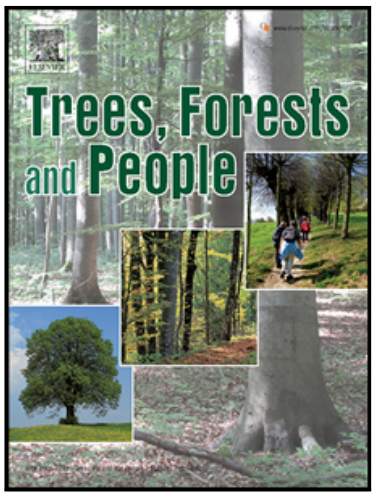

Agar (Aquilaria agallocha Roxb.) based small-scale enterprises in Bangladesh: management, production, marketing and role in socio-economic development

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Highlights

- Agar plantations were managed mainly based on traditional indigenous knowledge.
- Agar oil was extracted following a steam distillation process.
- Marketing of agar products was done through both formal and informal trading.
- Agar enterprises played a potential role in the socio-economic development of the rural people.
- The study provided a comprehensive overview of agar-based small enterprises in Bangladesh.

Agar (*Aquilaria agallocha* Roxb.) based small-scale enterprises in Bangladesh: management, production, marketing and role in socio-economic development

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Abstract

Agarwood (*Aquilaria agallocha* Roxb.) is one of the most expensive woods in the world. Agar-based enterprises are increasing due to the high demand for agar products worldwide including Bangladesh. Information on the socio-economic condition, silvicultural operation, extraction, processing, marketing and potential barriers are crucial for the formulation of a proper management plan. Therefore, the study was conducted in the Moulvibazar district of Bangladesh using a semi-structured questionnaire and focus group discussion to explore the aforesaid issues and provide subsequent recommendations for this sector. A total of 120 respondents (an equal number of agar nursery owners, growers, buyers and enterprise owners) were selected randomly based on the preliminary surveys. The growers and enterprise owners were mostly literate (77%) and had nurseries for raising seedlings. About 55% of the respondents were found to have private plantations while the reaming growers possessed homestead agar plantations mixed with other plant species. The majority of the enterprises were small in size (65%) and only 10% possessed large enterprises (more than 8 pans). The practice of nursery management, silvicultural

operation, and agar induction and extraction process was found conventional based on their indigenous knowledge. The study revealed that the nursery owners, tree sellers, enterprise owners and enterprise workers earned substantial income per month that ranged from US$<179 to >535, US$<119 to >476, US$119 to >595 and US$71 to 143 respectively indicating the potential role of agar-based enterprises in the socio-economic development of the study area. Such profitable agar-based enterprises are expected to flourish more, if financial and modern technical support, supply of high-quality seedlings together with raw materials and contemporary marketing facilities are adequately provided.

Keywords: Agarwood; Agar plantation; Wounding; Marketing channel.

1. Introduction

Agar is an important and expensive non-wood forest product in the world (Naziz et al., 2019). It is an alternative name of the resinous, fragrant and highly valuable heartwood which is mainly produced from the agar trees of the 'Thymelaeaceae' family (Barden et al., 2000; Das and Alam, 2001). In contrast to the healthy and luxuriant tree as the main concern of forest silviculturists, fungal infected diseased agar tree is the priority of the growers. Generally, agarwood is formed as a result of the plant defence mechanism against wounding, fungal infection, insect attack and animal grazing or due to natural or artificial inoculation. It is generally processed into fragrances, perfumes, incense, ornamental display, aromatherapy and medicines (Pojanagaroon and Kaewrak, 2005; Liu et al., 2013; Abdin, 2014; Lee and Mohamed, 2016). Historically, agar was used as incense in religious ceremonies by Buddhists, Hindus, Christians and Muslims (Liu et al., 2013). Incense is also used in the production of soap and shampoos (Schippmann, 2001).

The family 'Thymelaeaceae'is widely distributed in Australia, Africa and Asia. It consists of about 500 medium-sized tree species under 50 genera of which the genera *Aquilaria*, *Aetoxylon*, *Gyrinops*, *Gonystylus* and *Wikstroemia* are capable of producing agarwood (Rogers, 2009; Lok, 2016; Lee and Mohamed, 2016; Rasool and Mohamed, 2016). However, *Aquilaria* is cultivated mostly as the main source of agarwood. Out of 21 *Aquilaria* species, 13 are reported to produce agar while the remaining has not been investigated yet (Lee and Mohamed, 2016). *Aquilaria* is a medium-sized fast-growing evergreen tree that attains a height of 18-40m with an average diameter of 40cm (Elias et al., 2017) and widely distributed in Indo-Malaysia region (Lee and Mohamed, 2016). Agar trees (*Aquilaria* spp.) grow better in well-drained, light to medium textured acidic soil with a mean annual temperature of 22-18°C and mean annual rainfall of 1500-6500mm (Akter and Neelim, 2008). Major agarwood producing countries are Bangladesh, Brunei, Cambodia, Indonesia, India, Malaysia, Laos, Singapore and Vietnam. Globally, middle-eastern countries and countries in northeast Asia (Japan, South Korea and Taiwan) are the two major market places of agar products (Abdin, 2014). The global market value of agarwood chips varies from US$20 to US$6000 per kg based on the quality while the price of agar oil can be as high as US$30,000 per kg (Abdin, 2014). The global market contribution of agarwood has been estimated as US$6 billion to US$8 billion (Akter et al., 2013). Due to the high market price and demand, natural agar resources are being destroyed rapidly. Therefore, *A. malaccensis* has been declared as a threatened species by the Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES) in 1995. However, since 2004, '*Aquilaria*' has been listed as threatened by CITES (CITES, 2004).

Agar is one of the most promising non-wood forest products in Bangladesh that earns US$0.05 million to US$1.19 million per year (Chowdhury et al., 2018). Traditionally, two

species of agar (*A. agallocha* and *A. malaccensis*) were planted in the northeastern region of Bangladesh. Initially, the wild resources were the major source of agar raw material. But, due to the destruction of natural agar sources and increased demand, several agar plantations have recently been established in Chittagong, Chittagong Hill Tracks (CHT) and Sylhet division of Bangladesh (Rahman et al., 2015). At present, more than 3,009 ha of the areas are under the cultivation of agar trees in different regions of the country (Talucder et al., 2016). Besides, a total of 121 private agar gardens have been established in the Sylhet division of which 111 gardens are located in the Barlekha Upazila of Moulvibazar district.

Agar enterprise is a feasible business and the net return is about US$0.022 million per acres at a rotation of 12 years. Therefore, the number of agar-based enterprises increased to 300 by 2015 (Rahman et al., 2015). The increasing number of agar enterprises and agar plantations are creating employment and playing a significant role in the livelihood development of the rural people. Despite the important economic role of agar products, only a few studies have been carried out on agar plantations and agar-based small-scale enterprises in Bangladesh (Akter and Neelim, 2008; Akter et al., 2013; Islam et al., 2014; Rahman et al., 2015; Hossen and Hossain, 2016; Chowdhury et al., 2018; Das et al., 2018). Besides, very little information is available regarding the socio-economic condition, production and marketing of agar products. Therefore, the study was done to explore the socio-economic status of the people engaged in agar plantations and agar-based enterprises in the northeastern part of Bangladesh. The study also investigated the cultivation, production and marketing channel of agar products as well as the constraints and subsequent recommendations on agar plantations and agar-based small-scale enterprises in Bangladesh.

2. Methodology

2.1. Study site

Agar plantations are commonly found in the Sylhet, Chittagong and Chittagong Hill Tracts (CHTs) of Bangladesh. Moulvibazar district of Sylhet division is reputed for agar production as most of the agar plantations and agar-based enterprises are located there. Therefore, the study was carried out in the Maulvibazar district deliberately (Figure 1).

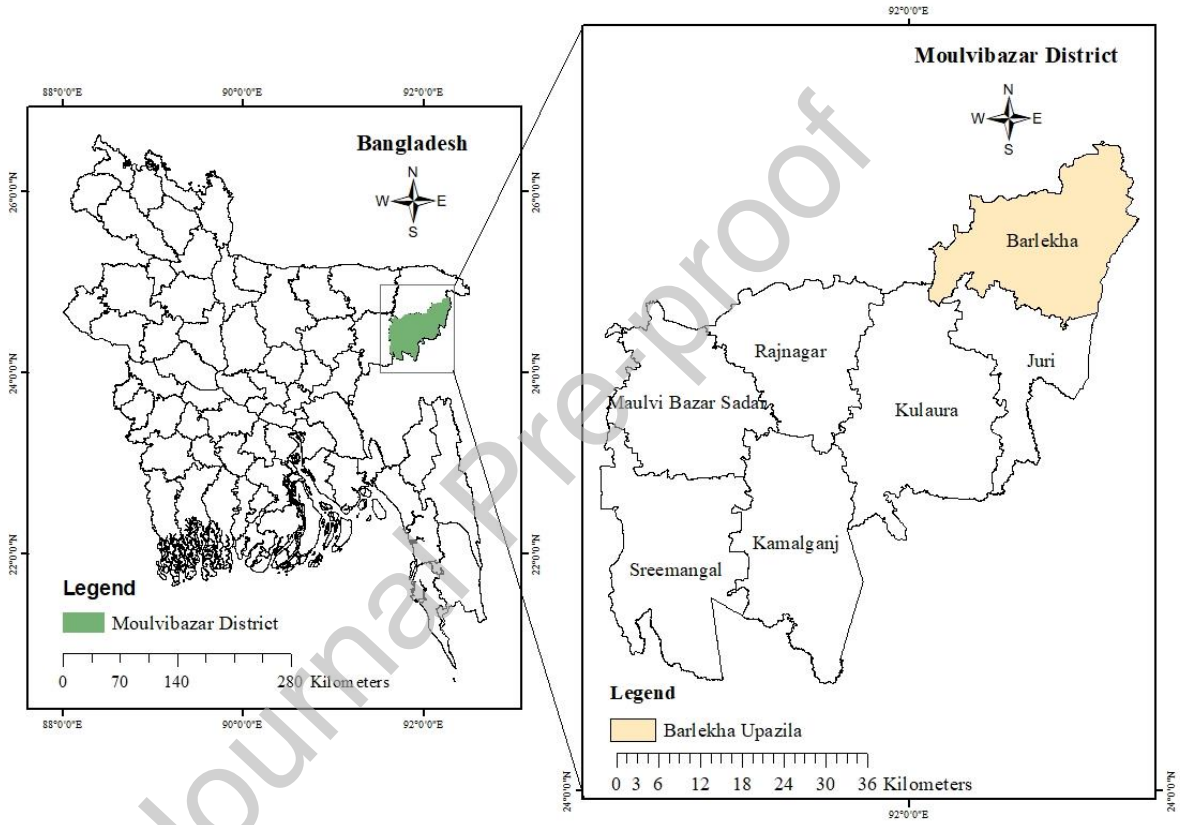

Fig. 1. Map of the study area

The study area is situated between 24°08' - 24°29' north latitudes and in between 91°36' - 92°17' east longitudes and covered an area of 2799.38 km^2 of which 310.41 km^2 is occupied by forests (BBS, 2011). It is surrounded by Sylhet district in the north, Habiganj district in the west and India in the south and east. Maulvibazar has a typical tropical monsoon climate according to Koppen climate classification. The minimum and maximum temperature of the Moulvibazar

district varies from 13.6°C to 33.2°C and the average rainfall is 3334 mm (BBS, 2011). Moulvibazar district falls within three agro-ecological zones namely Eastern Surma-Kusiyara Floodplain, Northern and Eastern Piedmont Plains, and Northern and Eastern Hills among the total of 30 agro-ecological zones of Bangladesh (Huq and Shoaib, 2013). The soil is acidic and the soil texture is sandy-loam to sandy-clay-loam (Shil et al., 2016).

2.2. Research method

Out of 7 upazilas (sub-district), the Barlekha upazilla of Moulvibazar district was selected for the study as most of the agar plantations and agar-based enterprises are located there. Besides, out of 10 unions (an upazila is composed of several unions) of Borolekha upazila, 2 unions (Sujanagar and Dakhinbag) were selected randomly. The study was conducted between 2019 and 2020. Surveys were carried out following a semi-structured questionnaire (both open and close-ended questions) and focus group discussion. A total of 120 respondents (60 from Sujanagar and 60 from Dakkhinbag) were selected randomly based on the reconnaissance surveys. Respondents from both unions consisted of 15 agar nursery owners, 15 tree growers, 15 tree buyers and 15 enterprise owners. Production and marketing of agar products were analysed based on the focus group discussion. Altogether four focus group discussions (two in Sujanagar and two in Dakkhinbag) were carried out and each focus group consisted of 8 participants (2 nursery owners, 2 tree growers, 2 tree buyers and 2 enterprise owners). Market chain analysis was also done based on the focus groups discussions to understand the driving channels of marketing of agar products at the local, national and international levels. A paired rank exercise was carried out among the respondents to identify the problems and constraints faced by the local agar-based entrepreneurs and their possible solutions.

3. Results

3.1. Demography and socio-economic status of the respondents

Most of the respondents (86%) in the study area were in the age group of 21-60. Among them, 53% of the enterprise owners and 46% of nursery owners belonged to the 41-60 year age group while most of the tree sellers (53%) and tree buyers (50%) were between 21 and 40 years (Table 1). About 23% of the total respondents were illiterate and 77% were literate. Most of the enterprise owners (27%) and tree buyers (33%) were found to complete their secondary education while 30% of the nursery owner obtained primary education and most of the tree sellers (33%) were illiterate (Table 1). Very few respondents from all classes were found to complete their graduation or post-graduation degrees. Most of the families of the respondents were medium in size and the average family size estimated was at 6.9. Among the families, 65% of the enterprise owners were found to have a medium family size followed by nursery owners (55%) and tree sellers (50%) (Table 1).

Table 1 Socio-economic and demographic status of the respondents (%)

	Nursery owner	Tree seller	Tree buyer	Enterprise owner
Age				
<21 years	4	0	0	0
21-40 years	43	53	50	40
41-60 years	46	33	27	53
>60 years	7	14	23	7
Education				
Illiterate	28	33	13	18
Primary	30	27	30	17
Secondary	20	23	33	27
Higher Secondary	12	10	10	20
Graduate	8	4	10	12
Post-graduate	2	3	4	6
Family size				
Small (<6)	20	33	43	25
Medium (6-10)	55	50	53	65

Large (>10)	25	17	4	10

3.2. Agar nursery owners and their income

A noteworthy number of people were found to engage in agar nursery and plantation activities. Most of the agar nurseries were situated in the village named Kalajura of the Dakshinbag union. The nurseries were classified into 3 categories based on the number of seedlings grown. The size of the nurseries was mostly found small (45%), followed by medium (25%) and large (30%) (Table 2). The average monthly income of the nursery owners varied based on the nursery size. The selling of agar seedlings was conducted more during the rainy season as agar seedlings were found to plant mainly in the rainy season. The monthly income of the maximum nursery owners (45%) was less than US$178 while only 15% of nursery owners earned more than US$535. Besides, 20% of owners earned US$179 to US$357 while another 20% earned US$358 to US$535 per month (Table 2).

3.3. Nursery labourers and their income

Depending on the season, each agar nursery was found to depend on two types of labour force i.e. temporary and permanent labourers. However, temporary labourers required mainly during the rainy season (April to May). The necessity of both permanent and temporary labourers also varied based on the nursery size. Small nurseries required only 1-2 permanent labourers while the medium and large nurseries needed 3-4 labourers and more than 4 labourers respectively (Table 2). The demand for temporary labourers was found to increase as many as 10-15 for small nurseries followed by medium (15-20 labourers) and large (more than 20 labourers) (Table 2). The permanent labourers earned a monthly salary of US$53.57 to US$59.52 while the temporary labourers were paid US$1.78 to US$2.38 per day (Table 2).

Table 2 Status of the nursery size, nursery owners and labourers

Nursery size (%)	
Small (1000-20000 seedlings)	45
Medium (20001-40000 seedlings)	25
Large (>40000)	30
Monthly income of the nursery owners (%)	
<179 US$	45
179-357 US$	20
358-535 US$	20
>535 US$	15
Number of nursery labourer	
Permanent labourer	
Small nursery	1-2
Medium nursery	3-4
Large nursery	>4
Temporary Labourer	
Small nursery	10-15
Medium nursery	15-20
Large nursery	>20
Income of nursery labourers (US$)	
Wages of the temporary labourers (per day)	1.78-2.38
Wages of the permanent labourer (monthly)	53.57-59.52

3.4. Agar tree sellers and their income

Almost all of the respondents were found to have agar plantations either mono or mixed in the homestead. Forty-six percent of the total respondents possessed homestead agar plantations containing 100-5000 trees. Besides, 27% of respondents were found to have agar plantations with 5000-10000 trees and another 27% was found to possess plantations with more than 10000 trees (Table 3). The income of the agar tree sellers was found to depend on the season and plantation size. As the extraction of agar increased during the winter season, the income of the tree seller also increased during this time. Maximum tree sellers (63%) earned less

than US$119 while only 3% earned more than US$476. Besides, 17% of tree sellers earned US$120 to US$238 and another 7% earned US$239 to US$357 (Table 3).

3.5. Pricing category of agar tree

The price of an agar tree was found to depend mostly on the diameter of the tree, the larger the diameter, the higher chance of getting a better price. Tree diameter more than 24 inches provided a maximum price of more than US$23.80 followed by US$11.90 to US$23.80 for 12-24 inches, US$3.57 to US$8.33 for 6-11 inches and US$1.19 to US$2.97 for 1-5 inches (Table 3).

Table 3 Status of agar tree sellers and agar pricing category

Plantation Size (%)	
100-5000 trees	46
5001-10000 trees	27
>10000 trees	27
Monthly income of tree seller (%)	
<119 US$	63
120-238 US$	17
239-357 US$	7
358-476 US$	10
>476 US$	3
Pricing category of agar tree (US$)	
Diameter of the tree (1-5 inches)	1.19-2.97
Diameter of the tree (6-11 inches)	3.57-8.33
Diameter of the tree (12-24 inches)	11.90-23.80
Diameter of the tree (>24 inches)	>23.80

3.6. Agar tree buyers and their income

Tree buyers were found to perform their business activities like a middleman and 70% of them did not have any agar plantation. They used to buy agar trees from the agar tree growers and sold them to the sellers based on the agreement between the buyer and seller. Most of the agreements were made for 5-10 years and only a few agreements were made for 10-20 years.

Short term agreements were made when there was a limited supply of raw materials. Usually, the rate of profit for the tree buyers was between 5-10% of the agar tree bought from the growers. However, the profit rate was found to depend mostly on the internal structure, diameter of the trees and development of agar inside the trees.

3.7. Income of field labourers

In the present study, the field labourers were found to earn more (US$ 6 to US$8 per day) than the other professional labourers. The fieldwork activities were laborious than the other related works. Activities performed by the field labourers were nailing of the agar stem, weeding and pruning, cutting of agar trees and transporting them to the factory sites from the field. But, there was a condition of nailing and cutting of trees i.e., a particular number of trees needed to be counted on this condition.

3.8. Agar tree enterprises and their income

Agar enterprises were classified into 3 types i.e., small, medium and large based on the number of distillation plants. A small enterprise consisted of 1-4 distillation plants while a medium and a large enterprise consisted of 5-8 and more than 8 respectively (Table 4). Considering the enterprise owners, a small percentage of the respondents were found to have a large factory. Most of the enterprises (65%) were small in size while 25% of enterprises were medium-sized and the remaining 10% were large-sized (Table 4). The agar factories particularly the smaller enterprises did not function to produce attar (fragrance) throughout the year. The production of agar factories increased during the winter season as it was the pick time for agar harvesting. However, most of the large agar factories were found to continue their production throughout the year. The income of the enterprises was found to depend on the size and production of the factories. The average monthly income of the small enterprises was between

US$119 to US$357 while the medium-sized and large-sized enterprises were found to earn US$358 to US$595 and more than US$595 respectively (Table 4).

3.9. Status of enterprise workers

The number of factory workers was found to depend on the factory size and working facilities. Each factory was found to depend on two types of labour force such as permanent and temporary. The enterprises mainly functioned by the temporary labourers as the number of permanent labourers was very few (15%). The demand for temporary labourers increased during the winter season. However, the small factories did not function throughout the year due to the lack of raw materials and workers. The ratio of the male and female workers in the factories was 2:1. About 45% of workers were unskilled or low-skilled and had no scientific knowledge of agar production (Table 4).

3.10. Income status of factory workers

Wages of the factory workers varied due to the nature of work. Work activities of males and females were different in each factory and wages varied between the male and female workers. Male workers were highly preferred for factory works. Females were selected mainly for cutting and chipping of woods. On the other hand, the male was preferred for the cutting, chipping and finding out the main black portion of agarwood and nailing. The average wages per day varied based on the nature of works, however, female workers were found to earn less compared to male workers. The wage for wood-cutting and logging was US$3.57 per day while US$2.38 was paid for wood chipping. The wage to find out the main black portion from agarwood was US$4.76 per day while for nailing out from the wood stem was US$2.98 per day was paid for nailing out from the wood stem (Table 4).

Table 4 Size and income status of agar-based enterprises

Size of enterprises (%)	
Small (1-4 pans)	65
Medium (5-8 pans)	25
Large (>8 pans)	10
Monthly income of the enterprises (US$)	
Small (1-4 pans)	119-357
Medium (5-8 pans)	358-595
Large (>8 pans)	>595
Enterprise workers (%)	
Male	67
Female	33
The average income of the enterprise workers (US$ per day)	
Logging and cutting	3.57
Agarwood chipping	2.38
Finding of Black agar by cutting agar trees	4.76
Nailing out from agar trees	2.98

3.11. Agar tree cultivation and management

Both seeds and seedlings were used for establishing agar plantations. About 96% of the respondents used seedlings while only 4% used seeds for raising agar plantations. Normally one-year-old seedlings were planted during the monsoon. About 86% of the respondents collected seedlings from the nearby agar nurseries while the remaining 14% were collected from homesteads, neighbouring homesteads, natural plantations and markets. The spacing used by the planters was either 1m×1m or 2m×2m for mono-plantations (Figure 2A). Apart from the mono-plantation, agar trees were also observed in home gardens growing with other plants as a mixed plantation. In addition, agar trees were also planted as intercropping with short rotated cash crops. The fields were prepared before 2-3 weeks of plantation by digging the pit and the holes were filled with a mixture of cow dung and urea. Only 16% of the respondents were found to use fertilisers at the time of planting the seedlings while 84% of the respondents planted the seedlings in the field without the application of fertilisers. The thinning operation was not

practised in the case of the mono-culture, however, sometimes it was also done in the home gardens. The pruning operation was carried out throughout the year up to 3-5 years. Weeding was practised during the early stage of rotation up to 3 years. Irrigation was provided only in the first year of the plantation, however, 21% of the respondents were found to provide irrigation during the dry season.

Agarwood was found to form due to both natural and artificial inoculation. All of the respondents were observed to practise artificial inoculation techniques for the quick formation of agarwood. Nailing was practised mainly as an artificial wounding technique by the respondents (Figure 2B). Besides, all the respondents opined that about 5-10% of agar trees were infected by fungus naturally. Artificial inoculation was generally exercised on 7-10-year-old agar trees. No external signs developed indicating the formation of agar inside the tree. Therefore, drilling, cutting and wood borer were used to determine the maturity of the agar trees.

Fig. 2. Production of agar oil in the study area: (A) an agar plantation, (B) artificial inoculation of an agar tree with nails, (C) a worker is chipping agarwood into small pieces, (D) a steam distillation plant with its owner, (E) a worker is separating agar oil from the water after steam distillation, (F) agar oil stored in a glass bottle.

3.12. Extraction of agar products

Matured trees were harvested mainly during the winter season. The quality of agarwood increases with the age, however, 10-15-year-old agar trees were harvested for the extraction of agarwood and agar-oil. After harvesting, the agar trees were de-nailed and cut into small pieces. The expert workers separated the best quality agarwood (black wood) from small pieces. The black agarwood produced the superior quality of agar oil and sometimes used for making aesthetic things. Then, the agar pieces were chipping into very small pieces and dumped in water for one to five weeks (Figure 2C). Later, fermented agar chips were taken in the container (distillation plant) of the agar oil extraction plant to extract oil by using the steam distillation

technique (Figure 2D). After the steam distillation, agar oil was separated manually from water and stored in a glass bottle (Figure 2E and 2F). Each container of the oil extraction plant contained 40-90 kg of agar chips. Approximately, 10kg of agarwood chip was required for the extraction of 10ml agar oil. The low-quality agarwood was used for making incense light after grinding.

3.13. Marketing of agar-based products

Marketing of agar-based products involved production and processing of raw materials, grading of agarwood and agar oil, distribution of agarwood, agar oil and agar byproducts to the local and international traders or retailers as well as distribution to the consumers. Both formal and informal dealing was maintained for the international trading of agarwood and agar oil while the agar byproducts were marketed locally through informal trading (Fig. 3 and 4). Agar tree growers were the main producer of raw materials and involved in the primary processing. The intermediaries were involved mainly in the aggregation of raw materials from the agar tree growers. Both tree growers and intermediaries were found to sell agar trees to the processors. Almost 60% of tree growers used to sell agar raw materials directly to the processors and the remaining 40% of tree growers were found to sell agar raw materials through the involvement of intermediaries based on the agreement between tree growers and processors. The processors were found to sell 80% of the processed raw material to the local traders, exporters and the remaining 20% was exported directly to the international retailers following informal trading. The local traders used to sell 90% of their purchased agar products to the exporters, international traders and reaming 10% was sold to the local retailers and international consumers. The local retailers were observed to sell their bought agar products to the local consumer as finished products. The exporters were found to export agar products to the international traders following

formal trading. The international traders used to sell agar products to international retailers. Finally, the international retailers were found to sell the finished goods to international consumers (Figure 3).

Agar byproducts such as agarwood chip residues, unused branches were marked locally. Byproducts were directly sold to the local consumers by the local traders (80%) and local retailers (20%) in the form of incense sticks (Figure 4).

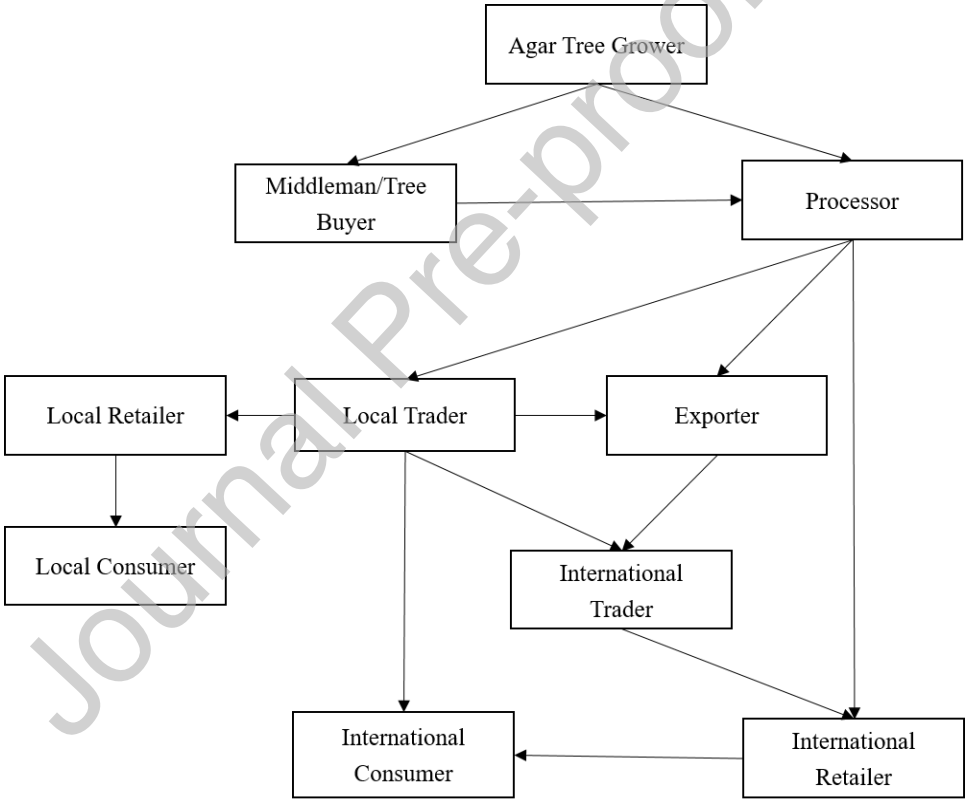

Fig. 3. Marketing channels of agarwood and agar oil

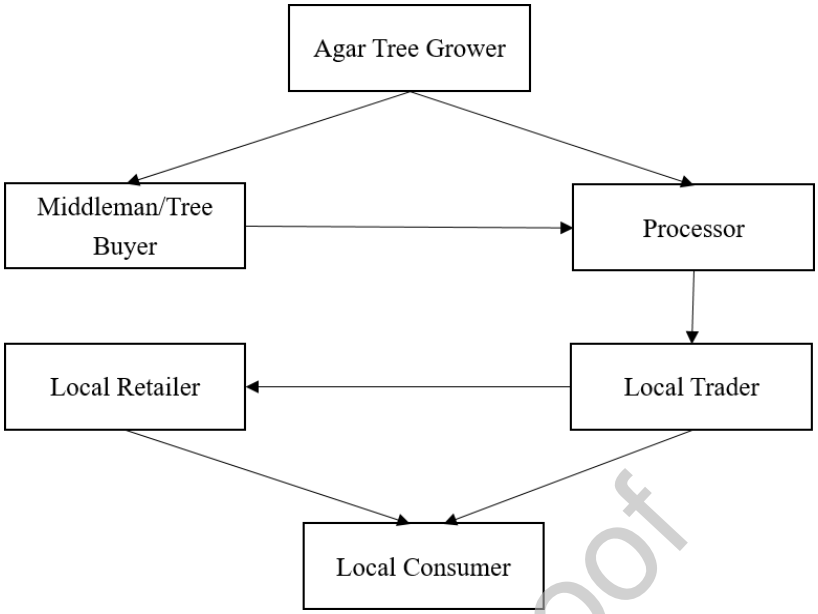

Fig. 4. Marketing channels of agar byproducts

3.14. Constraints and subsequent recommendations for the agar sector

Respondents were asked about the constraints and problems faced by the local agar-based enterprises. They pointed out that lack of capital investment, shortage of raw materials, lack of high-quality seedlings, scarcity of skilled manpower, lack of up-to-date information, inadequate supply of gas, involvement of middlemen and low technical knowledge were the main constraints. They also added that the profitability was sometimes limited due to lack of technical knowledge and inability to assure the product quality, lack of market information and insufficient international trading facilities. Respondents, therefore, suggested various measures at both local and national levels to increase profitability. About 77% of respondents suggested ensuring adequate credit facilities followed by technological improvement (60%). Besides, 53% of respondents opined for the establishment of a National Information Centre to ensure up-to-date information related to agar enterprises. 50% of the respondents suggested establishing an agar trading union for strengthening local and international agar trading. 46 % of the respondents

emphasised the formal training regarding agar production while 40% of the respondents opined proper regulatory and policy support of the government could play a vital role in international trade.

4. Discussion

Agar is an important non-wood forest product in the tropical forest regions of the world including Bangladesh. It is one of the most promising and expensive products generally processed into scent and incense and traded globally mainly in the Indo-Malaysian regions and middle-eastern countries. Agar plantations and agar-based small-scale enterprises have created job opportunities worldwide. It has been estimated that about 25,000-30,000 people are engaged in agar plantations and agar-based enterprises in Bangladesh (Baksha et al., 2009). The present study was carried out to explore the socio-economic condition of the people engaged in agar plantations and agar-based small-scale enterprises in the northeastern region of Bangladesh. Besides, the cultivation, production and marketing of agar products were also investigated.

Bangladesh is one of the most densely populated countries in the world with 164.6 million people lived in an area of 14.7 million ha (BBS, 2019). Only 9.8% (1.44 million ha) of the total land area of the country is covered by forest and 19.4% (2.86 million ha) land area is occupied by village area (FD and FAO, 2007). Due to overexploitation and population pressure, existing forests including the natural sources of agar have been degrading rapidly. Therefore, extensive agar tree plantations were carried out in the state-owned denuded forests and degraded areas, tea estates and homegardens of Sylhet division, Chittagong and Chittagong Hill Tracks (CHTs) (Talucder, 2016). Agar plantations play an important role in the context of socio-economic and environmental perspectives (Rahman et al., 2015). The present study revealed that agar plantations and agar-based small-scale enterprises were feasible and profitable businesses for

agar nursery owners, tree sellers, tree buyers, tree sellers and enterprise owners. Previously, Rahman et al. (2015) reported that the net present value of agar plantation was US$0.058 million per ha and the net annual return of agar-based small-scale enterprises was US$0.009 million that corroborated the findings of the present study. The agar sector has created employment for both educated and illiterate people and played a great role in socio-economic development. Most of the people engaged in this sector were found to be poor. From the present study, it was observed that about 80% of the workers were mostly poor. However, agar cultivation has changed the living and lifestyle of the rural poor people. Most of the people engaged in agar plantations and enterprises were male, besides, it has also created job opportunities for few rural women. Hence, the agar sector could act as a potential source of job and empowerment in Bangladesh to uplift the socio-economic conditions of the rural people. However, only 15% of the enterprise workers worked permanently as it is seasonal. As the agar enterprises were situated in remote and rural areas, the workers were paid relatively low daily wages ranging from US$2.38 to US$4.76 for various processing activities. The respondents opined that the availability of labourers was an important factor for such low wages. Moreover, a large number of workers worked temporarily besides their main activities such as agriculture**.** About one-third of the workers of the agar enterprises were female. In the study area, it was popularly believed that females were less capable of doing physical works than their male counterparts. Therefore the female workers were paid less than the male.

The formation of agarwood is the result of a plant defence mechanism mainly against any wounding and infection caused by fungal pathogens (Mohamed et al., 2010). Besides, other organisms like bacteria and small animals may promote the formation of agarwood (Chhipa and Kaushik, 2017; Tan et al., 2019). The growers of the study area were not aware of the

mechanisms for the formation of agarwood. Agarwood may also be formed both in natural and artificial processes. In our study, the respondents opined that 5-10% of agar trees were found to form agar naturally. The natural agar formation is mostly linked to physical damage caused by pests and disease infection, animal grazing and thunder strikes (Rasool and Mohamed 2016; Wu et al., 2017; Tan et al., 2019). The formation of agarwood through natural inoculations is a time delay process where artificial inoculations accelerate the process of agar formation (Rasool and Mohamed, 2016). Traditionally, almost all of the agar farmers in the present study area were found to use only nailing as a means of artificial inoculation. The findings of the present study matched with the findings of other studies where pegging of nails was the widely used technique of agar tree inoculation in Bangladesh (Rahman et al., 2015; Chowdhury et al., 2016; Talucder et al., 2016; Chowdhury et al., 2018). Besides, the hammering of nails was used in many countries like India, Malaysia and Indonesia (Saikia and Khan, 2012; Rasool and Mohamed, 2016). Besides, a lot of new wounding techniques such as drilling, cutting, bark removal, holing and nailing, partial-trunk-pruning, burning-chisel-drilling, aeration, fungi inoculation, whole tree agarwood inducing and cultivated agarwood kits have been developed (Zhang et al., 2012; Liu et al., 2013; Mohamed et al., 2014; Rasool and Mohamed, 2016; Wu et al., 2017; Tan et al., 2019). However, the farmers of the present study area had no information and knowledge on the new inoculation techniques. All the respondents opined that naturally forming agarwood is superior while the quality of nailed agarwood is inferior in quality. Agar trees are artificially nailed at the age of 7-10 years and mature agar trees are harvested at the age of 10-15 years. The farmers believed that the quality of agar dependent on the age of agar trees. The quality of agarwood could be improved similar to the natural agarwood when they are induced using a suitable inoculation method (Pojanagaroon and Kaewrak, 2005; Gao et al., 2014). But, no such kind of

initiative was taken for producing the best quality and quantity of agarwood by selecting or developing the best suitable inoculation techniques within the short rotation period. The conventional wounding techniques were responsible for the inferior quality of agarwood (Persoon, 2007) and the nailing technique was the main cause of the low quality and quantity of agarwood production in Bangladesh (Talucder et al., 2016). However, Parvin et al. (2012) reported that the nailing density (4cm×4cm) produced the maximum quantity of agarwood rather than small or large nailing distance and 95% oleoresin deposition was found in 15 years old agar trees in Bangladesh.

In the present study area, silvicultural operations carried out in the agar plantations were mostly based on the farmer's traditional and indigenous knowledge. Farmers had no scientific knowledge about the silvicultural operations to be performed in agar plantations. No thinning operation was carried out, even though when they planted agar trees at less than 2m×2m spacing particularly, in homegardens. For the best growth and development of the agar trees, the required spacing was suggested to be 2m×2m (Zabala, 1989). In the case of lower spacing (1m×1m), the thinning operation was needed to be done after 5-6 years of the plantations (Rahman et al., 2015). Most of the plantations were established using the seedlings propagated from seeds. The seedlings were propagated in the nursery beds based on the traditional knowledge and no proper nursery guidelines were established regarding the nursery techniques. Therefore, the poor quality seedling was produced which was one of the constraints of agar tree plantations and enterprises. Coppicing and micro-propagation techniques for the multiplication of the best quality agar tree (Sabdin et al., 2011; Hossen and Hossain, 2016; Ali and Kashem, 2019) were not found to practice by any of the growers. In the study area, agar oil was extracted through steam distillation following local technology. No initiative was taken to establish modern agar oil extraction

techniques, even the respondents did not have any knowledge about the modern technologies. However, Islam et al. (2014) developed a cost-effective system for agar oil extraction with a benefit-cost ratio of 2.33 in the context of Bangladesh.

Bangladesh is exporting agar products (agarwood and agar oil) for the last four hundred years. But, no official information is available on the exporting of agar products. However, the present study has reported both formal and informal trading for international marketing of agar products. Bangladesh Export Bureau took some initiatives to facilitate formal trading while a large market of this sector remained as an informal sector (Abdin, 2014). Most of the tree growers were found to sell agar raw materials to the processors directly after harvesting as they received maximum profits through this market channel. However, a large amount of agar raw materials was marketed based on the agreement between tree growers and processors and the agreement was made before or after the nailing of agar trees. As nailing is an expensive process, some tree growers permitted the processors to nail and harvest agar trees at their cost (Rahman et al., 2015). Sometimes, the middlemen were found to sign an agreement with the tree growers, and in this case, the middlemen were bound to nail and harvest. Besides, the middlemen were also found to take an influential part in the agreement between the tree growers and processors. The middlemen were also found to buy agar raw materials directly from the tree growers, even a few tree growers offered the middlemen to harvest and sell the agar plants spontaneously to avoid unwanted measures of the harvesting and selling. Besides, few tree growers did not have enough idea about the marketing of agar raw materials and they used to sell agar raw materials to the middlemen. Therefore, the middlemen were found to play an influential role in the marketing of agar products. Altogether, the middlemen received about 5-10% of the price margin of the agar products. So, the influence of the middlemen was a limiting factor for the maximization of

profit from the agar products. The processors marketed most of the agar products to local traders and exporters, though some of them were found to sell them to international retailers through both formal and informal trading. Informal trading occurred when the processors did not have a trade license, however, it ensured a high probability of getting the maximum price of agar products. Informal trading mainly occurred through close relatives living in a foreign country. The processors experienced in international trading used to transport agar products in handbags to those countries (Abdin, 2014; Rahman et al., 2015). The local traders and exporters exported agar products to international markets following a formal trade as most of them had a trade license. But, few local traders and exporters were found to export informally as they did not have a trade license. Agar byproducts were traded locally due to the lack of international market demand. Local retailers and traders marketed low-quality agar byproducts as fragrances and incense light to the local consumers. Agar tree growers were found to sell agar byproducts directly to processors. The middlemen also played an influential role in the marketing of agar byproducts due to their presence in various market channels. Although the involvement of the middlemen in the marketing of agar raw materials and byproducts provided limited benefits to the agar tree growers, it also created a potential source of income for those who were landless and did not have any agar plantation. The present study identified the major constraints of agar-based small-scale enterprises along with the way out suggested by the respondents. The constraints were similar to other non-timber forest products in Bangladesh as identified by a separate study conducted earlier (Kar and Jacobson, 2012).

5. Conclusions

Agar plantations and enterprises are financially viable and profitable both in the context of local and international trade. The cultivation and extraction of agar products were done following

the traditional indigenous knowledge and technology. Artificial inoculation by nailing produces the worst quality agar which resulted in less revenue. Though most of the jobs were temporary and seasonal, they played a potential role in the socio-economic development of the rural people including women empowerment. The main constraints enlisted were technical and financial limitations, scarcity of raw materials and skilled manpower, poor marketing information, involvement of the middlemen and paucity of high-quality seedlings. Despite having several major limitations, the agar sector is playing an important role in eradicating poverty and improving the socio-economic conditions of the rural people in Bangladesh. Both governmental and non-governmental organisations (NGOs) should come forward to explore the potential of agar-based enterprises. Further studies are necessary to find out the ecological aspects and feasibility of extending agar plantations across the country.

Declaration of Competing Interest

The authors declare no competing interests.

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