7: Global Distribution of *Aquilaria Species*

Table 1: Global Distribution of *Aquilaria Species*

Country	Species
India	*A. khasiana, A. malaccensis*
Nepal	*A. malaccensis*
Bhutan	*A. malaccensis*
Myanmar	*A. malaccensis*
China	*A. sinensis, A. yunnanensis*
Thailand	*A. crassna, A. hirta, A. malaccensis, A. rugosa, A. subintegra*
Laos	*A. crassna*
Cambodia	*A. baillonii, A. crassna*
Vietnam	*A. baillonii, A. banaensis, A. crassna, A. rugosa*
Peninsular Malaysia	*A. beccariana, A. hirta, A. malaccensis, A. microcarpa, A. rostrata*
Singapore	*A. beccariana, A. hirta, A. malaccensis, A. microcarpa, A. rostrata*

1.4.2 National

Aquilaria malaccensis (syn. *A. agallocha*) and *Aquilaria khasiana* are the two species of agar that naturally grow in India. *A. malaccensis* naturally occurs mostly in the foothills of the northeastern states and West Bengal, up to an altitude of 1000 meters above mean sea level. It is also cultivated along the Western Ghats in Kerala and Karnataka. There are also limited plantations in Tamil Nadu, Telangana, Andhra Pradesh, Goa, Maharashtra, and Gujarat. *Aquilaria khasiana* is endemic to the state of Meghalaya

According to the Botanical Survey of India, the estimated number of plants over 2 years of age or with a girth at breast height (GBH) greater than 10 cm in India is at least 139.89 million (13.989 crores).

Table 2: State-wise distribution of Agar Plants in India

Name of the state	Estimated number of agarwood plants
Assam	11,43,00,000
Tripura	1,51,50,000
Manipur	32,00,000
Karnataka	24,20,000
Nagaland	22,80,000
Andhra Pradesh	10,00,000
Kerala	10,00,000
Maharashtra	3,00,000
Meghalaya	1,72,000
Arunachal Pradesh	25,000
Telangana	20,000
Mizoram	10,000
Tamil Nadu	10,000
West Bengal	5,500
Others	3,000
Total	**13,98,90,000**

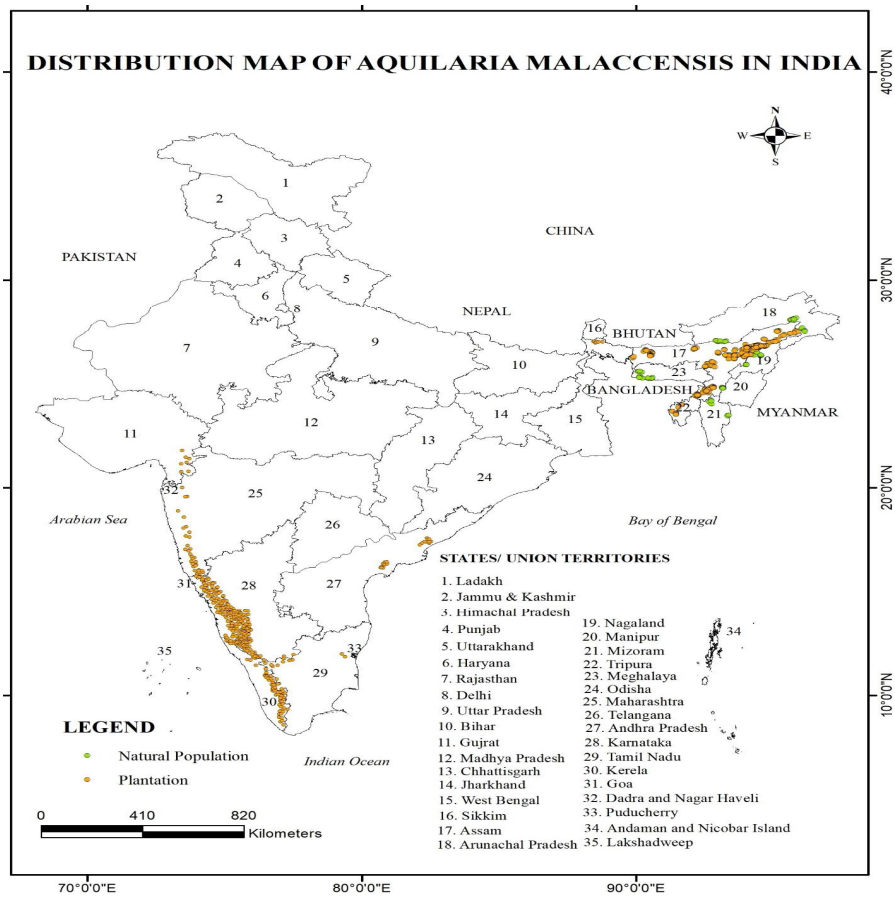


Figure 8: Distribution of *Aquilaria malaccensis* in India

1.4.3 Regional - Northeast India

In Northeast India, *Aquilaria malaccensis* occurs naturally in the foothills, with significant populations found in Assam, Manipur, Meghalaya, Mizoram, Nagaland, and Tripura. This region's climatic conditions and soil types favor the species' natural growth and cultivation. Major players in agarwood production are Assam and Tripura. Assam is a leading state in agarwood production and has extensive plantations, particularly in the Golaghat, Jorhat, Sivasagar, and Karimganj districts. Golaghat district alone is home to around 45 million agarwood plants, making it a significant hub for cultivation and trade. Tripura boasts approximately 15 million agarwood plants, with cultivation primarily concentrated in the North Tripura and Unakoti districts. In these regions, agarwood cultivation is common among households, contributing to the local economy.

The Jiribam district of Manipur is renowned for its extensive agarwood plantations. The natural infection rates in this area are high, leading to significant agarwood production. Agar tree grows sporadically across the catchment areas of major river tributaries in Mizoram, contributing to the state's overall production. In Nagaland, significant cultivation occurs in districts such as Mokokchung and Mon, where agar tree is extensively grown.

1.4.4 Meghalaya

In Meghalaya, all regions are suitable for agar plantation except the Shillong Plateau, other Khasi pine-bearing areas, and areas near the Brahmaputra banks prone to waterlogging. The state's diverse topography and climate make it an ideal location for cultivating *Aquilaria malaccensis*, auguring well for the region's economic development through sustainable agarwood farming.

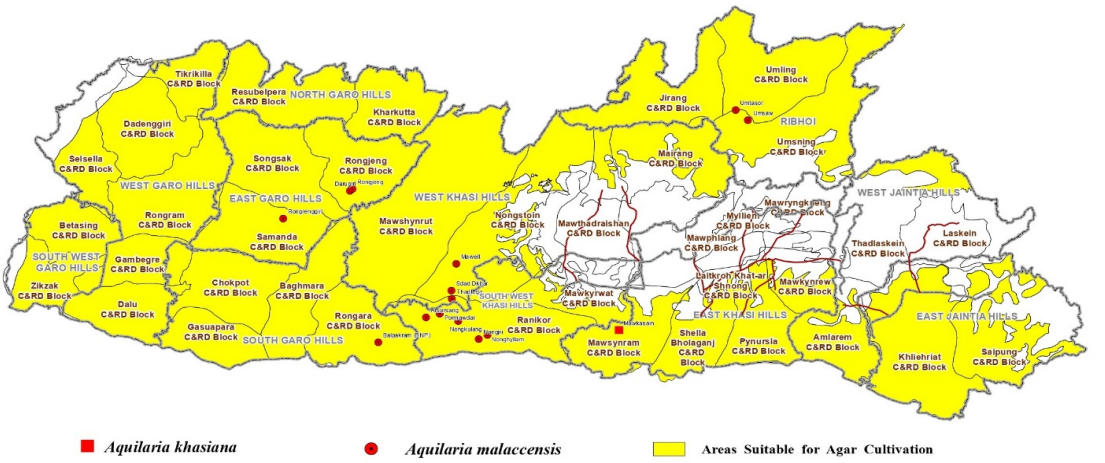


Figure 9: Areas suitable for Agar Plantation in Meghalaya

Chapter 2: AGARWOOD FORMATION

2.1 Process of Agar Formation

Agarwood formation results from the accumulation of oleoresins within the wood. This resin develops in stems and branches of agar trees as an immune response to biological, physical, and chemical stress. In wild populations, natural resin formation occurs in 10-15 percent of trees in response to fungal infection or borer attack. The process begins when the tree's stem is injured or bored by the larvae of the stem borer (*Neurozerra conferta*). It is believed that this insect might have carried the fungus in the mandibular part, which gets transferred to the tree trunk. The larvae creates zigzag tunnels inside the tree trunks, allowing microbes to enter and spread. These microbial infections gradually produce oleoresins, the dark aromatic compounds that form in the heartwood. Resin formation can also be induced artificially through injury, microbial infection, or chemical treatment. The most common method is artificial inoculation of fungal inoculants. The process of developing cost-effective techniques to ensure reliable resin formation is still ongoing.



Figure 10: *Neurozerra conferta*

In Northeast India, nearly 135.14 million agar trees are under cultivation. Due to the presence of the stem borer (*Neurozerra conferta*) most of the trees of Jorhat, Golaghat, Sivasagar, and Karbi Anglong districts of Assam and a very few pockets of Tripura are naturally infected. Additionally, there are approximately 2.5 million trees in South India, in the states of Karnataka, Tamil Nadu, and Kerala, all of these trees need artificially inoculated for Agarwood formation. Thus, artificial inoculation method is crucial for sustaining the production of agarwood.

2.2 Natural Formation

In natural conditions, agarwood formation is rare and slow. Agar trees generally start producing resin after 20 years. The natural formation of agarwood is primarily triggered by environmental factors such as insect infestation or physical damage to the tree, which provides an entry point for the microbes that, in turn, induce resin production.



Figure 11: Agarwood formation under natural conditions

2.3 Artificial Induction

2.3.1 Physical

Artificial agarwood formation can be achieved by wounding the tree trunks by cutting, cauterizing, drilling holes, nailing, axe chopping, chiseling, or removing bark to facilitate infection. Success depends on the availability of a sufficient load of appropriate pathogens that could induce agarwood formation. In the Garo hills of Meghalaya, farmers make wounds with the help of bamboo sticks. Using biodegradable material like bamboo to cause wounds can prevent agarwood contamination. In contrast, using metal and chemicals has a higher chance of contaminating the agarwood, which can reduce the price of agarwood.

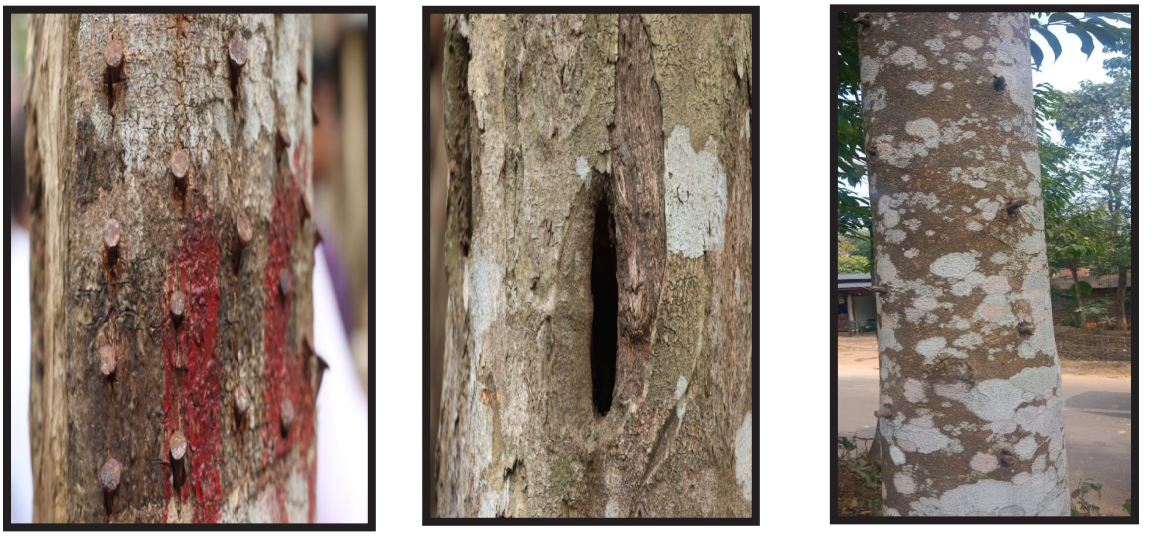


Figure 12: Different Physical Methods Employed for the Artificial Induction of Agarwood

2.3.2 Chemical

Chemical methods have been used to stimulate the tree for agar resin production. Different natural products, chemicals, and hormones (methyl jasmonate, soybean oil, jaggery, molasses, sodium chloride, *etc*.) stimulate agarwood formation. These materials are injected into the tree in different concentrations. The injected materials reach other parts of the tree through water transportation via the xylem and induce agarwood formation.



Figure 13: Different Chemical Methods Employed for Artificial Induction of Agarwood

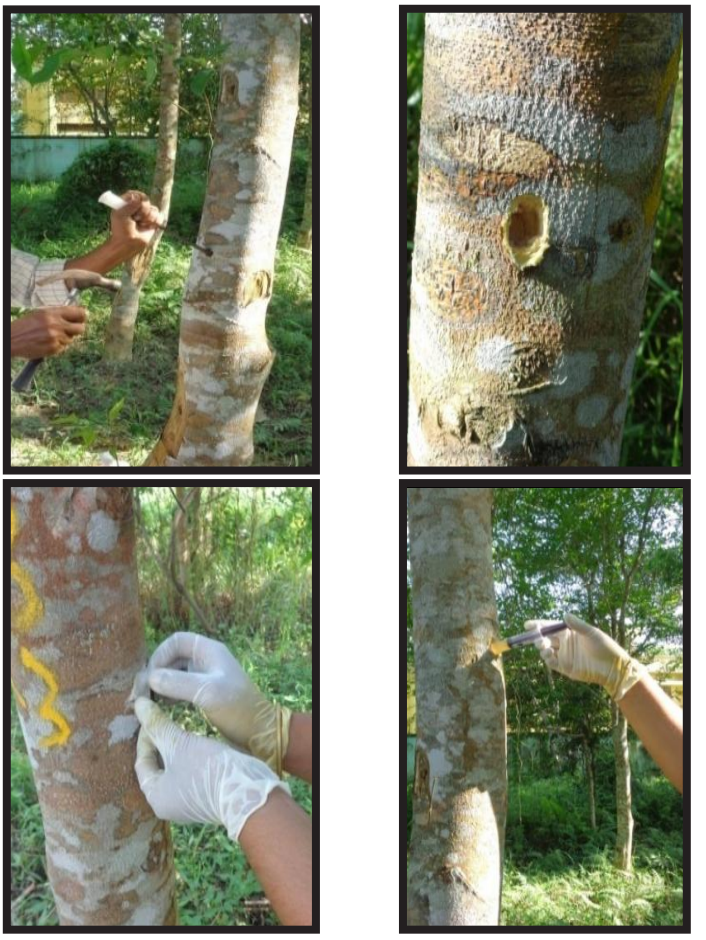


Figure 14: Biological Methods Employed for Artificial Induction of Agarwood

2.3.3 Biological

Biological methods are commonly used to stimulate the production of resinous compounds. In this process, trees are inoculated with microbial cultures, resulting in the formation of agarwood. The chances of agarwood formation are higher when sufficient inocula of the effective strains of microbes are inserted into the plant.

ICFRE-RFRI had identified and isolated four fungi responsible for agarwood formation from the naturally infected trees and has been maintaining their cultures. Trees are inoculated by making holes of 2 cm diameter in a spiral manner along the trunk using a borer or an electric drill up to a depth of 5-6 cm at an angle of 45^0.

The first hole is made 1 m above the ground, and the remaining holes are made 30 cm apart. A minimum of 10 holes are to be made on the tree with a girth of 35-40 cm and a height of about 15-20 m. Holes can be made throughout the clear bole if a climbing facility is available. Fungal broth (10 ml) is injected into the drilled holes using a syringe, after which the holes are closed with a thin layer of cotton. Formation of agarwood can be observed after a period of 1 month after the inoculation. It can be noticed by discoloration of wood surrounding the inoculated holes by removing the bark near the hole.

After 5-6 months, the discoloration zones merge, forming agarwood throughout the tree. Trees are ready for harvest two years after inoculation. However, to obtain a high-quality product, it is advisable to harvest them after 3-3.5 years.



Figure 15: Different Fungal Cultures Developed by ICFRE-RFRI, Jorhat for Artificial Inoculation

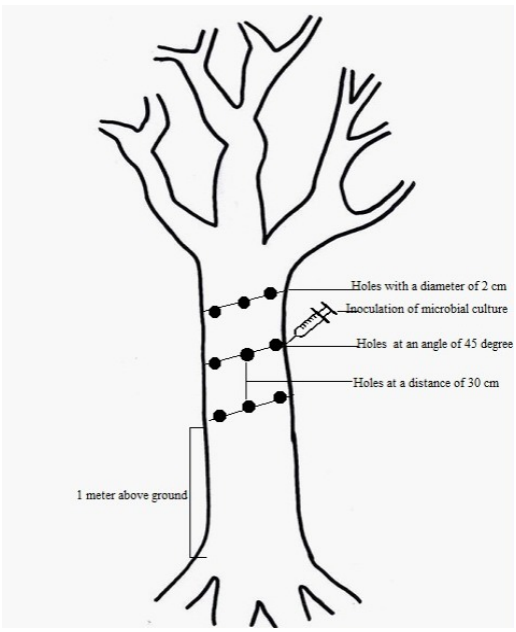


Figure 16: Layout for making holes in agar tree



Figure 17: "Sasi Inoculant" – A fungal inoculum for artificial agarwood inoculation in *Aquilaria malaccensis*.

ICFRE-RFRI has undertaken artificial inoculation in Assam, Meghalaya, Tripura and North Bengal. Artificial inoculation showed better results in terms of agarwood formation.



Figure 18:Agarwood formation in artificially inoculated trees in Assam



Figure 19: Agarwood formation in artificially inoculated trees in Meghalaya



Figure 20: Agarwood formation in artificially inoculated trees in Tripura



Figure 21: Agarwood formation in artificially inoculated trees in North Bengal



Figure 22: Artificial inoculation using powder formulation

Chapter 3: AGARWOOD AND ITS USE

3.1 Major Users of Agarwood

The major consumers of agarwood are primarily located in Asia and Middle East. The Gulf countries, particularly United Arab Emirates and Saudi Arabia, are significant markets where agarwood is highly prized for its use in incense and perfumes. China, Japan, and South Korea are also leading consumers, utilizing agarwood in traditional medicines, incense, and cultural rituals. The United States of America and the European Union use it as a stabilizer for high-grade perfume.

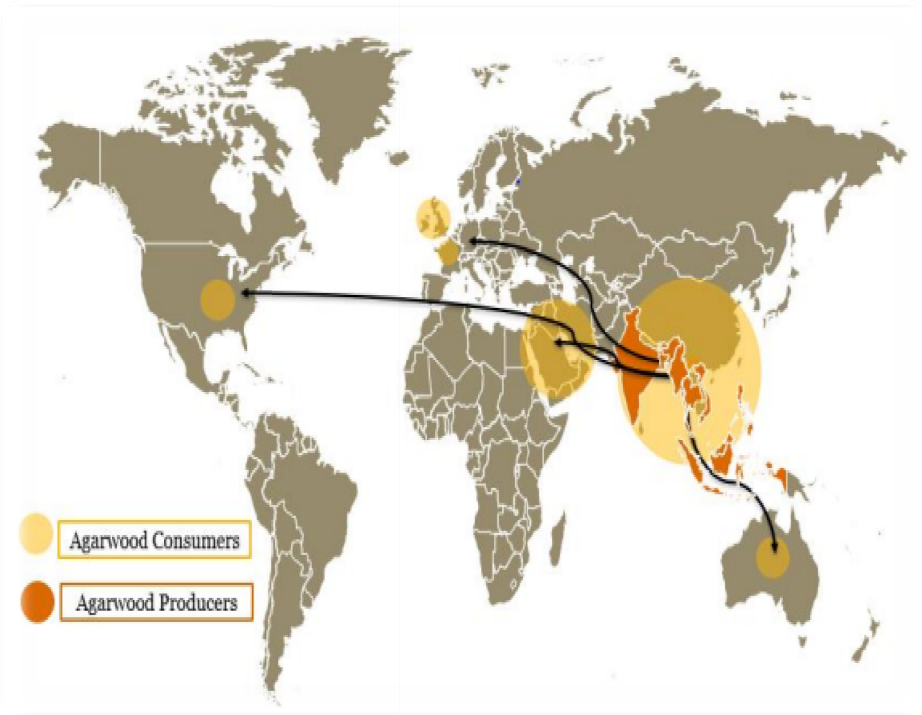


Figure 23: Map showing Agarwood producers and consumers

3.2 Types of Agar Products

3.2.1 Chips, Powder and Incense

Agarwood is highly valued for its traditional use as an incense in different cultural and religious ceremonies. Burning agarwood chips is an essential prevailing practice in the

Middle East to honor guests' visits. The agarwood powder is mainly used to manufacture fumigators, pastilles, and agarbatties. In India, low grade agarwood chips are widely used in making smokeless tobacco products ('*Gutka'*) to produce aromatic flavor. Agarwood powder is an insect repellent that is effective against fleas and lice. Some communities use agarwood in funeral pyres, and it is used as an aromatic ingredient in wine in Taiwan.



Figure 24: Agarwood chips, powder, and incense

3.2.2 Agar Oil

Agarwood oil, also known as '*Attar'* and '*Aguru*,' is traditionally used by various communities in water-based perfumes. Its distinctive, rich, and complex fragrance is highly prized, making it a coveted ingredient in high-end perfumery and personal care products. Agarwood oil is also used in aromatherapy and as a fragrant in cosmetics, soaps, and shampoos. In the Middle East, agarwood oil symbolizes wealth and is widely used during wedding ceremonies.

3.2.3 Personal Care Products

Agarwood oil is extensively used to manufacture high-end personal care products due to its uplifting fragrance and beneficial compounds. It is a key ingredient in perfumes, skincare products (anti-aging cream), and various cosmetics. The oil's properties make it suitable for treating damaged skin cells, detoxifying the body, and providing an aromatic experience in personal care routines.



Figure 25: Agarwood Personal Care Products

3.2.4 Medicinal Products

The medicinal parts of *Aquilaria malaccensis* include leaf, stem, essential oil, and resin infested heartwood. The leaves have anti-diabetic, antioxidant, antibacterial, and hepatoprotective properties and can relieve throat itching. The essential oil extracted from agarwood has anti-inflammatory, anti-rheumatic, analgesic, anti-oxidant, carminative, and stomachic properties. It can help detoxify the body, clean out excess salt and uric acid, and repair damaged skin cells. Indians and Chinese use agarwood oil in their traditional medicine to treat various skin diseases. The aqueous stem extract inhibits histamine secretion, thereby combating immediate hypersensitivity. In Ayurvedic medicine, the stem paste is used to treat skin disorders, while leaf paste is used for the treatment of leprosy and pruritus.

The wood of agar plants has been used as an anti-depressant to improve neural activity. Benzene extract from the wood shows Central Nervous System (CNS) depressant activity. Wood fumes of infected agarwood possess antiseptic, antioxidant, and insecticidal properties. The heartwood of *A. malaccensis* is found to be anti-arthritic and improve neural activity. The essential oil is known for its stimulant, cardiotonic, and carminative properties. The chemical constituents present in the essential oil prevent the denaturation of protein, accounting for anti-arthritic properties, and can also be used for anxiety and depression treatment, accounting for anxiolytic properties. The volatile oil of agarwood also contains various anti-tumor components, which have an inhibitory effect on cancer cells.

3.2.5 Handicrafts Products

Agarwood is extensively used to craft various handicrafts. Artisans skilfully transform this precious wood into intricate sculptures, bracelets, boxes, bead strings, and ornaments. The natural aromatic quality of agarwood enhance the appeal of these handicrafts, making them highly sought-after for their aesthetic and sensory attributes.



Figure 26: Agarwood Handicrafts

3.2.6 Agar Tea

The young shoots, especially the first and second leaflets, are selected for tea-making. Agar tea's pharmacological properties include anti-analgesic, anti-arthritic, anti-inflammatory, anti-cancer, anti-tumor, anti-oxidant, anti-bacterial, anti-fungal, and anti-diabetic. Agar tea offers several benefits. It is a natural detoxifier, providing a natural way to remove harmful toxins such as mercury from the body. Agar tea is a natural diuretic and helps maintain the digestive system. It promotes healthy and clear skin, stabilizes blood sugar, and helps to improve blood flow. Agar tea is free from caffeine and sugar.



Figure 27: Agar Tea

Chapter 4: CULTIVATION OF AGAR

4.1 Seed Collection

Agar tree is propagated by seeds. Matured yet green fruits are harvested for seed collection during the rainy season, from June to August. Fruits are dried in shade for two days, after which the bursting fruits release seeds. Weight of individual seeds ranges from 29 to 135 mg. Sowing heavy seeds, over 80 mg in fresh weight, is recommended as the germination percentage increases with seed weight, and heavier seeds also need less time for germination. Agar seeds are recalcitrant, meaning they lose viability upon drying. Since the seeds remain viable for a very short period, they should be sown in mother beds within 2-5 days after collection. Seeds do not require any pre-treatment. Agar tree starts bearing seeds at the age of 6-7 years. A full-grown agar tree can produce approximately 19,000 seeds per year.

4.2 Nursery Practices

Seeds are sown at a depth of about 1 to 1.5 cm, followed by regular watering, proper shading, and standard management practices. Seed germination is epigeal, beginning after 10-12 days and typically completing within one month. When the seedlings reach a height of 3 to 5 cm (around 40-45 days), they are transplanted into poly bags (9" x 6") arranged under temporary shade. A potting media of soil, sand, and well-decayed cow dung in equal parts (1:1:1) is used. The seedlings require raised beds, as they are sensitive to high moisture levels and waterlogging. Light watering, initial shading, regular shifting, and weeding are essential for healthy growth.



Figure 28: Seedling in Raised Mother Bed

Two-year-old agar seedlings having a height of about 2 feet are suitable for transplantation.



Figure 29: Seedling transferred to polybags

4.3 Plantations

4.3.1 Homesteads



Figure 30: Agar in Homestead

Agar trees with relatively small canopy can be raised in any vacant space, including homesteads, schools, hospitals, and other public offices. In addition to providing aesthetic beauty, shade, and protection from wind, agar trees can yield substantial income to

growers. In homestead plantations, agar trees are integrated into the household's existing garden or agricultural land, providing economic and ecological benefits.

4.3.2 Bunds and Boundary Plantation

Agar trees can be planted along bunds and the boundary of homesteads, agriculture fields, forests, wasteland, and other land parcels at close spacings as low as one foot.

The stem of a four to five-year-old agar tree is strong enough to hold and support barbed wire or wire mesh fencing. Apart from demarcation of the boundary, closely spaced agar trees planted along the bunds and boundaries of homesteads, agricultural fields, forests, and wastelands serve a dual purpose as fencing posts. Injury caused by nails, wire, and staples used to tie the barbed wire or wire mesh to agar trees induces resin production.

4.3.3 Block Plantation

Agar can be used as a preferred species to afforest hill slopes, river banks and wastelands. Agar can also be planted to replace non-productive senile horticulture plantations. To ensure higher seedling survival rates, agar trees should be planted at the beginning of the monsoon season. The availability of abundant moisture during the monsoon season helps the plants establish themselves more effectively. The recommended spacing for plantations is as follows:

- 2x3 meters to sustain about 1,700 plants per hectare with intercrops
- 2x2 meters to maintain about 2,500 plants per hectare with intercrops
- 1.5x1.5 meters to sustain about 4,400 plants per hectare for solo plantation

Proper drainage channels (2x2 feet) should be dug at 10-meter intervals to prevent water stagnation. Saplings are planted, preferably during the evening or in cloudy weather in pits of approximately 30-50 cm^3 size made in advance. Before planting, well-rotten cow dung may be applied at 10-15 kg per pit and mixed thoroughly with the soil to create a better microclimate for the establishment of the plant in the soil. The soil around the plant should be firmly pressed, and watering should be done until the saplings are established. Dead seedlings should be replaced within the same planting season.

After 8-10 years, about 40% of trees may be harvested to thin out the plantation, thereby increasing the spacing for better growth and development of the remaining trees.

Felling of naturally grown forests for planting agar trees shall be discouraged.

4.4 Agar Based Agroforestry

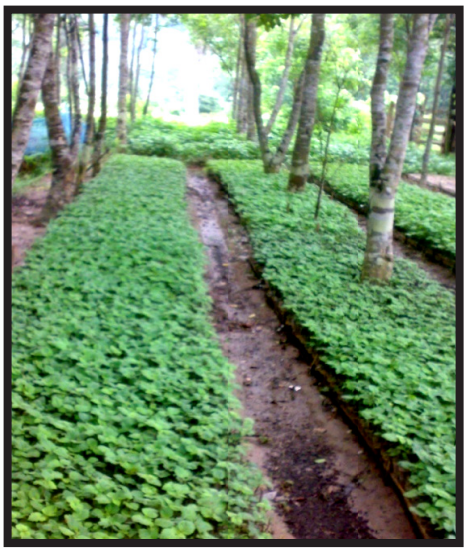



Figure 31: Plantation of Agar Plant with other Companion Crops

No adverse allelopathy effect of agar trees on agricultural and horticultural crops as well as forestry species commonly grown in Meghalaya has been reported, which make agar a preferred agroforestry species.

Agar-based agroforestry involves planting agar trees as a mixed crop at wider spacing as per the requirements of companion crops, and the purpose of planting. It can be combined with patchouli (*Pogostemon cablin*), sarpagandha (*Rauvolfia serpentina*), pepper (*Piper longum*), and other crops. Planting agar trees along the tea garden's periphery can serve as insurance against natural calamities. Crops like turmeric, ginger, and pineapple can also be planted with agar plants leaving about 50 cm around the base of the agar plant.



Figure 32: Agar with Pineapple



Figure 33: Agar with Tea Plantation



Figure 34: Agar with Pepper, Arecanut, and Tea





Figure 35: Agar-based plantation with Banana Plant

4.5 Manures and Fertilizers, including Microbial Fertilizers

Planting agar trees in virgin forest land and other fertile areas does not require initial fertilization. However, as the trees grow, fertilizers may be applied as necessary. To enhance soil aeration and fertility, it is recommended to apply organic manures like cow dung, compost, and coco-peat into the soil. It is important to avoid using fresh or un-decomposed cow dung. When organic manures are applied, the rhizosphere (the top 0-45 cm of soil surrounding the roots) of the agar tree exhibits an increased microbial population, benefiting overall soil and plant health.

Planting of agar trees in less fertile areas, 1-1.5 kg of well-decomposed cow dung should be thoroughly mixed with the soil before planting in pits of 30-50 cm^3 size. In subsequent years combination of nitrogen (N), P_2O_5, and K_2O in a 10:10:4 ratio may be

applied, preferably in two splits, as per the following schedule:

- Second year: 200 g/tree
- Third year: 300 g/tree
- Fourth year onward: 500 g/tree

From the sixth to seventh years, nitrogenous fertilizer at 400-500 g/tree per year may be applied in two splits during pre- and post-monsoon periods. This practice helps keep the tree wood soft, with a higher content of cell sap, enabling easy boring by insects and promoting fungal infection. This also leads to spread of the resin infested area over a larger wood volume, resulting in higher agarwood production.

4.6 Diseases and Control

4.6.1 Agar Leaf Defoliator

4.6.1.1 Symptoms

The most destructive pest for agar plantations and agar nurseries is the leaf-eating caterpillar, *Heortia vitessoides*. This pest poses a significant threat to nurseries and plantations, attacking twice yearly, first in May-June and then in August-September. The intensity of the attack during the drier season (March-April) is greater than during the rainy season (July-August). Agar trees grown in open conditions are more susceptible to this pest than those under shade. These caterpillars feed on the leaves of the agar trees, and seedlings resulting in significant damage and loss of foliage. The caterpillar can cause complete defoliation of the agar trees, severely impacting their growth and health.

4.6.1.2 Causal Organism

The primary organism responsible for the defoliation is the caterpillar *Heortia vitessoides*.

4.6.1.3 Control measures

Control measures include hand collection and destruction of caterpillars while they are in clusters. Severely infected areas should be treated with an extra dose of nitrogenous fertilizer to boost the growth of the infected trees. Biopesticides, such as neem kernel extract, can be sprayed at 7-14 days interval. Natural predators such as birds and frogs should be encouraged to control the pest.



Figure 36: *Heortia vitessoides* in Agar Tree

4.6.2 Branch Drying of *Aquilaria malaccensis*



Figure 37: Branch Drying of *Aquilaria malaccensis*

4.6.2.1 Symptoms

Rotting of the stem base and roots is observed. Branches become easily breakable, and trees become shriveled and ultimately die.

4.6.2.2 Causal Organism

It is observed that the nematode *Pratylenchus sp.* causes the primary infection in the roots of the agar tree, through which the fungus *Fusarium solani* enters and causes rotting.

4.6.2.3 Control Measure

The use of Biopesticides, such as neem oil (3%) or neem seed kernel extract (NSKE, 5%), around the base of the tree, either alone or in combination, is found to be effective.

4.6.3 Damping off Disease of *Aquilaria malaccensis*

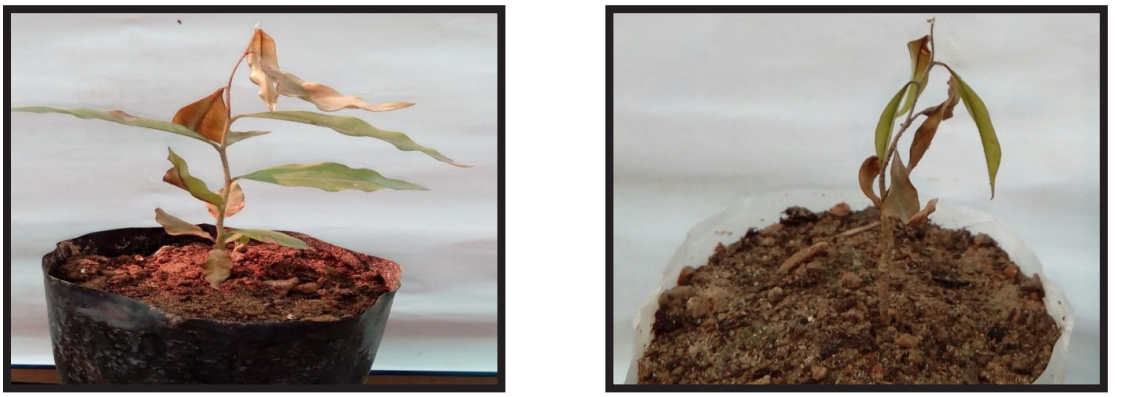


Figure 38: Damping off disease of *Aquilaria malaccensis*

4.6.3.1 Symptoms

The disease mainly occurs in young seedlings in nurseries. In the early stages, seedlings show stunted growth with typical discoloration of the collar region and form small lesions on the stem and root region near the soil surface. In later stages, the grey to brown spots on leaves coalesce together, covering the whole leaf surface. Seedlings are displaced due to water soaking and stem shriveling. Root rot occurs in case of severe infection, leading to seedling mortality.

4.6.3.2 Preventive Measure

Before sowing seeds, soil solarization or fumigation of nursery beds with 4% formaldehyde is recommended. Nursery beds should be covered with polythene sheets for 15 days.

Chapter 5: HARVESTING OF AGARWOOD

5.1 Harvesting Stage

Harvesting time depends on the extent of agarwood formation and the accumulation of oleoresin in the heartwood. The presence of black patches on the plant's bark indicates infection. By observing these black patches, infected trees, whose further growth is arrested, can be selected for harvesting. In nature, agarwood formation generally takes up to 40 years, but this process can be accelerated through artificial inoculation, reducing the agarwood formation time to 10 to 15 years.

5.2 Harvesting Time

The dry season between January and May is preferred for harvesting to obtain the maximum yield of oil and the presence of less waxy substances in the wood.

5.2.1 External Symptoms of Agarwood Formation

The external symptoms that aid in identifying the initiation or formation of agarwood in agar trees include appearance of borer holes, oozing out of watery substances from fresh borer holes, and accumulation of frass at the base of the tree. Other signs include the closing of borer holes by the growth of host tissue leaving a small spindle-shaped mark, longitudinal cracks on the trunk or bole, swelling or depression, and sometimes canker formation on the tree stem. Appearance of hordes of ants in the tissue, formation of ant nests, smaller and yellowish leaves, overall abnormality and ill health of the plant, and hearing a hollow sound when the trunk is hammered also indicate agar formation.

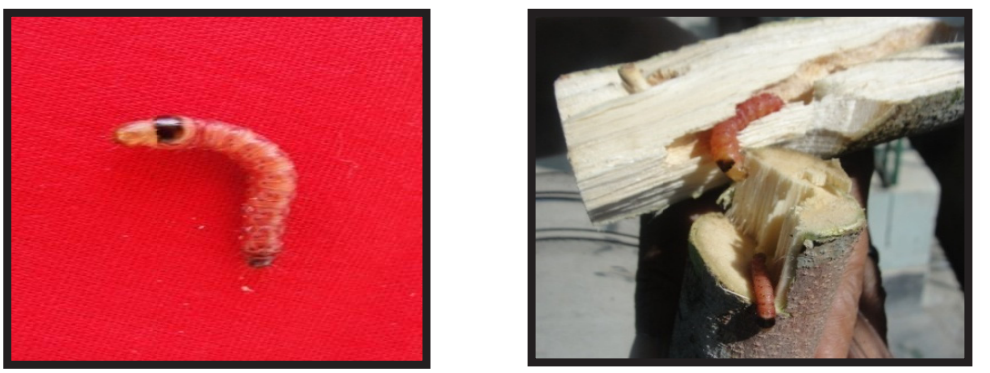


Figure 39: Larvae of stem borer found in naturally infected agar trees



Figure 40: Entry of borer into the holes



Figure 41: Oozing out of watery substances from fresh borer hole



Figure 42: Frass at the base of the tree



Figure 43: Natural closing of borer's hole



Figure 44: Cracking symptom



Figure 45: Formation of agarwood along the borer tunnels

5.3 Harvesting Procedure

After harvesting, agarwood logs are chopped into smaller pieces. The resin-embedded portions are carefully extracted by removing non-infected sections using specialized hand tools, a highly labor-intensive process.

To produce agar oil, the extracted agarwood chips are soaked in water for two to three days. They are then placed in a stainless-steel vessel connected to a distillation unit. Steam distillation is carried out for 30-36 hours, during which the essential oil is separated from the water. The extracted oil is stored in airtight containers, preferably aluminium bottles, to maintain its quality.



Figure 46: Harvested logs of agar trees



Figure 47: Chopping of agarwood into small pieces



Figure 48: Logs of infected agarwood along with tools used for making chips



Figure 49: Steam distillation unit



Figure 50: Manual extraction of agarwood



Figure 51: Agarwood chips



Figure 52: Soaking of agarwood chips before distillation

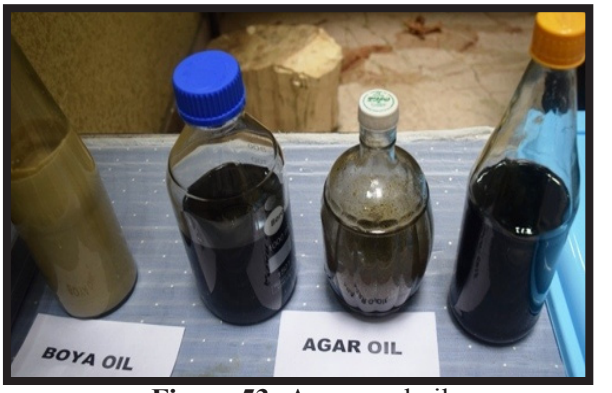


Figure 53: Agarwood oil

Chapter 6: YIELD AND ECONOMICS

6.1 Yield

A 10-year-old tree may yield 3-4 kg of chips. These chips, if distilled, can produce 10-15 g of oil.

6.2 Economics

Three grades of oil are being extracted from the agarwood, namely *Boya*, *Boha*, and *Khara*. The price of agar oil is highly variable. The price of agar oil ranges from Rs. 6 lakh/kg to Rs. 2 crore/kg, with a general range of Rs. 10-30 lakh/kg. Agar chips also have a very wide price range, with a general range of Rs. 80,000 – Rs. 100,000/kg. In 2001, a fully-infested single agar tree in Hojai Forest Division in Assam was sold for more than Rs. 1.10 crore. Several trees with values between Rs. 15-30 lakh still exist in Northeast India.

The estimated costs for establishing and maintaining a one-hectare agarwood plantation, consisting of approximately 1,700 trees planted with 2 x 3 meter spacing over a 15-year life cycle, is given in Table 3.

Table 3: Estimated expenditure on creation and maintenance of one hectare agarwood plantation consisting of 1700 agar plants over a 15 year life cycle.

Heads of Expenditure	**1st Year (Rs.)**	**2nd Year (Rs.)**	**3rd Year (Rs.)**	**4th Year (Rs.)**	**5th Year (Rs.)**	**6th – 8th Year (Rs.)**	**9th – 15th Year (Rs.)**	**Total**
Cost of Fencing and Repair	16,000	3,000	5,000	18,000	5,000	5,000	-	52,000
Land preparation and Pit Digging	85,000	-	-	-	-	-	-	85,000
Cost of Saplings	17,000	-	-	-	-	-	-	17,000
Cost of Planting of Saplings	5,100	-	-	-	-	-	-	5,100
Compost	10,000	10,000	9,000	10,000	10,000	-	-	49,000
Fertilizer	-	7,000	7,000	8,000	8,000	-	-	30,000
Cost of Application of Fertilizer	5,100	5,100	5,100	5,100	5,100	-	-	25,500

Heads of Expenditure	**1st Year (Rs.)**	**2nd Year (Rs.)**	**3rd Year (Rs.)**	**4th Year (Rs.)**	**5th Year (Rs.)**	**6th – 8th Year (Rs.)**	**9th – 15th Year (Rs.)**	**Total**
After-care	1,25,000	1,25,000	1,25,000	1,25,000	1,25,000	3,75,000	8,75,000	10,00,000
Inoculation	-	-	-	-	-	4,76,000	4,76,000	4,76,000
Miscellaneous expenditure	20,000	2,500	2,000	3,000	2,000	5,000	8,900	34,500
Total	**2,83,200**	**1,52,600**	**1,53,100**	**1,69,100**	**1,55,100**	**8,61,000**	**13,59,900**	**31,34,000**

The estimated return for one-hectare agarwood plantation, consisting of approximately 1,700 trees planted with 2 x 3 meter spacing over a 15-year life cycle, is detailed in Table 4.

Table 4: Estimated return from a one hectare agar plantation consisting of 1,700 trees over a 15 years cycle

Product	**No. of Trees**	**Quantity per Tree (Kg)**	**Rate (Rs. / Kg)**	**Return (Rs.)**
Boya*	250	25	10	62,500
Dum (Low Quality)	550	40	100	22,00,000
Dum (High Quality)	400	50	1,000	20,00,0000
Botali Mal	500	0.5	5,000	12,50,000
Total Gross Return				**2,35,12,500**

***Boya – After 7-8 years**

Net Return over a 15 year harvesting cycle: Rs. 2,03,78,500 (Rs. 2,35,12,500 - Rs. 31,34,000) or Say Rs. 2 crore per hectare.

Chapter 7: LEGAL FRAMEWORK

7.1 Felling and Transit

Felling of Agar trees standing in non-forest areas is governed by the Meghalaya Tree Felling (Non-Forest Areas) Rules, 2006. Rules require registration of tree plantations raised in private and community holding of non-forest areas without financial assistance from the Government or a Government Agency with the Chief Forest Officer of the concerned Autonomous District Council. As per these rules, tree plantations raised in Government owned or controlled areas and the tree plantations raised with full or partial financial assistance from the Government or Government agency, even if it is raised on private or community holding, shall be registered with the concerned Divisional Forest Officer dealing with Territorial matters.

As per these rules, felling of up to one hundred trees requires permission from the Conservator of Forests dealing with Territorial matters in the Forest and Environment Department. Felling of more than one hundred trees requires permission from the Chief Conservator of Forests dealing with Territorial matters.

For felling of the trees standing on the land owned or controlled by the Government, application to obtain permission of the Conservator of Forests or the Chief Conservator of Forests, as the case may be, is required to be submitted to the Divisional Forest Officer dealing with Territorial matters. For felling of trees raised with full or partial financial assistance from the Government or Government agencies, application is required to be submitted to the district level officer of the Department which has provided financial assistance to raise such trees. Application to fell trees from non-forest areas in registered private plantations raised without any financial assistance from the Government or Government agencies is required to be submitted to the Chief Forest Officer of the concerned Autonomous District Council.

Transport of timber and other agar products derived from the trees felled after obtaining required permission from the Conservator or the Chief Conservator, as the case may be, requires transit pass from the Divisional Forest Officer dealing with Territorial matters.

7.2 Processing

Establishment of agar processing unit is regulated by the Wood Based Industries

(Establishment and Regulation) Guidelines, 2016 of the Ministry of Environment, Forest and Climate Change, Government of India and rules framed by individual states. As per theses rules, agar based industries need to obtain license from the Forest and Environment Department.

7.3 International Trade

With increasing wealth in Gulf countries, which are the major consumers of agarwood and agar products, demand for agarwood has substantially increased in recent decades. This demand now exceeds supply, leading to higher prices, unsustainable harvesting, over-exploitation, natural resource decline, reduction in product quality, and increased interest in agarwood cultivation.

Due to the limited resource base and high demand, *Aquilaria malaccensis*, the primary source of agarwood in India, has been listed in Appendix II of the Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES) as a "potentially threatened species" to ensure that legal trade does not become a direct cause of its extinction.

Export of agarwood from wild sources is not allowed. Export from cultivated sources is permitted, subject to compliance with CITES provisions. International trade of all parts and derivatives except seeds and pollen; seedlings or tissue cultures obtained *in vitro*, in solid or liquid media, transported in sterile containers; fruits; leaves; exhausted agarwood powder, including compressed powder in all shapes; and finished products packaged and ready for retail trade requires an Export Permit from designated CITES Management Authority. In India, Additional Director General of Forests (Wildlife) in the Union Ministry of Environment, Forests and Climate Change has been designated as the CITES Management Authority.

An Export Permit may be issued by the CITES Management Authority on the basis of a Certificate of Legal Procurement (CLP) issued by an officer in the Forest and Environment Department not below the rank of Assistant Conservator of Forests. A CLP can be issued only after ascertaining that the product has been sourced from a sustainably managed cultivated agar resource and it has been processed by ensuring compliance to all statutory norms in the entire supply chain.

The exporter is required to produce a Certificate of Origin from the Divisional Forest Officer, file an affidavit on stamp paper as proof of transfer of ownership, obtain

a CLP from the Divisional Forest Officer after packing and sealing the consignment, and finally obtain an Export Permit from the CITES Management Authority.

Export of value-added products made from imported raw material is allowed on production of an affidavit on stamp paper to the effect that it has been sourced from the legally imported raw material.

The CITES Management Authority has four regional offices located in Kolkata, Mumbai, Chennai, and Delhi.

Import and export of agarwood and other value-added agar products is permitted from 12 designated ports of entry and exit located at Amritsar, Chennai, Delhi, Kandla, Kochi, Kolkata, Kozhikode, Mumbai, Mundra, Nhava Sheva, Thiruvanathapuram, and Tuticorin.

7.4 Annual Export Quota

The annual limit for the export is determined based on a study undertaken by the Scientific Authority designated by the CITES. The Scientific Authority monitors both the export permits granted for export of the Agar and its actual export.

Whenever the Scientific Authority determines that the export of specimens of agar should be limited to maintain that species throughout its range at a level consistent with its role in the ecosystems in which it occurs and well above the level at which that species might become eligible for inclusion in Appendix I of the CITES, the Scientific Authority advises the Management Authority of suitable measures to be taken to limit the grant of export permits for specimens of that species Collectively, these requirements are referred to as 'Non-detriment Findings' (NDFs).

Botanical Survey of India, which along with the Indian Council of Forestry Research and Education - Rain Forest Research Institute (ICFRE-RFRI) has been designated as Scientific Authority for India for the Agar, recently carried out a "Non-Detriment Findings Study" under the CITES to ascertain the annual quota for the export of agarwood for India. The study has recommended an annual export quota for agar chips and agar oil at 1,51,080 kg per annum and 7,050 kg per annum respectively.

The proposed quota for Meghalaya is 200 kg of chips/ powder/ non-exhausted sawdust and 9 kg of agar oil.

7.5 Exemptions for Household Use

Export of up to 1 kg woodchips, 24 ml oil, and two sets of beads or prayer beads (or two necklaces or bracelets) per person for household use is permitted without an export permit, provided both the countries of import and export implement the personal and household exemptions for the species.

7.6 Traded Products

Agarwood and its products are traded under specific ITC-HS Codes. ITC-HS Code 12119080 covers agarwood, including chips and powder, while ITC-HS Code 33013010 pertains to agar oil. In addition to chips, powder, and agar oil, agarwood is traded in various forms. These forms include carvings, derivatives, extracts, live plants, timber, timber pieces, wood products, sawn wood, specimens, medicine, and unspecified products. These products are often mixed with other similar items in the ITC-HS classification.

Chapter 8: CONCLUSION

Agarwood, with its rich historical significance and immense economic potential, presents a unique opportunity for sustainable development in Meghalaya. Cultivating, harvesting, and processing agarwood provides substantial income to local communities and contributes to preserving this precious resource. As detailed throughout this book, the meticulous processes involved in agarwood production—from seed collection to oleoresin extraction—underscore the dedication and expertise required to produce high-quality agarwood products.

The global demand for agarwood continues to rise, driven by its diverse applications in perfumery, traditional medicine, and religious rituals. This growing demand and sustainable cultivation practices ensure that agarwood can be a viable and lucrative agroforestry species for years to come. The legal frameworks and international trade regulations highlighted here are crucial in maintaining the balance between meeting market needs and conserving agarwood species.

As we look to the future, the advancements in artificial inoculation and other cultivation techniques promise to enhance resin production efficiency, further boosting the economic benefits for growers. The collaborative efforts of local farmers, researchers, and government agencies are essential in optimizing agarwood production while safeguarding its ecological and cultural heritage.

The cultivation and trade of agarwood hold immense promise for economic upliftment and sustainable development in Meghalaya. By adopting best practices and adhering to regulatory guidelines, stakeholders can ensure the continued prosperity of this valuable industry.



Dr. Rajib Kumar Borah, Scientist-G, is a Forest Pathologist with over 30 years of experience working under the Indian Council of Forestry Research & Education (ICFRE). He has also served as the Director-in-Charge of the ICFRE-Rain Forest Research Institute in Jorhat. Throughout his career, he has focused on forest diseases in nurseries, plantations, and natural forests, along with their integrated disease management strategies. Dr. Borah has been the Principal Investigator for six research projects and two consultancy projects on agarwood. He has published more than 50 research papers in various national and international journals. Currently, he is working as the Group Coordinator (Research) at the ICFRE-Rain Forest Research Institute, Jorhat.



Dr. Nitin Kulkarni is a Forest Entomologist with more than 30 years of experience working under the Indian Council of Forestry Research and Education (ICFRE). He has served as the Director of ICFRE-Institute of Forest Productivity and as Director-in-Charge of the Tropical Forest Research Institute, Jabalpur. During his service, he worked on the bioecology of major forest insect pests in nurseries, plantations, and natural forests, along with their integrated pest management strategies. He has published 160 research articles in various national and international journals. Currently, he is working as the Director of ICFRE- Rain Forest Research Institute, Jorhat.



Harish Chandra Chaudhary is an Indian Forest Service Officer with more than 31 years of experience of working under the Government of India, the Government of Meghalaya, the Indian Council of Forestry Research and Education (ICFRE), and the National Human Rights Commission. While working under the ICFRE for five years, he was involved in the planning and execution of several forestry research projects. During his more than six years with the Government of India, he dealt with matters relating to the Forest (Conservation) Act 1980 and the Green India Mission. Under the Government of Meghalaya, he has handled issues relating to forest management, protection, afforestation, wildlife, and forestry research, education, and training. Currently, he is working as Principal Chief Conservator of Forests, Working Plan, Research & Training, and District Council Affairs, Forest and Environment Department, Government of Meghalaya.

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