Project ID 418

Competitive Research Grant

Sub-Project Completion Report

on

Growth and Productivity Assessment of Agar Plant (*Aquilariamalaccensis* Roxb.) through Management Practices

Project Duration

7 May 2017 to 30 September 2018

Department of Soil Science
Sylhet Agricultural University, Tilagor, Sylhet 3100

Submitted to
Project Implementation Unit-BARC, NATP 2
Bangladesh Agricultural Research Council
Farmgate, Dhaka-1215

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Bangladesh.

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New Airport Road, Farmgate, Dhaka – 1215
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Acronyms

AEZ	=	Agro-Ecological Zone
BBS	=	Bangladesh Bureau of Statistics
BCR	=	Benefit Cost Ratio
BFRI	=	Bangladesh Forest Research Institute
CFI	=	Constraint Facing Index
cm	=	Centimeter
^oC	=	Degree Celsius
et al.	=	et alii (and others)
g	=	Gram
>	=-	Greater than
ha	=	Hectare
hrs	=	Hours
i.e.	=	id est (that is)
K	=	Potassium
Kg	=	Kilogram
<	=	Less than
m	=	Meter
m^2	=	Square meter
meq	=	Miliequivalent
ml	=	Milliliter
mm	=	Millimeter
µg		Micro gram
N	=	Nitrogen
No.	=	Number
NS	=	Non Significant
OM	=	Organic matter
P	=	Phosphorus
$plant^{-1}$	=	Per plant
%	=	Percentage
S	=	Sulpur
Std	=	Standard deviation
SRDI	=	Soil Resources Development Institute
$t\ ha^{-1}$	=	Tonnes per hectare
TK	=	Taka

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Executive Summary

The project was implemented during May 2017 to September 2018 at Baralekha upazila of Moulovibazar district with views to identify the farmers' management practices, growth, system productivity with intercropping of medicinal plants, processing and marketing. A survey and three experiments were conducted to fulfill the objectives of the project. The survey was conducted in Baralekha upazila under Moulvibazar district, Bangladesh during September 2017 to March 2018 to know the status of agar plantation, management practices of agar plant, harvesting, processing and marketing. A random sampling technique was followed to select the agar growing farmers. Total numbers of sample farmers, factory owners and factory workers were 104, 60 and 40 respectively. Lathichora and Sujanagar, Azimganj villages were selected randomly from the study areas. Data were collected on farmers' age, family size, farm size, agar plantation, fertilizer application, intercultural operations, training received, annual income, agar processing, marketing, production cost and returns of agar oil, BCR, problems of factory owners and workers etc. Majority of the farmersestablished their agar plantation through collection of seedlings from private nurseries and planted during May to July withdense spacing than recommended one. They nailed the plants using iron rod(*Tarkata*) at age range to 6-15 years. Agar wood harvesting is made 5 years after nailing for collection of agar oil through distillation process in the factories. Nailing is the major practices for production of quality agar oil but best quality agar oil produced due to insect infected agar trees. Lack of gas connection in industryis the majorproblem in case of agar oil production and low wage rate is the major constraints faced by the agar workers. Agar plantation and production of agar oil is the profitable enterprise in the area.

The biomass estimation experiment was conducted in the selected fifteen existing agar gardens for taking data on growth and biomass with 20 plants considered as replications. Estimation of above-ground biomass of agar tree was done by non-destructive method. Estimated biomass of agar plants in 15 years age category was 44.23 kg plant^{-1} and 110.58 t ha^{-1}. The 2ndexperiment was conducted with eleven treatments to see the performance of medicinal plants with agar plantation as intercrop. The experiment was carried out with five medicinal species namely Kalmegh (*Andrographispeniculata*), Bashok *(Justiciaadhatoda*), Tulsi (*Ocimun sanctum*), Sarpagandha (*Rouvolfiaserpentina*) and Aswagandha (*Withaniasomnifera)* with and without Agar plants (*Aquilariamelaccencis*).Results revealed that the medicinal plants may be grown in the agar plantation with intercropping. Kalmegh and Basakis most suitable as intercrop with agar plantation which gave the extra income from agar garden. The 3rd experiment was conducted on agarwood quality, fermentation and chemical content of agar oil. Insect infested agarwood was found best quality among the three wood categories (insect infested, nailed and white) in respect to wood density, production of phenolic compounds and resin. The microorganisms were identified in agarwood soaking water belongs to *Bacillus spp. Staphylococcus, E. coli, Pseudomonas, Aeromonas* and *Klebsiella*, they may contribute in the fermentation of agar wood to increase agar wood yield.

CRG Sub-Project Completion Report (PCR)

A. Sub-project Description

1. **Title of the CRG sub-project**: **Growth and Productivity Assessment of Agar Plant (*Aquilariamalaccensis* Roxb.) through Management Practices**

2. **Implementing organization:** Department of Soil Science, Sylhet Agricultural University, Tilagor, Sylhet 3100.

3. **Name and full address with phone, cell and E-mail of PI/Co-PI (s):**

Principal Investigator: **Professor Dr. Md. AbulKashem**
Department of Soil Science
Sylhet Agricultural University
Tilagor, Sylhet 3100.
Cell no. 01712213707
E-mail: makashem.agri@sau.ac.bd;
reem98k@yahoo.com

Co- Investigator: **Professor Dr. Md. SharafUddin**
Department of Agroforestry and Environmental Science
Sylhet Agricultural University
Tilagor, Sylhet 3100.
Cell no. 01716510538
E-mail:sharaf.aes@sau.ac.bd;
mdsharafuddin@yahoo.com

4. **Sub-project budget (Tk):**
   4.1 Total: Tk. 25000000.00**(Twenty Five Lac Only)**
   4.2 Revised (if any): Tk. 25000000.00 **(Twenty Five Lac Only)**
5. **Duration of the sub-project:**
   5.1 Start date (based on LoA signed): 7 May 2017
   5.2 End date: 30 September 2018
6. **Justification of undertaking the sub-project:**

'Agarwood' or 'eaglewood' ('Aguru' in Bengali), an occasional product of genera *Aquilaria* and *Gyrinops* in the plant family Thymelaeaceae is the most expensive wood in the world. Agar is a scented product, oleoresin, obtained from pathological conditions of the wood of live trees containing many aromatic substances. Various bacteria and fungi have been found to be associated with Agar wood preparation through formation, although it is still not absolutely clear which are important or even necessary. The quality of agar mostly depends on the plant species and the fungal species involved, as well as, certain other unknown factors. The issues are now to explore the new sources of agar wood to protect the endangered plant species, to ensure agar formation in 100% of the planted trees, upgrade in quality and most possibly quantity of agar yield per tree simultaneously minimizing the maturation time. This evergreen tropical tree species contain precious dark resinous heartwood (agar wood). The population of agar tree is rapidly declining in natural forests of Bangladesh, and the species is now being planted in government-owned degraded forest sites as well as privately-owned homestead forests. A survey conducted with 120 agar farmers and 20 agar-based enterprises in Moulvibazar district of Bangladesh, revealed that the traditional management practices were adapted based mostly on indigenous knowledge and technology to manage agar plantations and agar-based oil enterprises. Discounted cash flow analysis indicated that both agar plantations and agar-based oil enterprises are financially viable (Moriyum, 2017). The net present value of 1 ha of agar plantation (rotation period 12 years) was estimated to be Tk. 4.9 million. Despite some threats to agar farming posed by the traditional wounding techniques of agar trees and the involvement of intermediaries in the marketing channel of agar trees and agar-based products, this economic sector has potentiality to play a vital role in rural peoples' livelihood subsistence and agroforestry sector development in Bangladesh.

It is a fact that Agar tree is over harvested in the wild. IUCN-The World Conservation Union Red list categories of six species are considered at risk from over-exploitation for agar wood. According to convention on International Trade in Endangered species of wild Fauna and Flora (CITES), *Aquilariamalaccensis* rated vulnerable and *A. crassna* is "Critically Endangered" while there seems to be some confusion over A. agallocha. This species is considered a synonym for *Aquilariamalaccensis* (Anon, 1999; Anon, 2001, Ng et al, 1997) although some believe *A. agallacha* to be distinct species. The species, which attains a height of about 40 m, is tropical evergreen in nature and sometimes is also named as *A. malaccensis* (Hayder et al., 2005).

Agar tree is an aphrodisiac, both in oil form and in incense. They are generally used in tropical areas but the oil is also sold in Vietnamese pharmacies for internal use with the same goal (Aphrodisiac purpose). Chinese medicine uses powdered *Aquilaria*as treatment for cirrhosis of the liver and as a detector or focuser for other medicines. It has also been used as a treatment for lunge and stomach tumors. Mainly the Arabs are the proud customers of agar wood products. Agarwood incense has been burned to produce a pleasant aroma for centuries, on important religious ceremonies, by Buddhists, Hindus and Muslims (Ng and Azmi, 1997). The essence extracted from agarwood is now widely used as a fragrance to manufacture beauty soaps and shampoos.

Agarwood is highly prized incense that is extremely rare. It has at least a 3000 year history in the Middle East, China and Japan. There are also references to agarwood in the literature of India and France, and even in the Old Testament of the Bible. Agarwood remains today the world's most expensive incense. Agar tree is the soft, dark heartwood that is produced by any of various south-east Asian evergreen trees (genus, especially *A. malaccensis*synonym *A. agallocha*) when they become infected with fungus and that contains a fragrant resin used chiefly to produce incense, perfumes, and traditional medicines. When the inside of the tree becomes infected usually by insects, fungus or mold develops and bores into the tree, which attempts to defend itself by creating agarwood. Agar, eaglewood, gaharu and aloeswood are alternative names for the resinous, fragrant and highly valuable heartwood produced by *A. agallocha*Roxb. (Thymelaceae) and other species of the Indo-Malaysian tree genus *Aquilaria* (Barden et al., 2000).

The history of agar in Bangladesh is very ancient and grows naturally in Sythet, Chittagong, Cox's Bazar and Chittagong hill tracts from time immemorial but at present natural grown agar tree is very hard to find. Agar is found irregularly in the forests of Sylhet, Chittagong and the Chittagong Hill Tracts (CHT). Agar has never been cultivated commercially at wide range. At present, approximately 30 to 35 families of Patharia, Dakshinbhag and Sujanagar under Baralekhaupazila in Moulvibazar district are directly involved with agar production and processing. Agar trees are grown in their homestead in combination with other trees. Agar is one of the most promising non-timber forest products (NTFPs) of Bangladesh, and earned Tk.1300M through exports of attar (agar oil) in 2004 (Hayder et al. 2005). Despite the huge demand in local and international markets, no major extension program has so far conducted by governments or other agencies or research organization in Bangladesh. The Forest Department (FD) recently raised some agar plantations in denuded and encroached forest areas of the Chittagong and Sylhet districts. In the homestead, farmers have planted Agar tree in different micro sites e.g., homeyard, backyard, front yard, boundary and marginal land (Sarker, 2016).

There are also some privately owned agar plantations in the north-east, particularly in Moulvibazar district where many families have been engaged in production and marketing of agar and agar-based secondary products for several decades. Of the 121 registered agar-based factories nationally, 111 are located within this region, making a major contribution to regional employment and gross domestic product (Hayder*et al.*, 2005). Furthermore, there are potential opportunities that would arise in the future for improving the livelihoods of poor people in the region by providing income generating means. In addition, several reports have been come up with small scale and personal agarwood plantations in Sylhet, Habiganj and Chittagong Hill Tracts.

About 297 Unani and 204 Ayurvedic companies in Bangladesh are utilizing medicinal plants as main raw materials. Some of the 376 pharmaceutical companies (BBS 2009) are processing medicinal plants as raw materials. As the supply of the local medicinal plants is scarce, the companies are importing raw materials from adjoining countries. Present production and utilization of herbal medicine is increasing steadily. There is worth of 11 million US dollars medicinal plant market in Bangladesh, which have been imported but not in the name of medicinal plants rather in the name of spices and other products. Local merchandisers collecting raw materials from 5 different areas of the country, among those 90% are coming from Chittagong. Sylhet is a potential area for cultivation of medicinal plants to increase supply of raw materials for the herbal industries. Therefore, feasibility study can be initiated to increase the resource of medicinal plants through cultivation as intercrops in association with the existing agar plantation in Sylhet. Considering the economic importance, 5 medicinal plants viz. kalomegh (*Andrographispaniculata*), bashok (*Adhatodavasica*), sarpaganda (*Rauvolfiaserpentina*), aswagandha(*Withaniasomnifera*) and tulsi (*Ocimumtenuiflorum*)) can be grown to develop the cultivation, conservation and proper management technologies.

Bangladesh is favorable for Agar tree production commercially. The atmospheric and soil condition of Sylhet Region are also congenial for the growth and development of Agar wood. Very little information is available on cultivation practices, processing and its problem and profitability. However, a little research work was conducted at Baralekhaupazila, Moulvibazar on Agar biodiversity found that these plants are going to extinct from the studied areas due to infestation of insects, pest and lack of suitable agronomic management practices as well as rapid harvesting of immature plants. There is a pressing need to document and identify the species of agar trees are being cultivated by the farmers. Research and development may create an ample scope to boost up its production, particularly in south-east hilly regions in the country. A rigorous research is needed for development of agar enterprise and increase systems productivity with intercropping of medicinal plants. In view of this situation the present study is attempted to analyze management practices, processing and the benefit cost ratio of agar production in Sylhet region.

7. **Sub-project goal:** Productivity assessment of Agar plant through use of technologies.

8. **Sub-project objective (s):**

i) To identify the farmers best management practices for agar plant cultivation,

ii) To study the growth of agar plant and system productivity with intercropping of medicinal plants, and

iii) To suggest the policy and technological issues for improvement of agar production, processing and marketing.

9. **Implementing location (s):**The study area is located at Sujanagar union of Baralekhaupazila under Moulvibazar district.

10. **Methodology in brief:**

The project was implemented through survey and three experiments conducted in the site at villages of Moulvibazar district to fulfilled the objectives. The methodologies followed for individual experiment is given below.

Experiment 1: Field survey on present status of Agar plantation, agronomic management and processing in Sylhet region

The survey was conducted in Baralekhaupazila under Moulvibazar district, Bangladesh during September 2017 to March 2018 to know the status of agar plantation, management practices of agar plant, processing and marketing.As per the objectives of the study, a survey questionnaire was prepared for collecting the desired data from the sampledfarmers. On the basis of the pre-test of this schedule, necessary modification, addition and alteration were made to improve the validity and applicability of the schedule. A random sampling technique was followed to select the sample farmers. To minimize errors, several repeated visits were made to collect the data properly.Total numbers of sample farmers, factory owners and factory workers were 104, 60 and 40, respectively. Dakkhinbhag, Borthal, Gangkul, Rafinagar, Shalidigha, Hashimpur, Baghmara, Lathichora and Sujanagar, Azimganj villages were selected randomly from the selected areas. Data were collected on farmers' age, family size, farm size, agar plantation, fertilizer application, intercultural operations, training received, annual income, agar processing, marketing, production cost and returns of agar oil, BCR, problems of factory owners and workers, etc. The data were collected by the MS students through following the personal interview from both the agar farmer and owners. Before going to make an actual interview, a brief introduction of the aims and objectives of the study were explained to each respondent. When they were assured that the study was purely academic and had no adverse effect on them, then they provided full co-operation to the data collectors. After collection of data, the first step was to look over the data of each and every questionnaire whether every question was replied properly or not. Simultaneously, the data were edited and coded. The local units were converted into standard units for the preparation of final tables. All the collected data were summarized and scrutinized carefully and recorded in Microsoft Excel 2007 program, computer software. Finally, relevant tables were prepared according to the necessity of analysis and interpretation and to meet purpose of the study. Data were averaged and standard deviation was calculated according to necessity.

Experiment 2: Growth analysis of Agar plant under different age and soil type

The experiment was conducted at different villages of Sujanagar union, Barlekhaupazila, Moulvibazer district during April to September 2018. The experimental sites were located under the Agro-ecological zone 29 (Northern and Eastern Hills) having the red brown trace soils and acid basin clay.Fifteen existing agar gardens were selected for taking the data on growth and biomass estimation. Plant heights were measured from bottom to top and bottom to collar point of the plants under different ages ranges from one to fifteen years. Diameters and circumferences of the agar plants at base, breast height, middle, and collar area were measured. In each garden, 20 plants were considered as replications. Number of primary branches plant^{-1} was also counted from each garden under each age group of plants. Data then tabulated making average. Above-ground biomass of agar tree was done by non-destructive method. Live tree biomass is generally divided into five major components, including merchantable stem biomass (also called bole biomass including both bark and wood), stump biomass, foliage biomass, branches/top biomass, and root biomass. We focus on above-ground live tree biomass estimation including stump, stem, branch, and top (Xiaoping and Hemstrom, 2009). The following formulas were used for estimating agar tree biomasses which were used by Xiaoping and Hemstrom(2009) for lodge pole pine in the Pacific Northwest region:

1. CVTS = 10-2.615591 + 1.847504 × log(dbh) + 1.085772 × log(HT) (Bracket 1977)
2. BOLE = (CVTS × Wd) (Xiaoping and Hemstrom, 2009)
3. BRK = 3.2 + 9.1 × (dbhcm/100)2 × HTm (Standish *et al.,*1985)
4. BCH = 7.8 + 12.3 × (dbhcm/100)2 × HTm (Standish *et al*.,1985)
5. BT = BOLE + BRK + BCH (Xiaoping and Hemstrom, 2009)

Where, CVTS = total stem volume from ground to tip (cubic feet), Wd = wood density (kg/ft),BOLE = bole biomass (kg), BRK = bark biomass (kg), BCH = branch biomass (kg), BT = total aboveground biomass without foliage (kg), dbh = diameter at breast height (in) HT = total height from ground to the tip (ft), dbhcm = diameter at breast height (cm), HTm = total height from ground to the tip (m), log is the logarithmic function with base 10. This mix of units allows conversion from volume in cubic feet to mass in kilograms.

After estimation of biomass of individual plant, it was converted by multiplying population of agar plants per hectare basis.

Experiments 3: Effect of intercropping of medicinal plants in association with Agar plants

The experiment was conducted at Musagul village, Sujanagar union, Barlekhaupazila, Moulvibazer district during the period of September 2017 to September 2018. The experimental site was located under the Agro-ecological zone 29 (Northern and Eastern Hills) having the red brown trace soils and acid basin clay. The soil textural class was sandy loam with pH 3.74 which was done in SRDI, Sylhet station.Eleven treatments were included in the experiment to see the performance of medicinal plants with agar plantation as intercrop. The experiment was carried out with five medicinal species namely Kalmegh (*Andrographispeniculata*), Bashok*(Justiciaadhatoda*), Tulsi (*Ocimun sanctum*), Sarpagandha (*Rouvolfiaserpentina*) and Aswagandha (*Withaniasomnifera)* with Agar plant (*Aquilariamelaccencis*). The intercropping experiment consisted of six plant species of which Agar plant was the principal crop. The experiment was laid out in a randomized complete block design (RCBD) with five replications at farmers' fields. Total numbers of plots were 55, the unit plot size were 3 m × 2 m. Block to block distance was 1m and plot to plot distance 0.5 m was maintained during layout of the experiment. The initial soil samples were collected before land preparation from 0-15 cm soil depth. The samples were collected by an augar from different location covering the whole experiment plot and mixed thoroughly to make a composite sample. The soil analyses were done at the regional station of the laboratory of Soil Resources Development Institute (SRDI), Sylhet. The experimental field was clean out on 25-28 September, 2017 with the help of a spade, sickle etc. All weeds and other plant residues of previous plants were removed from the field. Immediately after final land preparation, the experimental layout was made on 29-30 September 2017. The plants were planting on 01-03 October according to experimental treatments. An intercultural operation has done as and when necessary. Irrigations were given during dry period of crop growing. The growth data were collected from each plot separately at 15 days interval starting from planting to harvesting. The biomass data were recorded at harvest.The growth and biomass parameters have taken for all the medicinal plants in the experimental field as plant height, leaf number, leaf length, leaf breadth, number of branches and spreading area. The harvesting of plant was done on 26 September 2018 to 28 September 2018 for whole plot basis of research field. The statistical analyses of data were done by using computer package program (R) and the means were separated using LSD test.

Experiment 4: Determination of Chemical Compositions in Agar wood and oil

The experiments were conducted in the laboratory of Biochemistry and Chemistry, laboratory of Biotechnology and Genetic Engineering, Sylhet Agricultural University, Sylhet, laboratory of Bangladesh Forest Research Institute, Chittagong, from October 2017 to May, 2018.

Plant materials and agarwood soaking water were collected from an agarwood industry named “Mukta Perfume Industry” in Rajnagar, Moulvibazar. Among those wood some were naturally insect infested, some were artificially screw iron rod inserted and some were white agar wood free from any infections.

4.1 Determination of density of Agarwood for their grading

Agarwood of three different categories were collected from Barlekha, Moulvibazar and were taken to the laboratory of Bangladesh Forest Research Institute, Chittagong, during October 2017. Collected agarwoods were dried for two hours at 50ºC to remove residual moisture from those woods. In this process of density metric method, a 200 ml cylinder was taken and filled with water. After that, each of individual samples was soaked in water and the final volume for each sample was measured. Then, the density of each of the supplied sample was determined through the mass and volume relationship. For standardization of the experiment, at first three different wood samples of *Swieteniamacrophylla*, commonly known as mahogany and *Tectonagrandis*commonly known as segun supplied from Bangladesh Forest Research Institute (BFRI) were used with their known density. The density of Mahogany and Segun were compared with the reference density of those two woods. Also, three different white agar woods were taken to determine their density. According to the above mentioned process, the density of the white agar wood was determined. After that, the density of different unknown graded agarwood was determined for the purpose of grading them into desired class and then those graded wood was cross checked by evaluation of ether extract with three replications.

4.2 Evaluation of Ether Extract from Graded Agarwood

Ether extract was evaluated with the help of soxhlet extraction apparatus and the method described by Khan (2012) was followed.

4.3 Determination of Total Phenolics

For the determination of total phenolics from agarwood oil, the Folin-Ciocalteu method (Singleton and Rossi, 2010) as described by Khan (2012) was followed. Gallic acid was used as standard.

4.4 Estimation of Total Flavonoid Content

To estimate total flavonoid content by Aluminium chloride colorimetric method, the method described by Pekal and Pyrzynska (2014) was followed.

4.5 Determination of Antioxidant Status

For the determination of antioxidant status of agarwood oil, the method described by Susanti and Sirat (2007) was followed. The percentage inhibition of DPPH free radical scavenging activity was calculated using the following equation:

Percent inhibition = $[(A_{DPPH} - A_{sample})/A_{DPPH}]*100$
Where: A_{DPPH} = Absorbance of DPPH
A_{sample} = Absorbance of sample (extract/ascorbic acid)

4.6 Biochemical Tests for Identification of Unknown Microorganisms

Agarwood soaking water was collected from Barlekha, Moulvibazar in order to identify the genus of unknown microorganisms present in the soaking water. After collection, serial dilutions from 1×10^{-1} to 10^{-10} of the microorganisms containing agarwood soaking water was made by using the dilution fluid. The nutrient media and the petri dishes were sterilised by autoclaving at 121^0C for 30 minutes. After the autoclaving the petridishes were dried and about 20ml of the sterile media was poured into the petri dishes. About 1 ml inoculum from each of the 10^{-4} to 10^{-10} serial dilutions was inoculated into the petri dishes inside the Laminar Air Flow. After inoculation the petri dishes were kept inside the incubator at 37^{o}C for 24 hrs.

Following biochemical tests were performed for identifying genus of existing microbes from the agarwood soaking water sample as described by Sharma et al., (2013).

Gram-staining

Gram-staining is used in order to distinguish between gram negative and gram positive bacteria.

Catalase Test

Purpose- Catalase is an enzyme produced by microorganisms that live in oxygenated environments to neutralize toxic forms of oxygen metabolites; H_2O_2 and protects them.

Oxidase Test

Purpose- An oxidase is an enzyme that catalyzes an oxidation-reduction reaction, specially one involving oxygen (O_2) as the electron acceptor.

Indole Test

Purpose- The indole test is a biochemical test performed on bacterial species to determine the ability of the organism to convert tryptophan into indole.

Carbohydrate Fermentation Test

Purpose- Glucose fermentation is a biological technique utilized in microbiology to determine the way a microorganisms metabolizes a carbohydrate.

MR (Methyl Red)

Purpose-Test-Methyl Red (MR) test determines whether the microbe performs mixed acids fermentation when supplied glucose.

VP (VogesProskuer) Test

Purpose- VogesProskauer or VP is a test used to detect acetoin in a bacterial broth culture. The test is performed by adding alpha-naphthol and potassium hydroxide to the Voges-Proskauer broth which has been inoculated with bacteria

Nitrate reduction Test

Purpose-Nitrate Reduction test is a microbiological test roughly named for its ability to test a microorganism's ability to produce hydrogen sulfide.

The genus present in the fermented water was identified. Data were analyzed and tabulated through the use of simple statistics like mean, standard deviation etc.

11. Results and discussion

Experiment 1: Field survey on present status of Agar plantation, agronomic management and processing in Sylhet region

The findings and discussions were presented in this chapter according to the objectives of the study. The findings were however discussed under the following sections:

Selected characteristics of the respondents

Some independent variables of the study and their characteristics were investigated and the descriptions of each of the individual characteristics are presented in Table 1.1

Age

Age of the respondents ranged from 14-65 years with an average of 33.61 years and standard deviation of 13.66 (Table 1.1). On the basis of their age the respondents were classified into three categories as presented in Table 1.2 which represented that the highest proportion of 61.54% was in the young age group, 25% middle age and 13.46% was in old age (Table 1.2). Age of respondents is categorized according to national policy (BBS, 2001).

Table 1.1 Description of sample farmer’s characteristics of BarlekhaUpazila in Moulvibazar District

Characteristics	Measuring system/ unit	Observed range	Mean	Standard deviation(±)
Age	Years	14-65	33.61	13.66
Education	Level of schooling	0-16	7.34	3.36
Family size	Number	2-9	5.58	1.70
Homestead size	Hectare	0-1.22	0.19	0.30
Farm size	Hectare	0.008-21.53	0.85	2.75
Annual income	Thousand	72-1500	256.52	222.32

Table 1.2 Categorization of respondents according to their age in BarlekhaUpazila under Moulvibazar district of Bangladesh

Category	Number of respondents	Percentage
Young age (up to 35)	64	61.54
Middle age (36 to 50)	26	25.00
Old age (above 50)	14	13.46
Total	104	100

Education

The sample farmers of the study area were categorized into five groups on the basis of their education viz. illiterate, primary (class 1 to 5), secondary (class 6 to 10), higher secondary (class 11 to 12) and Graduate (class 13-16 which indicates hons./ degree/ graduation/ postgraduation) (Table 1.3). The highest portions of agar producers were in the education group of class 6 to 10 and the corresponding percentage was 47.11 and the lowest in the education group of illiterate and the corresponding percentage was 1.92, while the rest of the respondents (35.58%) belong to the education group of class 1 to 5 and 10.58% belong to the education group of class 11 to 12 and 4.81% belong to the education group of class 13 to 16. The standard deviation belongs to the farmers' education was 3.36 (Table 1.3). The findings indicated that most of the farmers education status were upto primary and secondary level in Barlekhaupazila (Table 1.3). This observation is also in conformity with national average of education of Bangladesh (BBS, 2004).

Table 1.3 Categorization of respondents according to their education status in BarlekhaUpazila of Moulvibazar district

Education status (0-16)	No. of respondents	Percentage
Illiterate (0)	2	1.92
Primary (1 to 5)	37	35.58
Secondary (6 to 10)	49	47.11
Higher secondary (11 to 12)	11	10.58
Graduate (13 to 16)	5	4.81
Total	104	100

Family size

The family size of the farmers was categorized into 3 groups like small (1-4), medium (5-8) & large groups (>8). Most of the farmers (48.08 %) had medium family size having family members 5-8 compared to (37.50 %) small (1-4) and 14.42 % large family size having family members more than 8 in Barlekhaupazila (Table 1.4). In Bangladesh it is very common to live together with parents as join family and sometimes with relatives (BBS, 2001).

Table 1.4 Categorization of respondents according to their family members in BarlekhaUpazila, Moulvibazar district of Bangladesh

Family size	Number of Respondents	Percentage
Small (1-4)	39	37.50
Medium(5 -8)	50	48.08
Large (>8)	15	14.42
Total	104	100

Homestead size

Table 1.5 Categorization of respondents according to their homestead size in Barlekhaupazila under Moulvibazar district of Bangladesh

Category	Homestead size (ha)	No. of respondents	Percentage
Landlesss	Up to 0.05	48	46.15
Marginal	0.05-0.10	25	24.04
Small	0.11-0.20	5	4.81
Medium	0.21-0.3	4	3.85
Large	Above 0.30	22	21.15
Total		104	100

The homestead of the sample farmer ranged from 0-1.215 ha with an average of 0.19 ha with standard deviation of 0.29 (Table 1.1). Among the farmers 46.15% were landless, 24.04% were marginal, 4.81% were small, 3.85% were medium and least 21.15% were large homestead (Table 1.5). Farmers homestead size was categorized according to BBS, 2010.

Farm size

In the study area most of the farmers were under landless category (66.35%). In the marginal category the percentage was 12.50%. Besides these, in small category the percentage was 3.85%, in medium category the percentage was 11.54% and lastly in large category the percentage was 5.76% (Table 1.6).

Table 1.6 Categorization of respondents according to their farm size in Barlekhaupazila under Moulvibazar district of Bangladesh

Farm category	Number of Respondents	Percentage
Landless (upto 0.20 ha)	69	66.35
Marginal (0.21-0.60ha)	13	12.50
Small (0.61-1.00 ha)	4	3.85
Medium (1.01-3.00 ha)	12	11.54
Large (>3.00ha)	6	5.76
Total	104	100

Annual income

Annual income of the farmers ranged from Tk. 72000-15000000 with an average value of Tk. 256520.00 with standard deviation of Tk. 222320.00 (Table 1.7). The study indicates that most of the farmers (75.96 %) had medium income 19.23 % had high income and the least 4.81 % had low income (Table 1.7).

Table 1.7 Categorization of respondents according to their annual income in BarlekhaUpazila under Moulvibazar district of Bangladesh

Categories	Category range of annual income (Tk.)	No. of respondents	Percentage
Low income	Up to 100000	5	4.81
Medium income	100000-300000	79	75.96
High income	Above 300000	20	19.23
Total		104	100

Planting materials

The findings of the study indicated that most of the respondent farmers (79.81%) used seedling for agar cultivation, whereas only 20.19% of the respondent farmers used seed. From this table, it is clear that most of farmers depend on seeding from nursery for better agar cultivation in Barlekhaupazila (Figure 1.1).

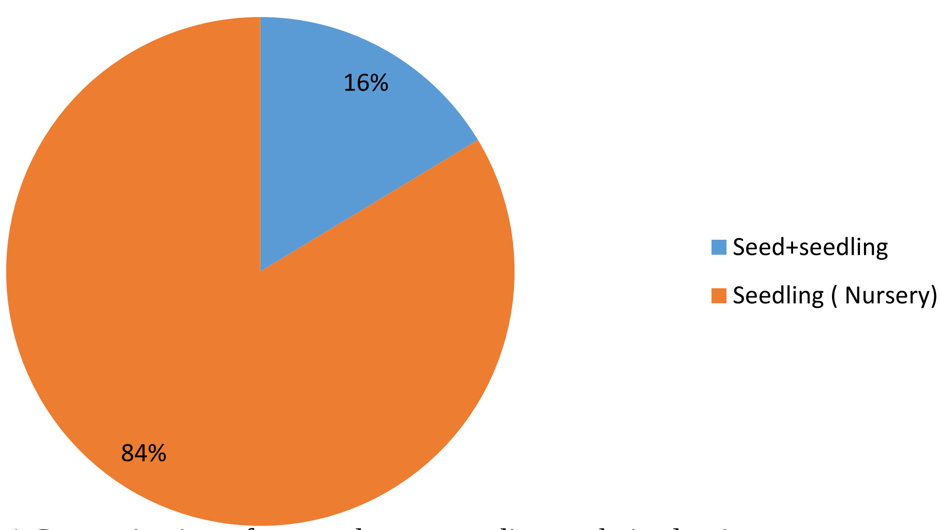

Figure 1.1 Categorization of respondents according to their planting materials for agar cultivation

Time of planting

Most of the farmers (61.54%) opined that seedlings were planted in the month of May-June, 36.54% in the month of July-August and only 1.92% in the month of September-October. Now it was observed that majority of the farmers planted the agar seedling mainly in rainy season,i.e in the month of May-August (Table 1.8).

Table 1.8 Categorization of respondents according to time of planting (month) in BarlekhaUpazila under Moulvibazar district of Bangladesh

Planting time	Number of Respondents	Percentage
May- June	64	61.54
July-August	38	36.54
September- October	2	1.92
Total	104	100

Age of seedling

Most of the sampled farmers (95.83%) opined that one year or less than 1 year aged seedlings were used for planting. In contrast 4.17% farmers opined that they used more than 1 year and upto 2 years aged seedlings were used for planting (Table 1.9).

Table 1.9 Categorization of respondents according to the age of seedling in BarlekhaUpazila under Moulvibazar district of Bangladesh

Age of seedling (yr)	Number of Respondents	Percentage
≥1 year	92	95.83
1 year – 2 years	4	4.17
> 2 years	0	0.00
Total	96	100

Satisfaction of agar plant cultivation

Table 1.10 Categorization of respondents according to satisfaction of agar plantcultivation in Barlekhaupazila of Moulvibazar district

Level of satisfaction	Number of Respondents	Percentage
Satisfied	99	95.19
Not satisfied	5	4.81
Total	104	100

Most of the farmers in the studied area opined that they were satisfied with agar cultivation. 95.19% farmers satisfied with agar cultivation whereas only 4.81% farmers was not satisfied with agar cultivation (Table 1.10).

Medicinal value

Table 1.11 described the data of farmers' perception about medicinal value of agar plant. Only 0.96% farmers opined that agar plant had a medicinal value and 99.04% farmers opined that agar plant had no medicinal value.

Table 1.11 Categorization of respondents according to their using of agar plant for medicinal value in Barlekhaupazila of Moulvibazar district

Using agar plants as medicinal purpose	Number of Respondents	Percentage
Yes	1	0.96
No	103	99.04
Total	104	100

The medicinal value they said that was agar leaves acts as remedial measurement of cold, cough etc. as well as the water remain after heating of agarwood is acts as gastric remedy (Table 1.11).

Insects-pests infestation in agar plants

Table 1.12 indicated that the positive response of the respondents about insects-pests infestation which was 45.19% and negative response was 54.81%. Farmers opined that the insects that are different types of ants, caterpillars etc. were observed in agar plants (Table 1.12).

Table 1.12 Categorization of respondents according to insects-pests infestation and disease infection of agar plants in Barlekhaupazila of Moulvibazar district

Farmers' opinion	Number of Respondents	Percentage
Yes	47	45.19
No	57	54.81
Total	104	100

Use of insecticide/pesticide/fungicide

No insecticide/ pesticide/ fungicide were used by any of the farmers in Barlekhaupazila for management of agar plants (Table 1.13).

Table 1.13 Categorization of respondents according to using of insecticide/ pesticide/ fungicide during agar plants nursing in Barlekhaupazila of Moulvibazar district

Using insecticide/ fungicide	Number of Respondents	Percentage
Yes	0	0.00
No	104	100
Total	104	100

Health hazard

The positive response about health hazard they faced during working in the agar garden was 53.33% and negative response was 46.67% (Table 1.14).

Table 1.14 Respondents according to facing health hazard during working in the agar garden in Barlekhaupazila of Moulvibazar district

Health hazard	Number of Respondents	Percentage
Yes	48	53.33
No	42	46.67
Total	90	100

They opined that most frequent health hazards were finger cutting and toe cutting during working in the agar plantarion (Table 1.14).

Type of health hazard

From Table 12 it was observed that 60.42% farmers faced finger cutting and rest 39.58% opined that they faced toe cutting while working in agar garden/ factory (Table 1.15).

Table 1.15 Types of health hazard faced of the worker during working in the agar garden/ factory in Barlekhaupazila of Moulvibazar district

Type of injury	No. of respondents	Percentage
Cutting of finger	29	60.42
Cutting of toe	19	39.58
Total	48	100

Days to seed germination

32.69% opined that agar seed took 6-10 days and 1.92% farmers opined that the agar seed took 1-5 days for germination (Table 1.16).

Table1.16 Respondents according to their opinion about days to seed germination in agar plantation in BarlekhaUpazilaof Moulvibazar district

Days to seed germination	Number of Respondents	Percentage
1-5	2	1.92
6-10	34	32.69
11-15	33	31.73
16-20	12	11.54
21-25	12	11.54
26-30	6	5.77
>30	5	4.81
Total	104	100

Use of fence in agar plantation

Table 1.17 Respondents according to use of fence in agar plantation in BarlekhaUpazilaof Moulvibazar district

Use of fence	Number of Respondents	Percentage
Yes	7	6.73
No	97	93.27
Total	104	100

From Table 1.17 it was observed that 93.27% farmers didn't use any fence and only 6.73% farmers used fence in agar plantation in Barlekhaupazila. (Table 1.17).

Time to flowering (years) after planting

Majority of the sampled farmers (61.54%) opined that the agar plant took 6-10 years for flowering after planting and 32.69% opined that it took 11-15 years and 5.77% opined that it took <5 years (Table 1.18).

Table 1.18 Time to flowering (years) after planting stated by the respondents in survey at BarlekhaUpazilaof Moulvibazar district

Time to flowering after planting (years)	Number of Respondents	Percentage
<5	6	5.77
6-10	64	61.54
11-15	34	32.69
Total	104	100

Plant Spacing

Spacing of agar plantation varies from <0.50 to >4.0(m) but majority use spacing 0.60-1.0 × 1.2-2.0m (Table 1.19).

Table 1.19 Respondents opined to plant spacing in agar plantation in BarlekhaUpazilaof Moulvibazar district

Plant Spacing (m)	Number of Respondents	Percentage
<0.50 × 1.0	31	29.81
0.60-1.0 × 1.2-2.0	64	61.53
1.0-2.0 × 2.0-4.0	8	7.69
>2.0 × >4.0	1	0.97
Total	104	100

Pit size

For Barlekhaupazila in agar production, 31.73% of the respondents opined that they maintained 20-30 × 20-30 × 20-30 cm pit size, 43.27% farmers maintained 31-40 × 31-40 × 31-40 cm, 4.81% farmers maintained 41-50 × 41-50 × 41-50 cm of pit size for planting the agar seedling and 20.19% farmers maintained >50 × >50 × >50 cm (Table 1.20).

Table 1.20 Respondents according to pit size maintained in agar plantation in BarlekhaUpazilaof Moulvibazar district

Pit size (cm × cm × cm)	Number of Respondents	Percentage
20-30 × 20-30 × 20-30	33	31.73
31-40 × 31-40 × 31-40	45	43.27
41-50 × 41-50 × 41-50	5	4.81
>50 × >50 × >50	21	20.19
Total	104	100

Collection of agar seeds

In Barlekhaupazila 69.23% farmers collected agar seeds while 30.77% farmers didn’t collect agar seed (Table 1.21).

Table 1.21 Categorization of respondents according to seed collection in agar plantation in BarlekhaUpazilaof Moulvibazar district

Collection of agar seed	Number of Respondents	Percentage
Yes	72	69.23
No	32	30.77
Total	104	100

Month of seed collection

In Barlekhaupazila 47.30% of the farmers collected agar seeds in the month of May-June, 43.24% farmers collected agar seed in the month of July-August and rest 9.46% farmers collected agar seed in the month of September-October (Table 1.22).

Table 1.22 Respondents according to month of seed collection from agar plantation in BarlekhaUpazilaof Moulvibazar district

Seed collection month	Number of Respondents	Percentage
May- June	35	47.30
July-August	32	43.24
September- October	7	9.46
Total	74	100

Source of seedling collection

In Barlekhaupazila 84.62% of the farmers collected their seedling from private nursery and only 15.38% farmers produced seedlings themselves for establish plantation (Table 1.23).

Table 1.23 Respondents categories according to source of seedling collection for agar plantation in BarlekhaUpazilaof Moulvibazar district

Source	Number of Respondents	Percentage
Private Nursery	88	84.62
Self production	16	15.38
Total	104	100

Time of flowering of agar

Flowering month was mainly considered March-April according to farmers' observation and the percentage was 69.23%. Some farmers (23.08%) opined that the flowering month was May-June and 7.69% farmers opined that flowering month of agar plant was February (Table 1.24).

Table 1.24 Categorization of respondents according to their perception about flowering month of agar tree in Barlekhaupazilaof Moulvibazar district

Flowering month	Number of Respondents	Percentage
February	8	7.69
March-April	72	69.23
May- June	24	23.08
Total	104	100

Average length of agar trees

Length of agar tree ranged from less than 6m to 15m. In this range 13.46% farmers opined that the length of agar tree was <6.0 m, 45.20% farmers opined that the length was 6.0-9.0m. 39.42% farmers opined that the length was 9.0-12.0 m. And rest 1.92% farmers opined that the length was 12.0-15.0 m (Table 1.25).

Table 1.25 Respondents categories according to their opinion about length of agar tree in Barlekhaupazilaof Moulvibazar district

Length(m)	Number of Respondents	Percentage
<6	14	13.46
6 - 9	47	45.20
9 - 12	41	39.42
12 - 15	2	1.92
>15	0	0.00
Total	104	100

Use of fertilizer

Table 24 indicated that 4.81% farmers used only fertilizer and 0.96% farmers used only manure and 1.92% farmers used both fertilizer & manure in agar production and 92.31% farmers didn't use fertilizer (Table 1.26).

Table 1.26Respondents according to use of fertilizer and manures in agar plants

Use of Fertilizer and Manure	Number of Respondents	Percentage
Only fertilizer	5	4.81
Only manure	1	0.96
Both Fertilizer and Manure	2	1.92
Neither Fertilizer nor Manure (None)	96	92.31
Total	104	100

Wounding techniques

Table 1.27 Respondents according to wounding techniques practiced on agar plants for increasing oil percentage

Wounding techniques	Number of respondents	Percentage
By nailing	90	86.54
Insect attack	14	13.46
Chemicals	0	0.00
Others	0	0.00
Total	104	100

The investigation showed that there were main two types of wounding techniques, by nailing and by natural insect attack. Majority farmer used nailing technique (86.54%) and rest 13.46% used to collect wood from natural insect attack. So, it was clear that most of the farmers used nailing technique for agar cultivation (Table 1.27). There were 97.12% farmers knew about the technique from their forefathers and 2.88% farmers knew from neighbors (Table 1.28).

Table 1.28 Respondents according to source of information about the wounding technique for agar plants

Category	**Number of respondents**	**Percentage**
Forefather	101	97.12
Neighbour	3	2.88
Others	0	0.00
Total	104	100

Profitable wounding techniques increase quality oil percentage

82.69% farmers thought that agar wood obtained from natural insect attack was more profitable while rest (17.31%) farmer supported nailing technique system. In the study it was clear that majority of the farmers opined that insect attack was more profitable than other techniques (Table 1.29).

Table 1.29 Respondents according to response about wounding technique in agar cultivation

Profitable wounding techniques	Number of respondents	Percentage
By nailing	18	17.31
Insect attack	86	82.69
Chemical	0	0.00
Others	0	0.00
Total	104	100

Age of plant used for nailing

The farmers were categorized as nail was pushed in the age of 1-5, 6-10, 11-15, >15 year. The percentage was 2.06, 32.99, 63.92, 1.03 in the year range 1-5, 6-10, 11-15, >15 respectively among the sampled farmers (Table 1.30).

Table 1.30 Respondents according to age of plants for pushing nail in agar trees in study areas

Age of plant for nailing	Number of Respondents	Percentage
1-5	2	2.06
6-10	32	32.99
11-15	62	63.92
>15	1	1.03
Total	97	100

Time of agar tree cutting after nailing

Followed by the findings time of agar tree cutting after nailing for agar oil extraction 86.46% farmers cut their tree within 5 years after nailing while 12.50% farmers cut their tree after 6-10 years of nailing and only 1.04% farmers cut their tree after 1 year of nailing. From the analysis of result it can be said that majority farmers in Barlekhaupazila cut their trees within 5 years after nailing (Table 1.31).

Table 1.31 Respondents opinion about the time of agar tree cutting after nailing

Range of year	Number	Percentage
<5	83	86.46
6-10	12	12.50
>11	1	1.04
Total	96	100

Nail size

Table 1.32 Respondents opinion about nail size (cm) pushed in the tree for agar tree wounding

Size of metallic rod (cm)	Number of respondents	Percentage
<5	2	2.06
7.5	15	15.46
10	15	15.46
12.5	12	12.37
>12.5	6	6.20
7.5 & 10	5	5.15
10 & 12.5	7	7.22
7.5,10 &12.5	35	36.08
Total	97	100

Metallic rod of different sizes were <5, 7.5, 10, 12.5, >12.5, 7.5 & 10, 10 & 12.5, 7.5, 10 & 12.5 cm used by 2.06%, 15.46%, 15.46%, 12.37%, 6.20%, 5.15%, 7.22%, 36.08% of the respondents, respectively.

Most of the farmers used three sizes like 7.5, 10 & 12.5 cm metallic rod for wounding the agar tree (Table 1.32).

Amount of nail used per tree

1.04% farmers used less than 10 kg nail per tree, 16.67% farmers used 11-25 kg nail, 43.75% farmers used 26-40 kg and 38.54% farmers used 41-55 kg nail per tree for wounding a tree (Table 1.33).

Table 1.33 Respondents categories according to nail used per tree

Nail used per tree (kg)	Number	Percentage
<10	1	1.04
11-25	16	16.67
26-40	42	43.75
41-55	37	38.54
Total	96	100

Use of old/new/both nail

This table represents the percentage of farmers using the type of nail i.e. new or old or both nail in nailing technique. There are 32.29% farmers used new nails but 38.54% farmers used old nail.Whereas 29.17% farmers used both new and old nails. The use of old nail is more then use of new and both (new & old) nails (Table 1.34).

Table 1.34 Respondents according to use of old/new/both nail for agar tree wounding

Category	Number of respondents	Percentage
New	31	32.29
Old	37	38.54
Both (New & old)	28	29.17
Total	96	100

Frequency of the nail reused

The statement showed that 2.08% farmer used nail for one time, 81.25% farmer use nail for 2 times, 15.63% farmers used nail for 3 times and 1.04% farmer used their nail for more than 4 times. From the analysis data we can say that most of the farmers' choice was reuse the nail for 2 times (Table 1.35).

Table 1.35 Respondents categories according to frequencies of the nail reused for agar cultivation

Frequency of reusing nail	Number of respondents	Percentage
1	2	2.08
2	78	81.25
3	15	15.63
>4	1	1.04
Total	96	100

Choice of reusing of nail

Table 1.36 indicates the choice of using nail on plant for agar production. In the study area 96.88% farmers like to reuse the nail and 3.12% farmers are not (Table 1.36).

Table 1.36 Respondents categories according to choice of reusing of nail for wounding in agar cultivation

Choice of reusing of nail	Number of respondents	Percentage
Yes	93	96.88
No	3	3.12
Total	96	100

Techniques used for pushing nail

Farmers used different techniques to push nails in agar tree. In this study 31.25% farmers pushed nail by climbing in the tree, 15.63% farmers using ladder and 53.12% farmers using bamboo trellis. Most of the farmers use bamboo trellis for nailing on tree in Barlekhaupazila (Table 1.37).

Table 1.37 Respondents categories according to technique used for pushing nail for wounding agar plants

Category	Number of respondents	Percentage
Climbing in the tree	30	31.25
Using ladder	15	15.63
Using bamboo trellis	51	53.12
Total	96	100

Choice of changing the wounding technique

Only 2.08% farmers want to change the technique but 97.92% farmers don’t want to change the technique (Table 1.38). Most of the farmers don’t want to change the technique for agar formation followed by wounding because they were satisfied by using this techniques and they were satisfied with their earning.

Table 1.38 Respondents according to their choice about changing the technique in agar cultivation

Choice of changing nailing techniques	Number of respondents	Percentage
Yes	2	2.08
No	94	97.92
Total	96	100

Vertical distance of nail to nail

Table 1.39 Respondents categories according to maintain vertical distance for pushing nail for wounding on agar plants

Size (inch)	No. of respondents	Percentage
1.0-2.0	10	10.41
2.1-3.0	67	69.79
>3.0	19	19.80
Total	96	100

Majority (69.79%) of the farmers maintained 2.1-3.0 inch distance for vertically nail pushing, 19.80% farmers maintained >3.0 inch and rest 10.41% farmers maintained 1.0-2.0 inch (Table 1.39).

Horizontal distance of nail to nail

Majority(64.58%) farmers maintained 1.0-1.5 inch distance for horizontal nail pushing, 18.75% farmers maintained 1.6-3.0 inch distance and rest 16.67% farmers maintained >3.0 inch distance (Table 1.40).

Table 1.40 Respondents categories according to maintain horizontal distance for pushing nail for wounding on agar plants

Size (inch)	No. of respondents	Percentage
1.0-1.5	62	64.58
1.6-3.0	18	18.75
>3.0	16	16.67
Total	96	100

Required fermentation days

From the observed data it can be said that majority (72.12%) respondents are soaking their agar wood chips for 11-20 days, 25.96% respondents soaked it for 1-10 days and least (1.92%) respondents done it for 21-30 days (Table 1.41).

Table 1.41 Categorization of respondents according to fermentation days of agar chips for cultivation of agar oil

Fermentation days	Number of respondents	Percentage
1-10	27	25.96
11-20	75	72.12
21-30	2	1.92
Total	104	100

Techniques of collecting agar oil

Table 1.42 Respondents opinion according to the technique of processing of agar oil in the agar factories

Techniques	Number of respondents	Percentage
Distillation	104	100
Others (if any)	0	0.00
Total	104	100

All the respondents opined that the processing of agar oil in the agar factories are used distillation technique for separation of agar oil from agar wood (Table 1.42).

Profitability of Agar Oil Production

Cost in and returns from agar oil production per liter were analyzed monthly.

Cost and Returns of Agar Oil Production

In order to analyze the profitability of agar oil production, it is mandatory to estimate the production cost of different items where the cost is to be deducted from the revenue. The cost of agar oil production includes both fixed cost and variable cost. Variable costs include the cost of human labor, cost of trees, repairing cost of machineries and equipments, transportation cost, electricity bill, gas bill, etc. The fixed costs include depreciation cost of factory building and machineries, the opportunity cost of land use and interest on operating capital. For calculating economic returns, the gross return, total return, and net return were calculated. In order to see the profitability, the BCR (undiscounted) was also estimated.

In calculating the production cost, the following cost item per liter has been considered:

a. Cost of human labor
b. Cost of trees
c. Cost of transportation
d. Repairing cost of equipment’s
e. Electricity bill
f. Gas bill
g. Interest on operating capital

h. Depreciation cost of factory building
i. Depreciation cost of machineries
j. Opportunity cost of land use

Cost of human labor

Human labor was one of the most important inputs for agar oil production. Human labor was broadly classified as permanent labor and hired labor. Permanent labors were like as family member. Hired labor included weekly labor, monthly labor, day to day contract basis labor, etc. Human labors were used to perform the following activities:

I. Turn the trees
II. Nail removing
III. Chipping trees into small pieces
IV. Soaking small pieces of trees in water
V. Collecting oil

The actual wage paid to the hired labor was considered in calculating the cost of human labor. This also includes the value of money was paid to individual labor. The standard average wage rate was considered Tk. 180 per man days and standard working hours were 8 hours per day. The Table 6.1 implied that in the study area, the use of human labor per liter of agar oil was 10. The total cost of human labor per liter was estimated Tk. 1800.

Cost of trees

In the study area, trees were purchased from both tree growers and middleman which were from Kulaura and Barlekha. In our calculation, the price of trees was considered that are actually paid by the owners to purchase trees from both the areas. The Table 1.43 revealed that the price of per tree was Tk. 2500. In the study area, per liter of oil production requirement of trees was 35 pieces and total cost of trees per liter was Tk. 87,500.

Cost of transportation

Cost of transportation included expenses on transportation for purchasing trees, equipments, collection marketing information, etc. Among the various transport costs, expenses incurred for purchased trees were the most important. The average transportation cost of trees for producing per liter oil was estimated at Tk. 4000.

Repairing cost of machineries and equipment's

Machineries and equipment's are very essential input in every factory. A large number of works were done by the machineries and equipments. Without equipment's turn, nail up and cutting of trees was impossible. Also, the works of human labor were largely depending on correct equipment's. Conversely, hydro-distillation was impossible without proper distillation machineries. So, every owner had to bare some repairing cost of equipments on monthly basis. The repairing cost of equipment's for per liter oil was Tk. 3056.99 which was appeared in Table 1.43.

Electricity bill

Another cost item of agar oil production was electricity bill. In every factory, proper supply of electricity played a vital role which was quite similar in agar oil production too. It was the cost that was paid by the owners on monthly basis. From the Table 1.43, it was seen that cost of electricity of per liter oil was Tk. 312.95.

Gas bill

Gas bill is one of the major costs in agar oil production. Production of agar oil mostly depends on this. Without the supply of gas, it is almost impossible to produced oil. Because the production of oil from soaks wood was depended on the proper heat. The Table 1.43 showed that the cost of gas bill per liter oil was Tk. 80000

Opportunity cost of land

The land is an essential input in any production process. It is the base of any production. The value of land was different in the different places based on distance, location, and topography. In the study area, every owner had their own land in which they established their factories. For this reason, the opportunity cost of land was calculated. Opportunity cost refers to a benefit that a person could have received, but gave up, to take another course of action. In investing, it is the difference in return between a chosen investment and one that is necessarily passed up. Here, the opportunity cost of land was indicating that owners used their land in factory purpose rather than used it for agricultural cultivation. The opportunity cost of land for 1 year was calculating here which Tk. 2761.65.

Depreciation cost of factory building and machineries

The factory building was the place where every technical work has been done. Soaking of wood chips, hydro-distillation, and processing of oil was done in the factory with the help of machineries. Depreciation of factory building and machineries was fixed cost. Depreciation was the allocation of the net cost of assets to each year of its operation. Here depreciation was calculated by using the method of the straight line. According to the straight line method, depreciation was calculated by differentiating the purchasing price and the salvage value and dividing by the total life-span. The Table 1.43 appeared that the cost of depreciation of factory building and machineries was Tk. 2443.41 and Tk. 1786.88, respectively. The main productproduced by the factory owners were agar oil and per ml price of agar oil was 500 Tk. The by-products were white agarwood sticks and *Kosh*wood sticks and the selling price of these products were 200 Tk. and 50 Tk. per sack, respectively which was appeared in Table 1.43.

Table 1.43 Activity budget: per liter cost and return of agar oil in the study area

Item	Unit	No./ Quantity	Price (Tk./unit)	Total value (Tk.)
A. Variable cost				
Cost of trees	Tk.	35	2500	87500
Cost of transportation	Tk.	2	2000	4000
Repairing cost of machineries & equipment’s	Tk.	-	-	3056.99
Electricity bill	Tk.	-	-	312.95
Gas bill	Tk.	-	-	80000
Human labor cost	Man-days	10	180	1800
Total variable cost	Tk.	-	-	176669.94
B. Fixed cost				
Opportunity cost of land	Tk.	-	-	2761.66
Depreciation cost of factory building	Tk.	-	-	2443.41
Depreciation cost of machineries	Tk.	-	-	1786.88
Interest on operating capital	Tk.	-	-	848.02
Total fixed cost	Tk.	-	-	7839.97
C. Total cost (A+B)	Tk.	-	-	184509.91
D. Gross return	Tk.	-	-	
Agar oil	ml/Tk.	1000	500	500000
Agar wood sticks	Sack/Tk.	13,110	200,50	8100
Gross return	Tk.	-	-	508100
E. Gross margin(D-A)	Tk.	-	-	331430.06
F.Net return (E-C)	Tk.	-	-	146920.15
BCR (Undiscounted)	-	-	-	2.75

Source: Field Survey, 2017

Interest on operating capital

Interest on operating capital was determined on the basis of opportunity cost principle. It was assumed that instead of investing the money in the agar oil production if he kept the money in the bank, he would have received interest on it. In our calculation, we considered 12 percent rate of interest and the period of time is considered 1 month.

Table 1.44 Percentage of total cost of per liter agar oil in the study area

Cost item	Total cost (Tk.)	% of total cost
Cost of trees	87500	47.42
Cost of transportation	4000	2.17
Human labor	1800	0.98
Repairing cost of machineries &equipments	3056.99	1.66
Electricity bill	312.95	0.17
Gas bill	80000	43.36
Interest on operating capital	848.02	0.46
Opportunity cost of land	2761.66	1.50
Depreciation cost of factory building	2443.41	1.32
Depreciation cost of machineries	1786.88	0.97
Total	184509.91	100

Source: Field Survey, 2017

Interest on operating capital was calculated on variable cost: such as trees cost, transportation cost, repairing cost of machineries and equipment's, human labor cost, cost of electricity and cost of gas supply, etc. The following formula was used to calculate the interest on operating capital (Dillon and Hardaker, 1993).

$$\text{Interest on operating capital} = \frac{\text{Operating capital} \times \text{Rate of interest} \times \text{Time considered}}{2}$$

In the study area, the interest on operating capital for agar oil production per liter was calculated Tk. 848.02 in Table 1.43.

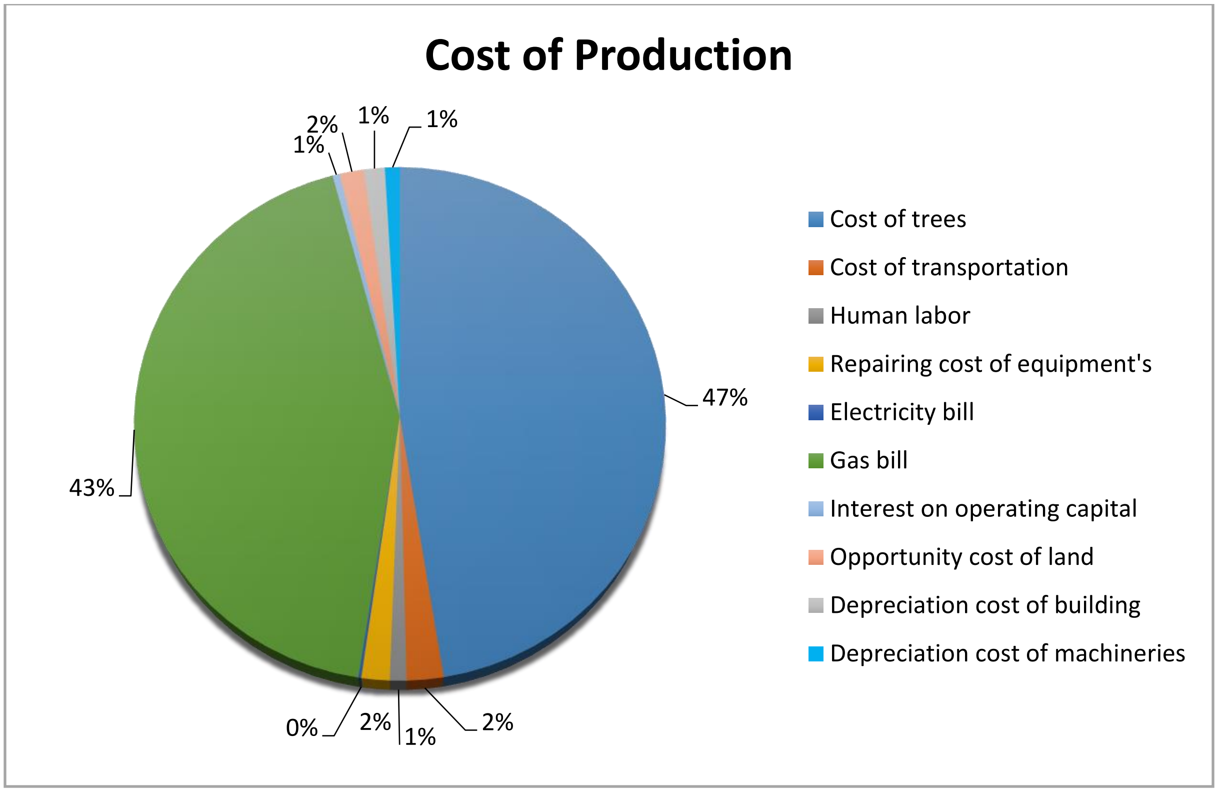

Figure 1.2 Percentage of per liter total cost of agar oil production

Total cost

To estimate the average total cost per liter, all resources used in the agar oil production as mentioned earlier has been computed together. Table 1.43 confessed that per liter total cost of the agar oil production was Tk. 1,84,509.91 where total variable cost and total fixed cost were Tk. 1,76,669.94 and Tk. 7,839.97, respectively.

Gross return

Per liter gross return of the agar oil production was obtained by multiplying the total amount of production with their respective market prices. Gross return also includes by-product also. Table 1.43 displayed that the gross return per liter of the agar oil production was Tk. 5,08,100.

Gross margin

Gross margin was calculated by deducting the variable cost from the gross return. The result of Table 1.43 shows that gross margin of per liter agar oil production was Tk. 3,31,430.06.

Net margin

Net margin obtained by deducting the total cost from gross margin. Table 1.43 indicated that the net margin per liter of the agar oil production in the study area was Tk. 1,46,920.15.

Benefit cost ratio (BCR)

BCR is the very important tool to measure the financial profitability or financial performance of any kind of agribusiness. It is indicating whether a business is profitable or not. Also whether a business is prevailing or not are largely depends on the benefit-cost ratio (BCR). The Table 1.43 exhibits that the BCR (undiscounted) for agar oil production per liter was 2.75 indicating high profitability and at the same time which implied that 2.75 would be earned by spending every Tk. 1 investing in the agar oil production. From the previous study on essential oil extraction system for agar tree growers, the benefit-cost ratio (BCR) was found 2.33 which was quite close to the present study where BCR (undiscounted) was 2.75 (Islam et al. 2014).

Concluding Remarks

Based on the cost-effective assessment, it could be concluded that agar oil production was more economically profitable for the agar oil factory owners rather than other agricultural crops. The total expenditure, gross return, and benefit-cost ratio (BCR) were Tk. 1,84,509.91, Tk. 5,08,100 and 2.75 per liter, respectively and maximum incomes of owners were earned from agar oil production. There was the opportunity for raising the profit from agar oil production and the livelihood of the peoples in that area were considerably depend on agar oil production. So, the production of agar oil could change the economic conditions of both factory owners and workers

CONSTRAINTS FACED BY AND POSSIBLE SUGGESTION FOR THE AGAR OIL FACTORY OWNERS AND WORKERS

Constraint Facing Index (CFI)

Constraints faced by factory owners and workers in the study area were estimated by using organized questionnaire. A four-point rating scale was used for computing the constraint score of a respondent. The factory owners were asked to give their opinion on 10 selected constraints and at the workers level, 8 constraints were selected. Efforts were made to find out suggestions from the respondents to overcome the identified problems.

Constraints Faced By the Factory Owners

The problems related to agar oil production which were faced by the owners were lack of capital, lack of transportation, lack of information, lack of workers, lack of credit, lack of industrial gas connection, introspection by forestry, lack of modern technology, lack of modern laboratory, difficulty of not getting CITES assurance, etc. A brief description of these problems was discussed below:

Lack of capital

Lack of adequate capital is one of the major problems to run any type of business. Without capital, it is almost impossible for the owners to run their factory in the study area. Out of 60 factory owners in Barlekha, 5 faced this constraint at the high extent, 35 faced at the medium extent, 15 owners faced at the low extent and about 5 owners did not face this constraint. In this case, the computed value of CFI was 100 [(5*3) + (35*2) + (15*1) + (5*0)] against a possible range from 0 to 180 for each (Table 1.45).

Lack of transportation

Lack of transportation facilities can interrupt the success of any business. The transportation system in the study area was not poor. But the problem of transportation has arisen in the rainy season. Out of 60 factory owners in Barlekha, 1 faced this constraint at the medium extent, 30 faced at the low extent, 29 owners did not face this constraint. In this case, the computed value of CFI was 32 against a possible range from 0 to 180 for each (Table 1.45).

Lack of information

Proper business information played a principal role in agar oil trading. But the study area this problem was not very high. Out of 60 factory owners in Barlekha, only 24 owners faced at the low extent and about 36 owners did not face this constraint. In this case, the computed value of CFI was 24 against a possible range from 0 to 180 for each (Table 1.45).

Lack of workers

Manpower is real power to run any type of business. Without efficient manpower work in any sector was not possible. In the rainy season shortage of human labor were prevailed in the study area. Out of 60 factory owners in Barlekha, 9 faced at the medium extent, 12 owners faced at the low extent and about 39 owners did not face this constraint. In this case, the computed value of CFI was 30 against a possible range from 0 to 180 for each (Table 1.45).

Lack of industrial gas connection

Lack of industrial gas connection is one of the major problems in the study area. As the production of agar oil was depended on the proper heating system, the owners were bare the highest cost of production because of commercial gas connection. Out of 60 factory owners in Barlekha, 52 faced this constraint at the high extent, 2 faced at the medium extent, 2 owners faced at the low extent and about 4 owners did not face this constraint. In this case, the computed value of CFI was 162 against a possible range from 0 to 180 for each (Table 1.45).

Introspection by forestry

Sometimes the owners of the study area were faced introspection by forestry in case of trading. So, the introspection made by forestry sector exists in the study area. Out of 60 factory owners in Barlekha, 2 faced this constraint at the high extent, 6 faced at the medium extent, 28 owners faced at the low extent and about 24 owners did not face this constraint. In this case, the computed value of CFI was 52 against a possible range from 0 to 180 for each (Table 1.45).

Lack of modern technology

Lack of modern technology the development of business is impossible. In the study area, there was a huge gap of modern technology which was the obstacle in the path of proper development. Out of 60 factory owners in Barlekha, 9 faced this constraint at the high extent, 17 faced at the medium extent, 23 owners faced at the low extent and about 11 owners did not face this constraint. In this case, the computed value of CFI was 84 against a possible range from 0 to 180 for each (Table 1.45).

Lack of modern laboratory

Lack of modern laboratory the quality testing of agar oil was not performed. In the study area, no laboratory has been established yet to test the oil quality which was a major problem faced by the owners nowadays.

Table 1.45 Constraints faced by agar oil factory owners

Constraints	Factory owners					
	High (3)	Medium (2)	Low (1)	Not at all (0)	CFI	Rank
Lack of capital	5	35	15	5	100	3
Lack of transportation	0	1	30	29	32	8
Lack of information	0	0	24	36	24	10
Lack of workers	0	9	12	39	30	9
Lack of industrial gas connection	52	2	2	4	162	1
Introspection by forestry	2	6	28	24	52	7
Lack of modern technology	9	17	23	11	84	5
Lack of modern laboratory	25	17	12	6	121	2
Difficulty of not getting CITES assurance	10	15	10	25	70	6
Lack of credit	9	26	20	5	99	4

Source: Author's calculation, 2017

Out of 60 owners in Barlekha, 25 faced this constraint at the high extent, 17 faced at the medium extent, 12 owners faced at the low extent and about 6 owners did not face this constraint. In this case, the computed value of CFI was 121 against a possible range from 0 to 180 for each (Table 1.45).

Difficulty of not getting CITES assurance

CITES certification is beneficial for every owner in order to get rid of from the problem of forestry. It was a way to run the business smoothly without the introspection of forestry. But this certificate was not available for everyone. So, the owners faced the problem of not getting CITES assurance. Out of 60 factory owners in Barlekha, 10 faced this constraint at the high extent, 15 faced at the medium extent, 10 owners faced at the low extent and about 25 owners did not face this constraint. In this case, the computed value of CFI was 70 against a possible range from 0 to 180 for each (Table 1.45).

Lack of credit

All the owners in the study area were not economically solvent. They have acquired money from different sources with the high rate of interest rate. In the study area, owners mentioned that lack of credit with the low interest rate. Out of 60 factory owners in Barlekha, 9 faced this constraint at the high extent, 26 faced at the medium extent, 20 owners faced at the low extent and about 5 owners did not face this constraint. In this case, the computed value of CFI was 99 against a possible range from 0 to 180 for each (Table 1.45).

An overall situation of the constraints faced by the agar oil factory owners at Barlekha was implied the Table 1.45. It revealed that, industrial gas problem with CFI 162 was ranked first, whereas, lack of modern laboratory with CFI 121, lack of capital with CFI 100, lack of credit with CFI 99, lack of modern technology with CFI 84, difficulty of not getting CITES assurance with CFI 70 , introspection by forestry with CFI 52, lack of transportation with CFI 32, lack of workers with CFI 30, and lack of information with CFI 24, were ranked as second, third, fourth, fifth, sixth, seventh, eighth, ninth, and tenth, respectively.

Constraints Faced By the Factory Workers

The factory workers faced different types of problems which are related to their works and livelihood. The problems faced by factory workers were described below:

Low wage rate

The livelihood of every worker was largely depending on their wage. But in the study area wage rate of the workers were not sufficient. As a result, the low wage rate is a major problem for the workers. Out of 40 workers in Barlekha, 35 faced this constraint at the high extent, 2 faced at the medium extent, and about 3 workers did not face this constraint. In this case, the computed value of CFI was 109 [(35*3) + (2*2) + (0*1) + (3*0)] against a possible range from 0 to 120 for each (Table 1.46).

Lack of training

Training is essential for every worker to do their work without any obstacles. But in the study area, lack of training facility has existed. Out of 40 workers in Barlekha, 15 faced this constraint at the high extent, 25 faced at the medium extent. In this case, the computed value of CFI was 95 against a possible range from 0 to 120 for each (Table 1.46).

Lack of transportation

Lack of transportation problem has prevailed in the workers level as most of the time the workers covered their distance on foot. In the study area, lack of transportation problem has also exists. Out of 40 workers in Barlekha, 5 faced this constraint at the high extent, 15 faced at the medium extent, 5 faced at the low extent, and about 15 workers did not face this constraint. In this case, the computed value of CFI was 50 against a possible range from 0 to 120 for each (Table 1.46).

Lack of capital

Lack of adequate capital is one of the major problems for the workers. Out of 40 workers in Barlekha, 35 faced this constraint at the high extent, 2 faced at the medium extent, 2 faced at the low extent, and about 1 worker did not face this constraint. In this case, the computed value of CFI was 111 against a possible range from 0 to 120 for each (Table 1.46).

Table 1.46Constraints faced by agar oil factory workers

Constraints	Factory workers response rank					
	High (3)	Medium (2)	Low (1)	Not at all (0)	CFI	Rank
Low wage rate	35	2	0	3	109	2
Lack of training	15	25	0	0	95	3
Lack of transportation	5	15	5	15	50	7
Lack of capital	35	2	2	1	111	1
Lack of accommodation	5	5	12	18	37	8
Lack of other work	15	20	3	2	88	4
Long working hour	18	9	7	6	79	5
Lack of health facilities	16	8	8	8	72	6

Source: Author's calculation, 2017

Lack of accommodation

Lack of accommodation is one of the major problems as most of the workers did not have proper housing facilities to live. Out of 40 workers in Barlekha, 5 faced this constraint at the high extent, 5 faced at the medium extent, 12 faced at the low extent, and about 18 workers did not face this constraint. In this case, the computed value of CFI was 37 against a possible range from 0 to 120 for each (Table 1.46).

Lack of other work

In the study area, agar oil production is the major source of occupation. As a result, lack of other working facilities exists there. Out of 40 workers in Barlekha, 15 faced this constraint at the high extent, 20 faced at the medium extent, 3 faced at the low extent, and about 2 workers did not face this constraint. In this case, the computed value of CFI was 88 against a possible range from 0 to 120 for each (Table 1.46).

Long working hour

The long working hours is one of the major problems of the workers. This was the reason for different health problems of workers. Out of 40 workers in Barlekha, 18 faced this constraint at the high extent, 9 faced at the medium extent, 7 faced at the low extent, and about 6 workers did not face this constraint. In this case, the computed value of CFI was 79 against a possible range from 0 to 120 for each (Table 1.46).

Lack of health facilities

Lack of health facilities was another problem which was faced by the workers. Lack of health facilities exists in the study area. Out of 40 workers in Barlekha, 16 faced this constraint at the high extent, 8 faced at the medium extent, 8 faced at the low extent, and about 8 workers did not face this constraint.

In this case, the computed value of CFI was 72 against a possible range from 0 to 120 for each (Table 1.46).

Table 1.46 appeared an overall situation faced by factory workers in the study area. It disclosed that, lack of capital with CFI 111 was ranked as first, whereas, low-wage rate with CFI 109, lack of training with CFI 95, lack of other work with CFI 88, long working hour with CFI 79, lack of health facilities with CFI 72, lack of transportation with CFI 50, and lack of accommodation with CFI 37 were ranked as second, third, fourth, fifth, sixth, seventh, and eighth, respectively.

Possible Suggestion to Overcome the Constraints

Different types of problems are mention by the respondents which create obstacles with their way of life. Those problems make their life more ambiguous. These affect their production system, profitability and also income patterns resulting gradually reduction in their standard of living. So, the proper suggestion against those problems will help them to overcome different problems. Those suggestions are described below:

Suggestions by the factory owners:

- **Ensure industrial gas connection**

Most of the respondent argued that commercial gas connection is very costly for them which cover almost half of total production expenses. But, there doesn't have any industrial gas connection in the study area. So, the government should take the initial step to establish the industrial gas connection for their factories which is essential for the production of agar oil to reduce its cost of production.

- **Reduce introspection by forestry**

The main input of agar oil is agar trees which are come from different forests. So, the introspection by forestry is a common affair for the owners. In these aspects, the owners have to bear some cost which is irrelevant for them. So, the government should take the step to provide CITES assurance to overcome such problem.

- **Include modern technology**

Technology is the collection of techniques, skills, methods, and processes used in the production of goods or services or in the accomplishment of objectives, such as scientific investigation. Technology can be the knowledge of techniques, processes, and the like, or it can be embedded in machines to allow for operation without the detailed knowledge of their workings. So, the involvement of modern technology helps to reduce the work stress. And at the same time, it helps to save productive time.

- **Establishment of modern laboratory**

A laboratory is a facility that provides controlled conditions in which scientific or technological research, experiments, and measurement may be performed. A laboratory is also a room or building with scientific equipment for doing scientific tests or for teaching science. A laboratory can help the owners to improve the quality of agar oil through the proper testing process. So, in this aspect government support is very essential.

- **Increase institutional credit**

Credit encompasses any form of deferred payment. Credit is extended by a creditor, also known as a lender, to a debtor, also known as a borrower. As the production cost of agar oil is very high so the owners were not always capable to bear the all type of cost by themselves. Institutional credit with the lower interest rate is very obligatory for them to meet up their needs. So, the government should give more emphasis to increase institutional credit with the lower interest rate to save the money they pay in case of commercial credit.

Desirable suggestions for the factory workers:

- **Increase wage rate**

Wage means payment for units of time or units of product as valued under a wage rate agreement. The wage rates of the workers are very low in the study area. So, the necessary steps should be taken to increase the wage rate in order to improve the livelihood of the workers by fulfilling the basic necessities.

- **Providing training facilities**

Training is teaching or developing in oneself or others, any skills and knowledge that relate to specific useful competencies. Training has specific goals of improving one's capability, capacity, productivity, and performance. Providing proper training can help the workers to do their works easily and smoothly without any difficulties.

- **Reduce working hour**

Working time is the period of time that a person spends at paid labor. Working time may vary from person to person, often depending on location, culture, lifestyle choice, and the profitability of the individual's livelihood. All the workers in the study area do their work for the long period of time. As a result, they are faced different health problems. So, the reduction of working hours can prevent different health problems.

- **Increase health facilities**

Waist pain, head pain, hand infection and malnutrition are very common in the workers level which interrupts their work spirit. So, the government should take essential step to establish health centers in which they can take the proper treatment with less money or can receive free treatment.

- **Increase other work opportunities**

In the study area, agar oil production is the main source of income. So, everyone is directly or indirectly engaged with this. Very fewer work opportunities have prevailed there. So, the workers are willing or unwilling doing this work having different health problems. So, proving other working sources can help those workers who are not capable of doing such hard work. So, in this aspect government support is very imperative to secure their lives.

Experiment 2: Growth performance analysis of Agar plant under different age and soil type

Plant heights of agar plants increased with age of plantation (Table 2.1). Agar plant of one year age attained an average1.11 m height.

Table 2.1 Plant height and number of branches of agar plant under different ages

Age of agar plantation (year)	Plant height m (Bottom to top)	Plant height m (Bottom to collar)	Primary branches plant^{-1} (no.)
1	1.11	0.57	4.95
2	1.65	0.87	6.85
3	2.48	1.30	10.35
4	3.19	1.47	11.95
5	3.69	1.71	15.20
6	4.05	1.90	14.50
7	4.40	2.30	13.85
8	5.49	2.62	17.10
9	6.22	2.66	18.60
10	6.73	3.57	19.60
11	7.36	2.33	19.95
12	8.15	3.57	20.60
13	9.25	4.46	21.55
14	9.85	4.64	22.03
15	10.21	4.80	22.55

It was attained 10.21 m height during 15 year of age. Plant height from bottom of the plant to collar level showed 0.565 m at the age of one year and it was reached to 4.30 m at 15 year of age. The number primary branches plant^{-1} was counted 4.95 in one tree whereas at 15 years plantation primary branches plant^{-1} was 22.55.

Agar plant circumferences were measured at base, breast height, middle and collar levels. The base circumference of one year plant was 2.64 cm and at 15 years of age base circumference recorded 56.97 cm (Table 2.2). It showed increasing trend with increasing age. Circumferences of breast height at 1.37 m above from bottom were measured 1.33 cm to 12.32 cm. Middle point circumferences were ranged from 1.99 cm at 1 year age to 56.97 cm at 15 years age. Collar point circumferences were observed 1.59 cm at one year age to 36.27 cm at 15 years of age.

Agar plant diameter was measured at base, breast height, middle and collar levels. Likewwise circumference the plant diameter at base, middle and collar height showed increasing trend with increasing the plant age. The diameter at base of one year plant was 0.90 cm and at 15 years of age it was 14.23 cm (Table 2.3). At middle and collar height it was 0.68 cm and 0.53 cm for one year plant while 11.55 cm and 9.75 cm for 15 years plant respectively.Diameter at breast height (from 1.37 m above the bottom) was also increased with the increasing the plant age only with the exception of 6 years age group and at 15 years of age it was the maximum (12.32 cm).

2.2 Agar plant circumference at different position of agar plant under different age group

Age of agar plantation (year)	Circumference (cm)			
	Base (20 cm from bottom)	Breast height (1.37 m from bottom)	Middle	Collar
1	2.64	-	1.99	1.59
2	4.28	-	3.19	2.56
3	10.53	4.51	6.83	5.04
4	12.11	10.71	8.30	6.35
5	13.69	17.44	11.43	10.56
6	21.53	14.45	21.53	12.26
7	27.37	17.81	27.37	14.90
8	28.40	19.25	28.40	17.17
9	30.90	22.05	30.90	18.65
10	35.97	25.59	35.97	21.82
11	40.20	28.38	40.20	22.35
12	41.98	30.92	41.98	24.78
13	47.20	35.55	47.20	26.55
14	51.67	38.87	51.67	28.50
15	56.97	43.99	56.97	36.27

2.3 Agar plant diameter at different position of agar tree under different age group

Age of agar plantation (year)	Diameter (cm)			
	Base (20 cm from bottom)	Breast height (1.37 from bottom)	Middle	Collar
1	0.90	-	0.68	0.527
2	1.34	-	1.03	0.855
3	3.27	1.326	2.105	1.433
4	2.10	2.10	2.40	2.608
5	4.02	5.24	3.27	3.015
6	6.98	4.41	4.49	3.530
7	8.38	5.48	5.57	4.538
8	8.54	5.93	6.555	5.185
9	9.27	6.76	6.655	8.06
10	10.62	7.96	7.525	5.82
11	11.27	8.70	8.265	6.485
12	11.74	9.17	8.495	7.315
13	12.77	10.42	9.655	8.005
14	13.94	11.19	9.82	8.43
15	14.23	12.323	11.553	9.753

Estimated biomass of agar plants under different age categories 3-15 years were 15.81 kg plant^{-1} to 44.23 kg plant^{-1}. The biomasses were estimated 39.53, 52.05, 61.88, 70.48, 76.20, 80.80, 85.50, 90.55, 94.15, 95.08, 103.00, 106.45 and 110.58 t ha^{-1} at the age of 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14, and 15 years of agar gardens establishment (Table 2.4).

2.4 Estimation of Biomass production of agar trees under different age categories

Age of the agar plants	Agar biomass (kg/plant)	Agar biomass (t/ha)
3	15.81	39.53
4	20.82	52.05
5	24.75	61.88
6	28.19	70.48
7	30.48	76.20
8	32.32	80.80
9	34.2	85.50
10	36.22	90.55
11	37.66	94.15
12	38.03	95.08
13	41.2	103.00
14	42.58	106.45
15	44.23	110.58

Soil nutrients status of different aged (1-15 years) agar plantation under Baralekhaupazila were analyzed. The pH values were acidic and ranged from 4.1 to 4.8 (Table 2.5). pH limits the growth of agar plants due to lower availability of P and S. Organic matter ranged from 1.55 to 3.00 percent. Total N was observed within a range of 0.09 to 0.15%. Available P and S lies under critical level. Available P ranged from 2 to 10 ppm while available S limits to 3-9 ppm. Exchangeable K observed from 0.10 to 0.25 meq 100 g^{-1} soil.

2.5 Soil nutrient status of different aged agar plantation under Baralekhaupazila

Age of agar plant garden (year)	pH	OM (%)	Total N (%)	Available P (ppm)	Exchangeable K (meq 100 g^{-1})	Available S (ppm)
1	4.7	2.95	0.14	7	0.23	8
2	4.5	2.36	0.12	6	0.20	4
3	4.2	2.04	0.11	5	0.21	5
4	4.6	3.00	0.15	8	0.18	7
5	4.1	1.15	0.09	2	0.10	4
6	4.3	1.44	0.10	3	0.11	3
7	4.8	2.80	0.15	10	0.25	6
8	4.3	2.61	0.14	8	0.22	4

9	4.5	2.42	0.13	7	0.19	8
10	4.4	2.15	0.12	6	0.16	7
11	4.2	2.27	0.12	7	0.17	9
12	4.5	2.01	0.11	5	0.15	8
13	4.6	2.58	0.13	7	0.16	5
14	4.3	2.71	0.14	9	0.12	8
15	4.4	2.87	0.14	8	0.16	9

Experiments 3: Effect of intercropping of medicinal plants in association with Agar plants.

3.1 Kalmegh

3.1.1 Growth parameters of Kalmegh

Plant height of Kalmegh did not vary significantly at different days after intervals up to 225 days after planting for intercropping with agar plants (Table 3.1). The plant heights of Kalmegh recorded were of 19.12 to 53.33 cm at 15 to 225 days after planting under sole crop respectively, while corresponding values at different dates were 16.66 to 59.95 cm respectively, under intercrop with agar plant.

Number of leaves plant^{-1} of Kalmegh did not show any significant variation at different days intervals up to 225 days after planting for intercropping with agar plants (Table 3.2). Number of leaves plant^{-1} of Kalmegh were recorded 8.40 to 66.28 at 15 to 225 days after planting respectively, under sole crop while corresponding numbers at different dates were 9.80 to 68.06 respectively under intercrop with agar plants.

Table 3.1 Effect of intercropping on plant height of Kalmegh with agar plantation at different days after intervals

Days after planting	Plant height (cm)		Standard error	Level of significance
	Sole crop	Intercrop		
15	19.12	16.16	0.91	NS
30	20.19	17.92	1.02	NS
45	21.29	21.18	0.95	NS
60	21.99	21.98	0.95	NS
75	23.35	22.58	0.48	NS
90	24.33	23.68	0.74	NS
105	25.22	25.50	0.80	NS
120	26.10	26.47	0.89	NS
135	27.76	29.22	1.58	NS
150	29.66	30.27	1.89	NS
165	33.30	34.06	1.97	NS

180	38.70	40.30	2.72	NS
195	45.77	47.33	2.10	NS
210	46.73	54.89	4.53	NS
225	53.33	59.95	4.70	NS

NS= Not significant

Table 3.2 Effect of intercropping on number of leaves plant^{-1} of Kalmegh with agar plantation at different days after intervals

Days after planting	Number of leaves plant^{-1}		Standard error	Level of significance
	Sole crop	Intercrop		
15	8.40	9.80	0.57	NS
30	10.72	12.36	0.68	NS
45	12.34	12.78	1.45	NS
60	11.64	12.24	1.10	NS
75	12.46	11.24	1.66	NS
90	14.48	13.97	1.54	NS
105	16.71	15.82	1.14	NS
120	17.92	19.15	1.71	NS
135	18.92	20.36	1.73	NS
150	20.77	22.37	1.86	NS
165	30.68	30.40	2.78	NS
180	39.14	37.54	4.70	NS
195	46.42	46.72	4.42	NS
210	54.78	56.70	4.96	NS
225	66.28	68.06	5.69	NS

NS= Not significant

Leaf length of Kalmegh had no significant variations at most of the days intervals up to 225 days after planting except 30, 45, 60 and 75 days after planting for intercropping with agar plants (Table 3.3). At 30 to 75 days after intervals leaf length of Kalmegh showed significant differences at 5% level of significance. At 30 days after planting, leaf length of Kalmegh produced higher in sole (11.24 cm) than intercrop (9.28 cm). At 45 days after planting, higher leaf length of Kalmegh was recorded in sole (13.32 cm) in comparison to intercrop (9.54 cm). At 60 days after planting, leaf length of Kalmegh sole (13.50 cm) produced higher than intercrop (10.52 cm).

At 75 days after planting, the leaf length is produced higher in sole (12.65 cm) and lower leaf length produced in intercrop (10.00 cm). Leaf length of Kalmegh recorded 11.16 to 13.56 cm at 15 to 225 days after planting under sole crop while corresponding values at different dates were 8.76 to13.80 cm under intercrop with agar plants.

Leaf breadth of Kalmegh showed no significant differences at most of the days after intervals up to 225 days after planting except 45 and 75 days after planting due to intercropping with agar plants (Table

3.4). At 45 and 75 days after intervals leaf breadth of Kalmegh showed significant differences at 5% level of significance. At 45 days after planting of Kalmegh, higher leaf breadth (2.72 cm) was produced in Kalmegh sole in comparison to intercrop (1.09 cm) with agar plants. At 75 days after planting, leaf breadth (2.68 cm) of Kalmegh was recorded higher in sole crop and lower in intercrop (2.22 cm). Leaf breadths of Kalmegh recorded were 2.26 to 3.34 cm at 15 to 225 days after planting under sole crop while corresponding values at different dates were 1.64 to 3.04 cm respectively under intercrop with agar plants.

Table 3.3 Effect of intercropping on leaf length of Kalmegh with agar plantation at different days after intervals

Days after planting	Leaf length (cm)		Standard error	Level of significance (LSD value)
	Sole crop	Intercrop		
15	11.16	8.78	0.64	NS
30	11.24a	9.28b	0.43	* (1.72)
45	13.32a	9.54b	0.83	* (3.29)
60	13.50a	10.52b	0.57	* (2.24)
75	12.65a	10.00b	0.59	* (2.32)
90	11.27	10.27	0.97	NS
105	12.50	10.20	0.97	NS
120	12.44	11.09	1.17	NS
135	12.64	10.22	1.15	NS
150	12.89	10.41	1.16	NS
165	11.64	11.26	0.96	NS
180	12.64	12.26	0.81	NS
195	12.77	13.13	1.00	NS
210	12.90	13.34	0.73	NS
225	13.56	13.80	0.72	NS
Mean	13.80	10.94	-	

In a row, the figure(s) having dissimilar letter(s) differ significantly * = Significant at 5 % level of probability, NS= Not significant, LSD= Least significance difference

Table 3.4 Effect of intercropping on leaf breadth (cm) of Kalmegh with agar plantation at different days after intervals

Days after planting	Leaf breadth (cm)		Standard error	Level of significance (LSD value)
	Sole crop	Intercrop		
15	2.26	1.64	0.19	NS
30	2.58	2.22	0.24	NS
45	2.72a	1.90b	0.17	* (0.68)
60	2.72	2.42	0.15	NS
75	2.68a	2.22b	0.10	* (0.40)
90	2.51	2.05	0.14	NS
105	2.49	1.87	0.18	NS
120	2.60	2.34	0.17	NS
135	2.73	2.58	0.21	NS
150	2.86	2.64	0.17	NS
165	2.62	2.66	0.06	NS
180	2.73	2.74	0.09	NS
195	2.98	2.76	0.21	NS
210	3.20	2.90	0.21	NS
225	3.34	3.04	0.24	NS
Mean	2.55	3.04		-

In a row, the figure(s) having dissimilar letter(s) differ significantly * = Significant at 5 % level of probability, NS= Not significant, LSD= Least significance difference

Spreading area of Kalmegh did not differ significantly at different days intervals up to 225 days after planting for intercropping with agar plants (Table 3.5). Spreading areas were recorded 13.10 to 26.47 cm^2 at 15 to 225 days after planting respectively, under sole crop while corresponding spreading area values at different dates were 11.36 to 29.25 cm^2respectively, under intercrop with agar plants.

Table 3.5 Effect of intercropping on spreading area of Kalmegh sole and intercrop with agar plantation at different days after intervals

Days after planting	Spreading area (cm^2)		Standard error	Level of significance
	Sole crop	Intercrop		
15	13.10	11.36	0.60	NS
30	14.80	13.48	0.83	NS
45	16.46	14.24	1.14	NS
60	15.52	14.54	0.88	NS
75	16.20	17.34	0.83	NS
90	16.76	17.12	0.63	NS
105	17.16	19.16	1.99	NS
120	18.93	22.23	1.76	NS

135	18.55	21.35	0.60	NS
150	19.34	21.92	1.89	NS
165	20.88	23.88	2.16	NS
180	22.23	25.44	2.06	NS
195	23.59	26.86	2.27	NS
210	25.06	28.47	2.05	NS
225	26.47	29.25	2.15	NS

NS= Not significant

Table 3.6 Effect of intercropping on number of branches plant^{-1} of Kalmegh with agar plantation at different days after intervals

Days after planting	Number of branches plant^{-1}		Standard error	Level of significance
	Sole crop	Intercrop		
15	0.80	0.00	0.41	NS
30	1.60	1.20	0.52	NS
45	1.72	1.20	0.36	NS
60	1.80	1.60	0.56	NS
75	1.36	0.98	0.61	NS
90	1.66	1.76	0.76	NS
105	2.84	2.59	0.48	NS
120	3.22	3.93	0.73	NS
135	3.53	4.46	0.87	NS
150	4.02	4.86	0.94	NS
165	4.92	6.22	0.93	NS
180	5.92	7.44	0.93	NS
195	6.80	8.54	0.90	NS
210	7.80	9.60	0.86	NS
225	9.30	10.32	1.28	NS

NS= Not significant

Number of branches plant^{-1} of Kalmegh did not significantly influences by different days intervals up to 225 days after planting for intercropping with agar plants (Table 3.6). Number of branches plant^{-1} of Kalmegh were recorded 0.80 to 9.30 at 15 to 225 days after planting respectively, under sole crop while corresponding number of branches plant^{-1} at different dates were 0 to 10.32 respectively, under intercrop with agar plants.

3.1.2 Biomass production of Kalmegh

The biomass production of kalmegh did not vary significantly for intercropping with agar plants. Fresh weight of leaf was found higher in intercrop with agar plantation (6040 kg ha^{-1}) and the lower in sole crop (3080 kg ha^{-1}).

Table 3.7 Biomass production of Kalmegh under intercropping system with agar plantation

Biomass	Fresh weight (kg/ha)		Dry weight (kg/ha)	
	Sole (Std)	Intercrop (Std)	Sole (Std)	Intercrop (Std)
Leaf	3080 (±1306)	6040 (±2113)	1028 (±278)	2106 (±826)
Stem	3239 (±2998)	4430 (±1433)	1246 (±1255)	1461 (±974)
Root	1834 (±1537)	2230 (±722)	960 (±1022)	1360 (±467)
Total	8153 (±5678)	12700 (±4152)	3235(±2411)	4928(±2160)

Std= Standard deviation

The higher fresh weight of stem was produced by intercrop (4430 kg ha^{-1}) than sole crop (3239 kg ha^{-1}). Fresh weight of root was produced higher in intercrop (2230 kg ha^{-1}) as compare to sole crop (1834 kg ha^{-1}). Finally total fresh biomass was produced in intercrop (12700 kg ha^{-1}) than sole crop (8134 kg ha^{-1}). As same as fresh biomass leaf, stem, root and total dry biomass production is higher in intercrop as compare to sole crop (Table 3.7). Results revealed that Kalmegh preferred shady place than sunny one for their better growth.

3.2 Bashok

3.2.1 Growth parameters of Bashok

Plant height of Bashok did not differ significantly at different days intervals up to 225 days after planting for intercropping with agar plants (Table 3.8). Plant heights of Bashok were recorded 19.98 to 44.00 cm at 15 to 225 days after planting under sole crop respectively while corresponding values at different dates were 20.16 to 47.79 cm respectively under intercrop with agar plants.

Table 3.8 Effect of intercropping on plant height of Bashok with agar plantation at different days after intervals

Days after planting	Plant height (cm)		Standard error	Level of significance
	Sole crop	Intercrop		
15	19.98	20.16	0.71	NS
30	21.86	21.68	0.94	NS
45	24.37	23.76	0.93	NS
60	25.77	25.26	1.06	NS
75	26.97	28.00	1.39	NS
90	28.12	29.55	1.57	NS
105	28.72	31.94	1.78	NS

120	29.75	33.98	1.51	NS
135	31.75	34.69	0.93	NS
150	32.18	35.22	0.96	NS
165	34.25	37.74	1.22	NS
180	36.49	40.06	1.93	NS
195	37.96	41.94	2.21	NS
210	41.17	44.57	2.71	NS
225	44.00	47.79	2.67	NS

NS= Not significant

Table 3.9 Effect of intercropping on number of leaves plant^{-1} of Bashok with agar plantation at different days after intervals

Days after planting	Number of leaves plant^{-1}		Standard error	Level of significance
	Sole crop	Intercrop		
15	7.80	5.60	0.75	NS
30	10.90	7.90	0.84	NS
45	10.00	9.18	1.45	NS
60	11.20	10.02	1.22	NS
75	10.74	11.29	1.19	NS
90	12.79	12.09	1.47	NS
105	14.61	13.76	1.13	NS
120	16.45	15.99	1.38	NS
135	18.60	17.84	1.28	NS
150	19.97	19.16	1.49	NS
165	21.16	20.12	2.04	NS
180	22.84	20.82	2.45	NS
195	24.17	21.80	2.99	NS
210	25.08	23.26	2.80	NS
225	26.16	25.34	2.92	NS

NS= Not significant

Number of leaves plant^{-1} of Bashok did not show any significant differences at different days intervals up to 225 days after planting for intercropping with agar plants (Table 3.9). Number of leaves plant^{-1} of Bashok were recorded 7.80 to 26.16 at 15 to 225 days after planting under sole crop respectively, while corresponding numbers at different dates were 5.60 to 25.34 respectively under intercrop with agar plants.

Leaf length of Bashok did not vary significantly at different days intervals up to 225 days after planting for intercropping with agar plants (Table 3.10). Leaf length of Bashok recorded 10.40 to 15.18 cm under

15 to 225 days after planting respectively, under sole crop while corresponding values at different dates were 10.54 to 15.64 cm respectively, under intercrop with agar plants.

Table 3.10 Effect of intercropping on leaf length of Bashok with agar plantation at different days after intervals

Days after planting	Leaf length (cm)		Standard error	Level of significance
	Sole crop	Intercrop		
15	10.40	10.54	0.92	NS
30	11.94	10.96	1.04	NS
45	11.38	8.68	1.07	NS
60	8.04	9.58	0.75	NS
75	9.62	10.35	0.66	NS
90	9.50	11.53	0.75	NS
105	11.64	12.69	1.39	NS
120	11.33	13.73	1.08	NS
135	11.54	13.48	1.28	NS
150	11.77	13.38	1.12	NS
165	12.36	13.16	1.27	NS
180	13.14	13.84	1.16	NS
195	14.22	14.99	1.19	NS
210	14.70	15.30	1.23	NS
225	15.18	15.64	1.33	NS
Mean	11.78	12.52	-	-

NS= Not significant

Leaf breadth of Bashok did not differ significantly at different days intervals up to 225 days after planting for intercropping with agar plants (Table 3.11). Leaf breadths of Bashok recorded were 3.26 to 5.16 cm at 15 to 225 days after planting respectively under sole crop while corresponding values at different dates were 3.32 to 5.04 cm respectively under intercrop with agar plants.

Table 3.11 Effect of intercropping on leaf breadth of Bashok with agar plantation at different days after intervals

Days after planting	Leaf breadth (cm)		Standard error	Level of significance
	Sole crop	Intercrop		
15	3.26	3.32	0.21	NS
30	3.52	4.24	0.20	NS
45	3.44	2.90	0.32	NS
60	3.50	3.06	0.37	NS

75	3.68	3.88	0.12	NS
90	4.18	4.30	0.26	NS
105	4.76	4.86	0.67	NS
120	4.93	4.87	0.67	NS
135	5.00	4.96	0.56	NS
150	5.18	5.03	0.58	NS
165	4.86	4.62	0.34	NS
180	4.44	4.54	0.23	NS
195	4.60	4.62	0.30	NS
210	4.86	4.90	0.36	NS
225	5.16	5.04	0.37	NS
Mean	4.09	3.96	-	-

NS= Not significant

Table 3.12 Effect of intercropping on spreading area of Bashok with agar plantation at different days after intervals

Days after planting	Spreading area (cm^2)		Standard error	Level of significance
	Sole crop	Intercrop		
15	10.72	10.18	0.55	NS
30	11.48	15.42	1.64	NS
45	14.36	13.30	1.56	NS
60	13.76	13.52	0.74	NS
75	16.82	18.86	0.97	NS
90	19.87	21.56	2.26	NS
105	19.98	24.17	1.37	NS
120	21.66	25.64	1.33	NS
135	23.09	23.09	1.66	NS
150	24.30	26.61	1.86	NS
165	25.18	27.42	1.99	NS
180	26.76	29.10	1.96	NS
195	27.48	30.20	2.20	NS
210	28.61	31.49	1.97	NS
225	29.54	32.96	2.00	NS

NS= Not significant.

Spreading area of Bashok did not show any significant difference at different days intervals up to 225 days after planting for intercropping with agar plants (Table 3.12). Spreading areas were recorded 10.72 to 29.59 cm^2 at 15 to 225 days after planting respectively, under sole crop while corresponding spreading area values at different dates were 10.18 to 32.96 cm^2 respectively, under intercrop with agar plants.

Table 3.13 Effect of intercropping on number of branches plant^{-1} of Bashok with agar plantation at different days after intervals

Days after planting	Number of branches plant^{-1}		Standard error	Level of significance (LSD value)
	Sole crop	Intercrop		
15	2.00	1.20	0.34	NS
30	2.40	1.40	0.31	NS
45	2.20	1.60	0.28	NS
60	2.20	1.80	0.31	NS
75	1.80	1.08	0.30	NS
90	1.99a	1.33b	0.16	* (0.65)
105	1.86	1.40	0.45	NS
120	2.13	1.80	0.34	NS
135	2.40	2.80	0.72	NS
150	2.59	2.93	0.77	NS
165	2.80	3.58	0.64	NS
180	3.24	3.84	0.68	NS
195	3.54	4.22	0.61	NS
210	3.76	4.90	0.53	NS
225	3.98	5.04	0.46	NS

In a row, the figure(s) having dissimilar letter(s) differ significantly * = Significant at 5 % level of probability, NS= Not significant, LSD= Least significance difference

Number of branches plant^{-1} did not vary significantly at different days intervals up to 225 days after planting except 90 days after planting which show significant at 5 % level of significance (Table 3.13). At 90 days after planting, higher number of branches plant^{-1} produced by sole crop (1.99) and lower produced by intercrop (1.33). Number of branches plant^{-1} were recorded 2 to 3.98 at 15 to 225 days after planting under sole crop while corresponding number of branches plant^{-1} at different dates were 1.20 to 5.04 under intercrop with agar plants

3.2.2 Biomass production in Bashok

The biomass production of bashok showed no significant variations for intercropping with agar plants. The highest fresh weight of leaf was found in sole crop (2355 kg ha^{-1}) and the lowest in intercrop (1048 kg ha^{-1}). Fresh weight of stem was produced higher in sole crop (2630 kg ha^{-1}) as compare to intercrop (1371 kg ha^{-1}). The higher fresh weight of root was found in sole crop (1448 kg ha^{-1}) and lower in intercrop (1338 kg ha^{-1}). Total fresh weight was produced higher in sole crop (6433 kg ha^{-1}) than intercrop (3757 kg ha^{-1}). As same as fresh biomass leaf, stem, and total dry biomass production is higher in sole as compare to intercrop except root dry weight which was highest found in intercrop and lowest in sole crop (Table 3.14).The reason of low biomass production through Bashokmight be as it produced broad leaf and needs more penetration of sun light in leaf for food production of the plant. But in intercrop system sun light is less penetrated in the Bashok plant due to canopy system of Agar wood. Due to insufficient food supply Bashok in intercrop system produced lower biomass than sole Bashok.

Table 3.14 Biomass production of Bashok under intercropping system with agar plantation

Biomass	Fresh weight (kg/ha)		Dry weight (kg/ha)	
	Sole (Std)	Intercrop (Std)	Sole (Std)	Intercrop (Std)
Leaf	2355 (±2590)	1048 (±571)	682 (±772)	312 (±202)
Stem	2630 (±4122)	1371 (±567)	655 (±936)	500 (±204)
Root	1448 (±1656)	1338 (±573)	461 (±482)	659 (±346)
Total	6433 (±7267)	3757 (±1670)	1799(±2004)	1472(±698)

Std= Standard deviation

3.3 Tulsi

3.3.1 Growth parameters of Tulsi

Plant height of Tulsi had showed no significant variation at different days intervals up to 225 days after planting for intercropping with agar plants (Table 3.15). Plant heights were recorded 19.02 to 41.49 cm at 15 to 225 days after planting respectively, under sole crop while corresponding values at different dates were 15.50 to 46.33 cm respectively, under intercrop with agar plants.

Number of leaves plant^{-1} of Tulsi did not influence by any significant variation at different days intervals up to 225 days after planting except 15 and 30 days after planting which show significant relation at 1% of level of significance and 5% of level of significance respectively (Table 3.16). At 15 days after planting, number of leaves plant^{-1} of Tulsi recorded higher in sole crop (20.80) and lower was recorded in intercrop (14.80). At 30 days after planting, number of leaves plant^{-1} of Tulsi found higher in sole crop (26.66) in comparison to intercrop (17.86). Number of leaves plant^{-1} were recorded 20.18 to 7.98 at 15 to 225 days after planting respectively under sole crop while corresponding numbers at different dates were 14.8 to 67.73 respectively under intercrop with agar plants.

Table 3.15 Effect of intercropping on plant height of Tulsi with agar plantation at different days after intervals

Days after planting	Plant height(cm)		Standard error	Level of significance
	Sole crop	Intercrop		
15	19.02	15.50	1.00	NS
30	20.25	16.56	1.17	NS
45	21.88	17.66	1.48	NS

60	22.97	18.66	1.57	NS
75	24.52	20.58	1.58	NS
90	25.82	22.61	1.53	NS
105	27.10	25.23	1.10	NS
120	28.60	27.84	1.44	NS
135	30.43	30.41	1.67	NS
150	31.49	31.45	1.70	NS
165	33.31	34.16	1.86	NS
180	35.48	36.54	1.40	NS
195	37.44	39.54	1.74	NS
210	39.54	42.22	1.67	NS
225	41.49	46.33	2.11	NS

NS= Not significant

Table 3.16 Effect of intercropping on number of leaves plant^{-1} of Tulsi with agar plantation at different days after intervals

Days after planting	Number of leaves plant^{-1}		Standard error	Level of significance (LSD value)
	Sole	Intercrop		
15	20.80a	14.80b	0.63	** (2.48)
30	26.66a	17.86b	1.66	* (6.55)
45	26.44	21.24	2.54	NS
60	29.90	25.44	3.21	NS
75	31.50	27.14	3.06	NS
90	34.42	31.03	2.45	NS
105	39.57	38.03	2.37	NS
120	44.56	46.62	4.33	NS
135	46.88	48.38	3.63	NS
150	49.96	50.41	3.64	NS
165	54.58	54.82	3.86	NS
180	58.80	59.56	3.79	NS
195	60.90	61.32	4.11	NS
210	63.56	65.04	4.65	NS
225	67.98	67.73	4.86	NS

In a row, the figure(s) having dissimilar letter(s) differ significantly, **= Significance at 1% level, * = Significant at 5 % level of probability, NS= Not significant, LSD= Least significance difference

Leaf length of Tulsi did not differ significantly at different days intervals up to 225 days after planting except 195 days after planting which show significant relation at 5% of level of significance (Table 3.17). At 195 days after planting, leaf length of Tulsi was recorded higher in sole crop (4.51 cm) and lower in intercrop (4.02 cm). Leaf lengths were recorded 3.70 to 4.74 cm at 15 to 225 days after planting respectively under sole crop while corresponding values at different dates were 3.46 to 4.34 cm respectively under intercrop with agar plants.

Table 3.17 Effect of intercropping on leaf length of Tulsi with agar plantation at different days after intervals

Days after planting	Leaf length (cm)		Standard error	Level of significance (LSD value)
	Sole	Intercrop		
15	3.70	3.46	0.41	NS
30	4.70	3.76	0.51	NS
45	4.64	5.40	0.63	NS
60	4.76	3.64	0.31	NS
75	4.66	3.42	0.66	NS
90	4.53	4.03	0.54	NS
105	4.47	4.21	0.60	NS
120	4.71	4.11	0.47	NS
135	4.64	4.37	0.40	NS
150	4.76	4.68	0.43	NS
165	4.46	4.08	0.33	NS
180	4.29	4.17	0.06	NS
195	4.51a	4.02b	0.10	* (0.41)
210	4.58	4.36	0.16	NS
225	4.74	4.34	0.11	NS

In a row, the figure(s) having dissimilar letter(s) differ significantly * = Significant at 5 % level of probability, NS= Not significant, LSD= Least significance difference

Leaf breadth of Tulsi did not influence by any significant variation at different days intervals up to 225 days after planting except 30 days after planting which show significant relation at 5% of level of significance (Table 3.18). At 30 days after planting, leaf breadth of Tulsi was recorded higher in sole crop (3.02 cm) in comparison to intercrop (2.00 cm). Leaf breadth were recorded 2.12 to 2.36 cm at 15 to 225 days after planting respectively under sole crop while corresponding values at different dates were 1.96 to 2.30 cm respectively under intercrop with agar plants.

Table 3.18 Effect of intercropping on leaf breadth of Tulsi with agar plantation at different days after intervals

Days after planting	Leaf breadth (cm)		Standard error	Level of significance (LSD value)
	Sole crop	Intercrop		
15	2.12	1.96	0.29	NS
30	3.02a	2.00b	0.22	* (0.86)
45	2.88	2.46	0.31	NS

60	2.28	2.16	0.26	NS
75	2.25	2.10	0.33	NS
90	3.13	1.73	0.58	NS
105	2.05	1.94	0.12	NS
120	2.32	2.06	0.16	NS
135	2.42	2.24	0.14	NS
150	2.54	2.46	0.11	NS
165	2.16	2.18	0.05	NS
180	2.28	2.38	0.07	NS
195	2.12	2.12	0.02	NS
210	2.24	2.24	0.07	NS
225	2.36	2.30	0.06	NS
Mean	4.54	4.13	-	-

In a row, the figure(s) having dissimilar letter(s) differ significantly * = Significant at 5 % level of probability, NS= Not significant, LSD= Least significance difference

Table 3.19 Effect of intercropping on Spreading area (cm^2) of Tulsi with agar plantation at different days after intervals

Days after planting	Spreading area (cm^2)		Standard error	Level of significance
	Sole crop	Intercrop		
15	4.78	5.18	0.38	NS
30	6.04	5.96	0.73	NS
45	6.56	6.98	0.82	NS
60	7.12	7.44	0.74	NS
75	7.93	8.54	0.82	NS
90	8.72	10.53	0.82	NS
105	10.49	11.53	0.74	NS
120	11.40	11.40	1.27	NS
135	12.70	15.32	1.26	NS
150	13.81	16.33	1.44	NS
165	15.24	17.10	1.81	NS
180	16.44	18.30	1.96	NS
195	17.06	19.25	1.91	NS
210	17.96	20.15	1.81	NS
225	19.02	21.56	2.05	NS

NS= Not significant

Spreading area of Tulsi did not show any significant differences at different days intervals up to 225 days after planting for intercropping with agar plants (Table 3.19). Spreading areas were recorded 4.78 to 19.02 cm^2 at 15 to 225 days after planting respectively under sole crop while corresponding spreading area values at different dates were 5.18 to 21.56 cm^2 respectively under intercrop with agar plants.

Table 3.20 Effect of intercropping on no. of branches plant^{-1} of Tulsi with agar plantation at different days after intervals

Days after planting	Number of branches plant^{-1}		Standard error	Level significance (LSD value)
	Sole crop	Intercrop		
15	2.00	1.20	0.34	NS
30	3.00	1.40	0.61	NS
45	3.92	2.26	0.72	NS
60	5.06	3.00	0.96	NS
75	5.90a	4.24b	0.37	* (1.48)
90	6.92	5.27	0.51	NS
105	7.38	5.98	0.44	NS
120	8.35	6.94	0.44	NS
135	9.16	7.64	0.51	NS
150	9.52	8.32	0.65	NS
165	10.06	9.22	0.56	NS
180	10.06	9.22	0.62	NS
195	11.98	10.60	0.63	NS
210	12.66	11.08	0.57	NS
225	13.22	11.66	0.72	NS

In a row, the figure(s) having dissimilar letter(s) differ significantly * = Significant at 5 % level of probability, NS= Not significant, LSD= Least significance difference

Number of branches plant^{-1} of Tulsidid not influence by any significant variation at different days intervals up to 225 days after planting except 75 days after planting which show significant relation at 5% of level of significance (Table 3.20). At 75 days after planting, number of branches plant^{-1} of Tulsi was produced higher by sole crop (5.90) than intercrop (3.20). Number of branches plant^{-1} of plant were recorded 2.0 to 13.22 at 15 to 225 days after planting respectively under sole crop while corresponding number of branches plant^{-1} at different dates were 1.2 to 11.66 respectively under intercrop with agar plants.

3.3.2 Biomass production in Tulsi

In tulsi the biomass production had no significant variations for intercropping with agar plants. Fresh weight of leaf was produced higher in sole crop (676 kg ha^{-1}) in comparison to intercrop (508 kg ha^{-1}). The higher fresh weight of stem was found in sole crop (1536 kg ha^{-1}) and the lower in intercrop (896 kg ha^{-1}). The higher fresh weight of root was found in sole crop (794 kg ha^{-1}) and lower in intercrop (478 kg ha^{-1}). Total fresh weight was produced higher in sole crop (3006 kg ha^{-1}) than intercrop (1882 kg ha^{-1}). Fresh biomass leaf, stem, root and total dry biomass production followed the similar patterns stated as fresh weight is higher in sole as compare to intercrop (Table 3.21).

Table 3.21 Biomass production of Tulsi under intercropping system with agar plantation

Biomass	Fresh weight (kg/ha)		Dry weight (kg/ha)	
	Sole (Std)	Intercrop (Std)	Sole (Std)	Intercrop (Std)
Leaf	676 (±1025)	508 (±366)	301(±348)	169(±104)
Stem	1536 (±2775)	896 (±842)	813(±1467)	432(±495)
Root	794 (±1234)	478 (±470)	462(±666)	210(±178)
Total	3006 (±5031)	1882 (±1670)	1577(±2475)	812(±769)

Std= Standard deviation

3.4 Sarpagandha

3.4.1 Growth parameters of Sarpagandha

Plant height of Sarpagandha showed significant relation at 15 days after planting to 90 days after planting at 5 % level of significance only at 30 days after planting showed significant at 1 % leval of significance. And 105 days after planting to 225 days after planting did not show any significant variation for plant height of Sarpagandha (Table 3.22). At 15 days after planting, plant height of Sarpagandha produced the higher in sole crop (18.20 cm) and lower in intercrop (14.86 cm) with agar plants. At 30 days after planting, higher plant height of Sarpagandha produced by sole crop (19.72 cm) in comparison to intercrop (15.64 cm). At 45 days after planting, plant height of Sarpagandha produced higher in sole crop (21.78 cm) than intercrop (17.08 cm) with agar plants. At 60 days after planting, higher plant height of Sarpagandha was recorded in sole crop (23.60 cm) and lower in intercrop (18.32 cm). At 75 days after planting, plant height of Sarpagandha found higher in sole crop (25.66 cm) and lower in intercrop (19.30 cm). At 90 days after planting, higher plant height of Sarpagandha was recorded sole crop (27.48 cm) in comparison to intercrop (20.80 cm). Plant heights were recorded 18.to 38.99 cm at 15 to 225 days after planting respectively under sole crop while corresponding values at different dates were 14.86 to 33.90 cm respectively under intercrop with agar plants.

Table 3.22 Effect of intercropping on plant height of Sarpagandha with agar plantation at different days after intervals

Days after planting	Plant height (cm)		Standard error	Level of significance (LSD value)
	Sole crop	Intercrop		
15	18.20a	14.86b	0.55	* (2.17)
30	19.72a	15.64b	0.48	** (1.91)
45	21.70a	17.08b	1.02	* (4.03)
60	23.60a	18.32b	1.12	* (4.14)
75	25.60a	19.30b	1.26	* (4.95)

90	27.40a	20.80b	1.64	* (6.46)
105	29.11	21.74	1.94	NS
120	30.27	23.44	1.96	NS
135	30.74	25.02	1.94	NS
150	31.74	26.47	1.76	NS
165	33.14	28.65	2.28	NS
180	33.39	30.17	2.45	NS
195	36.43	31.85	3.13	NS
210	38.64	32.25	3.23	NS
225	38.99	33.90	2.74	NS

In a row, the figure(s) having dissimilar letter(s) differ significantly, ** = Significant at 1 % level of probability,* = Significant at 5 % level of probability, NS= Not significant, LSD= Least significance difference

Table 3.23 Effect of intercropping on number of leaves plant^{-1} of Sarpagandha with agar plantation at different days after intervals

Days after planting	Number of leaves plant^{-1}		Standard error	Level of significance
	Sole crop	Intercrop		
15	2.40	3.40	0.31	NS
30	2.80	4.00	0.41	NS
45	3.00	5.40	1.06	NS
60	4.00	5.00	0.70	NS
75	5.86	5.56	0.71	NS
90	7.70	9.01	0.96	NS
105	12.80	11.58	2.18	NS
120	11.75	11.12	2.56	NS
135	12.75	13.36	2.78	NS
150	14.75	15.27	3.16	NS
165	12.60	14.32	1.91	NS
180	12.98	14.88	2.01	NS
195	12.57	15.44	2.59	NS
210	13.28	15.80	2.70	NS
225	13.57	16.06	2.71	NS

NS= Not significant

Number of leaves plant^{-1} of Sarpagandha did not show any significant differences at different days intervals up to 225 days after planting for intercropping with agar plants (Table 3.23). Number of leaves plant^{-1} were recorded 2.40 to 13.57 at 15 to 225 days after planting respectively, under sole crop while corresponding numbers at different dates were 3.40 to 16.06 respectively, under intercrop with agar plants.

Leaf lengths of Sarpagandha had no significant variations at different days intervals up to 225 days after planting for intercropping with agar plants (Table 3.24). Leaf lengths were recorded 6.40 to 9.15 cm at 15 to 225 days after planting respectively under sole crop while corresponding values at different dates were 4.60 to 9.18 cm respectively under intercrop with agar plants.

Table 3.24 Effect of intercropping on leaf length of Sarpagandha with agar plantation at different days after intervals

Days after planting	Leaf length (cm)		Standard error	Level of significance
	Sole crop	Intercrop		
15	6.40	4.60	0.78	NS
30	6.50	5.40	0.44	NS
45	5.32	6.50	0.96	NS
60	4.82	5.82	0.92	NS
75	5.54	4.90	0.30	NS
90	7.77	7.88	1.88	NS
105	8.71	7.97	0.98	NS
120	8.40	9.32	1.10	NS
135	4.03	9.15	1.02	NS
150	9.02	9.25	1.02	NS
165	8.14	8.44	1.65	NS
180	8.40	8.62	1.70	NS
195	8.96	8.83	1.81	NS
210	8.90	9.00	1.83	NS
225	9.15	9.18	1.87	NS
Mean	7.34	7.65		-

NS= Not significant

Leaf breadth of Sarpagandha did not vary significantly at different days intervals up to 225 days after planting for intercropping with agar plants (Table 3.25). Leaf breadths were recorded 2.16 to 3.30 cm at 15 to 225 days after planting respectively under sole crop while corresponding values at different dates were 1.78 to 3.98 cm respectively under intercrop with agar plants.

Table 3.25 Effect of intercropping on leaf breadth of Sarpagandha with agar plantation at different days after intervals

Days after planting	Leaf breadth (cm)		Standard error	Level of significance
	Sole crop	Intercrop		
15	2.16	1.78	0.20	NS
30	2.54	2.50	0.22	NS
45	2.34	2.54	0.18	NS

60	1.94	2.14	0.24	NS
75	2.30	2.07	0.14	NS
90	2.81	2.46	0.20	NS
105	2.87	2.71	0.28	NS
120	3.09	3.20	0.36	NS
135	3.21	3.34	0.30	NS
150	3.39	3.47	0.37	NS
165	2.76	3.12	0.45	NS
180	2.86	3.02	0.45	NS
195	3.00	3.20	0.61	NS
210	3.16	3.34	0.63	NS
225	3.30	3.98	0.78	NS
Mean	2.28	2.50	-	-

NS= Not significant

Table 3.26 Effect of intercropping on spreading area of Sarpagandha with agar plantation at different days after intervals

Days after planting	Spreading area (cm^2)		Standard error	Level of significance
	Sole crop	Intercrop		
15	6.04	4.38	0.77	NS
30	7.14	7.14	0.75	NS
45	6.52	8.16	1.08	NS
60	6.28	8.52	1.19	NS
75	9.00	9.44	1.00	NS
90	12.87	11.11	1.21	NS
105	14.76	13.75	1.94	NS
120	15.86	17.11	1.75	NS
135	17.25	18.23	2.27	NS
150	19.55	18.15	2.16	NS
165	19.03	20.44	2.29	NS
180	20.03	21.03	2.58	NS
195	21.17	21.84	2.97	NS
210	21.82	22.54	3.03	NS
225	22.31	22.77	2.99	NS

NS= Not significant

Spreading area of Sarpagandha did not influence by any significant variation at different days intervals up to 225 days after planting for intercropping with agar plants (Table 3.26). Spreading area recorded were 6.04 to 22.31 cm^2 at 15 to 225 days after planting respectively under sole crop while corresponding spreading area values at different dates were 4.38 to 22.77 cm^2 respectively under intercrop with agar plants.

Table 3.27 Effect of intercropping on number of branches plant^{-1} of Sarpagandha with agar plantation at different days after intervals

Days after planting	Number of branches plant^{-1}		Standard error	Level of significance
	Sole crop	Intercrop		
15	0.80	0.00	0.34	NS
30	1.00	0.00	0.44	NS
45	0.60	0.40	0.56	NS
60	1.00	0.40	0.61	NS
75	0.46	0.62	0.17	NS
90	0.66	0.88	0.56	NS
105	1.06	0.80	0.56	NS
120	0.86	0.80	0.48	NS
135	1.00	0.93	0.60	NS
150	1.12	1.20	0.71	NS
165	1.12	1.60	0.50	NS
180	2.08	1.70	0.73	NS
195	2.58	2.52	0.38	NS
210	2.68	2.78	0.40	NS
225	2.84	2.96	0.42	NS

NS= Not significant

Number of branches plant^{-1} of Sarpagandha did not show any significant differences at different days intervals up to 225 days after planting for intercropping with agar plants (Table 3.27). Number of branches plant^{-1} were recorded 0.80 to 2.84 at 15 to 225 days after planting respectively, under sole crop while corresponding number of branches plant^{-1} at different dates were 0 to 2.96 respectively, under intercrop with agar plants.

3.4.2 Biomass production in Sarpagandha

In sarpagandha the biomass production did not show any significant variations for intercropping with agar plants. Fresh weight of leaf was produced higher in sole crop (310 kg ha^{-1}) in comparison to intercrop (132 kg ha^{-1}). The higher fresh weight of stem was found in sole crop (410 kg ha^{-1}) in comparison to intercrop (191 kg ha^{-1}). The higher fresh weight of root was found in sole crop (470 kg ha^{-1}) over intercrop (238 kg ha^{-1}). Total fresh weight was produced higher in sole crop (1190 kg ha^{-1}) than intercrop (562 kg ha^{-1}). Similar patterns were followed in dry biomass production of leaf, stem, root and total which were higher in sole as compare to intercrop (Table 3.28).

Table 3.28 Biomass production of Sarpagandha under intercropping system with agar plantation

Biomass	Fresh weight (kg/ha)		Dry weight (kg/ha)	
	Sole (Std)	Intercrop (Std)	Sole (Std)	Intercrop (Std)

Leaf	310 (±387)	132 (±96)	99(±64)	51(±35)
Stem	410 (±398)	191 (±153)	155(±84)	84(±74)
Root	470 (±408)	238 (±233)	223(±145)	109(±112)
Total	1190 (±1194)	562 (±481)	478(±286)	245(±221)

Std= Standard deviation

3.5 Ashwagandha

3.5.1 Growth parameters of Ashwagandha

Plant height of Ashwagandha did not vary significantly at different days intervals up to 150 days after planting for intercropping with agar plants (Table 3.29). Plant heights were recorded 8.98 to18.88 cm at 15 to 150 days after planting respectively under sole crop while corresponding values at different dates were 7.50 to 19.22 cm respectively under intercrop of Ashwagandha with agar plants.

Table 3.29 Effect of intercropping on plant height of Ashwagandha with agar plantation at different days after intervals

Days after planting	Plant height (cm)		Standard error	Level of significance
	Sole crop	Intercrop		
15	8.98	7.50	0.52	NS
30	10.16	8.70	0.31	NS
45	11.50	10.12	0.58	NS
60	12.08	10.92	0.69	NS
75	12.94	10.86	0.66	NS
90	13.73	12.17	0.71	NS
105	15.35	14.21	0.78	NS
120	17.28	16.08	0.90	NS
135	18.20	17.82	1.34	NS
150	18.88	19.22	1.33	NS

NS= Not significant

Number of leaves plant^{-1} did not show significant variation at different days intervals up to 150 days after planting except 90 days after planting at 5 % level of significance (Table 3.30). At 90 days after planting, number of leaves plant^{-1} of ashwagandha was recorded higher in sole crop (12.76) and lower in intercrop (10.50) with agar plants. Number of branches plant^{-1} of ashwagandha recorded were 3.0 to 16.66 at 15 to 150 days after planting respectively under sole crop while corresponding numbers at different dates were 3.40 to 17.71 respectively under intercrop with agar plants.

Table 3.30 Effect of intercropping on number of leaves plant^{-1} of Ashwagandha with agar plantation at different days after intervals

Days after planting	Number of leaves plant $^{-1}$		Standard error	Level of significance (LSD value)
	Sole crop	Intercrop		
15	3.00	3.40	0.28	NS
30	3.80	3.80	0.22	NS
45	6.40	5.20	0.68	NS
60	6.00	5.8 0	0.60	NS
75	10.16	8.74	0.74	NS
90	12.76a	10.50b	0.57	* (2.25)
105	12.88	13.56	0.99	NS
120	14.44	15.15	0.83	NS
135	15.43	16.30	1.43	NS
150	16.66	17.71	1.15	NS

In a row, the figure(s) having dissimilar letter(s) differ significantly * = Significant at 5 % level of probability, NS= Not significant, LSD= Least significance difference

Table 3.31 Effect of intercropping on leaf length of Ashwagandha with agar plantation at different days after intervals

Days after planting	Leaf length (cm)		Standard error	Level of significance
	Sole crop	Intercrop		
15	3.78	4.42	0.61	NS
30	5.98	4.60	0.51	NS
45	4.82	5.98	0.69	NS
60	4.96	5.14	0.75	NS
75	5.11	4.40	0.25	NS
90	5.75	4.86	0.29	NS
105	5.94	5.58	0.78	NS
120	6.95	6.18	0.70	NS
135	7.41	6.41	0.75	NS
150	7.39	6.72	0.71	NS
Mean	3.87	3.60	-	-

NS= Not significant

Leaf length of Ashwagandha did not influence by any significant differences at different days intervals up to 150 days after planting for intercropping with agar plants (Table 3.27). Leaf lengths of Ashwagandha recorded were 3.78 to 7.39 cm at 15 to 150 days after planting respectively, under sole crop while corresponding values at different dates were 4.42 to 6.72 cm respectively, under intercrop with agar plants.

Leaf breadth of Ashwagandha did not show significant variation at different days intervals up to 150 days after planting except 30 days after planting at 1 % level of significance (Table 3.28). At 30 days after planting, leaf length of Ashwagandha was recorded equal in sole crop (3.54 cm) and in intercrop (3.56 cm). Leaf length of Ashwagandha recorded were 2.74 to 3.89 cm at 15 to 150 days after planting respectively under sole crop while corresponding values at different dates were 2.62 to 3.88 cm respectively under intercrop with agar plants.

Table 3.32 Effect of intercropping on leaf breadth of Ashwagandha with agar plantation at different days after intervals

Days after planting	Leaf breadth (cm)		Standard error	Level of significance (LSD value)
	Sole crop	Intercrop		
15	2.74	2.62	0.24	NS
30	3.54a	3.54a	0.08	** (0.32)
45	3.02	3.54	0.35	NS
60	2.78	2.82	0.24	NS
75	2.67	2.76	0.17	NS
90	3.07	3.03	0.13	NS
105	3.50	3.34	0.21	NS
120	3.87	3.71	0.33	NS
135	3.94	3.70	0.43	NS
150	3.89	3.88	0.36	NS
Mean	2.20	2.19		-

In a row, the figure(s) having dissimilar letter(s) differ significantly, ** = Significant at 1 % level of probability, NS= Not significant, LSD= Least significance difference

Spreading area of Ashwagandha did not influence by any significant relation at different days intervals up to 150 days after planting except 75 days after planting which significant at 5 % level of significance (Table 3.33). At 75 days after planting, higher spreading area of Ashwagandha was recorded in sole crop (10.19 cm^2) and lower in intercrop (8.17 cm^2) with agar plants.Spreading areas were recorded 5.60 to 16.57 cm^2 under 15 to 150 days after planting respectively under sole crop while corresponding spreading area values at different dates were 6.54 to 14.38 cm^2 respectively under intercrop with agar plants.

Table 3.33 Effect of intercropping on spreading area of Ashwagandha with agar plantation at different days after intervals

Days after planting	Spreading area cm^2		Standard error	Level of significance (LSD value)
	Sole crop	Intercrop		
15	5.60	6.54	0.36	NS
30	6.58	8.38	1.48	NS
45	8.58	9.88	0.51	NS

60	8.18	8.46	0.76	NS
75	10.19a	8.17b	0.36	* (4.43)
90	11.67	9.38	0.88	NS
105	14.33	10.96	1.34	NS
120	15.63	12.22	1.49	NS
135	15.17	13.29	1.35	NS
150	16.57	14.38	1.43	NS

In a row, the figure(s) having dissimilar letter(s) differ significantly, * = Significant at 5 % level of probability, NS= Not significant, LSD= Least significance difference

Number of branches plant^{-1} of Ashwagandha did not show significant differences at different days intervals up to 150 days after planting except 45 days after planting which was significant at 5 % level of significance (Table 3.34). At 75 days after planting, higher number of branches plant^{-1} of Ashwagandha was produced by sole crop (1.60) and no branches were produced by intercrop (0). Number of branches plant^{-1} of Ashwagandha recorded 0.80 to 3.12 under 15 to 150 days after planting respectively under sole crop while corresponding number of branches plant^{-1} at different dates were 0.4 to 3.06 respectively under intercrop with agar plants.

Table 3.34 Effect of intercropping on number of branches plant^{-1} of Ashwagandha with agar plantation at different days after intervals

Days after planting	Number of branches plant^{-1}		Standard error	Level of significance (LSD value)
	Sole	Intercrop		
15	0.80	0.40	0.52	NS
30	0.80	0.00	0.34	NS
45	1.60a	0.00b	0.28	* (1.11)
60	1.20	1.20	0.63	NS
75	2.04	1.27	0.46	NS
90	1.84	1.59	0.47	NS
105	2.40	2.06	0.14	NS
120	2.85	2.60	0.31	NS
135	2.86	2.66	0.35	NS
150	3.12	3.06	0.37	NS

In a row, the figure(s) having dissimilar letter(s) differ significantly * = Significant at 5 % level of probability, NS= Not significant, LSD= Least significance difference

3.5.2 Biomass production in Ashwagadha

The biomass production of ashwagandha had no significant variations for intercropping with agar plants. Biomass production would higher if harvested prior to other medicinal crops. Fresh weight of leaf was produced higher in sole crop (136 kg ha^{-1}) in comparison to intercrop (100 kg ha^{-1}). The higher fresh weight of stem was found in sole crop (159 kg ha^{-1}) and the lower in intercrop (137 kg ha^{-1}). The fresh weight of root was found higher in sole crop (164 kg ha^{-1}) over intercrop (146 kg ha^{-1}). Total fresh weight was produced in sole crop (459 kg ha^{-1}) was higher than intercrop (383 kg ha^{-1}). The leaf, stem, root and total dry biomass production was followed similar patterns as of fresh biomass production (Table 3.35).

Table 3.35 Biomass production of Ashwagandha under intercropping system with agar plantation

Biomass	Fresh weight (kg/ha)		Dry weight (kg/ha)	
	Sole (Std)	Intercrop (Std)	Sole (Std)	Intercrop (Std)
Leaf	136 (±148)	100 (±59)	28(±31)	21(±12)
Stem	159 (±163)	137 (±120)	41(±42)	35(±31)
Root	164 (±159)	146 (±142)	65(±63)	58(±57)
Total	459 (±471)	383 (±321)	135(±137)	115(±100)

Std= Standard deviation

3.6 Cost of production

Cost of production is required for the estimation of cost and profitability of a crop. From the biomass data it was revealed that the biomass yield of tulsi, sapragandha and ashwagandha were not satisfactory. It is not feasible with agar plant. That's why the cost of production of tulsi, sapragandha and ashwagandha are not presented here. As kalmegh and bashok is feasible with agar plant, the cost of production of these three plants was estimated below.

3.6.1 Agar plant

The costs of production of agar plant for fifteen year were estimated as Tk. 632920. The total biomass in fifteen years recorded 110.58 t ha^{-1}.The total returns of fifteen year were Tk. 6282954. From estimation gross margin was revealed Tk. 5650034. Finally the benefit cost ration was found 9.93.

In fifteen year, the gross margin of agar plant estimated Tk. 5650034. The profitability of agar plant cultivation in one year was estimated Tk. 376668 by converting fifteen year to one year.

3.6.2 Kalmegh

For one year the cost of production of kalmegh plant estimated Tk. 81804. Total dry biomass yield recorded 4928 kg ha-^{1}for kalmegh plant. Total return was Tk 295680 ha-^{1} per year. The gross margin from a year was Tk 213876. Finally the benefit cost ratio was found 3.61.

The costs of production of medicinal plants were estimated for one year. The harvesting of agar plant is started from 15 years old. In agar garden, medicinal plants can be intercropped for around 8-10 years. Due to experimental purpose it was not possible to extend more than one year intercropping in agar garden. But to know the actual profitability, it needs total estimation of biomass for fifteen years.

In one year, the gross margin of kalmegh plant estimated Tk. 213876. The profitability of kalmegh cultivation in eight year was estimated Tk. 1711008.

3.6.3 Bashok

In order to analyze the profitability of bashok production, it is mandatory to estimate the cost of production. The cost of production includes both non-material and material cost. Non- material cost includes the preparation of land, application of manure and fertilizer, pit preparation, planting seedling, weeding, irrigation and harvesting. On the other hand, the material cost includes seedling, fertilizer and miscellaneous cost. . For one year the cost of production of bashok estimated Tk. 69960. The total dry biomass of bashok found 1472 kg ha-1. Total return from yield in one year was Tk. 117760. Gross margin of one year were Tk. 47800. Finally the study calculated that benefit cost ratio was 1.68.

In one year, the gross margin of kalmegh plant estimated Tk. 47800. The profitability of kalmegh cultivation in eight year was estimated Tk. 382400.

Table.3.36 Agro-economic performance of agar plant with medicinal plants

Sl. No.	Plants	Cost of production (Tk ha^{-1})	Gross return (Tk ha^{-1})	Gross margin (Tk ha^{-1})
01	Agar	632920	6282954	5650034
02	Kalmegh	81804	295680	213876
03	Bashok	69960	117760	47800
04	Tulsi	62240	40600	-21640
05	Sarpagandha	95120	85750	-9370
06	Ashwagandha	95120	46000	-49120
07	Agar + Kalmegh	714724	6578634	7361042
08	Agar + Bashok	702880	6400714	6032434
09	Agar + Tulsi	695160	6323554	5628394
10	Agar + Sarpagandha	728040	6368704	5640664
11	Agar + Ashwagandha	728040	6328954	5600914

Nutrient status of initial and post-harvest soil

Initial and post-harvest soils were analyzed to see the status of before and after cropping of nutrients in soil (Table 3.36). The pH value of initial soil was 3.75. Post-harvest soil analysis showed that the pH values were higher than initial sample. Post-harvest soil pH values were 4.4, 4.0, 4.1, 4.6, 3.9, 4.2, 4.1, 4.4, 4.8 and 4.3 in the treatments T1, T2, T3, T4, T5, T6, T7, T8, T9 and T10, respectively.
The total N of the initial soil was 0.17%. Post-harvest soil analysis showed that the total N was as similar as initial sample. Post-harvest soils total N were 0.12, 0.15, 0.16, 0.14, 0.19, 0.13, 0.17, 0.12, 0.14 and 0.12% showed in the treatments T1, T2, T3, T4, T5, T6, T7, T8, T9 and T10, respectively.
The soil organic matter status not so varied in the post-harvest soil. The initial soil organic matter was 3.10 %. Post-harvest organic matters were 2.16, 2.83, 3.03, 2.56, 4.04, 2.29, 3.24, 2.16, 2.63 and 2.16 % in T1, T2, T3, T4, T5, T6, T7, T8, T9 and T10, treatments,respectively.

The available P of the initial soil was 3.85 ppm. Post-harvest soil analysis showed that the available P was higher than initial sample. Post-harvest soil available P were observed 70, 11, 7, 16, 8, 15, 11, 6, 14 and 55 ppm T1, T2, T3, T4, T5, T6, T7, T8, T9 and T10, treatments, respectively.
The exchangeable K of the initial soil was 0.09 meq/100 g. Post-harvest soil analysis showed that the exchangeable K values were lower than initial sample. Post-harvest soil exchangeable K values were 0.03, 0.04, 0.06, 0.08, 0.09, 0.04, 0.07, 0.05 and 0.11 meq/100 g in the treatments of T1, T2, T3, T4, T5, T6, T7, T8, T9 and T10, respectively.

Table 3.37Nutrient status of Initial and Post-harvest soils before and after the medicinal plant cultivation in Agar – Medicinal plant intercropping

Treatments	pH	Total-N %	OM %	Exchangeable K (meq/100g)	Available P (ppm)	Available S (ppm)
Initial Soil	3.74	0.17	3.10	0.09	3.85	18.38
Kalmegh (T_1)	4.4	0.12	2.16	0.03	70	14
Bashok (T_2)	4.0	0.15	2.83	0.04	11	17
Tulsi (T_3)	4.1	0.16	3.03	0.06	7	20
Sarpagandha (T_4)	4.6	0.14	2.56	0.08	16	21
Ashwagandha (T_5)	3.9	0.19	4.04	0.08	8	28
Agar + Kalmegh (T_6)	4.2	0.13	2.29	0.09	15	13
Agar + Bashok (T_7)	4.1	0.17	3.24	0.04	11	10
Agar + Tulsi (T_8)	4.4	0.12	2.16	0.07	6	15
Agar + Sarpagandha (T_9)	4.8	0.14	2.63	0.05	14	10
Agar + Ashwagandh (T_{10})	4.3	0.12	2.16	0.11	55	10

Similar results were reported in case of available S. The available S of the initial soil was 18.38 ppm. Post-harvest soil available S were 14, 17, 20, 21, 28, 13, 10, 15, 10 and 10 ppm of T1, T2, T3, T4, T5, T6, T7, T8, T9 and T10, treatments, respectively.

Experiment 4. Determination of Chemical Compositions in Agar wood and oil

4.1 Determination of density of Agarwood for their grading

For the determination of desity of agarwood, the method as described by Bangladesh Forest Research Institute was followed with necessary modifications. After determination of the density of supplied agarwood sample, those three categories of agarwood samples were graded with three replications. Density was the highest in case of insect infested agarwoods (0.641 ± 0.85 g/cm^3) and were graded as Grade-1 agarwood, followed by Nailed (0.436 ± 0.052 g/cm^3) and White agarwood (0.361 ± 0.46 g/cm^3) and those two type agarwoods were classified as Grade-2 and Grade-3 agarwood, respectively (Table 4.3). Determined density of different agarwoodswere completely similar with the result from eye estimation and also with the information obtained from different agarwood businessman.

Table 4.1 Determined density of supplied reference wood from BFRI

Sample	Reference density (g/cm^3)	Determined density (g/cm^3)
Mahogony-1	0.740	0.742
Mahgony-2	0.742	0.743
Segun	0.831	0.832

Table 4.2 Determined density of white agar wood

Sample	Weight (g)	Volume (ml)	Density (g/cm^3)	Comment
Std-1a	4.789	16.5	0.291	All three results of density shows that the obtained results from the agar forming wood are comparable with our real agarwood sample
Std-2a	4.666	17.0	0.273	
Std-3a	5.323	17.5	0.304	

Table 4.3 Density of different agarwood sample

Categories of agarwood	Sample weight (g)	Volume of sample (ml)	Density of the sample (g/cm^3)	Determined grade of agarwood	Comment
White agarwood	5.411	76.0	0.361 ± 0.46	Grade-3	Increase density means more agar resin
Nailed agarwood	7.414	77.5	0.436 ± 0.052	Grade-2	
Insect infested agarwood	8.983	72.5	0.641 ± 0.85	Grade-1	

4.2 Evaluation of Ether Extract from Graded Agarwood

The results of ether extract (Table 4.4)indicate insect infested agarwood contained highest amount of essential oil extract (18.90 ± 0.60%) than Nailed (11.03 ± 0.19%) and White agar wood (1.84 ± 0.04%). Market price of insect infested agarwood oil is the highest which is supporting the present results of ether extract content.

Table 4.4 Ether extract content from agarwood samples

Agarwood samples	Ether extract %
Insect infested agarwood	18.90 ± 0.60
Nailed agarwood	11.03 ± 0.19
White agarwood	1.84 ± 0.04

4.3 Determination of Total Phenolics and Total Flavonoid

Results of total phenolics and flavonoid were expressed as mg GAE/g of agar wood samples (Yadav and Malpathak, 2016) which is shown in Table 5 and µg QE/ml for agar oil samples (Benslama and Harrar, 2016) which is shown in Table 6.

The phenolic content in insect infested agarwood, nailed agarwood and white wood were 3.5 ± 0.06 mg GAE/g, 2.98 ± 0.07 mg GAE/g and 2.50 ± 0.05 mg GAE/g, respectively. Results indicated that phenolic content was the highest in insect infested agarwood and the lowest in white agarwood.

In case of oil extracts, phenolic content in insect infested agarwood oil was 33.25 ± 0.66 µg GAE/ml and in nailed agarwood oil was 27.54 ± 1.97 µg GAE/ml. Among the two oil sample, insect infested agarwood oil possessed flavonoid content of 7.82 ± 0.23 µg QE/ml and nailed agarwood contained 6.58 ± 0.62 µg QE/ml.

Table 4.5 Total phenolics estimation from agarwood

Agarwood sample source	Phenolic content (mg GAE/g)
Insect infested	3.5 ± 0.06
Nailed	2.98 ± 0.07
White wood	2.50 ± 0.05

Table 4.6 Total phenolics and total flavonoid estimation of agar oil extract

Agarwood oil source	Phenolic content in µg GAE/ml	Flavonoid content in µg QE/ml
Insect infested wood oil	33.25 ± 0.66	7.82 ± 0.23
Nailed wood oil	27.54 ± 1.97	6.58 ± 0.62

4.4 Estimation of Antioxidant Status

Table 4.7 The inhibitory concentration of oil extracts on DPPH radical

Concentration (µg/ml)	Ascorbic %SCV	Sample % SCV	IC_{50} (µg/ ml) of Ascorbic acid	IC_{50} (µg/ ml) of agar oil sample
0.50	61.29032	32.25806		
0.75	82.25806	45.16129	0.268	0.904
1.00	90.32258	53.22581		

*SCV= scavenging activity

DPPH radical scavenging capacities of nailed agarwood essential oil extracts were tested at 0.50, 0.75 and 1.00 µg/ml concentrations. The inhibitory concentration of oil extract on DPPH are summarized in Table 4.7. All oil extracts were found to possess concentration-dependent inhibitory activity against DPPH radical. The antioxidant capacity is also expressed as 50% inhibitory concentration (IC_{50}). A lower IC_{50} value corresponds to a higher antioxidant activity of the oil extract (Singh et al., 2014). The scavenging activity on DPPH radical shown by agarwood essential oil was 0.904 µg/ ml of IC_{50} value. IC_{50} value of 0.904 µg/ml was observed in oil extracts of nailed agar wood.

4.5 Biochemical Tests for Identification of Genus of Microorganisms

Among, thirty (30) isolates the prevalence percentage of different genus of microorganisms has been listed in Table 8. Most of the microorganism present in agarwood soaking water belongs to *Bacillus spp.* Genus of some other microorganism like *Staphylococcus, E. coli, Pseudomonas, Aeromonas* and *Klebsiella* were also found but with lower occurrence, It can be concluded that the genus of most of the isolated bacteria was *Bacillus spp.* with identifying characteristics and may contribute in the fermentation of agarwood to increase agarwood yield.

Table 4.8 Number of bacterial isolates found with their prevalence percentage

Isolated bacteria	No. of isolates found	Prevalence (%)
Bacillus spp	20	66.7
Staphylococcus spp	6	23.3
E. coli	5	20
Pseudomonas spp	5	13.3
Aeromonasspp	4	20
Klebsiella spp.	2	6

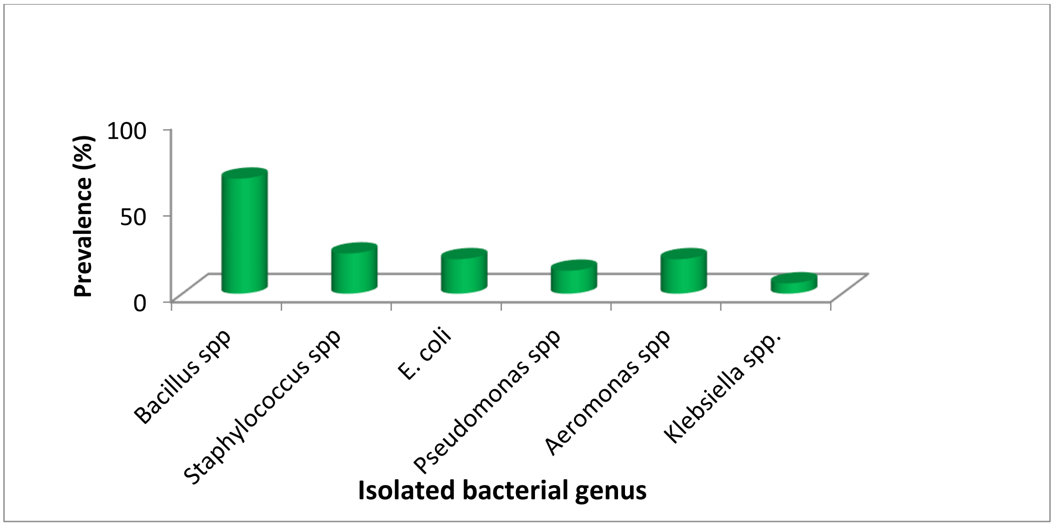

Figure 4.1Overall prevalence of bacterial isolates in agarwood soaking water

11. Research highlight/findings:

- Agar oil is collected from the agar wood through distillation process in the factories
- Lack of industrial gas connection is the major problems in case of agar oil production
- Lack capital, training and low wage rate is the major constraints faced by the agar workers
- Nailing is the major practices for production of quality agar oil
- Insect infested agarwood is found best quality among the three wood categories (insect infested, nailed and white) in respect to wood density, production of phenolic compound and resin
- Best quality agar oil produced due to insect infected agar trees
- Agar plantation and production of agar oil is the profitable enterprise
- Medicinal plants can be grown in the agar garden with intercropping
- Kalmegh and Basak is most suitable as intercrop with agar plantation
- The microorganisms were identified in agarwood soaking water belongs to *Bacillus spp.Staphylococcus, E. coli, Pseudomonas, Aeromonas* and *Klebsiella*, they may contribute in the fermentation of agarwood to increase agarwood yield.

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B. Implementation Position

1. **Procurement:**

Description of equipment and capital items	PP Target		Achievement		Remarks
	Phy (#)	Fin (Tk)	Phy (#)	Fin (Tk)	
(a) Office equipment	Desk Top Computer with printers, scanner, UPS and others: 1 set Camera: 1	80000/- 25000/-	Desk Top Computer with printers, scanner, UPS and others: 1 set Camera: 1	80000 /- 2500 /-	
(b) Lab &field equipment	Balance: 1 Oven: 1	35000 /- 80000 /-	Balance: 1 Oven: 1	35000 /- 79850 /-	
(c) Other capital items	-	-	-	-	

2. **Training/ study tour/ seminar/ workshop/ conference organized**

Workshops/Seminars	Date	Organized by
Training Workshop on Implementation Procedure of CRG sub-project	18 .06.2017	BARC
Research Review Workshop on CRG Sub-projects	21.12.2017	BARC
Monitoring workshop on CRG Sub-projects	15-16.05.2018	BARC
Annual research review workshop	17.09.2018	SAURES
Annual workshop on CRG sub-project	25.09.2018	BARC

C. Financial and physical progress

Fig in Tk

Items of expenditure/activities	Total approved budget	Fund received	Actual expenditure	Balance/ unspent	Physical progress (%)	Reasons for deviation
A. Contractual staff salary	844775	844775	573634		100	
B. Field research/lab expenses and supplies	792499	792499	587350		100	
C. Operating expenses	303931	303931	213975		100	
D. Vehicle hire and fuel, oil & maintenance	130000	130000	90000		100	
E. Training/workshop/seminar etc.	0	0	0			
F. Publications and printing	145000	145000	30000		100	
G. Miscellaneous	63945	63945	27495		100	
H. Capital expenses	219850		219850		100	

D. Achievement of Sub-project by objectives: (Tangible form)

Specific objectives of the sub-project	**Major technical activities performed in respect of the set objectives**	**Output(i.e. product obtained, visible, measurable)**	**Outcome(short term effect of the research)**
To identify the farmers best management practices for agar plant cultivation.	Survey	Report and Thesis	Information generation
To study the growth of agar plant and system productivity with intercropping of medicinal plants.	Experiment on biomass production	Report	Estimation of agar biomass
To suggest the policy and technological issues for improvement of agar production, processing and marketing	Survey, Experiment on intercropping of medicinal plants	Report and thesis	Confirmation of intercropping of medicinal plants with agar plants

E. Materials Development/Publication made under the Sub-project:

Publication	Number of publication		Remarks (e.g. paper title, name of journal, conference name, etc.)
	Under preparation	Completed and published	
Technology bulletin/ booklet/leaflet/flyer etc.	1		**Intercropping of Basak and Kalmegh in the agar plantation**
Journal publication		1	Evaluation of density metric grading of Agarwood, antioxidant potentiality in agar oil prevalence of unknown bacteria in Agarwood soaking water
Information development			
Other publications, if any (Thesis)	3	1	1. Determination of Chemical Compositions in Agar wood and oil 2. Effect of intercropping of medicinal plants in association with Agar plants 3. Farmers perception on Agronomic Practices of Agar Plant Cultivation in BarlekhaUpazila of Moulvibazar District 4. Farmers Awareness towards Agar Wounding Techniques at BarlekhaUpazila of Moulvibazar District in Bangladesh

F. Technology/Knowledge generation/Policy Support (as applied):

i. **Generation of technology (Commodity & Non-commodity)**

- Kalmegh and Basak is the suitable medicinal plants as intercrop with agar plantation
- The microorganisms were identified in agarwood soaking water belongs to *Bacillus spp.Staphylococcus, E. coli, Pseudomonas, Aeromonas* and *Klebsiella*, they may contribute in the fermentation of agarwood to increase agarwood yield.

ii. **Generation of new knowledge that help in developing more technology in future**

- Further research on balance fertilization, liming and other intercultural operation forhigher yield of Kalmegh and Basakas well as agarwood production with quality oil may be undertaken
- The identified microorganisms in agarwood soaking water *Bacillus spp.Staphylococcus, E. coli, Pseudomonas, Aeromonas* and *Klebsiella* are the new avenue for future research and development to improve the yield and quality of agar oil.

iii. **Technology transferred that help increased agricultural productivity and farmers' income**

Not applicable

iv. **Policy Support**

- Industrial gas connection should be the top priority to solve the problems in case of agar oil production
- Financial support for capital and training should be arranged for the agar workers
- Minimum wage rate should be adopted for the agar workers
- Financial support should be given to nail the agar plants for production of quality agar oil
- Medicinal plants Kalmegh and Basakmay be promoted as intercrop with agar plantation

G. Information regarding Desk and Field Monitoring

i) **Desk Monitoring[description & output of consultation meeting, monitoring workshops/seminars etc.**

Monitoring team	Date (s) of visit	Total visit till date	Remarks
Technical Division/ Unit, BARC	17.02.2018	01	The monitoring team recommended for time extension of the project
PIU-BARC, NATP-2	07.04.2018	01	
Internal Monitoring	08.01.2018 03.06.2018	02	
Others visitors (if any)	30.06.2018	01	

ii) **Field Monitoring (time& No. of visit, Team visit and output):**

Team visit	No. of visit	Date (s)	output
PIU-BARC, NATP-2	01	18.02.2018	
PIU-BARC, NATP-2	01	07.04.2018	
Internal Monitoring	02	08.01.2018 03.06.2018	

I. Lesson Learned/Challenges (if any)

i) Intercropping of medicinal plants in agar plantation is profitable

ii) Distillation efficiency for agar oil production can be improved

J. Challenges (if any)

I. Cost of nailing is very high
II. Export of agar oil is a cumbersome process
III. Extreme dry during February March limits the growth of agar plants as well as

Signature of the Principal Investigator
Date ………………………….
Seal

Counter signature of the Head of the
organization/authorized representative
Date …………………………..
Seal

PHOTOGRAPHS

Photograph 1.1 Visiting Agar garden in Barlekhaupazila

Photograph 1.2 Talking with Agar farmers

Photograph 1.3 Nailing pattern in Agar tree

Photograph 1.4 Natural insect infestation in agar old tree

Photograph 1.5Separating agar tree

Photograph 1.6 Separation of iron stick

Photograph 1.7 Cutting of agar wood in small pieces

Photograph 1.8 Chopped Agar wood soaking in water

Photograph 1.9 Data collection through questionnaire

Photograph 1.10 Burner for distillation of agar oil at Agar industry

Photograph 1.11 Distillation of agar oil

Photograph 2.1 Recording growth performance of Agar plant under different age

Photograph 2.2 Recording of biomass through different measuring scale

Photograph 2.3 Collecting soil sample from different Agar garden

Photograph 2.4 Agar plant in nursery

Photograph 3.1 Site selections in Barlekhaupazila, Moulvibazar district

Photograph 3.2 Preparation of experimental field

Photograph 3.3 Experimental field

Photograph 3.4 Tulsi and Bashok plants in experimental field

Photograph 3.5 Data collection on growth parameters

Photograph 3.6 Diagnosis of leaf blight of Kalmegh

Photograph 3.7 Monitoring of experimental field by BARC monitoring team


Photograph 3.8 Selection of $1m^2$ area for harvesting

Photograph 3.9 Harvested medicinal plants with farmers

Photograph 3.10 Harvested Kalmegh plant


Photograph 3.11 Recording data after harvesting


Photograph 3.12 Measuring of height of Kalmegh plant after harvesting

Photograph 4.1 Agarwood of different grades

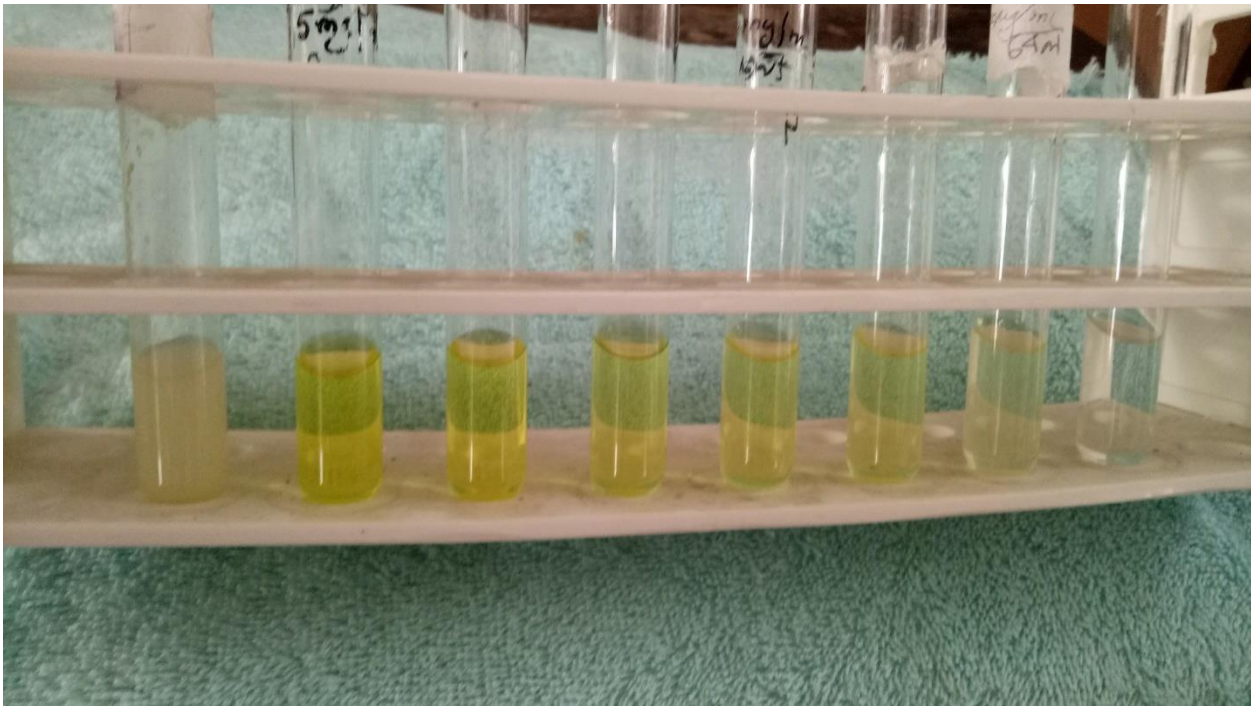
Photograph 4.2 Mechanically grinded agarwood

Photograph 4.3 Preparation of different series of solution for calibration curve and their reading in colorimeter

Photograph 4.4 Determination of total phenolics from different agarwood and agarwood oil

$$\text{Density} = \frac{\text{Mass}}{V_f - V_i}$$

Photograph 4.5 Determination of density of agarwood



Photograph 4.6 Preparation of different series of solution for calibration curve and their reading in colorimeter

Photograph 4.7 Total flavonoid determinations from agarwood oil