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Medicinal and Aromatic Plants

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Medicinal and Aromatic Plants

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Preface

India has rich diversity of medicinal plants. The supply base of 90% herbal raw drugs used in the manufacture of Ayurveda, Siddha, Unani and Homoeopathy systems of medicine is largely from the wild. This wild source is speedily shrinking day-by-day. Therefore, there is a need for conservation to sustain use of medicinal plants. Cultivation is clearly an alternative to maintain the present collection of medicinal plants from the wild. It was an integral part of the development of modern civilization. Primitive man observed and appreciated the great diversity of plants available to him. Even today, use of medicinal plants in primary health care system is very important, especially in remote rural communities and poorly accessible areas. Much of the medicinal use of plants seems to have been developed through observations of wild animals, and by trial and error. As time went on, each tribe added the medicinal power of herbs in their area to its knowledgebase. They methodically collected information on herbs and developed well defined herbal pharmacopoeias. In this context, to inculcate recognition and motivation of the young researcher, students and industries to emerging disease threat and to design effective management strategies through various conventional and modern approaches is need of the hour. The chapters in the book provide a current and detailed account of cultivation, utilization and conservation of medicinal plants.

We hope that this edited book would help the students, teachers, researchers, policy makers and stakeholders to foster traditionally used ethno-medicinal plants and their conservation strategies. We sincerely thank all the authors for their valuable contributions for providing us valuable research material for shaping the book. All the words in the lexicon will be futile and meaningless if fail to express our reference to faculty members and students for their blessing, affection, sacrifice and cheerful cooperation to overcome the hurdle. We thank New India Publishing Agency, Pitam Pura, New Delhi for accepting such valuable publication.

Editors

Contents

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Agarwood (*Aquilaria malaccensis* Lam.): A Promising Agroforestry Species Being Exploited for Ethno-Medicinal Uses in Northeast India

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1. Introduction

The *Aquilaria malaccensis* (Agarwood) is an Appendix II species of the Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES, 1994). The species is also red listed under International Union for Conservation of Nature and Natural Resources (IUCN) and is classified as 'Vulnerable' globally but 'Critically Endangered' in India (Oldfield *et al.*, 1998; IUCN, 2009) and almost 'Extinct in wild' in Assam (Anon., 2003; Saikia and Khan, 2012a). The species due to its multipurpose uses is overexploited which is threatening its existence from the wild (Lee and Mohamed, 2016; Talucder *et al.*, 2016). There are 21 reported *Aquilaria* species, of which 13 are fragrant resin producers, while the rest are yet to be studied (Lee and Mohamed, 2016; Talucder *et al.*, 2016). Eleven of the domesticated species are *A. malaccensis, A. crassna, A. subintegra, A. hirta, A.rostrata, A. beccariana, A. filaria, A. khasiana, A.microcarpa, A. grandiflora and A. sinensis* (Zuhaidi, 2016). Species reported from Asia *viz., A. apiculata, A. baillonii, A. banaense, A. beccariana, A. brachyantha, A. cumingiana, A. filaria, A. hirta, A. khasiana, A. malaccensis, A. microcarpa, A. rostrata, A. sinensis, A. subintegra* and *A. crassna* are

known to produce essential oils (Sulaiman *et al.*, 2015). Only three species i.e. *Aquilaria khasiana*, *A. macrophylla* and *A. malaccensis* has centre of origin in India with *A. macrophylla* endemic to Nicobar Islands (Anon., 2003; Giri, 2003) and *A. khasiana* endemic to Khasi Hills of Meghalaya and surroundings (Kanjilal *et al.*, 1982), while *A. malaccensis* is native to evergreen rain forests in the foothills of northeastern India (Chakrabarty *et al.*, 1994; Saikia and Khan, 2012b) and West Bengal (Barden *et al.*, 2000).

2. Taxonomy

The agarwood tree (*Aquilaria malaccensis* Lam., also called as *A. agallocha* and *A. secundaria*), commonly known as Sasi, Sanchi, Agaru (Assamese); Agar, Agaru (Bengali); Agarwood, Malayan Aloe Wood, Malayan Eagle Wood (English) (Haridasan and Bhuyan, 2016); Agaru (Sanskrit), belongs to family Thymelaeaceae, is a fast-growing tropical tree (Chakrabarty *et al.*, 1994; Saikia and Khan, 2012b; Haridasan and Bhuyan, 2016). The taxonomy of *Aquilaria malaccensis* is as follows:

Kingdom- Plantae

Phylum- Tracheophyta

Class- Magnoliopsida

Order- Myrtales

Family- Thymelaeaceae

Genus- *Aquilaria*

Species- *malaccensis*

Synonym- *Aquilaria agallocha*

Climate and Soil

Agarwood grows well over sandy loam soil in high humid sub-tropical climate with rainfall 1800-3500 mm per annum at an altitude up to 1200 m above the sea level; and requires a good amount of sunlight. It is also well suited to slightly acidic soil with low temperature variations between 20°C and 28°C and relative humidity around 80% (Chang *et al.*, 1997; Chowdhury *et al.*, 2003; Uddin *et al.*, 2008; Kalita *et al.*, 2015).

3. Centres of Origin and Distribution

3.1. Cytogenetic

The genus "*Aquilaria*" is economically important for its oleoresinous product 'Agar attar' (Trotter, 1940). Basic chromosome number of the different genera

of this family have been reported to be x = 8 and 9 (Elaise, 1959; Subramanyam and Kamble, 1967; Bhat *et al.,* 1974; Malla *et al.,* 1977). The chromosome count of *A. malaccensis* is n = 8 and 2n = 16. The karyotype is symmetric with 5 metacentric pairs and 3 sub-metacentric pairs, one of which has secondary constriction but no meiotic irregularities (Debnath *et al.,* 1995).

3.2. Distribution

The genus "*Aquilaria*" is distributed in evergreen rainforest of tropical and sub-tropical region of South East Asia (Barden *et al*., 2000; Gunn *et al*., 2003). Burkill (1966) reported the species, growing from Hong Kong to Papua New Guinea and he mentioned the place "Java and Hainan (south China)" as being historical sources of agarwood product. Chakrabarty *et al.* (1994) stated that *Aquilaria* grows mainly across South Africa and Australia. Zich and Compton (2001) observed natural populations of *Aquilaria* species in different location of Indonesia. But among all the *Aquilaria* species, *A. malaccensis* is the principal source of agarwood and is highly valued in current trade and markets. This species is widely distributed in south and south-east Asia including India but mostly in the foothills of northeastern region (*i.e.*, Arunachal Pradesh, Assam, Manipur, Meghalaya, Mizoram, Nagaland, Sikkim and Tripura) and West Bengal (Chakrabarty *et al.,* 1994; Barden *et al.,* 2000; Saikia and Khan, 2014a). But, mostly it has been reported intermittently from different sites of Tropical semi-evergreen forests of the foothill areas of Kameng, Lower Subansiri, Siang, Changlang, Lohit and Tirap districts of Arunachal Pradesh (Chakrabarty *et al.*, 1994; Tabin *et al*., 2009) and also been reported to occur frequently in the homegardens of Sibsagar, Sadiya, Nagaon, Darrang, Goalpara and Cachar districts of Assam (Atal and Kapoor, 1982). Earlier, wild population of this species was reported from plains and few places in Barak valley of Darrang, Nagoan, North Cachar, and Sivasagar districts (Chakrabarty *et al.*, 1994). The commercial plantations at home garden specially in Golaghat district and Hojai town of Assam and nearby foot hill areas had been reported to grow *A. malaccansis* for agar trade (Nath *et al*., 1999; Ahmed and Gogoi, 2000; Barden *et al*., 2000).

4. Botanical Description

In order to know the medicinal plants and be able to identify them on the land, Botanical Description is important and necessary. Botanical description of *Aquilaria malaccensis* (Agarwood) has been elaborated in this section.

4.1. Morphological Characteristics

4.1.1. Stem and Branches

Agarwood tree grows up to 40 meters tall (Fig. 1) and 60 centimeters in diameter (Blanchette and van Beek, 2005; Lee *et al.,* 2013). Bark is smooth and whitish in colour but young bark is light brown in colour having fine hairs on the surface, whereas inner bark is creamy white in colour and fibrous in type. The sapwood is white in color (Adelina *et al.*, 2004) but the healthy wood is white, soft and even-grained (Blanchette and van Beek, 2005). Moreover, the agarwood process takes place in the stem or the main branches where an injury has occurred (Lee *et al.,* 2013).

Fig. 1: Agarwood tree (*Aquilaria malaccensis)*

Fig. 2: Flowers, fruit and seeds of agarwood tree

4.1.2. Twigs and leaves

The twigs are greenish, glabrous and slender. The leaves are spiral, alternate, ellipticobovate or lanceolate to oblong-lanceolate, 5 - 12 cm long, 2.5 - 5.5 cm wide, base acute, apex acute to acuminate, fibrous, not brittle, secondary or lateral veins 12 - 16 pairs, rather irregular, often branched, distinct beneath and obscure above. Petioles are 3 - 6 mm long (Blanchette and van Beek, 2005; Lee *et al.,* 2013).

4.2. Floral Characteristics

4.2.1. Flowering

The inflorescences are generally terminal, axillary and branched with 10-flowered umbels (Fig. 2). Flowers are reported to be green or dirty yellow,

bell-shaped, 5 - 6 mm long, bisexual, fragrant, petaloid appendages twice as many as the lobes, free, stamens twice as many as lobes, stamens 10 in mumber, ovary ovoid, 1 - 1.5 mm long, stigma sessile (Blanchette and van Beek, 2005; Lee *et al.*, 2013). It was also reported that, the agarwood producing species have a small flower similar to that of 'Jasmine' (Hashim *et al.*, 2016).

4.2.2. Fruiting

Generally, the agarwood tree starts flowering and fruiting at the age of 5 - 6 years. The medium sized trees are reported to produce about 1.5 kg of seed during good seed years. Fruits are obovoid or obovoid-oblong, 3 - 4 cm long, 2.5 cm in diameter, leathery exocarp with fine hairs, green in colour and the fruit base is wedge shaped with round apex (Fig. 2). The seeds are ovoidal, 2 in numbers, 10 mm long, 6 mm in diameter and are densely covered with red-brown hairs or sometimes blackish brown (Fig. 2). Flowering and fruiting take place during June - August and November - December respectively (Adelina *et al.*, 2004; Lee *et al.*, 2013).

5. Socio-Economic Importance

The agarwood is not only important for its aromatic properties, but also being important for other uses like ethno-medicinal, ethnobotanical and pharmacological uses. Many researchers had reported the pharmacognostical properties of agarwood with great values and applications (Sathyanathan *et al.*, 2012). Following are the socio-economic importance mentioned here under:

5.1. General uses of Agarwood

5.1.1. Incense Sticks

The high quality wood is used as incense in Arabian households and for the 'koh-doh' incense ceremony in Japan (Compton and Ishihara, 2004). Wood chips are powdered for distillation of oil and making of incense (Persoon, 2008; Sitepu *et al.*, 2011). Compton and Ishihara (2004) mentioned the use of agarwood as incense products during ceremony where the wood is cut into very small pieces and broken down into powder or some of these pieces were directly used as incense. In Japan and other south East Asian countries, use of incense was believed to be found during the period of introduction of Buddhism around 1500 years ago (Compton and Ishihara, 2004) and in Egypt and Arab countries, it was used for Mohammedan prayer (Chakarbarty *et al.*, 1994). During cultural and religious functions of Buddhist, a devotee use to burn agarwood chips or incense as an offering to purify the spaces surrounding the statues of the Buddha.

5.1.2. Perfumes and Personal Care Products

The oil is also used as a fragrance in the production of cosmetics and personal care products, such as soaps and shampoos (Chakrabarty *et al.,* 1994). The market value of agarwood derivative products is dependent on the classification or grading of agarwood, which is determined by a cumulative factor of the fragrance strength and longevity, resin content, geographical origin and oil purity (Barden *et al.,* 2000). In India, the agarwood has been used as fuel for fumigation, and the bark has been used to make cloth and rope.

5.1.3. Medicine

The essential phytochemicals present in the agarwood are proteins, sugar, alkaloids, tannins and essential oils which are crucial for medicinal values. Other secondary metabolites like lignin, saponin, flavonoid, quinine, terpenoid, sterol and alkaloids are also found. The leaves, stems and bark extracts of agarwood with different solvents showed antioxidant, anticancer, anti-hyperglycemic, anti-inflammatory, antibacterial and antifungal properties as reviewed by Jok *et al.* (2015). The seeds of *A. malaccensis* were reported to have anti-allergic properties (Korinek *et al.*, 2016). In the countries like China and Korea, the agarwood powder is used for distillation of oil followed by preparation of medicinal wine (Persoon, 2008; Sitepu *et al.,* 2011).

5.2. Ethnobotanical Uses

The medicinal uses of agarwood since time immemorial, has provided clues to their pharmacological properties (Hashim *et al.,* 2016). . People use the fragrance of agarwood oil for personal devotion, even applied on the hair, behind the ears, neck, nostrils, and clothes. The agarwood pieces are also made into beads for religious purpose. Traditionally, the rosary beads made from agarwood were being used by the Buddhist masters (Antonopoulou *et al.*, 2010). In Indonesia, the smoke of the wood is used to cure orthopedic disorders (Grosvenor *et al.,* 1995). In Assam, the bark (a strip of 2 - 6 m long and 7 - 70 cm breadth) was once used for preparing a writing material called 'Sanchi Pat' for writing history, mythology, folk songs, medicinal and holy scripts (Nath and Saikia, 2002).They also described agarwood as divine capable of gratifying the human needs.

5.3. Ethno-medicinal Uses

On account of effectiveness as a sedative, detoxification of body and maintaining stomach health, the agarwood is used as a traditional medicine in Southeast Asian countries, Bangladesh and Tibet (Hashim *et al.,* 2016). It is used for treating sore throats extreme fatigue including bear bile, cattle gallstone, ginseng and camphor (Compton and Ishihara, 2004), small pox and various abdominal

complaints. It is also used for dropsy, as a carminative, a stimulant, a tonic especially during pregnancy, after child birth and for diseases of the female genital organs. The Malayans and the Chinese do use the discarded soft wood for the treatment of jaundice and body pains (Chakrabarty *et al.*, 1994). It was also reported that, the heartwood is useful for nervous system disorders, nervine, sedative, and refrigerant for heart disorder, ethno-pharmacologically relevant biological activities *i.e.*, analgesic, and positive effect on central nervous system (Okugawa *et al.*, 1993; Chen *et al.*, 2012; Wangchuk *et al.*, 2017). The heartwood is also used as a stimulant in sexual debility and also in skin disease. The juice extracted from bark, is also used for the treatment of diarrhea (Hashim *et al.*, 2016).

Moreover, traditionally extracted oil is used in the production of traditional medicine as anti-asthma, antitoxic, antioxidant, hypertension, hepatitis, sirosis, diuretic, painkiller, and many other diseases. In Assam, agarwood is used as stimulant, tonic, aphrodisiac, carminative and astringent; and also used in diarrhea, constipation, vomiting and snakebite (Sharma and Das, 2018). It is also used in the treatment of gastro-intestinal ailments, respiratory tract infections, kidney and urinary ailments (Saikia and Khan, 2011a). In Tripura, the branches and stem or bark are used as firewood while burying any dead bodies. It is believed that it purifies the soul of the dead person and makes the departed soul pure if it is used for cremation (Sharma *et al.*, 2013).

5.4. Pharmacological Uses and Properties

The plant materials of *Aquilaria* spp. had been reported to exert various bioactivities, including antidiabetic (Feng *et al.*, 2011; Pranakhon *et al.*, 2015), anti-allergic, anti-cancer (Gunasekera *et al.*, 1981; Hashim *et al.*, 2014; Dahham, 2015), anti-inflammatory (Sattayasai *et al.*, 2012), anti-ischemic (cardioprotective), antimicrobial, anti-oxidant (Sattayasai *et al.*, 2012), anti-depressant activities (Okugawa *et al.*, 1993), as well as hepatoprotective, laxative and mosquitocidal effects (Hashim *et al.*, 2016). Many literatures revealed that, they contain sesquiterpenes, 2(-2-phenylethyl)-4H-chromen-4-one derivatives, genkwanins, mangiferins, iriflophenones, cucurbitacins, terpenoids and phenolic acids (Hashim *et al.*, 2016). It was also reported that the agarwood is safe to be used for pharmacological studies. The major compounds found in agarwood plant materials are 5-O-β-primeveroside, stigmasterol, 3b-friedelanol, 4-hydroxybenzoic acid, syringic acid and isovanillic acid (Hashim *et al.*, 2016). Moreover, the sesquiterpenes and 2-(2-phenylethyl)-4H-chromen-4-one derivatives were reported as the characteristics of the resin-infiltrated wood of the tree. In another studies, aromatics (such as benzylacetone) and triterpenes were also reported to be present in the resin of agarwood tree (Chen *et al.*, 2012).

5.5. Other Uses

Recently, the agarwood tree (*A. malaccensis*) had been reported as a potential plant species, which can be grown at sewage sludge area for the purpose to help in uptaking and translocating heavy metals into plant cell (Rajoo *et al.*, 2013). Thus, these indicate its importance in different line of applications. Moreover, a small piece of agarwood either in normal or in any attractive shapes, is having the highest value in the current market. The solid pieces of agarwood are highly valued as "natural art" in Japan, Korea and Taiwan; but, a very small potion of agarwood chips is used to make tea and several types of liquor products (Antonopoulou *et al.*, 2010).

6. Chemical Composition Of Scented Agarwood Oil

Many literatures revealed that, the aromatic smell in the agarwood oil is due to having the following chemical composition like dihydroagarofuran and isodihydroagarofuran, sesquiterpene (*i.e.*, sesquiterpene alcohols : jinkohol II and jinkoheremol; agarospirol, jinkohol-eremol and kusenol) (Hashim *et al.*, 2016; Chen *et al.*, 2012), agarol and a couinarinolignan, aquillochin. The woody chips have an essential oil (commonly known as agarwood oil) constitutes from 0.8% to 2.2% in fungal infested wood of 8 - 50 years old plant. The wood also contains hexadecanoic acid (25.0%), pentadecanoic acid (6.7%), oleic acid (4.9%) and other constituents range from 0.1 to 2.1% (Talucder *et al.*, 2016).

7. Trade And Market

This species had got importance in the foreign markets and the trade; and India was the main source of agarwood during that period since 600 AD (Chakrabarty *et al.*, 1994). It was also reported that international traders were the most influential factors in the marketing channel of agarwood products and used to receive the greatest share of revenue in the product distribution chain (Uddin *et al.*, 2008; Saikia and Khan, 2014a).

The trade in agarwood-based products was growing rapidly in the world due to their recent adoption as an ingredient in the cosmetics and pharmaceuticals sector. Agarwood, the most exalted perfumery and fragrance raw materials obtained from the infected wood of agarwood tree due to association of borer insect (like *Zeuzera conferta* Walker) on agarwood formation, is considered as the myth of perfumery world (Kalita *et al.*, 2015).

Apart from the perfumery and fragrance value, agarwood and agarwood oil are widely used in preparations of various cosmetic products and in Unani and Ayurvedic medicines (Hussain *et al.*, 1992). Although, many efforts had been made to artificially inoculate the fungi in the tree for getting infection (Chakrabarty *et al.*, 1994; Barden *et al.*, 2000; Liu *et al.*, 2013), but the quality

of agarwood produced from artificial inoculation was not at par with the naturally occurring agarwood (Kalita *et al.*, 2015). Moreover, both agarwood smoke and oil are customarily used as perfume in the Middle East which had been highly prized by European perfumers in the mid-1990s (Chakrabarty *et al.*, 1994).

Considering the above all facts and usefulness of this species, the people had started indiscriminately growing this species in their home garden in the state of Assam (Saikia and Khan, 2014a). Even few people from many north eastern states *viz.*, Tripura, Assam and Meghalaya had started commercially growing this species in the form of block plantation and few were seen to grow along with cash crops like Tea plantation. The species is largely cultivated with community participation, especially in Lohit and Changlang districts in Arunachal Pradesh, Dimapur in Nagaland, Garo hills in Meghalaya, Agartala in Tripura, Upper Assam in Assam *etc.* (Haridasan and Bhuyan, 2016).

8. Origin of Agarwood Business

The origin of agarwood business in Assam dates back to 1930's, when a few enterprising families from the Sylhet district of Bangladesh adjoining to the Golaghat district of Assam started its trade. The business then slowly got shifted to many places in Assam *viz.*, Golaghat, parts of Jorhat and Hojai of Nagaon districts, and later, those districts became the most important locations for small-scale agarwood chip preparation and oil extraction. Growers generally sell the standing trees to the local traders, who consecutively, sell the wood and wood-chips to the agarwood oil extraction industries (Saikia and Khan, 2012a). Many local and small-scale traders then sell the agarwood oil or perfume either in the local markets or to the grand companies like Ajmal Group of Companies (Saikia and Khan, 2012a). The agarwood and it's processed products in Assam, used to be sent to Kolkata and Mumbai and from where it is then exported to other countries like Turkey, Arabia, Persia, Europe, *etc.* (Nath and Saikia, 2002).

It was also reported that, the average cost of a mature tree in home gardens in upper Assam fetches the price from Rs. 28986 (US$ 580) to 2008238 (US$ 40165) during 2013-14 with an average of Rs. 249090 (US$ 4982). Borah *et al.* (2014) had explained the importance of agarwood in terms of low input and flexibility in sites requirement, improved economic opportunities for people and inter cropping opportunities (Borah *et al.*, 2014).

9. Factors Affecting Agarwood Oil Formation

Artificial wounding of tree trunk by nails or by cutting is common in Upper Assam for oil formation.. Factors such as tree age, seasonal variations in growth, and environmental and genetic factors may also play an important role in oil formation (Ng *et al.*, 1997). Overexploitation is a major problem for *A.*

malaccensis in India for which this species became highly threatened (Chakrabarty *et al.*, 1994; Saikia and Khan, 2012a).

9.1. Socio-economic Aspects of Agarwood Production

There is hardly any information available related to the socio-economic aspects of agarwood production in India. This could be due to the restricted distribution of the species and lack of attention. Other reasons might be due to the socio-economic impacts of agarwood trade including the problems in quantifying the volume traded, lack of knowledge about the year-wise price rate per unit volume and unwillingness to share any information by the agarwood growers (Saikia and Khan, 2012a).

9.2. Artificial methods of producing agarwood

Chowdhury *et al.* (2016) reported that it would be better to consider artificial inoculation to get better quality and yield. In one experiment, Chowdhury (2014) developed a novel technique called "aeration method", for producing good quality agarwood in cultivated agarwood trees. Some of the artificial methods of producing agarwood are being discussed hereunder.

9.3. Artificial Induction Technique

Many of the following artificial induction techniques had been well described by Talucder *et al.* (2016) in one of their review:

9.3.1. Customary Induction

Agarwood inductionon trees growing in the natural environment when the old trees receive any stroke due to natural calamities like lightning or sudden attack by animals, insects or microbes (Talucder *et al.*, 2016). The formation of agarwood is usually takes place at the wounded or decaying parts of the trunk or stem or branch or even roots and twigs too. There are many conventional methods (*viz.*, Nailing Method, Drilling method, Partly-Trunk-Pruning Method, Burning-Chisel-Drilling Method, Fungi-Inoculation Method, *etc.*) had been developed so far which are explained under the following sub-heads:

Nailing method: In this method, the hammering of nails into the tree trunks often with hundreds or even thousands of nails per tree and placed into the trunk spirally to make injury into the tree. This process is extremely labor intensive and time taking. After many years, each nail wound produces a slight amount of low quality resinous wood. But, agarwood yielded from this treatment is generally of inferior quality and cannot meet the desired market demand (Persoon, 2007).

Drilling method: Drilling on stems, roots and large branches followed in spiral form from tree base upward, is a common method. In this method, it is done at 3 to 5 cm apart and kept open for easy access of animals, insects or microbes. After every 2 – 3 months, drilling is again done at the already wounded part to rewind it (Blanchette, 2006).

Partly-Trunk-Pruning method: In this, the cuts of 2 - 4 cm wide and 3 - 5 cm deep are given along one side of the main trunk of the tree at 50 cm above the ground and proceed upwards. The space between every two cuts is kept about 20 cm (Liu *et al.,* 2013).

Burning-Chisel-Drilling method: In this method, the holes (each with 20 cm apart) in the trunk from approximately 50 cm above the ground to the top of the trunk are made by a 1.2 cm wide burning and red-hot iron drill bit (Liu *et al.,* 2013).

Fungi-inoculation method: The holes of approximately 8 cm deep on a trunk from 50 cm above the ground onwards are made by a drill following two or three holes made horizontally but vertically spaced at 20 cm apart. The fungi (*Melanotus flavolivens*) cultured in the growth media is then inserted as the bait into each hole, which is then wrapped by rubberized fabrics (Liu *et al.,* 2013).

Other method: In Assam, the Deori tribe has reported to use certain secret formula wherein they use a sort of jaggery solution into the wood by piercing with long nails in the tree trunk (Beniwal, 1987).

9.3.2. Modern Technologies

Following are some of the artificially induced modern techniques:

Aeration Method: In this method, a device is inserted into the wound part to prevent healing the pores and to establish prolonged infection (Blanchette, 2006). Such device is known as aeration device. This device may contain aeration holes in it and/or it may contain grooves on its exterior surface. It may be made of plastic, bamboo, wood or other organic material or metal such as iron with about two cm in diameter. The author also reported that, this method may involve applying a resin-inducing agent to stimulate resin production in the tree.

Whole-tree Agarwood Inducing Technique (Agarwood-Wit): Whole-tree agarwood inducing technique (also known as Agarwood-Wit) is very simple, where agarwood inducers are injected into the xylem part of the tree (Zhang *et al.*, 2012). The inducer is basically a liquid form. Liu *et al.* (2013) reported that the substances like formic acid that have a low pH and NaCl that has a high pH, both have the ability to disrupt live cells and induce large amount of agarwood.

They also reported that, because of this method of inducing agarwood had turned into an increase of 4 to 28 times high yield of agarwood than the yield obtained from other methods of inducing agarwood.

Cultivated Agarwood Kits: In the cultivated agarwood kits method, tubes are placed in the tree trunk as a mean to introduce microbes and to stimulate production of the defense compounds by the tree naturally (Blanchette and Van Beek, 2009). In another studies, Blanchette *et al.* (2015) reported that this technology has a proven record of success in *Aquilaria* plantations located in other countries like in Vietnam. Hence, this technology has the potential which can also be followed in North-eastern region and in other states of India.

10. Propagation

Considering the importance of this agarwood tree in terms of socio-economic development, it became necessary to overcome market demand and to conserve this species. Many countries had started cultivating the species following many such artificial means of agarwood productions as already described above. Moreover, the ever increasing demand of the agarwood by industries worldwide, the natural stock of agarwood tree is not enough to feed into unless artificial mass plantation follows to reduce the pressure on its natural population (Rasool and Mohamed, 2016). On the other hand, one has to identify the best genotypes or plus trees (Hegde *et al.,* 2009) from which clonal propagation of the stand can be achieved and can go long way to propagate on large scale. Even, not only planting better genotypes can help, but one has to extend modern techniques that are efficient at inducing agarwood and practicable for application in plantation setting (Rasool and Mohamed, 2016). Hence, sustainable agarwood production to support socio-economic development and conservation of the species in its natural habitat is possible only through domestication of the wild species (Saikia and Khan, 2012a).

10.1. Propagation through Seeds

Agarwood tree can be propagated by seeds, which are generally available in the month of June-July (Anon., 2004). The propagation must take place when seed is matured. The germination of seed is epigeal, therefore, special care should be taken in nursery management. The seeds are first germinated in sand beds and then transferred to poly bags (Anon., 2004). Raising seedlings in poly-bag is preferred in some places. Seed germination is reported as more than 80% (Talucder *et al.,* 2016). Since the seeds of agarwood are recalcitrant *i.e.,* having viability for 7-10 days, hence raising them in the nursery must be done very soon after the fruit has opened and the seed exposed. It was also reported that, successful seed storage is difficult and loss of viability occurs very quickly

once seeds are exposed to the environment. However, with good planning, proper management and modern nursery practices, the seedlings can be produced in large numbers (Blanchette *et al.*, 2015).

Agarwood tree is a long-term plantation crop. A profitable plantation may be of 15 years cycle or more. Zabala (1989) reported that, the short cycle plantation yields only essential oil or 'agarwood or agar attar' of low quality (Boya oil). Hence, to maximize the agarwood production, the plantation may be planned in the following two ways:

10.1.1. Planting at Wider Spacing

Planting along with some suitable intercrops and harvesting at the end of the crop cycle.

10.1.2. Planting at Closure Spacing

Planting at comparatively closure spacing and harvested at 2 - 3 phases. In the second approach about 8 - 10 years of planting about 40% selected trees may be harvested with a view to thin out the plantation for better growth and development of the remaining trees and also to get a substantial income (Anon., 2004). Agarwood trees require 2 m × 2 m spacing for rapid growth and development (Zabala, 1989). Around 4500 plants per hectare are required.

10.2. Vegetative Propagation

The normal propagation of *A. malaccensis* by seed is difficult because the moisture content in the seeds get decreased rapidly during the first few hours or days. Hence, the viability of seeds is lost very fast (Anon., 2004; Blanchette *et al.*, 2015). Moreover, insect pest infestation of the seeds often inhibits the growth of the tree. Hence, other modes of propagation can be tried to raise large number of seedlings. Vegetative propagation is relatively easy through either by stem cuttings, grafting, air-layering and tissue culture may therefore be appropriate to accelerate the establishment of planting stock (Adelina *et al.*, 2004). But, very rare studies on vegetative propagation had been done so far in this species. In one of the studies on growth of shoot cuttings of agarwood tree, the plant growth regulators like IBA and NAA with a concentration of 50, 100, 150 and 200 ppm and various soil media were able to increase the average percentage live shoot cuttings almost reach 100%, where very few rooting success were reported (Yusnita *et al.*, 2017). Indeed, many authors had tried even to propagate through the tissue culture technique which is being described below.

10.3. Tissue Culture

Generally, this technique offer a viable system for rapid, true-to-type mass multiplication and germplasm conservation of endemic, rare and endangered plants (Mallon *et al.*, 2010). Qi (1995) studied the *in vitro* culture and the production of agarwood. Highest growth of the callus was recorded on MS medium supplemented with a higher amount of growth hormones *i.e.*, 2,4-D (6 mg L^{-1}) + Kinetin (2 mg L^{-1}) and 4% sucrose between 30- 45 days (Talukdar and Ahmed, 2001). Talukdar and Ahmed (2004) also reported the increase in fresh callus biomass after 45 days of culture with fructose (at 30 g L^{-1}) but the least growth rate was in the culture with Maltose. *In vitro* response, growth and maintenance of callus of *A. malaccensis* was also observed by Debnath (2013) and reported that 2,4-D (2-4 mg L^{-1}) in MS medium induced callus. Meng-ling *et al.* (2005) studied the rapid *in vitro* propagation of *A. malaccensis* and established an efficient plant regeneration system via organogenesis from shoots developed from seedlings. *In vitro* multiplication of shoot buds of this tree was also studied and found that optimum numbers of shoots were induced in MS medium supplemented with 4 mg L^{-1} BAP+ 0.5mg L^{-1} NAA (Debnath *et al.*, 2013). Shoots generated many buds on MS medium supplemented with 1.3 μ mol L^{-1} BA (6-benzyladenine) in the first seven weeks and the buds elongated on MS + 1.3 μ mol L^{-1} BA+0.5 μ mol L^{-1} NAA in another seven weeks (Meng-ling *et al.*, 2005). About 96.7% plantlets were rooted after two weeks on 1/2 MS medium after being immersed in 5 μ mol L^{-1} NAA for 48 h.

11. Diseases and Pest Control in Agarwood Tree

Kalita (2002) reported that, the insect like *Heortia vitessoides* Moore (Lepidoptera : Pyralidae) is a serious pest of agarwood plant, and generally observed during the months from May to August. This insect causes defoliation of whole tree. However, application of "Thiodan @ 2 ml L^{-1} at 15 days interval" during infestation is found to control the pests effectively.

12. Plantation

12.1. Homegarden

The economy of Upper Assam is agriculture-based and homegardens are a prominent land use system of the state (Devi and Das, 2010). Homegardens are traditional agroforestry systems with complex structure and multiple functions (Das and Das, 2005). Although rice (*Oryza sativa* L.), sugarcane (*Saccharum officinarum* L.) and tea (*Camellia sinensis* (L.) O. Kuntze) are the major crops of the region, but many homegardeners have started growing agarwood for greater returns and the species has become an important plantation crop of Upper Assam (Saikia and Khan, 2012a). Saikia *et al.* (2012) also reported a

good population stock of agarwood with highest density and frequency in homegardens of upper Assam. Two distinct morphs of agarwood/*Agaru* (*Bhola Sanchi* and *Jati Sanchi*) are cultivated in homegardens of upper Assam with different life form characteristics (Saikia and Khan, 2012b). Whereas, the variant "*Bhola Sanchi*" is the fast growing and less agarwood yielding than the other variant *Jati Sanchi* which is slow growing but high agarwood yielding and preferred for commercial cultivation (Saikia and Khan, 2014b). Nath and Saikia (2002) also reported similar variations among the population of agarwood growing in homegarden and they identified three "races" (*viz.*, "variant I (RRLJ 2729)" is a medium sized tree with slender trunk, oblong-lanceolate leaves known as *Bhola Sanchi*; "variant II (RRLJ 2726)" is a large sized tree with obovate lanceolate leaves known as *Sanchi*; "variant III (RRLJ 2730)" is a much branched small to medium sized tree with lanceolate leaves known as *Jati Sanchi*) from different areas of Assam.

Because of the high economic potential, attempts are now being made to cultivate it at the adjoining areas of Assam in Northeast India and other parts around the world (Saikia and Khan, 2014a). They also reported the tree density of agarwood as 260 to 7913 individuals ha^{-1} in different homegardens of upper Assam with an average of 1466 individuals ha^{-1}, which contributes 34% of the total tree density (Saikia and Khan, 2014a) and 20% of the total annual income of the dependent family (Saikia and Khan, 2014b).

12.2. Plantation as Cash Crops

The agarwood and tea are the most commonly cultivated cash crops, found in 100% and 30% of the studied homegardens respectively in upper Assam (Saikia and Khan, 2011b). They also reported that, homegarden products including agarwood and tea contributed a good amount of subsidiary income up to 45% (with a mean of 14% ±1.15) of the total annual income of the family, which is higher than the reported 7% average annual gross income per household of Meghalaya, Northeast India (Tynsong and Tiwari, 2011). Moreover, Saikia and Khan (2012a) reported that low input needs and flexibility in site requirements as well as suitability for intercropping make agarwood a preferred cash crop in the homegardens of upper Assam.

12.3. Block Plantation

In many places, block plantation is very common in this agarwood species. Rahman *et al.* (2015) reported that agarwood trees are found to grow in the form of monoculture and block plantations in many other countries like Bangladesh. There is hardly any information available regarding the block plantation (monoculture) in Northeast India; even though few block plantations

are seen to exist in some places but hardly any studies or reports are available till date. Hence, there is an opportunity to the farming communities of Northeast India who can come forth for large-scale block plantation of agarwood for better management and maximum earnings.

12.4. Boundary Plantation

Ha and Nghi (2011) reported that, agarwood tree is suitable for growing on field boundaries and for dividing whole plot into sub-plots. Moreover, it is also grown on borders of gardens, school compounds, office compounds, parks and residential sites. The canopy of the tree is such that it allows sunshine penetration partly. Thus, it can be planted in field boundaries, bunds *etc.*, without affecting the field crops. Besides, agarwood tree has been successfully grown for strip planting along banks of ponds, tanks, canals and roads. In hilly areas / tillas, it can be planted on poor soils on hill slopes and tilla tops. They help in reducing soil erosion and land sliding caused by running water during rainy season.

12.5. Agarwood Tree Based Agroforestry System

The agarwood is seen to be intercropped with cassava, sweet potato and oil palm in agroforestry systems in the hilly regions of North central Vietnam (Ha and Nghi, 2011). Even, this tree can also be intercropped with acacia, upland rice and pineapple. Some farms in Vietnam also integrate agarwood and fruit trees in their home and forest gardens (Ha and Nghi, 2011). Even, it can be intercropped with a combination of other agricultural crops and fruit trees such as upland rice, beans, sweet potato, yam, banana, jackfruit and many more (Talucder *et al.*, 2016). In Northeastern region of India, Patchouli based agroforestry model was found promising since the patchouli plants are highly suitable for planting in shade under the agarwood tree species (Gera and Bhojvaid, 2013). Kunio and Lahjie (2015) reported that the future of forest industry would be better diverted to the non timber forest products by intercropping agarwood with vanilla. Blanchette *et al.* (2015) reported that it can be grown along with rubber, teak, banana and even oil palm in Southeast Asia. Introduction of agarwood tree in Tea growing area is also an ideal option (Blanchette *et al.*, 2015). Borah *et al.* (2014) also stated that, this agarwood species can be planted along with other crops like Patchouli (*Pogostemon cablin*), sarpagandha (*Rouvolfia serpentine*), Jatropha, pepper (*Piper longum*), pineapple, tea, turmeric, arecanut and with other agricultural crops.

Hence, this agarwood based agroforestry systems should be promoted to fully harness the potentials of the tree species (Ha and Nghi, 2011). Moreover, the good capacity for pollarding and coppicing of agarwood has made it suitable to fit in agroforestry (Anon., 2004). The increasing.

13. Conclusion

Having being exploited the species *Aquilaria malaccensis* for traditional medicine as well as uses in pharmaceutical industries, its demand has drawn more attention to the farming communities to start with an agarwood based enterprises. In fact, agarwood contains a surplus of bioactive compounds that support their use in traditional medicine. Moreover, globally this species has been listed as critically endangered and vulnerable under IUCN red list. Therefore, sustainable agricultural and forestry practices are necessary for further development and utilization of agarwood as a source of health beneficial compounds. The widespread cultivation of agarwood tree in Assam, Tripura, Meghalaya, Arunachal Pradesh and other states of Northeast India, offers a potential *ex situ* reservoir for the future conservation and management of this threatened tree. This tree is one such promising component for diversified agroforestry systems of this region due to its favorable climatic and edaphic conditions. Though, having great challenges of getting good quality planting materials can draw attention to the growers or the researchers to find out the possible means and ways of propagating the best genotypes thereby maintaining the better genetic diversity. Molecular based studies can only be the most recent study that one can think of in indentifying the ways to improve the agarwood production to a greater extent.

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