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Study on Juvenile Phase of *Aquilaria malaccensis* (Agar) in Terai Zone of West Bengal

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A B S T R A C T

Agar scientifically known as *Aquilaria malaccensis* Lamk, belonging to the family Thymelaeceae. It is an economically important native tree species of sub-tropical-tropical rainforests of northeast India. The species is included in the Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES). *Aquilaria malaccensis* seeds having recalcitrant in nature and viviparous. The species is also listed as 'Vulnerable' globally, 'Critically Endangered' in India (IUCN). Study was carried out in the Department of Forestry during 2015-2018. The aim of this investigation was to measure the variability of seedling traits. Collection of seed was carried out across the population of *Aquilaria malaccensis* throughout Mizoram, Nagaland, Assam, West Bengal and Tripura to select well represented nineteen seed sources viz. Basistha, Ganakpokhari, Hathipara, Hmarveng, Hybergyon, Islam nagar, Kumar ghat, Lanka, Lonigodam, Nagariborline, Naharani, Namti, Nazari, Nelbagan, Newdiakkawan, Rajabhatkhawa, Sephizala, Sukhana and Thikau, Juvenile phase study was carried out each respective seed source were raised in randomized block design to assess growth performance with respect to plant height (cm), collar diameter (mm), root length (cm), fresh weight leaf (g), fresh weight of shoot (g), fresh weight of root (g), dry weight of leaf (g), dry weight of shoot (g), dry weight of root (g), number of secondary root, number of tertiary root, number of branch, root length/shoot length ratio, volume index ($cm.mm^2$), total biomass (g) recorded respectively range 40.05-45.42 cm, 4.95-6.43 mm, 20.01-22.9 cm, 3.92-7.53 g, 3.55-7.91 g, 2.35-5.20g, 1.22-2.34, 1.13-2.51, 0.79-1.74, 25.64-36.90, 221.05-358.57, 3.67-6.79, 0.42-0.51, 992.60-1897.19 $cm.mm^2$, 3.13-6.58g.

***Key words*:** *Aquilaria malaccensis,* GCV, Genetic gain, Heritability (h^2), PCV

Natural resources and astounding biodiversity of India is being depleted by various factors like increasing rate of human and livestock population, hunger, poverty, destitution and famine. Besides these factors, economic growth, modernization and civilization accelerate this problem. However, people are still dependent on the renewable natural biological resources, mainly forests for food, fodder, medicine, household goods and not the least, spiritual and cultural sustenance. Since ancient times, the forest is interwoven with the progress of civilization. Unable to meet their basic needs from agriculture, people are forced to exploit forest not only for fodder and fuel but also to generate cash income through sale of wood and other forest produce. Illegal approach as well as unsustainable harvesting of timber and other produce makes the dwindling of the forest which ultimately leads the widening gap between the demand and supply of needs. This resulted into a situation that per capita forest land at present is only 0.064 ha, down from 0.2 ha in 1951 against the world average 0.64 ha whereas the productivity is 1.34 m3 per hectare per year against the world's average of 2.1 m3 per hectare per year [1].

Aquilaria malaccensis is one of the economic tree species of tropical and sub-tropical rain forest of North East India. The species is also listed as 'Vulnerable' globally, 'Critically Endangered' in India (IUCN). *Aquilaria malaccensis* Lamk (Syn: *Aquilaria agallocha* Roxb.) belonging to family Thymelaeaceae, the species is included in the Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES). This species is commonly known as agar wood or aloe wood or eagle wood or gaharu, a highly commercial resinous wood used for incense [2-3]. It is an evergreen tree found growing naturally in the foothills of the North Eastern States of India (Assam, Arunachal Pradesh, Nagaland, Manipur, Mizoram, and Tripura) and West Bengal up to an altitude of 1000 msl [4-5]. Recently, natural population of the species has been reported existing in pockets in Assam and Arunachal Pradesh [6]. This species also occurs in Burma, Malaysia, Philippines, Indonesia and China. Also, it is found in primary and secondary forest, mainly in lowland and on hillsides between altitudes of 100 m up to 1000 msl under high humid, subtropical climate i.e., Koeppen climate type A – B with temperatures of 14 – 32°C with rainfall 2000 - 4000 mm

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[7]. This species is well adapted to live in various habitats. It grows well on sandy clay soil.

The main objective of *A. malaccensis* breeding programme is to improve the species oil quantity and quality. This could be achieved through selection of superior genotypes among the population. Stem diameter is particularly focused for oil exploitation and it is associated with a number of components which are interrelated. Because of the recalcitrant type of seeds, very few works have been done on agarwood like seed source variation, genetic variation in growth and to understand the response of agarwood seedlings to environmental factors. The genetic resources of this species are depleting because of large scale commercial exploitation. Therefore, there is an urgent need to harness variation for better results, determining the amount and nature of variation present for future multiplication of the superior selections. Looking at the vital importance and the paucity of sufficient information, the present investigations were carried out Juvenile phase study of *Aquilaria malaccensis (*Agar) in terai zone of West Bengal.

MATERIALS AND METHODS

The present study entitled as "Juvenile phase study of *Aquilaria malaccensis (*Agar) in terai zone of West Bengal" was carried out to study the pattern of plant height (cm), collar diameter (mm), root length (cm), fresh weight leaf (g), fresh weight of shoot (g), fresh weight of root (g), dry weight of leaf (g), dry weight of shoot (g), dry weight of root (g), number of secondary root, number of tertiary root, number of branch, root length/shoot length ratio, volume index ($cm.mm^2$), total biomass (g) of *Aquilaria malaccensis*, in the experimental field of the Department of Forestry, Uttar Banga Krishi Viswavidyalaya, Pundibari, Cooch Behar, West Bengal during the year 2015 to 2018. (Table 1) show Geographic characteristics of seed sources of *A. malaccensis*. (Fig 1-2) showing capsules and seed of the *A. malaccensis*.

Fig 1 capsules of the *A. malaccensis*

Fig 2 Seed of the *A. malaccensis*

Table 1 Geographic characteristics of seed sources of *A. malaccensis*

Name of seed source	District/ State	Latitude (N)	Longitude (E)	Altitude (msl)
Basishta	Guwahati,Assam	26°05' 55.7'' N	91°47' 40.8' E	55.3
Ganakpokhari	Golaghat,Assam	26°37' 58.6'' N	93°58' 58.6' E	89.6
Hathipara	Agartala, Tripura	23°53' 01.4'' N	91°17' 07.3' E	40.6
Hmarveng	Kolasib, Mizoram	24°19' 18.1'' N	92°45' 30.6' E	682.7
Hybergyon	Nagaon, Assam	26°31' 38.7'' N	93°58' 23.6' E	91.1
Islamnagar	Hojai, Assam	21°39' 37.6'' N	92°17' 49.9' E	87.5
Kumarghat	Unakoti, Tripura	24°09' 51.9'' N	92°01' 19.5' E	42.5
Lanka	Nagaon, Assam	25°46' 10.5'' N	92°48' 22.9' E	98.2
Lonigodam	Nagaon, Assam	26°21' 95.7'' N	92°46' 80.7' E	86.5
Nagariborline	Der Gyon, Assam	21°03' 48.6'' N	92°54' 05.3' E	89.3
Naharani	Sivsagar, Assam	27°08' 10.5'' N	94°48' 56.1' E	93.4
Namti	Sivsagar, Assam	26°51' 24.6'' N	94°37' 44.2' E	90.2
Nazaria	Sivsagar, Assam	26°54' 02.3'' N	94°43' 00.7' E	75.1
Nilbagan	Hojai, Assam	21°03' 48.6'' N	92°54' 05.3' E	89.3
New Diakkawn	Kolasib, Mizoram	24° 13' 16.8'' N	92° 41' 09.7' E	520.5
Rajabhatkhawa	Alipurduar, West Bengal	26°37' 00.9'' N	89°31' 59.0' E	76.3
Sephizala	Agartala, Tripura	23°39' 37.6'' N	91°17' 49.9' E	78.6
Sukhana	Jorhat, Assam	26°43' 37.6'' N	94°11' 41.8' E	110.3
Thikau	Dimapur, Nagaland	25°53' 17.8'' N	93°43' 24.5' E	121.3

Description of experiment site

The experimental site is located on plains of Terai zone of West Bengal with an elevation of 43 m above mean sea level. It is located at 15 km south west direction of Cooch Behar district with 26°23'86'' N latitude and 89°25'53'' E longitude.

Juvenile phase growth studies

Three months old seedlings were transplanted in the experimental field during the month of October, 2015 in randomized block design with three replications having 20 seedlings per seed source. Pits of 30 cm x 30 cm x 30 cm size were dugout at a spacing of 2 m x 2 m for seedling plantation. The following growth parameters were recorded for a year at the interval of 6 months. Data recorded collar diameter (mm), plant height (cm), root length (cm), root-shoot length ratio, number of branches, number of primary root, number of secondary root, root / shoot ratio (r/s), leaf fresh weight (g), root fresh weight (g), shoot fresh weight (g) , leaf biomass (g), root and shoot dry biomass (g), total biomass per plant (g), and volume index of seedling: Volume index was calculated on the basis of the following equation as given by Hatchell [8] on periodic interval of 6 and 12 months respectively.

$$VI = \text{Diameter (mm)}^2 \times \text{Height (cm)}$$

Statistical analysis

The field experiment data analyzed according to the procedure of analysis of variance for two factor randomized block design with three replications for field level growth performance. The data were subjected to Statistical analysis as described by Panse and Sukhatme [9]. A suitability index was worked out on the basis of height, collar diameter, total leaf area

and total biomass of the seedlings. Genres software were used all data analysis.

Computation of variability parameters

Variances estimation

Genotypic, phenotypic and environmental variances were calculated using the following equations as given by Burton and Devane [10].

Phenotypic coefficient of variation (PCV)

It is the measure of total variation existing in a particular character, expressed in percentage which was calculated as suggested by Burton and Devane [10].

Genotypic coefficient of variance (GCV)

GCV represents the manner of total genetic variability existing in a particular character, expressed in percentage and it was calculated as per Burton and Devane [10].

Broad sense heritability (h^2)

Broad sense of heritability is the ratio of genetic variance to the phenotypic variance and was estimated as suggested by Burton and Devane [10] and Johnson *et al*. [11].

Genetic advance (GA)

Genetic advance is the expected increase in the magnitude of a particular character when a selection pressure of chosen intensity is applied. This was calculated as per Johnson *et al.* [11].

Genetic gain

Genetic gain is expressed in percentage and was calculated using the formula as put forth by Johnson *et al.* [11].

Correlation coefficient

Simple correlation (Karl Pearson's), multiple correlation and regression equation were worked out as per the procedure mentioned by Gupta [12].

RESULTS AND DISCUSSION

Height of plant

Under field evaluation studies, data on mean values of height recorded at the age of 6 and 12 months have been presented in (Table 2). Wide variations in height were observed among different seed sources at all periodic intervals. On an average, the height varied from 30.48 to 42.82 cm from 6 to 12 months of growth in field. After attaining the age of 6 and 12 months, maximum height increment was recorded in Rajabhatkhawa (36.67 and 45.42 cm) seed source and minimum was found in Basistha (24.27 cm) and Nazaria (40.05 cm) at 6 and 12 months, respectively. The seed source of Rajabhatkhawa (36.67 cm) was statistically at par with Hmarveng (35.18 cm) and Ganakpokhari (45.33 cm) at 6 and 12 months, respectively in relation to height among the seed sources. Analysis of variance (ANOVA) of the data showed that the differences between the seed sources were statistically significant (p = 0.05) at all periodic intervals. (Fig 3) showing growth performance of *A. malaccensis* after one year.

Table 2 variation in plant height, collar diameter and root length

Name of seed source	6 month	12 month	6 month	12 month	6 month	12 month
	Plant height		Collar diameter		Root length	
Basistha	24.27^{j}	43.22^{abcd}	2.29^{h}	5.14^{bc}	15.64^{def}	20.60
Ganakpokhari	29.38^{fgh}	45.33^{ab}	2.88^{fg}	6.06^{a}	16.06^{de}	22.30
Hathipara	31.02^{cdef}	41.81^{de}	3.34^{cd}	5.25^{bc}	16.44^{cd}	20.30
Hmarveng	35.18^{ab}	42.10^{de}	3.58^{bc}	5.40^{b}	15.76^{def}	20.01
Hybergyon	30.88^{cdef}	43.34^{abcd}	3.06^{def}	5.22^{bc}	15.81^{def}	20.20
Islamnagar	28.74^{fghi}	42.64^{cde}	2.67^{g}	5.14^{bc}	15.36^{efg}	20.50
Kumarghat	32.66^{bcde}	41.78^{de}	3.18^{def}	5.27^{bc}	15.62^{def}	21.11
Lanka	29.90^{efg}	42.16^{de}	3.15^{def}	5.17^{bc}	13.90^{h}	20.90
Lonigodam	30.50^{defg}	41.21^{de}	3.21^{de}	5.25^{bc}	17.56^{b}	20.70
Nagariborline	30.93^{cdef}	43.19^{abcd}	3.71^{b}	5.48^{b}	17.48^{b}	20.11
Naharani	32.44^{bcde}	44.92^{abc}	3.38^{cd}	6.40^{a}	17.18^{bc}	20.50
Namti	26.71^{hij}	41.73^{de}	2.93^{efg}	5.27^{bc}	15.04^{fg}	20.70
Nazaria	26.24^{ij}	40.05^{e}	3.17^{def}	4.95^{c}	15.47^{efg}	20.40
Nelbagan	27.80^{ghi}	42.01^{de}	3.62^{bc}	5.25^{bc}	17.59^{b}	21.50
New diakkawn	33.60^{bc}	41.78^{de}	3.35^{cd}	5.37^{b}	15.11^{fg}	20.40
Rajabhatkhawa	36.67^{a}	45.42^{a}	4.25^{a}	6.43^{a}	18.56^{gh}	22.90
Sephijala	33.22^{bcd}	45.01^{abc}	4.31^{a}	6.09^{a}	14.61^{gh}	21.90
Sukhana	32.62^{bcde}	43.00^{abcd}	3.37^{cd}	5.33^{bc}	14.67^{a}	21.03
Thikau	26.33^{ij}	42.80^{bcd}	3.12^{def}	5.28^{bc}	15.28^{efg}	20.70
Mean	30.48	42.82	3.29	5.46	15.95	20.73
CV (%)	5.62	3.75	5.77	4.28	3.54	4.86
S.Em (±)	0.989	0.425	0.109	0.134	0.326	0.575
CD (p=0.05)	2.839	2.656	0.314	0.3869	0.936	NS

Collar diameter of plant

With regard to collar diameter, it showed increasing trend in all seed sources at each periodic intervals (Table 2). The collar diameter of seedling was statistically significant variation (p = 0.05) among different seed sources at 6 and 12 months growth in field condition. The collar diameter varied from 2.29 mm in Basistha to 4.31 mm in Sephizala seed source at 6 months where as it ranged from 4.95 mm (Nazaria) to 6.43 mm (Rajabhatkhawa) at 12 months. The highest collar diameter (4.31 mm) was recorded in Sephizala which was closely followed by Rajabhatkhawa (4.25 cm) at 6 months and Rajabhatkhawa (6.43 mm) closely followed by Naharani (6.40 mm), Sephizala (6.09 mm) and Ganakpokhari (6.06 mm) and statistically at par with each other at 12 months among the seed sources. After attaining the age of 12 months, the seed source of Nazaria recorded minimum (4.95 mm) collar diameter.

Analysis of variance (ANOVA) indicated significant differences (p = 0.05) among the different seed sources for collar diameter at all periodic intervals.

Root length

An appraisal of (Table 2), indicates that the different seed sources recorded increasing trend of root length of seedling and showed statistically significant variation (p = 0.05) among different seed sources. On an average, the root length of plants ranged between 13.90 to18.56 cm with a mean value of 15.95 cm and 20.01 to 22.90 cm with an average value of 20.73 cm at the age of 6 and 12 months, respectively among the seed sources. Maximum root length was noted for Rajabhatkhawa (18.56 and 22.90 cm) whereas minimum was recorded in Lanka (13.90cm) and Hmarveng (20.01 cm) at 6 and 12 months growth, respectively in field. Root length differed significantly (p = 0.05) among the seed sources in field.

Fig 3 One year old seedling of *A. malaccensiso* seed sources

Table 3 Variation in root length/shoot length ratio, number of branches per plant, number of secondary and tertiary roots of different seed sources of *Aquilaria malaccensis* at different growth period in field

Seed source	Root length/shoot length ratio		Number of branches/plant		Number of secondary roots		Number of tertiary roots	
	6 month	12 month	6 month	12 month	6 month	12 month	6 month	12 month
Basistha	0.64^{a}	0.48^{abcd}	2.67^{bcde}	4.67b^{cdef}	13.87	26.06^{aef}	124.61	249.27^{defgh}
Ganakpokhari	0.55^{cd}	0.49^{abc}	2.78^{bcde}	5.55^{abcd}	16.45	25.64^{f}	146.68	221.05^{h}
Hathipara	0.53^{cde}	0.46^{bcde}	2.89^{bcd}	5.71^{abc}	16.01	36.09^{b}	137.87	333.69^{a}
Hmarveng	0.45^{gh}	0.48^{abcd}	1.67^{e}	4.67^{bcdef}	12.28	26.64^{ef}	109.08	229.10^{gh}
Hybergyon	0.51d^{ef}	0.47^{abcd}	2.33^{bcde}	5.77^{abc}	15.19	26.05^{ef}	133.76	244.59^{defgh}
Islamnagar	0.53^{cde}	0.48^{abcd}	2.41^{bcde}	5.67^{abc}	13.93	26.25^{ef}	127.77	235.70^{fgh}
Kumarghat	0.48^{efg}	0.50^{ab}	2.63^{bcde}	3.78^{f}	13.04	28.95^{cde}	113.09	275.57^{cd}
Lanka	0.46^{fg}	0.47^{abcd}	2.00^{bcde}	4.67^{bcdef}	15.8	36.94^{def}	141.13	358.57^{cdefg}
Lonigodam	0.58^{bc}	0.50^{abc}	2.41^{bcde}	4.67^{bcdef}	12.65	28.46^{a}	108.98	349.37^{a}
Nagariborline	0.57^{cd}	0.46^{bcde}	3.33^{ab}	5.85^{ab}	14.79	29.88^{cde}	136.89	283.92^{cb}
Naharani	0.53^{cde}	0.46^{cde}	2.22^{cde}	5.04^{bcde}	14.52	25.71^{f}	135.38	239.07^{efgh}
Namti	0.56^{cd}	0.50^{abc}	2.44^{cde}	5.67^{ab}	15.09	27.47^{def}	141.24	246.98^{cdefgh}
Nazaria	0.59^{abc}	0.51^{a}	3.22^{abc}	4.44^{cdf}	13.99	28.86^{cdef}	123.54	261.67^{cde}
Nelbagan	0.63^{ab}	0.51^{a}	3.11^{abc}	5.22^{bcde}	15.89	27.72^{def}	143.31	261.12^{cdefg}
New diakkawn	0.45^{gh}	0.49^{abcd}	1.74^{de}	3.67^{def}	13.93	26.75^{ef}	124.87	253.61^{cdefg}
Rajabhatkhawa	0.40^{h}	0.45^{de}	4.00^{a}	6.79^{a}	13.94	29.18^{cdef}	121.64	265.84^{cdef}
Sephizala	0.44^{gh}	0.42^{e}	2.48^{bcde}	4.00^{ef}	13.76	32.47^{bc}	120.7	309.84^{ab}
Sukhana	0.57^{cdg}	0.49^{abcd}	2.00^{bcde}	4.77^{bcdef}	14.17	30.94^{cd}	124.12	296.75^{bc}
Thikau	0.58^{bc}	0.48^{abcd}	1.33^{e}	4.67^{bcdef}	13.72	25.85^{f}	124.12	232.24^{gh}
Mean	0.53	0.48	2.51	5.01	14.37	28.73	128.36	265.68
CV (%)	6.93	5.70	23.09	16.24	13.85	8.17	13.87	7.18
S.Em (±)	0.0212	0.0157	0.367	0.4831	1.148	1.354	10.282	10.905
CD (p=0.05)	0.060	0.045	1.055	1.38	NS	3.886	NS	31.282

Root length / shoot length ratio

A perusal of (Table 3) reveals that the significant variation of root-shoot length ratio among the different seed sources. On average, the root-shoot ratio was found to be 0.53 and 0.48 at the age of 6 and 12 months, irrespective of seed sources, indicating the decreasing trend. But individually, it did not follow the decreasing trend in each seed sources. At 6 months, highest root - shoot length ratio was recorded in Basistha (0.64) followed by Nelbagan (0.63) whereas Nelbagan and Nazaria; both had same ratio (0.51), showed maximum at 12 months. Lowest (0.40 and 0.42) was exhibited in Rajabhatkhawa and Sephizala seed source, respectively at 6 and 12 months growth among the seed sources.

Number of branches / plant

(Table 3), represents the data on number of branches per plant at periodic intervals in field condition. Number of branches per plant differed significantly among the seed sources. The development of number of branches per plant showed increasing trend with all periodic intervals. At the age of 6 and 12 months, maximum (4.12 and 6.79) number of branches per plant was initiated in Rajabhatkhawa seed source where as Thikau and Kumarghat registered minimum (1.33 and 3.67) number of branches per plant when plants attained 6 and 12 month old in the field. On an average, the number of branches per plant increased twice from 6 to 12 months growth period, irrespective of seed sources.

Number of secondary and tertiary root

Wide variations in the number of secondary and tertiary roots were observed in each periodic growth in seedlings of all seed sources and are given in table 3. Number of secondary and tertiary roots increased with successive increase in age. The number of secondary roots varied from 12.28 to 16.45 with a mean value of 14.37 and 25.64 to 36.94 with an average of 28.73 at 6 and 12 months, respectively, irrespective of seed sources. Among the seed sources Ganakpokhari exhibited maximum (16.45) number of secondary roots followed by Hathipara (16.01) and Hybergyon (12.28) followed by (12.65) at 6 months growth in field. Similarly, number of secondary roots was highest in Lonigodam (36.94) followed by Hathipara (36.09) seed source at 12 months old seedlings. Number of tertiary roots was maximum in Ganakpokhari (146.68) followed by Nelbagan (143.31) and Namti (141.24) among the all-seed sources and minimum was in Lonigodam (108.98) followed by Hmarveng (109.08) at 6 months growth. At the end of 12 months growth, Lanka seed source exhibited highest (358.57) followed by Lonigodam (349.37) and lowest was seen in Ganakpokhari (221.05) followed by Hmarveng (229.10) among the seed sources (Table 3). Seedlings generally produce one or several main roots directly from seeds which then give rise to laterals and subsequent laterals [13]. The variations may be attributed due to the genetic character of the species and physical condition of the soil [14-15].

Table 4 Variation in fresh weight leaf (g), fresh weight of shoot (g) and fresh weight of root (g) of different seed sources of *Aquilaria malaccensis* at different growth period in field

Seed source	Fresh weight leaf (g)		Fresh weight of shoot (g)		Fresh weight of root (g)	
	6 month	12 month	6 month	12 month	6 month	12 month
Basistha	1.13^{efgh}	4.18^{gh}	0.73^{e}	5.01^{cdefg}	0.43^{i}	3.43^{defgh}
Ganakpokhari	1.20^{bcd}	4.57^{efgh}	0.73^{e}	4.53^{efg}	0.73^{b}	2.65^{hij}
Hathipara	1.04^{ghi}	3.92^{h}	0.82^{bcde}	3.55^{h}	0.52^{fg}	2.35^{j}
Hmarveng	1.54^{a}	5.63^{bcdef}	0.88^{abcd}	5.71^{bcde}	0.51^{gh}	3.28^{efghij}
Hybergyon	1.15^{defgh}	5.06^{cdefgh}	0.72^{ef}	5.58^{bcdef}	0.59^{e}	4.25^{bcde}
Islamnagar	1.11^{fgh}	4.47^{efgh}	0.83^{bcde}	4.21^{gh}	0.44^{i}	2.64^{hhij}
Kumarghat	1.30^{bcdef}	5.62^{bcdf}	0.89^{abcd}	5.83^{bcd}	0.85^{a}	3.37^{efghi}
Lanka	1.22^{cdefg}	5.52^{bcdefg}	0.86^{bcd}	6.47^{b}	0.45^{hi}	4.57^{bc}
Lonigodam	0.88^{i}	4.23^{gh}	0.61^{f}	4.68^{defgh}	0.71^{bc}	2.38^{ij}
Nagariborline	1.33^{bcd}	4.57^{defgh}	0.72^{e}	4.72^{defgh}	0.59^{e}	3.56^{defgh}
Naharani	0.96^{hi}	5.88^{bcd}	0.73^{e}	6.21^{bc}	0.61^{de}	5.06^{a}
Namti	1.47^{ab}	5.65^{bc}	0.72^{e}	5.84^{bcd}	0.61^{de}	3.79^{cdefg}
Nazaria	0.89^{i}	4.18^{gh}	0.77^{de}	3.96^{fgh}	0.48^{a}	2.76^{hij}
Nelbagan	1.25^{cdef}	5.19^{a}	0.94^{ab}	5.57^{a}	0.67^{bc}	3.33^{ab}
New Diakkawn	1.48^{ab}	6.53^{ab}	0.78^{de}	6.31^{b}	0.57^{ef}	$3.^{89cdef}$
Rajabhatkhawa	1.59^{cdef}	$7.53^{bcdefgh}$	1.00^{a}	7.91^{bcdef}	0.89^{ghi}	5.20^{fghij}
Sephizala	1.36^{abc}	5.81^{bcd}	0.92^{abc}	6.24^{b}	0.31^{j}	4.41^{bcd}
Sukhana	1.32^{bcde}	4.47^{defgh}	0.78^{de}	3.87^{gh}	0.66^{cd}	2.87^{ghij}
Thikau	1.46^{ab}	4.76^{cdefgh}	0.81^{cde}	4.03^{gh}	0.51^{fg}	2.85^{ghij}
Mean	1.23	5.15	0.80	5.28	0.58	3.56
CV (%)	9.89	15.73	9.02	14.63	5.86	16.97
S.Em (±)	0.070	0.468	0.041	0.448	0.019	0.347
CD (p=0.05)	0.202	1.344	0.119	1.286	0.056	0.995

Fresh weight of leaf, shoot and root

The results pertaining to fresh weight of leaves, shoot and root are presented in (Table 4). A critical observation on ANOVA, the data showed the significant differences (p = 0.05) for all traits among all provenances at all periodic intervals. The fresh weight of leaves ranged from 0.88 – 1.59 g/plant with a mean value of 1.23 g/plant and 3.92 – 7.53 g/plant with an average value of 5.15 g/plant at 6 and 12 months of growth of seedling, respectively. On an average, fresh weight increased by a factor of 4 times more in between 6 to 12 months growth in field as compared to 6 months growth. At 6 and 12 months growth, maximum (1.59 and 7.53 g/plant) fresh leaf weight was recorded in Rajabhatkhawa and minimum was in the seed source of Lonigodam (0.88 g) and Hathipara (3.92 g/plant). The average fresh shoot weight was found to be 0.80 and 5.28 g/plant at the age of 6 and 12 months, respectively, irrespective of seed sources. It also increased by a factor 6.5 times in 6 – 12 months growth under field condition. Wide and significant variations were noticed among the seed sources for fresh shoot weight at two periodic intervals. Highest fresh shoot weight was

recorded in Rajabhatkhawa (1.00 and 7.91g/plant) at two periodic intervals whereas lowest was in Lonigodam (0.61 g/plant) and Hathipara (3.55 g/plant) at 6 and 12 months growth in field. The average fresh root weight ranged from 0.31 – 0.89 g/plant and 2.35 – 5.20 g/plant at 6 and 12 month old seedlings in field condition. It exhibited increasing trend with increasing age. The maximum fresh root weight was observed in Rajabhatkhawa (0.89 and 5.20 g/plant) at two periodic intervals while minimum was noticed in Sukhana (0.31 g) and Hathipara (2.35 g) at the age of 6 and 12 months.

Dry weight of leaf, shoot and root

The (Table 5) depicts that dry weight of leaf, shoot and root biomass increased gradually at two periodic intervals. Leaf biomass in different seed sources varied from 0.40 (Lonigodam) – 0.72 g/plant (Rajabhatkhawa) with an average value of 0.57 g/plant at the age of 6 months and varied from 1.22 (Hathipara) - 2.34 g/plant (Rajabhatkhawa) with a middle value of 1.60 g/plant after 12 months of field growth. In two periodic intervals, Rajabhatkhawa seed source registered maximum leaf biomass among the different seed sources. At the age of 6 and 12 months, Lonigodam and Hathipara seed sources recorded minimum (0.40 and 1.22 g/plant) leaf biomass, respectively. With regards to shoot biomass per plant, the average shoot dry weight was 0.29 and 1.67 g/plant at the age of 6 and 12 months of field growth, respectively. The maximum shoot biomass was observed in Rajabhatkhawa (0.36 and 2.51 g/plant) in both periods among different seed sources whereas Lonigodam (0.22 g/plant) and Hathipara (1.13 g/plant) exhibited minimum shoot biomass when seedlings were 6 and 12 months old. The trend was similar to leaf biomass. On an average, the root dry weight of seedling ranged in between 0.28 to 1.19 g/plant from 6 to 12 months after field plantation. After 6 months, the maximum root biomass was achieved by Rajabhatkhawa (0.43 g/plant) followed by Ganakpokhari (0.35 g/plant) and minimum was recorded in Sukhana (0.15 g/plant) seed source. Similarly, highest (1.74 g/plant) was found in Rajabhatkhawa and lowest was in Hathipara (0.79 g/plant) among the seed sources at 12 months field growth.

Total biomass

The total biomass comprising leaf, shoot and root dry weight increased at two periodic intervals among the seed sources. On an average, the total biomass varied from 1.32 to 4.46 g/plant from 6 to 12 months of growth in field (Table 6). Irrespective of seed sources, the total biomass increased nearly 3.5 times during the period of study. At the age of 6 months, Rajabhatkhawa and Lonigodam registered maximum and minimum (1.51 and 0.85 g/plant) biomass respectively whereas the highest total biomass was exhibited in Rajabhatkhawa (6.58 g/plant) followed by Naharani (5.81 g/plant) and lowest was noted for Hathipara (3.13 g/plant) after 12 months of growth. It was observed that the shoot contributed little more biomass than leaves and root to accomplish the total biomass the age of 12 months. Significant difference (p = 0.05) was observed among different seed sources for total biomass at two periodic intervals.

Volume index

The results pertaining to variation in the volume index at two periodic intervals in field are depicted in (Table 6). The volume index differed significantly (p = 0.05) among the seed sources in each growth period. At the age of 6 months, the volume index varied from 127.35 to 663.29 with a mean value of 345.12 where as it was varied from 992.60 to 1897.19 with an average value of 1293.22 at 12 months. Rajabhatkhawa (663.29) seed source showed maximum volume index closely followed by Sephizala (618.42) and Minimum volume index were recorded in Basistha (127.35) at the age of 6 months. After completion of 12 months growth in field, Rajabhatkhawa seed source exhibited highest volume index (1897.19) which was closely followed by Naharani (1866.10) and minimum volume index was observed in Nazaria (999.60) [16].

Table 5 Variation in dry weight of leaf (g)), dry weight of shoot (g) and dry weight of root (g) of different seed sources of *Aquilaria malaccensis* at different growth period in field

Seed source	Dry weight of leaf (g)		Dry weight of shoot (g)		Dry weight of root (g)	
	6 month	12month	6 month	12 month	6 month	12 month
Basistha	0.52^{defg}	1.30^{ef}	0.2^{6def}	1.59^{cdef}	0.21^{h}	1.15d^{efgh}
Ganakpokhari	0.55^{cdef}	1.42^{cdef}	0.26def	1.44^{efg}	0.35^{b}	0.89^{hi}
Hathipara	0.48f^{gh}	1.22^{f}	0.29^{bcde}	1.13^{g}	0.25f^{g}	0.79^{i}
Hmarveng	0.71^{a}	1.75^{bcd}	0.32^{abc}	1.81^{bcde}	0.24^{g}	1.10^{efghi}
Hybergyon	0.53^{def}	1.57^{cdef}	0.26^{ef}	1.77^{bcde}	0.28^{e}	1.42^{bcde}
Islamnagar	0.51^{efg}	1.39^{de}	0.30^{bcd}	1.34^{fg}	0.21^{h}	0.88^{hi}
Kumarghat	0.60^{bdc}	1.74^{bcd}	0.32^{abc}	1.85^{bcd}	0.41^{a}	1.13^{efghi}
Lanka	0.56^{cde}	1.71^{bcde}	0.31b^{c}	2.05^{b}	0.21^{h}	1.53^{bc}
Lonigodam	0.40^{h}	1.31^{ef}	0.22^{f}	1.48^{defg}	0.34^{bc}	0.80^{i}
Nagariborline	0.61^{bc}	1.42^{cdef}	0.26^{def}	1.50^{defg}	0.28^{e}	1.19^{cdefgh}
Naharani	0.44^{gh}	1.82^{bc}	0.26^{def}	1.97^{bc}	0.29d^{e}	1.65^{a}
Namti	0.68^{ab}	1.75^{bcd}	0.26^{def}	1.85^{bcd}	0.29^{de}	1.27^{cdefg}
Nazaria	0.41^{h}	1.30^{ef}	0.28^{cde}	1.26^{fg}	0.23^{a}	0.92^{ghi}
Nelbagan	0.58^{cde}	1.61^{a}	0.34^{ab}	1.77^{a}	0.32^{bc}	1.11^{ab}
New diakkawn	0.68^{ab}	2.03^{ab}	0.28^{cde}	2.00^{b}	0.27^{ef}	1.30^{cdef}
Rajabhatkhawa	0.72^{cde}	2.34^{bcdef}	0.36^{a}	2.51^{bcde}	0.43^{gh}	1.74^{efghi}
Sephizala	0.63^{abc}	1.80^{bcde}	0.33^{ab}	1.98^{bc}	0.15^{i}	1.47^{bcd}
Sukhana	0.61^{bcd}	1.38^{df}	0.28^{cde}	1.23^{fg}	0.32^{cd}	0.96^{fghi}
Thikau	0.67^{ab}	1.48^{cdef}	0.29^{bcde}	1.28^{fg}	0.24^{fg}	0.95^{ghi}
Mean	0.57	1.60	0.29	1.67	0.28	1.19
CV (%)	9.22	15.95	9.23	14.41	5.82	17.58
S.Em (±)	0.0300	0.146	0.015	0.139	0.0094	0.120
CD (p=0.05)	0.086	0.42	0.044	0.39	0.027	0.346

Table 6 Variation in total biomass (g), volume index among the seed sources of *Aquilaria malaccensis* at different growth period in field

Seed source	Total biomass(g)/ seedlings		Volume index (cm.mm^2)	
	6 month	12 month	6 month	12 month
Basistha	0.86^{hi}	4.03^{def}	127.35^{j}	1143.39^{cd}
Ganakpokhari	1.02^{cd}	3.74e^{fg}	244.64^{hi}	1665.28^{b}
Hathipara	0.89^{ghi}	3.13^{g}	345.84^{cdef}	1152.29^{cd}
Hmarveng	1.06^{ab}	4.65^{cd}	453.78^{b}	1224.78^{c}
Hybergyon	0.94^{fgh}	4.76^{cd}	289.71^{efghi}	1181.94^{cd}
Islamnagar	0.90^{ghi}	3.60^{defg}	206.11^{ij}	1128.18^{cd}
Kumarghat	1.18^{a}	4.72^{c}	330.57^{defg}	1158.55^{cd}
Lanka	0.95^{efg}	5.29^{bc}	297.46^{dfgh}	1137.45^{cd}
Lonigodam	0.85^{i}	3.59^{efg}	313.87^{defgh}	1125.25^{cd}
Nagariborline	0.99^{cde}	4.10^{def}	425.61^{bc}	1294.79^{c}
Naharani	0.90^{hi}	5.81^{ab}	378.56^{bcd}	1866.10^{ab}
Namti	1.03^{bc}	4.87^{cd}	229.52^{hi}	1160.42^{cd}
Nazaria	0.92^{def}	3.48^{fg}	263.70^{fghi}	992.60^{d}
Nelbagan	1.09^{bc}	4.49^{a}	363.87^{cde}	1159.02^{c}
New diakkawn	0.98^{bc}	5.33^{bc}	377.19^{bcd}	1203.36^{cd}
Rajabhatkhawa	1.51^{cde}	6.58^{cde}	663.29^{a}	1897.19^{a}
Sephizala	1.28^{def}	5.2^{5bc}	618.42^{a}	1668.72^{ab}
Sukhana	1.03^{bc}	3.57^{fg}	372.51^{cd}	1220.16^{cd}
Thikau	1.35^{bc}	3.71^{efg}	255.21^{ghi}	1191.62^{cd}
Mean	1.32	4.46	345.12	1293.22
CV (%)	4.43	12.25	14.96	10.75
S.Em (±)	*0.028*	*0.315*	*29.812*	*80.274*
CD (p=0.05)	0.083	0.904	85.516	230.26

Table 7 Mean, range, coefficient of variation, PCV, GCV, heritability (h^2), genetic advance and genetic gain for seedling characters of *Aquilaria malaccensis* (one year old)

Characters	Mean	Range	CV%	PCV%	GCV%	h^2	Genetic advance	Genetic gain
Plant height (cm)	42.82	40.05-45.42	3.75	4.61	2.68	33.89	1.40	3.22
Collar Diameter (mm)	5.46	4.95-6.43	4.28	8.82	7.71	76.49	0.76	13.90
Root length (cm)	20.73	20.01-22.9	4.86	4.99	1.12	5.08	0.11	0.52
Fresh weight leaf (g)	5.15	3.92-7.53	15.73	22.24	15.73	49.99	1.18	22.91
Fresh weight of shoot (g)	5.28	3.55-7.91	14.63	24.35	19.47	63.91	1.70	32.06
Fresh weight of root (g)	3.56	2.35-5.20	16.97	31.37	26.39	70.75	1.62	45.73
Dry weight of leaf (g)	1.60	1.22-2.34	15.95	22.21	15.45	48.43	0.35	22.15
Dry weight of shoot (g)	1.67	1.13-2.51	14.41	24.41	19.71	65.16	0.55	32.77
Dry weight of root (g)	1.19	0.79-1.74	17.58	31.21	25.79	68.28	0.52	43.90
Number of secondary roots	28.73	25.64-36.90	8.17	13.39	10.61	62.80	4.98	17.32
Number of tertiary roots	265.68	221.05-358.57	7.18	13.10	10.96	69.97	49.68	18.88
Number of branches	5.01	3.67-6.79	16.24	19.85	11.40	33.02	0.60	13.50
Root length/shoot length ratio	0.48	0.42-0.51	5.70	6.67	3.47	27.10	0.07	3.72
Volume index (cm.mm^2)	1293.22	992.60-1897.19	10.75	22.41	19.66	76.98	459.48	35.53
Total biomass (g)	4.46	3.13-6.58	12.25	22.91	19.36	71.43	1.50	33.71

Variability and genetic studies in growth and biomass traits in field condition

Variability and genetic parameters on growth and biomass characters were worked out at 12 months of age in field with regards to mean, range, coefficient of variation (%), genotypic and phenotypic coefficient of variation, heritability, genetic advance and genetic gain and are presented in (Table 7). Among all these characters, volume index showed wider range (992.60 – 1897.19) in terms of minimum and maximum values. Coefficient of variation ranged from 3.75% for plant height to 17.58% for dry weight of root per plant. It is marked that phenotypic coefficient of variation (PCV) was higher than genotypic coefficient of variation (GCV) with higher estimates of heritability for some growth and biomass character and lower estimates of heritability in some characters. The maximum phenotypic and genotypic coefficient of variation was recorded for fresh weight of root (31.37 and 26.39) followed by dry weight of root (31.21 and 25.79), dry weight of shoot (24.24.41 and 19.71), total biomass (22.91 and 19.36) and volume index (22.41 and 19.66). All other characters showed low to moderate estimates of phenotypic and genotypic coefficient of variation. The heritability was ranged from 5.08 – 76.98% among the different characters. The higher estimates of heritability with moderate genetic gain were observed for volume index (76.98%

and 35.53) followed by total biomass (71.43% and 33.71) and fresh weight of root (70.75% and 45.73) whereas higher estimates of heritability with lower genetic gain was observed for collar diameter (76.49%, and 13.90). A higher estimate of heritability with higher genetic advance and medium genetic gain (76.98%, 459.48 and 35.53) was noticed in volume index. All other characters showed the lower estimates of heritability with low genetic advance and genetic gain. Higher estimates of heritability coupled with higher genetic advance and medium genetic gain with moderate GCV for volume index and moderate genetic gain with GCV for total biomass, fresh weight of root could be utilized for further improvement of this species while all other character showed medium estimates of heritability with low genetic gain and GCV thus indicating of non-additive gene action with little scope for selection [17-19].

Genotypic and phenotypic correlations between growth and biomass character pairs were estimated and are presented in (Table 8). It revealed that genotypic and phenotypic association were in same direction and that the genotypic estimates were higher than phenotypic ones for most character pairs, indicating an inherent association between the characters. Significant correlations were observed between many character pairs. It was observed that the plant height was positively and significantly correlated with collar diameter (G = 1.141 and P = 0.617 and volume index (G = 1.100 and P = 0.717) whereas significantly and negative correlation was observed between plant height and root-shoot length ratio (G = -0.788 and P = -0.595). collar diameter was significantly and positively correlated with volume index (G = 1.004 and P = 0.986). Similarly, the character pairs like fresh weight of leaf with fresh weight of shoot, fresh weight of root, dry weight of leaf, dry weight of shoot, dry weight of root and total biomass; fresh weight of shoot with fresh weight of root, dry weight of leaf, dry weight of shoot, dry weight of root and total biomass; fresh weight of root with dry weight of leaf, dry weight of shoot, dry weight of root and total biomass; dry weight of leaf with dry weight of shoot, dry weight of root and total biomass; dry weight of shoot with dry weight of root and total biomass; dry weight of root with total biomass; number of primary root with number of secondary root were positively and significantly correlated with each other [20-21].

Table 8 Genotypic and phenotypic coefficient correlation for one year field study characteristics of *Aquilaria malaccensis*

Character		Collar Diameter (mm)	Root length (cm)	Fresh weight leaf (g)	Fresh weight of shoot (g)	Fresh weight of root (g)	Dry weight of leaf (g)	Dry weight of shoot (g)	Dry weight of root (g)	Secondary roots	Tertiary roots	Number of branches	Root length/shoot length ratio	Volume index (cm.mm^2)	Total biomass (g)
Plant height (cm)	G	1.141*	0.891*	-0.076	-0.010	0.211	0.066	0.033	0.238	-0.230	-0.199	0.404	-0.788*	1.100*	0.078
	P	0.617*	0.175	0.050	0.126	0.161	0.069	0.103	0.204	-0.075	-0.079	0.291	-0.595*	0.717*	0.139
Collar diameter	G		0.139	0.219	0.263	0.370	0.235	0.264	0.433	-0.153	-0.121	0.407	-1.022	1.004*	0.321
(mm)	P		0.248	0.198	0.230	0.302	0.204	0.223	0.319	-0.042	-0.052	0.156	-0.337	0.986*	0.216
Root length (cm)	G			0.625*	0.475	-0.001	0.654*	0.501*	-0.020	-1.238*	-1.102*	-0.758*	-0.192	0.245	0.370
	P			0.150	0.116	0.040	0.148	0.118	0.041	-0.059	-0.229	0.034	0.623*	0.236	0.133
Fresh weight leaf	G				1.023*	0.857*	1.001*	1.037*	0.863*	-0.426	-0.349	-0.361	0.129	0.169	0.989*
(g)	P				0.796*	0.594*	0.993*	0.791*	0.602*	-0.215	-0.178	0.023	0.050	0.161	0.880*
Fresh weight of	G					0.853*	1.039*	1.001*	0.868*	-0.328	-0.216	-0.277	0.007	0.214	0.988*
shoot (g)	P					0.752*	0.789*	0.989*	0.757*	-0.169	-0.139	-0.039	-0.061	0.216	0.945*
Fresh weight of	G						0.874*	0.856*	1.000*	-0.402	-0.246	-0.120	-0.298	0.332	0.933*
root (g)	P						0.592*	0.742*	0.993*	-0.304	-0.222	-0.062	-0.124	0.289	0.864*
Dry weight of	G							1.053*	0.880*	-0.431	-0.348	-0.405	0.122	0.184	1.001*
leaf (g)	P							0.783*	0.600*	-0.211	-0.172	0.014	0.038	0.170	0.879*
Dry weight of	G								0.871*	-0.343	-0.248	-0.221	0.020	0.215	0.993*
shoot (g)	P								0.748*	-0.190	-0.159	-0.013	-0.037	0.208	0.944*
Dry weight of	G									-0.408	-0.252	-0.085	-0.329	0.392	0.940*
root (g)	P									-0.302	-0.216	-0.011	-0.150	0.312	0.872*
Secondary roots	G										1.000*	-0.084	-0.356	-0.158	-0.399
	P										0.890*	-0.037	-0.031	-0.047	-0.260
Tertiary roots	G											-0.099	-0.362	-0.129	-0.284
	P											-0.179	-0.186	-0.054	-0.202
No. of branch	G												-0.390	0.411	-0.232
	P												-0.088	0.193	-0.005
Root length /	G													-0.961*	-0.074
shoot length ratio	P													-0.408	-0.057
Volume index	G														0.273
(cm.mm^2)	P														0.255

*Significant variations (CD=0.05)

CONCLUSION

The present investigation entitled "Juvenile phase study of *Aquilaria malaccensis* (Agar) in terai zone of West Bengal" study was carried out each respective seed source were raised in randomized block design to assess growth performance w.r.t plant height (cm), collar diameter (mm), root length (cm), fresh weight leaf (g), fresh weight of shoot (g), fresh weight of root (g), dry weight of leaf (g), dry weight of shoot (g), dry weight of root (g), number of secondary root, number of tertiary root, number of branch, root length/shoot length ratio, volume index (cm.mm2), total biomass (g) recorded respectively range 40.05-45.42 cm, 4.95-6.43 mm, 20.01-22.9 cm, 3.92-7.53 g, 3.55-7.91 g, 2.35-5.20g, 1.22-2.34, 1.13-2.51, 0.79-1.74, 25.64-36.90, 221.05-358.57, 3.67-6.79, 0.42-0.51, 992.60-1897.19 cm.mm^2, 3.13-6.58g. Seed source screening provides a great opportunity to the tree improvement or breeding programme. Present study identifies three best seed sources based upon seedling characteristics which are Rajabhatkhawa, Sephizala and Ganakpokhari were sampled. These location trees may be used for further selection to maintain broad genetic base in any tree improvement programme.

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LITERATURE CITED

1. FAO. 2015. WFP. 2015. The state of food insecurity in the world. pp 348.
2. Sidiyasa K, Sutomo S, Soewanda AP. 1986. Exploration and study of regeneration of Gaharu' producing species in Kintap forest region, South Kalimantan. *Buletin Penelitian Hutan* 474: 59-66.
3. Ng LT, Chang YS, Kadir AA. 1997. A review on agar (Gaharu) producing *Aquilaria* species. *Journal of Tropical Forest Products* 2: 272-285.
4. Palit P, Sasmal BC, Bhattacharryya AC. 1996. Germplasm diversity and estimate of genetic advance of four morphology-physiological traits in a world collection of jute. *Euphytica* 90(1): 49-58.
5. Roy M, Datta BK. 2014. Seedling morphology and regeneration for conservation strategy of *Aquilaria malaccensis* Lamk. in Tripura. *Science Culture* 80(5/6): 179-184.
6. Tabin T. 2012. A thesis on Studies on fungal diversity associated with *Aquilaria agallocha* and their role in the formation of agarwood, department of Forestry, NERIST, Arunachal Pradesh.
7. Adelina N, Harum F, Schmidt L, Joker D. 2004. *Seed Leaflet*: *Aquilaria malaccensis Lam. Forest and Landscape*, Denmark.
8. Hatchell GE. 1985. *In*: Proc. Third B. C. South S. J. Ref. Conf. (Eds) Shoulders E. Attanta, G.A. Nov. 18. GTR 80-84. pp 395-402.
9. Panse V, Sukhatme G. 1978. *Statistical Methods for Agricultural Workers*. Indian Council of Agricultural Research, New Delhi.
10. Burton GW, Devane EH. 1953. Estimating heritability in tall fescue (*Festuca arundinacea*) from replicated clonal material 1. *Agronomy Journal* 45(10): 478-481.
11. Johnson HW, Robins HF, Comstock RE. 1955. Estimation of genetic and environmental variability in soybeans. *Agronomy Journal* 47: 314-318.
12. Gupta SP. 1981. *Statistical Methods*. 15th Edition Sultan Chand and Sons, Daryaganj, New Delhi.
13. Rose DA. 1983. The description of the growth of the root systems. *Plant and Soil* 75: 405-415.
14. Abdi E, Majnounian B, Rahimi H. 2010. A comparison of root distribution of three hardwood species grown on a hill side in the Caspian forest, Iran. *Journal of Forest Research* 15: 99-107.
15. Verma KS, Kohli S, Kaushal R, Chaturvedi OP. 2014. Root structure, distribution and biomass in five multipurpose tree species of western Himalayas. *Journal of Mountain Science* 11(2): 519-525.
16. Mohamed MBN, Parthiban KT, Ravi R, Kumar P. 2015. Provenance variation in growth and genetic potential of *Aquilaria malaccensis* under nursery condition. *African Journal of Biotechnology* 14(24): 205-213.
17. Dhanai CS, Uniyal AK, Todaria NP. 2003. Seed Source variation in seed and seedling characteristics of *Albizi chinensis*. *Silvae Genetica* 52(5/6): 259-266.
18. Thakur IK, Chauhan KC, Singh C. 2009. Evaluation and genetic improvement through progeny trials in different provenances of *Bauhinia variegata* suitable for foothills of the Himalayas. *Indian Journal of Soil Conservation* 37(3): 185-192.
19. Mohamed MBN, Parthiban KT, Ravi R. 2014. Genotypic and phenotypic variability among morphological traits of *Aquilaria malaccensis* Lam. genetic resources. *Indian journal of Agroforestry* 16(2): 24-31.
20. Allard RW. 1960. Hybrid vigour and genetic control of some quantitative traits of tomato (*Solanum lycopersicum* L. *Principles of Plant Breeding*. New York, John Willey and Sons Inc. pp 458.
21. Bischetti GB, Chiaradia EA, Simonato T. 2005. Root strength and root area ratio of forest species in Lombardy (Northern Italy). *Plant and Soil* 278: 11-22.