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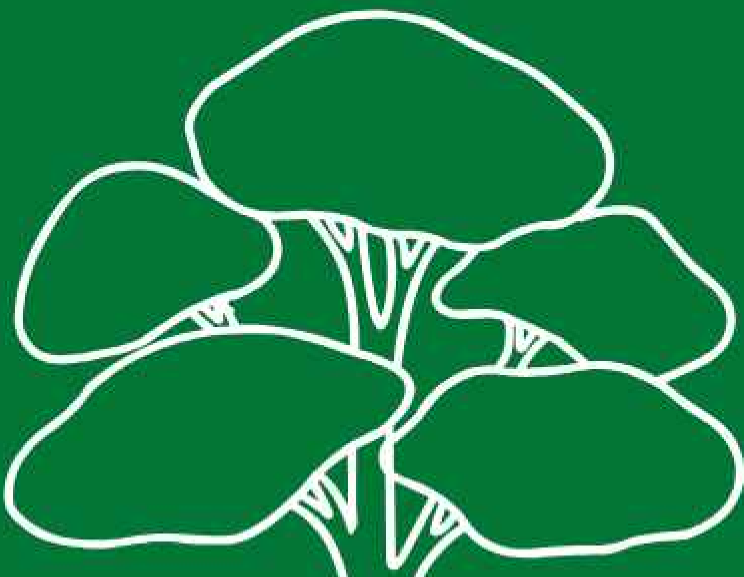

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Research Article

Nursery and Plantation Techniques of Sandalwood (*Santalum album* L.): An Important Economic Aromatic Plant

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Abstract

Sandalwood (Santalum album L.) is a significant fragrant tree species that is rapidly degrading due to habitat fragmentation and human activities. To address this issue, mass propagation and plantation programs are urgently required. The current study aimed to increase germination percentage and growth performance of S. album through seed pre-sowing treatments and host plants. Five pre-sowing treatments were used, i.e., seeds soaked in tap water for 12, 24, 36, and 48 hours, and a control (0 hour) group. Seedlings were sown with five different host plants to determine the growth performance of S. album. Results showed that the highest germination percentage (72%) was found in seeds soaked in tap water for 36 hours, followed by 48, 24, 12 hours, and the control group, respectively. Pre-sowing treatments accelerated germination period and germination percentage. The maximum height growth and diameter at breast height of S. album were 4.70m and 8.0cm, respectively, in association of Mimusops elengi and Vitex negundo at six and a half years old, followed by Casuarina equisetifolia and Cajanus cajan; Albizia lebbeck and C. equisetifolia; and A. lebbeck and C. cajan. The minimum height growth and diameter at breast height of S. album were 3.90m and 6.50cm, respectively, in association of C. equisetifolia. The study demonstrated that germination percentage and growth of S. album were significantly influenced by pre-sowing treatments and host plants (P<0.05). Therefore, the results suggest that seeds soaked in tap water for 36 hours and the association of M. elengi and V. negundo are the best techniques for higher germination and growth of S. album, respectively. These findings will be helpful for mass plantation programs of S. album in Bangladesh.

সারসংক্ষেপ

শ্বেতচন্দন (*Santalum album*) একটি উল্লেখযোগ্য এরোমেটিক বৃক্ষ প্রজাতি যা আবাস সংকট এবং মানুষের কার্যকলাপের কারণে দ্রুত ক্ষয়প্রাপ্ত হচ্ছে। এই সমস্যা সমাধানের জন্য ব্যাপকভাবে শ্বেতচন্দনের চারা উত্তোলন ও বৃক্ষরোপণ জরুরি। বর্তমান স্টাডির লক্ষ্য হল বীজ বপনের পূর্বে বিভিন্ন ট্রিটমেন্ট এবং সহায়ক গাছের (*Host plant*) মাধ্যমে যথাক্রমে শ্বেতচন্দনের অঙ্কুরোদগম ও বৃদ্ধির হার ত্বরান্বিত করা। বর্তমান গবেষণায় পাঁচটি প্রাক-বপন ট্রিটমেন্ট যথা ১২, ২৪, ৩৬ এবং ৪৮ ঘন্টা ট্যাপের পানিতে ভিজিয়ে রাখা বীজ এবং একটি নিয়ন্ত্রণ (০ ঘন্টা) গ্রুপ ব্যবহার করা হয়েছে। শ্বেতচন্দনের বৃদ্ধি পর্যবেক্ষণের জন্য পাঁচটি ভিন্ন হোস্ট প্লান্টের সাথে চারা বপন করা হয়েছে। ৩৬ ঘন্টা ট্যাপের পানিতে ভিজিয়ে রাখা বীজে সর্বোচ্চ অঙ্কুরোদগম হার (৭২%) পাওয়া গেছে, তারপরে ছিল যথাক্রমে ৪৮, ২৪, ১২ ঘন্টা এবং নিয়ন্ত্রণ গ্রুপ। সাড়ে ছয় বছর বয়সে *Mimusops elengi* (বকুল) এবং *Vitex negundo* (নিশিন্দা) সহযোগে শ্বেতচন্দনের সর্বোচ্চ উচ্চতা এবং ব্যাস (*DBH*) ছিল যথাক্রমে ৪.৭০ মি. এবং ৮.০ সে.মি., তারপরে ছিল *Casuarina equisetifolia* (ঝাউ) এবং *Cajanus cajan* (অড়হর), *Albizia lebbeck* (কড়ই) এবং *C. equisetifolia* (ঝাউ) এবং *A. lebbeck* (কড়ই) এবং *C. cajan* (অড়হর)-এর সংমিশ্রণ। *C. equisetifolia* এর মিশ্রণে শ্বেতচন্দনের উচ্চতা সর্বনিম্ন ৩.৯০ মি. এবং ব্যাস (*DBH*) ৬.৫০ সে.মি.। গবেষণায় দেখা গেছে যে, প্রাক বপন ট্রিটমেন্ট এবং হোস্ট প্লান্ট শ্বেতচন্দনের অঙ্কুরোদগম হার এবং চারার বৃদ্ধিতে উল্লেখযোগ্যভাবে প্রভাবিত (*P* <০.০৫) করেছে। অতএব ৩৬ ঘন্টা ট্যাপের পানিতে বীজ ভিজিয়ে বপন করলে শ্বেতচন্দনের সর্বোচ্চ অঙ্কুরোদগম এবং সহায়ক হিসেবে *M. elengi* এবং *V. negundo*-এর সংমিশ্রণ চারার বৃদ্ধির জন্য সর্বোত্তম কৌশল। অত্র গবেষণার ফলাফল শ্বেতচন্দনের বাগান উত্তোলনে ব্যাপক ভূমিকা পালন করবে।

Keywords: Germination, Host plant, Pre-sowing treatment, Santalum album, Seedling growth.

Introduction

Santalum album L. is a tropical evergreen tree species that belongs to the family Santalaceae, which includes 28 genera and 400 species (Ahmed *et al.* 2009). It is widely distributed and has been introduced to many countries, including India, Sri Lanka, Indonesia, Malaysia, Cambodia, Vietnam, Myanmar, Thailand, China, Papua New Guinea, Fiji, New Caledonia, and Hawaii (Srinivasan *et al.* 1992). There is evidence that, *S. album* is an exotic in India and introduced from East Indonesia by traders (Effendi 1994). Clarke (2006) revealed that *S. album* is introduced in Australia as commercial plantation in the private sectors. The tree is known as Shewt Chandan in Bengali, Chandana in Sanskrit, Santal in French, and sandalwood in English.

Sandalwood is famous and costly due to its fragrant heartwood and oil. It is commercially valuable because of its high concentrations and best quality oil, and a small proportion of the wood is used for carving decorative articles (Santisuk and Larsen 2005). The oil is used in perfumery industries and traditional medicine sectors, and is effective in treating major diseases such as fever, piles, hemorrhagic conditions, diabetics, dropsy, mental disorders, management of poisons, and skin disorders (Oyen and Dung 1999; Rao *et al.* 2007). In China, the oil is used to treat vomiting, stomach-ache, and gonorrhea, and the bark is also used as an insecticide (Purkayastha 1996). Despite its commercial importance, the population of *S. album* is declining rapidly due to habitat fragmentation and various anthropogenic activities. These threats have resulted in the degradation of natural habitats where sandalwood once thrived. Consequently, urgent action is needed to mitigate these negative impacts and conserve this valuable species. Mass propagation and plantation efforts have been identified as crucial strategies to counteract the decline of *S. album* and restore its populations in degraded environments (Mapa *et al.* 1999).

However, the successful propagation of *S. album* faces several challenges, particularly in the germination and survival stages. One significant hindrance is the species' reliance on specific perennial host plants for its survival and growth. This dependence on host plants presents a limitation in the propagation of sandalwood, as it restricts the areas where the species can be effectively cultivated. Moreover, the germination process of *S. album* seeds can be unpredictable and inconsistent, further complicating efforts to propagate the species (Panbokke 1996). To address these challenges, the present study focuses on enhancing the germination percentage and growth of *S. album* through the utilization of pre-sowing treatments and host plants. The study provides valuable information for the mass propagation of *S. album* through seeds and increasing the germination rate and growth of the tree. These findings could be applied to develop massive plantation programs in the field to accelerate high germination percentage and growth of *S. album*.

Materials and Methods

Study area

The study was carried out in the nursery of Bangladesh Forest Research Institute (BFRI), Chattogram, Bangladesh over a period of seven years from March 2015 to July 2022. The study area lies between 22°22′.27″ and 22°29′.0″ N latitude and 91°46′.30″ and 91°49′.44″ E longitudes. The climate of the study area is tropical in nature and characterized by hot humid summer and cool dry winter. The maximum and minimum temperature in the area varies from 28.30-15.2°C (Hossain *et al.* 2005). Mean annual rainfall is around 3000 mm mainly occurred from June to September.

Seed collection and preparation of germination experiments

Seeds of *S. album* were collected from 15 years old mother trees from BFRI area, Chattogram in the last week of March 2015. Collected seeds were dried in room temperature for 2-3 days. Then sound and desirable seeds were separated from discolored and damaged seeds. The number of seeds varied from 6000-6500 in one kg and selected seeds were used for the experiments. The viability of seeds has decreased quickly due to the recalcitrant in nature. The best germination rate is found within one week after collection of seed.

Experimental design and pre-sowing treatments

Experiment was conducted following Completely Randomized Design with five replications. To determine the effect of pre-sowing treatments on seed germination and seedlings growth attributes, five treatments were applied. The pre-sowing seed treatments were: i) control (T_0) (seeds without any treatment) ii) soaking seeds in tap water for 12 hrs (T_1), iii) soaking seeds in tap water for 24 hrs (T_2), iv) soaking seeds in tap water for 36 hrs (T_3), and v) soaking seeds in tap water for 48 hrs (T_4). There were five treatments, five replications in each treatment and 50 seeds were in each seed bed for each replication at 1.50 to 2.50 cm depths of soil in the last week of March. Thus, a total of 1,250 seeds were used for the germination experiments. Watering was carried out regularly. A visual representation of the different stages of sandalwood seed germination, growth, and plantation, which are essential for mass propagation and plantation efforts (Fig. 1). These stages involve appropriate pre-sowing treatments and host plants.

Figure 1. Seed germination, growth, and plantation of sandalwood. (A) Seeds, (B) Seeds on experimental dish, (C) Germinated seedling (D) Seedlings in polybags (E) Saplings with host plant in pot (F) Plantation with host plants.

Assessment of seed germination

The number of germinated seeds in each treatment was recorded daily. The starting and closing dates of germination and other parameters were counted carefully. The numbers of germinated seeds at each day in each replication of treatments were counted to calculate the germination percentage (Kumar 1999; Almodares *et al.* 2007). Cumulative germination was recorded next day of sowing and continued till ending the germination.

Germination percentage

Germination percentage is an estimate of the germinability of the population of seeds. The equation to calculate germination percentage is (Ellis and Roberts 1981):

$$G\% = \frac{\Sigma n}{N} \times 100 \text{ ---------------------------- (1)}$$

Where,

n= number of seeds germinated

N= total number of seeds used

Relativized percentage

The germination percentage can be relativized by the following equation (Fitch *et al.* 2007):

$$R\% = \frac{AP}{HP} \times 100 \text{ ------------------------(2)}$$

Where,

AP= actual percentage

HP= highest percentage among group of data

Mean germination time

Mean germination time is a measure of the rate and time spread of the germination. It indicates time spent to germinate or emerge. Following formula was used to calculate the mean germination time (Ellis and Roberts 1981):

$$\bar{t} = \frac{\sigma\ n}{\Sigma n} \text{ --(3)}$$

Where,

nt= The product of seeds germinated at interval with the corresponding time interval

n= number of seeds germinated

Mean germination rate

Mean germination rate is the reciprocal of the mean germination time as shown below (Ranal *et al.* 2009).

$$v = \frac{1}{t} \text{ --(4)}$$

Where,

t = mean germination time

Coefficient of variation of germination time

Coefficient of variation of the germination time is calculated by the following expression (Ranal *et al.* 2009)

$$CVt = \frac{St}{t} \times 100 \text{ ----------------------------(5)}$$

Where,

St= standard deviation of germination time

t = mean germination time

Coefficient of velocity of germination

Coefficient of velocity of germination can be calculated using the following expression (Jones and Sanders 1987):

$$CVG = \frac{\sigma\ n}{\Sigma n} \times 100 \text{ -----------------------(6)}$$

Where,

nt= the product of seeds germinated at interval with the corresponding time interval

n= number of seeds germinated

Germination index

Germination index is an estimate of the time (in days) it takes a certain germination percentage to occur. Germination index can be calculated by using following expression (AOSA and SCST 1993):

$$GI = \sigma\ \frac{n}{t} \text{ --------------------------------------(7)}$$

Where,

n= number of seeds germinated

t= time taken for seeds to germinate

Mean daily germination percent

It represents the mean number of seeds germinated per day. This can also be defined as the number of seeds germinating daily relative to the maximum number of germinated seeds. It is calculated using the following expression (Adams and Farrish 1992):

$$\overline{G} \quad \frac{GP}{Tn} \text{---}(8)$$

Where,

GP= final cumulative germination percentage

Tn= total number of intervals required for final germination

Peak value

It is the accumulated number of seeds germinated at the point on the germination curve at which the rate of germination starts to decrease. It is computed as the maximum quotient obtained by dividing successive cumulative germination values by the relevant incubation time (Adams and Farrish 1992).

Germination value

Germination value is obtained by combining both speed and completeness of germination into a composite score as described by Czabator (1962).

GV=MDG × PV----------------------(9)

Where,

MDG= mean daily germination percent

PV= peak value for germination

Seedling growth performance in the nursery

To determine the seedlings growth performance in the nursery, healthy seeds were sown in the nursery bed. One month old seedlings were transferred in polybags (15×23 cm) filled with soils mixed with cow dung (3:1) and allowed to grow them in polybags. At initial stages, the polybags were kept under nursery shade for one week and then exposed to partial sunlight. Watering carried out regularly. Data were recorded at 3 and 6 months after transferring them to the polybags.

Assessment of seedlings vigor index

Vigor index is the most important parameter and its values depend on seed germination percentage, length of roots and length of shoots (Labouriau and Valadares 1976). The following formula was used for determination of seedlings vigor index (Abdul-Baki and Anderson 1973).

Seedling vigor index

(SVI)=(Lr+Ls)×GP -------------------------(10)

Where,

Lr= the length of root, Ls=the length of shoot and GP=Seed germination percentage.

Assessment of seedlings growth performance in the field levels

The estimation of growth performance of seedlings was the most important part of the present study. One year old seedlings were planted with the following host plants namely, *M. elengi*, *V. negundo*, *C. equisetifolia*, *A. lebbeck* and *C. cajan*. Selected host plants were as follows: i) *C. equisetifolia* ii) *A. lebbeck* and *C. cajan* iii) *A. lebbeck* and *C. equisetifolia*, iv) *M. elengi* and *V. negundo* and v) *C. equisetifolia* and *C. cajan*. Growth of host plants was controlled by pruning. Proper management was done in the field for available sunlight and aeration.

Statistical analysis

Statistical analysis of data was performed using the computer software Statistical Package for the Social Sciences (SPSS) version 25. The analysis of variance (ANOVA) was studied by applying Duncan's Multiple Range Test (DMRT).

Results

Effects of pre-sowing treatments on germination parameters

The study was carried out in the nursery of Minor Forest Products Division under BFRI, Chattogram. The results showed that there was significant effects of pre-sowing treatments on germination value, relative germination percentage, mean germination time, mean germination rate, mean daily germination, peak value, coefficient of variation of germination time, coefficient of variation of germination rate, germination index and germination capacity of *S. album* (Table 1).

The results showed that the highest germination value 0.66 was in T_3, which was significantly higher than all other treatments. T_0 produced the significantly lowest germination value 0.10. The relative germination percentage was significantly highest for T_3 (97.0%), indicating that the treatment was highly effective in promoting germination compared to other treatments. The lowest relativized percentage of germination was 45.20% noticed in T_0. MGR, which measures the speed of germination, was significantly maximum for T_3 (0.024), followed by T_4 (0.022) and the lowest (0.016) was in T_0. MDG, which measures the average number of seeds that germinated per day, was also significantly maximum in T_3 (0.53), followed by T_4 (0.37) and the lowest MDG (0.25) was recorded from T_0.

Table 1. Effects of pre-sowing treatments on germination behaviour of *S. album* seeds.

Treatment	Germination value	Relativized (%)	Mean Germination Rate (MGR)	Mean Daily Germination (MDG)
T_0	0.10^d	45.20 ± 2.27^d	0.016^d	0.25^d
T_1	0.19^c	61.00 ± 2.12^c	0.016^d	0.33^c
T_2	0.23^c	64.00 ± 0.95^{bc}	0.018^c	0.35^{bc}
T_3	0.66^a	97.00 ± 1.34^a	0.024^a	0.53^a
T_4	0.31^b	67.00 ± 0.95^b	0.022^b	0.37^b

Notes: Means followed by same letters are not significantly different at ($P < 0.05$); according to Duncan's Multiple Range Test (DMRT); ± indicates the standard error of the mean.

Mean Germination Time (MGT), which is the time required for 50% seed germination was minimum in T_3 (40.59), followed by T_4 (44.74) and the maximum MGT was T_0 (61.40) (Fig. 2). The peak value represents the maximum amount of germination achieved in each treatment. As seen in the results (Table 2), the highest peak value was observed in treatment T_3, where seeds were soaked in normal water for 36 hrs. T_3 recorded a peak value of 1.24, which was significantly higher than the other treatments. On the other hand, treatment T_0,

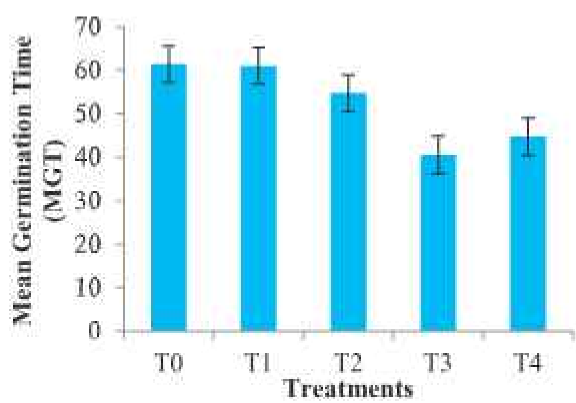

Figure 2. Effect on Mean Germination Time (MGT) of *S. album* in different treatments.

which was the control group, had the lowest peak value of 0.42. This is indicated that soaking the seeds in normal water for a prolonged period of time positively affects the germination rate and overall growth of the seeds. The peak value results also suggested that the duration of soaking is an important factor in seed germination, as treatment T_3 with 36 hrs of soaking time had significantly higher peak value compared to other treatments. These results demonstrated the importance of pre-sowing treatment in promoting the germination of seeds.

The coefficient of variation (CV) is a measure of variability or dispersion of a set of data. In this case, CV_t refers to the coefficient of variation of the germination time for each treatment, and CVG refers to the coefficient of variation of the germination rate. A lower CV indicates less variability in the data. The results showed that the CV_t values range from 8.82 to 15.90, with (T_0) having the highest CVt value (Table 2). This indicated that the germination values for T_0 have the highest degree of variability, which may suggest that this treatment is less consistent in its effects on germination. Similarly, the CVG values range from 1.63 to 2.47, with (T_0) having the highest CVG value. This suggests that T_0 is also the treatment with the highest variability in germination rate, meaning that the rate of germination may be less consistent with this treatment. Overall, the higher CV values for T_0 suggest that this treatment may have less predictable effects on germination compared to the other treatments. In terms of the germination index and germination capacity, T_3 exhibited the highest values of 0.81 and was categorized as 'good' respectively. This indicates that T_3 treatment was the most effective in promoting seed germination and providing favorable germination conditions. Overall, these results suggest that soaking seeds in normal water for 36 hrs (T_3) was the most effective treatment in promoting germination compared to the other treatments (Table 2).

Table 2. Different pre sowing treatments and their effects on seed germination.

Treatment	Peak Value	CV_t	CVG	Germination Index	Germination Capacity
T_0	0.42^d	15.90^b	2.47^d	0.25^e	Very poor
T_1	0.58^c	11.08^b	2.24^d	0.33^d	Poor
T_2	0.67^c	9.72^b	1.83^c	0.39^c	Poor
T_3	1.24^a	8.82^a	1.63^a	0.81^a	Good
T_4	0.83^b	9.15^b	1.64^b	0.50^b	Average

Notes: Means followed by same letters are not significantly different at ($p< 0.05$); according to Duncan's Multiple Range Test (DMRT)

Impact of pre-sowing treatments on germination and growth of seedlings

The present study indicated that the germination period and germination percentage was significantly accelerated by different pre-sowing treatments. T_3 (soaking seeds in tap water for 36 hrs) scored the significantly highest germination percentage (72%) in the shortest germination period of 30-62 days, indicating that it was the most effective treatment for promoting germination. T_0 (seeds without any treatment) produced the significantly lowest germination percentage (30%) at the longest germination period of 52-75 days. In terms of shoot and root length, treatment T_3 produced the longest shoot length

(32cm) and the longest root length (26cm), indicating the highest growth rate among all the treatments. On the other hand, treatment T_0 scored the shortest shoot length (25cm) and the shortest root length (19cm), indicating the lowest growth rate among all the treatments. Finally, the vigor index (VI) was calculated to provide an overall measure of plant vigor. The highest vigor index 3712 was noticed in T_3 while the lowest vigor index 1320 was recorded in control (T_0). Overall, the results indicated that treatment T_3 produced the significantly highest germination, growth, and vigor, while treatment T_0 scored the lowest. (Table 3).

Table 3. Germination period, germination percentage of seeds under various treatments and initial growth performances of *S. album* seedlings in the nursery condition.

Treatment	Germination (%)	Germination period (days)	Shoot length (cm) (6 months)	Root length(cm) (6 months)	Vigor index (VI)
T_0	30 ± 1.41^{d}	$52\text{-}75^{d}$	25 ± 0.12^{d}	19 ± 0.10^{d}	1320^{d}
T_1	40 ± 1.41^{c}	$48\text{-}75^{c}$	30 ± 0.14^{c}	23 ± 0.19^{c}	2120^{c}
T_2	42 ± 0.63^{bc}	$45\text{-}70^{c}$	29 ± 0.23^{c}	22 ± 0.13^{c}	2142^{c}
T_3	72 ± 0.89^{a}	$30\text{-}62^{a}$	32 ± 0.17^{a}	26 ± 0.12^{a}	3712^{a}
T_4	44 ± 0.63^{b}	$36\text{-}70^{b}$	31 ± 0.21^{b}	25 ± 0.14^{b}	2464^{b}

Notes: Means followed by same letters are not significantly different at ($p< 0.05$); according to Duncan's Multiple Range Test (DMRT); ± indicates the standard error of the mean.

Seedlings growth performance

The present study reveals that the growth performance of *S. album* seedlings was accelerated by germinating seeds with different treatments and supported by various types of host plants. The highest diameter at breast height (DBH) (8.0 cm) and height (H) (4.70 m) of *S. album* were obtained in the association with *M. elengi* and *V. negundo* at 6.5 years and followed by association of *C. equisetifolia* and *C. cajan*, A. lebbeck and *C. equisetifolia* and *A. lebbeck* and *C. cajan*. The lowest diameter at breast height (6.50 cm) and height (3.90 m) of *S. album* saplings were found at 6.5 years of age in association of *C. equisetifolia* (Table 4).

Table 4. Growth performance of *S. album* saplings with different host plants at 6.5 years old.

Name of host plants	DBH (cm)	Height (m)
C. equisetifolia	6.50 ± 0.54^{d}	3.90 ± 0.81^{d}
A. lebbeck and *C. cajan*	6.70 ± 0.51^{c}	4.00 ± 0.95^{c}
A. lebbeck and *C. equisetifolia*	7.10 ± 0.64^{b}	4.10 ± 0.54^{c}
M. elengi and *V. negundo*	8.00 ± 0.45^{a}	4.70 ± 0.28^{a}
C. equisetifolia and *C. cajan*	7.20 ± 0.75^{b}	4.20 ± 0.91^{b}

Notes: Means followed by same letters are not significantly different at ($p< 0.05$); according to Duncan's Multiple Range Test (DMRT); ± indicates the standard error of the mean.

The findings of the study also indicated that association of two host species was better than a single species in the growth of *S. album* saplings (Table 4). The statistical analysis showed that the growth of diameter at breast height (DBH) and height were significantly influenced by different types of host plants ($P<0.05$).

Discussion

The germination percentage was accelerated by different pre-sowing treatment in different types of seeds (Labouriau 1978). Germination percentage of *Terminalia chebula* Retz. was influenced by pre-sowing treatments (Hossain *et al.* 2005). Seed germination percentage of *Acacia catechu* Willd. was also highly influenced by pre-sowing treatments (Haider *et al.* 2014). About 8-9% germination rate was increased with the help of pre sowing treatments of *S. album* in India (Sudhir and Jagatpati 2017). This study reveals that germination percentage was significantly influenced by pre- sowing treatments ($P< 0.05$). The initial growth performance of *S. album* seedlings was also influenced by different pre-sowing treatments. Soleymani and Sharajabian (2018) noticed that germination is influenced through environmental factors. There is evidence that soaking of seeds in water helps in softening the seeds coat, removal of inhibitors and reduces require time for germination and enhances germination (Hartman *et al.* 2007). The positive results were noticed in the present study which was similar to the previous findings. Germination percentages were increased with the increasing soaking period in water (Gupta 2003), but up to certain period. Seed germinations were accelerated by different types of pre-sowing treatments was also reported by Das and Tah (2013). Sudhir and Jagatpati (2017) worked on *S. album* and its different host plants and they observed that *C. cajan* and *Ocimum sanctum* were the best host plants in different locations for the growth and development of *S. album* seedlings. In some cases, *Catheranthus roseus* was also proved to be good host plant for the growth and survival of *S. album* (Sudhir and Jagatpati 2017). *S. album* is mainly sun-loving and growth is influenced by complementary competition of hosts. When host is introduced in the pot at the early stage, there is possibility of competition for soil moisture and nutrient between sandalwood and host. Sandalwood with a haustorial adaptation on its roots which parasitize the roots of other plants and create a relationship with other plants like *Pongamia pinnata* and *C. equisetifolia* (Nagaveni and Vijiayalakshmi 2004). Nodule and microbial features of *Cajanus* and *Pongamia* were parasitized by sandalwood (Subbarao *et al.* 1990). They observed that the parasitic dependence of sandalwood plants on nodulated host plants was evident in the gradual increase of their nitrogen content. In nature, the establishment and survival of sandalwood tree is entirely dependent on other woody plants in its vicinity which serve as host. Coolbear *et al.* (1984) reported that sandalwood can be parasitic over 300 species of host plants found in nature from grasses to leguminous trees. Sandalwood shows different growth patterns with different host species and lack of understanding of the host plants relationship cause the failure of sandalwood seedling production (Srinivasan *et al.* 1992; Surata *et al.* 1995). It is proved that host is essential in all stages of sandalwood and *C. cajan* is the most essential host plant at the nursery stages (Fox *et al.* 1996). For sustainable growth and development of sandalwood, the following host species were selected as host plants for sandalwood in the field levels. These were *Cynodon dactylon*, *A. saman*, *C. equisetifolia* (Rai 1990; Taide *et al.* 1994; Srivastava *et al.* 2003) and *P. pinnata* (Nagaveni and Vijayalakshmi 2004). It is clear that, host plants are essential for the growth of sandalwood tree and it depends on host plants for potential components which help survival of sandalwood. According to Rangaswamy *et* *al.* (1986), *S. album* cannot survive without host plants. It is depended on its host plants for nutrients such as; N, P, K and Mg etc. Tennakon *et al.* (2000) observed that perennial host plants are also better than annual host plants.

Conclusion

The study demonstrated that pre-sowing treatments and host plants significantly influenced the germination and growth of *S. album*. Seeds soaked in tap water for 36 hrs resulted in the highest germination percentage, while the association of *M. elengi* and *V. negundo* yielded the tallest and thickest *S. album* trees. These findings could be used in massive plantation programs to improve the growth and germination percentage of *S. album* in the field, which is urgent due to the species' rapid degradation from habitat fragmentation and human activities. The study highlights the importance of using appropriate pre-sowing treatments and host plants for successful mass propagation and plantation of *S. album*.

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Research Article

In vitro Direct Regeneration of Hilly Edible Bamboo *Dendrocalamus longispathus* in Bangladesh

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Abstract

The Dendrocalamus longispathus, localy name Ora bamboo is one of the preferred bamboo species by the tribal people for homestead plantation, in hills, especially for edible shoot production. The demand for bamboo seedlings is increasing day by day but the seeds are very rare because of the long flowering time. Besides, the conventional method through rhizome culture is not economically viable for large-scale seedling production of this bamboo. The purpose of the study is to develop an in vitro protocol for mass production of healthy bamboo seedlings. Branch nodal buds were used as the explant for culture initiation through axillary shoot formation. MS medium supplemented with lower concentrations of BAP (0.0, 0.5, 1.0, 1.5, 2.0 mg/L) deployed for bud breaking and shoot formation along with control. About 90% of explants responded to initiate axillary shoots in media having MS+1.0 mg/L BAP+3% sugar after 28 days of culture. Optimization of shoot production was carried out in MS medium supplemented with different concentrations (0.0, 1.0, 2.0, 3.0, 4.0, and 5.0 mg/L of BAP and Kn alone or in combination). The highest number (25) of young shoots per culture were recorded in medium having MS+3.0 mg/L BAP+4% sugar+2.75 g/L gelrite after 28 days of culture. Rooted plantlets were produced in ½ MS medium supplemented with IBA (1.0 mg/L). The tissue culture plantlets were successfully hardened in soil and 95-98% plants were survived and were well grown. The protocol developed through this study enables the production of a large number of bamboo seedlings for mass propagation in a short period of time that could be the opportunity to supply the bamboo seedlings for the future demand.

সারসংক্ষেপ

Dendrocalamus longispathus (ওরা বাঁশ), উপজাতীয় অধিবাসীদের পছন্দনীয় একটি বাঁশ যার সদ্য গজানো নতুন কোড়ল খাদ্য হিসেবে ব্যবহারের উদ্দেশ্যে তারা বাসস্থান সংলগ্ন স্থানে চাষ করে থাকে। এ বাঁশের চারার চাহিদা দিন দিন বৃদ্ধি পাচ্ছে কিন্তু বাঁশের ফুল খুবই দুষ্প্রাপ্য হওয়ার ফলে বীজ থেকে চারা উত্তোলন সম্ভবপর নয়। তাছাড়া প্রচলিত মোথা ও অন্যান্য পদ্ধতিতে অধিক সংখ্যক চারা উৎপাদন অর্থনৈতিকভাবে সাশ্রয়ী নয়। এমতাবস্থায় ইনভিট্রো পদ্ধতিতে এ বাঁশের স্বল্প সময়ে ব্যাপক চারা উৎপাদনের কৌশল উদ্ভাবনের উদ্দেশ্যে গবেষণাটি সম্পন্ন করা হয়। ওরা বাঁশের কঞ্চির গীট *MS* খাদ্য মাধ্যমে স্বল্পমাত্রায় *BAP (০.০, ০.৫, ১.০, ১.৫, ২.০ mg/L)* প্রয়োগে *bud* থেকে *shoot* উৎপাদন করা হয়। *MS+১.০mg/L BAP+৩% sugar* খাদ্য মাধ্যমে প্রায় ৯০% *nodul bud, shoot* উৎপাদন করে। অতঃপর *shoot* উৎপাদনের মাত্রাকে *optimize* করা হয় এবং *MS+৩.০mg/L BAP+৪% sugar+২.৭৫g/L gelrite* মিডিয়ামে গড়ে সর্বোচ্চ ২৫টি *shoot* প্রতি কালচারে পাওয়া যায়। উৎপাদিত *shoot* গুলিকে অর্ধশক্তির *MS* মিডিয়ামের সাথে বিভিন্ন মাত্রায় *IBA* প্রয়োগ করে ১০০% উৎপাদন করা হয় এবং উৎপন্ন *plantlet* গুলিকে যথাযথভাবে মাটি ভর্তি পলিব্যাগে স্থানান্তর করে গ্রীণ হাউজ এবং নার্সারিতে হার্ডেনিং করা হয়। প্রাকৃতিক পরিবেশে ৯৫-৯৮% চারা বেঁচে থাকে এবং বৃদ্ধিপ্রাপ্ত হয়। উদ্ভাবিত টিস্যুকালচার প্রযুক্তির মাধ্যমে কম সময়ে প্রচুর পরিমাণ উন্নত মানের চারা উৎপাদন করে চাহিদা পূরণ করা সম্ভব হবে।

Keywords: *Branch nodal bud, Dendrocalamus longispathus, In vitro, Mass propagation.*

Introduction

Bamboo is regarded as one of the most important 21st century crop since its produces food and wood. It is well situated to address shelter, food security, livelihood and ecological security. The young shoots of some bamboo species are high value low fat and vegetables, with high percentage of protein, edible cellulose, many kinds of amino acids and mineral elements. There are more than 1500 species in 75 genera of bamboos in the world. The total area of bamboo forest in the world amounts to 14 million ha distributed mainly in bamboo zones of Asia, Pacific, Americas and Africa. However, East Asia and Southeast Asia have the largest bamboo forest areas including some 80% of the species of the world. Bangladesh lies in the north-east part of South Asia roughly between 20.75°C and 25.75°C. The country enjoys generally tropical monsoon climate As a result the soil and climatic conditions are favorable for the growth and development of bamboos. About 9 genera and 36 species of bamboos are growing throughout the country (Rahman *et al*. 2017). It has 5 lac hectares bamboo plantations occupied both in village and forest lands. Seven bamboo species are grown in the forest land covering 2 lac hectares and others 26 species are found as the cultivated bamboos in the village land covering 3 lac hectares. *Dendrocalamus longispathus*, local name ora Bansh (Fig.1) is one of the important forest bamboos. It is native to the hill forest of Bangladesh likely Chittagong, Chittagong Hill Tracts, Cox's Bazar and Sylhet. It is a clump forming bamboo with sympodial rhizome system. The culm attains about 10-16m height with 4-10cm diameter of 0.2-1.8cm thickness. This bamboo is commonly used for making baskets, furniture and food grain containers. It is also used as floats and rafts for timber transportation. Provides raw materials of paper pulp industries. Young shoots are edible. It is a handsome species and also cultivated as an ornamental (Banik 2000). It is one of the preferred species by the tribal people especially for edible shoot production. Young bamboo shoots have nutritious food and medicinal value regarded as "King of health keeping food" and "Street cleaner" for the intestine. (Fue *et al*. 2007).

Bangladesh has about 21 ethnic groups of people mainly residing in different forest areas. Among all the forest grown bamboo species local people mostly utilize and prefer only three species - *Melocanna baccifera*, *D. longispathus* and *Schzostachyum dullooa*. To the hill people, bamboo is a traditional building material. Their houses are built entirely of bamboos. The floor and walls are made of bamboo splits and flattened out and then woven together. The framework of the roof is also made from bamboo. The long internodes of *S. dullooa* are used for carrying water in steep slopes. Bamboos are also used for many medicinal purposes. Local people play an important role in conserving bamboo resources as well. The greatest problem in the cultivation of this renewable resource is difficulty in raising propagules every year because of the long and often unpredictable flowering cycle (25-80 years). Bangladesh presently suffers a deficit in bamboo supply. Forecasts are that the shortfall will increase alarmingly day by day due to the large-scale death of forest bamboo and gregarious flowering. The current accelerated rate of deforestation alarmingly erodes the genetic resources of trees and bamboos. Therefore, there is an urgent need to conserve genetic resources of bamboos both in their natural habitat (*in situ*) and in *ex situ* conservation plots. Though bamboos are propagate through rhizome, seed, branch cutting, culm cutting, ground layering, etc. in different parts of the world but no one method of propagation of bamboos is universal and effective for all the species. Among the propagation methods, branch cutting techniques have been found to be successful for several thick-walled village bamboo species but difficult and slow for thin-walled and forest bamboo species (Banik 1987). The tissue culture technology was therefore, considered as an alternative clonal propagation tool for large scale production of several bamboo species (Rao and Rao 1990; Sultana *et al.* 2020). Considering these limitations, an effort has been taken for the *in vitro* propagation of *D. longispathus* from branch nodal bud explant for mass propagation. So far no report has not yet been published on nodal culture *in vitro* regeneration technique on this species.

Thus the present research project has therefore been designed to develop an efficient tissue culture protocol for mass production of this important hilly bamboo species of Bangladesh.

Figure 1. A clump of *D. longispathus* bamboo at BFRI bambusetum.

Materials and Methods

Sources of explants

The study was conducted in the Plant Tissue Culture Laboratory under the Silviculture Genetics Division of Bangladesh Forest Research Institute (BFRI), Bangladesh. The experiment was conducted by using the explants of nodal buds of suggested bamboo branches. Branches of a 1-2 years old healthy culm was selected as a source of explant. The germplasm of this bamboo species was collected from Hathazari, Chattogram and conserved at BFRI bambusetum in 1979.

Explants preparation and sterilization

Each single node with a bud was dissected from the branch with a length of 4.0-5.0cm for further processing. The explants were taken in a bottle and washed with detergent and rinsed under running tap water for 30 min. Then it was carried under laminar air flow. The surface sterilization was started with one drop of tween 20 for 7-10 min. with frequent shaking. Later on it was washed with sterilized distilled water for 2-3 times. After washing, the explants were immersed in 70% ethanol for 1 min and then surface sterilized with 20% Clorox® for 15 min followed by rinsing with sterilized distilled water for three times. Finally, sterilization was done with 0.1% $HgCl_2$ treatment twice for 10 and 5 min. subsequently followed by rinsing with sterilized distilled water for 4 to 5 times to remove the $HgCl_2$ traces.

Culture media preparation

The sterilized nodal buds were inoculated onto MS (Murashagi and Skoog 1962) medium comprising 3% sucrose as a carbon source and 2.8 gm/L gelrite as solidifying agent. Various plant growth regulators such as; cytokinins (BAP & Kn) and auxins (IBA & NAA) were used to prepare MS medium for culture establishment, multiple shoots production and root induction from the base of excised new shoots. The pH of the medium was adjusted to 5.8 using 0.1N NaOH or 0.1N HCl before addition of gelrite and sterilized by autoclaving at 1.08 kg/cm² pressure and 121°C for 20 min.

Culture conditions

The cultures were incubated at 25±2°C under cool white and fluorescent light of 2000-2500 lux, relative humidity about 60-80% and 16/8 hours photo and dark period were maintained in growth chamber, respectively. These culture conditions were used in all the experiments mentioned below unless otherwise stated. Observations were made at regular intervals and recorded the responses of explants at every step.

Culture establishment, multiple shoots production and optimization

The aseptic nodal buds were cultured on MS medium supplemented with 0.0 (MS0/control), 0.5, 1.0, 1.5 and 2.0 mg/L of BAP alone for bud breaking and shoot production. Number of explants induced shoots through bud breaking and their morphological responses were observed periodically. The shoots were separated from the node and cultured on shoot producing medium. To optimize the shoot production, single shoot was cultured on MS medium supplemented with different concentrations of BAP (0, 1.0, 2.0, 3.0 4.0 and 5.0 mg/L) and Kn alone and/or in combination. Similarly, the effect of sub-culturing and the strength of sucrose level and culture periods were evaluated. Rate of multiplication of shoots and their growth were recorded up to 3-8 weeks of each culture.

Development of roots at the base of the shoot, hardening and acclimatization of plantlets

In vitro elongated shoots (6-7cm) with at least 3-4 nodes were taken out from the culture vessel and transferred to half strength MS medium with different concentrations (0.0, 0.5, 1.0 and 2.0 mg/L) of IBA for root induction. The rooted shoots were taken out of the culture vessels, washed thoroughly under running tap water to remove the debris gelling agent with care and transferred to a pot (10cm x 9cm) filled with 2:1 garden soil and compost. The potted plants were kept inside the green house for adaptation and maintained the humidity and temperature through misting. Within 10-15 days each plant produced new leaves with shoots and resumed its growth. The tissue culture plants were brought out of the greenhouse and putted under full sunlight in the nursery for further growth up to the planting season. About 95% potted plants were established successfully.

Statistical analysis

All experiments were performed as Completely Randomized Design (CRD). Data were analyzed using statistical analysis system (SAS v9.3) and means were statistically compared using LSD test. The significance level was set up at $p < 0.05$. Three replications were considered for each treatment and repeated three times.

Results

In vitro culture initiation and axillary shoot formation

In vitro culture initiation of *D. longispathus* was started with nodal bud breaking through axillary shoot formation. The nodal explants were cultured in full-strength MS medium supplemented with or without growth regulators adding vitamin B5. In the present study, experiments were conducted in MS medium supplemented with BAP 0.5, 1.0, 1.5 and 2.0 mg/L, and without any growth regulator as a control for bud breaking and shoot production. The influence of growth regulators on bud breaking and shoot formation was observed. It was found that addition of growth regulators in culture medium resulted in faster growth and maximum bud breaking of explants, while the culture without growth regulator (MS0) takes longer time to initiate the culture and further growth. The highest (92%) of explants established and produced axillary shoots in MS medium supplemented with 1.0 mg/L BAP followed by 1.5 mg/L BAP (70%)

and the lowest (20%) in the PGRs-free (MS0) medium (Table 1, Fig. 3A). It was observed that media with BAP took 7 days to initiate the culture whereas media without BAP it took more than 15 days. The growing shoots with 2.0cm in length were separated and sub-cultured in the same media for multiple shoot production and optimization.

Table 1. Effect of BAP in MS media on *D. longispathus* bud breaking and axillary shoot formation from nodal explant after 28 days of culture.

Treatments MS + BAP (Mg/L)	% of explant induced shoots	Mean no. of shoots	Mean length of shoots (cm)	Days till initiation
0.0	20 ±0.57	1.00 ±0.28	1.52±0.002	15 ±0.28
0.5	51 ±0.28	3.00 ±0.28	2.80±0.05	10 ±0.28
1.0	**92 ±0.76**	**6.20 ±0.05**	**4.95±0.002**	**7 ±0.50**
1.5	70 ±0.28	4.30 ±0.1	3.76±0.07	8 ±0.28
2.0	62 ±0.57	3.45 ±0.005	3.55±0.01	8 ±0.50

Notes: Means followed by same letters are not significantly different at (P< 0.05); according to Duncan's Multiple Range Test (DMRT); ± indicates the standard error of the mean.

Shoot multiplication and optimization

The effect of plant growth regulators on multiple shoot formation of *D. longispathas* and optimization were tested on MS medium supplemented with different concentrations (0.0, 1.0, 2.0, 3.0, 4.0, and 5.0 mg/L) of BAP and Kn. The results showed that MS medium without plant growth regulators produced a small number of shoots, whereas the supplementation of plant growth regulators enhanced shoot formation rate. Between the two cytokinins, BAP was found to have more potential than Kn for new shoot formation. The maximum number of shoots produced per culture in MS medium supplemented with 3 mg/L BAP, followed by 3 mg/L Kn. Where the mean number of shoots was found to be 28.66 and 18.0 per culture, respectively, after 8 weeks of culture (Fig. 2, Fig. 3B & 3C).

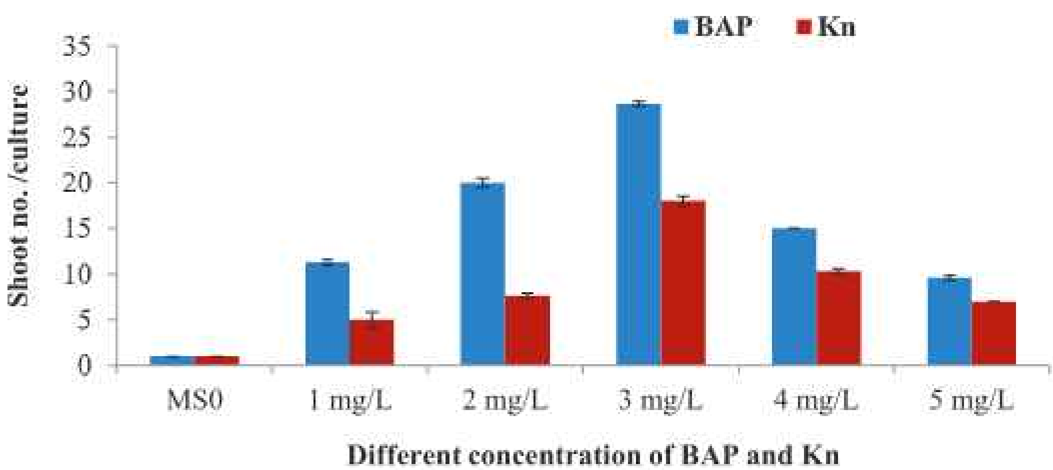

Figure 2. Effect of different concentrations of BAP and Kn supplemented with MS medium on multiple shoot production of *D. longispathus*. The vertical bar represents the standard error.

The multiple shoots production rate increased in both cytokinins BAP and Kn ranges from 1.0 mg/L to 3.0 mg/L. However, both the cytokinins BAP and Kn alone enhanced the shoot proliferation, but the regenerated shoots remain stunted in their growth. To enhance the shoot growth, the combined effect of BAP and Kn was evaluated. The optimized concentration of BAP (3.0 mg/L) was tested with different concentrations of Kn (0.0, 1.0, 2.0, 3.0, and 4 mg/L) at the same MS media. A positive effect was observed in both shoot proliferation and shoot growth as well. The highest shoot number per culture was 18.33 and shoot length were recorded as 6.28cm in medium containing MS + 3.0 mg/L BAP + 1.0 mg/L Kn + 4% sugar after 28 days of culture (Table 2, Fig. 3D).

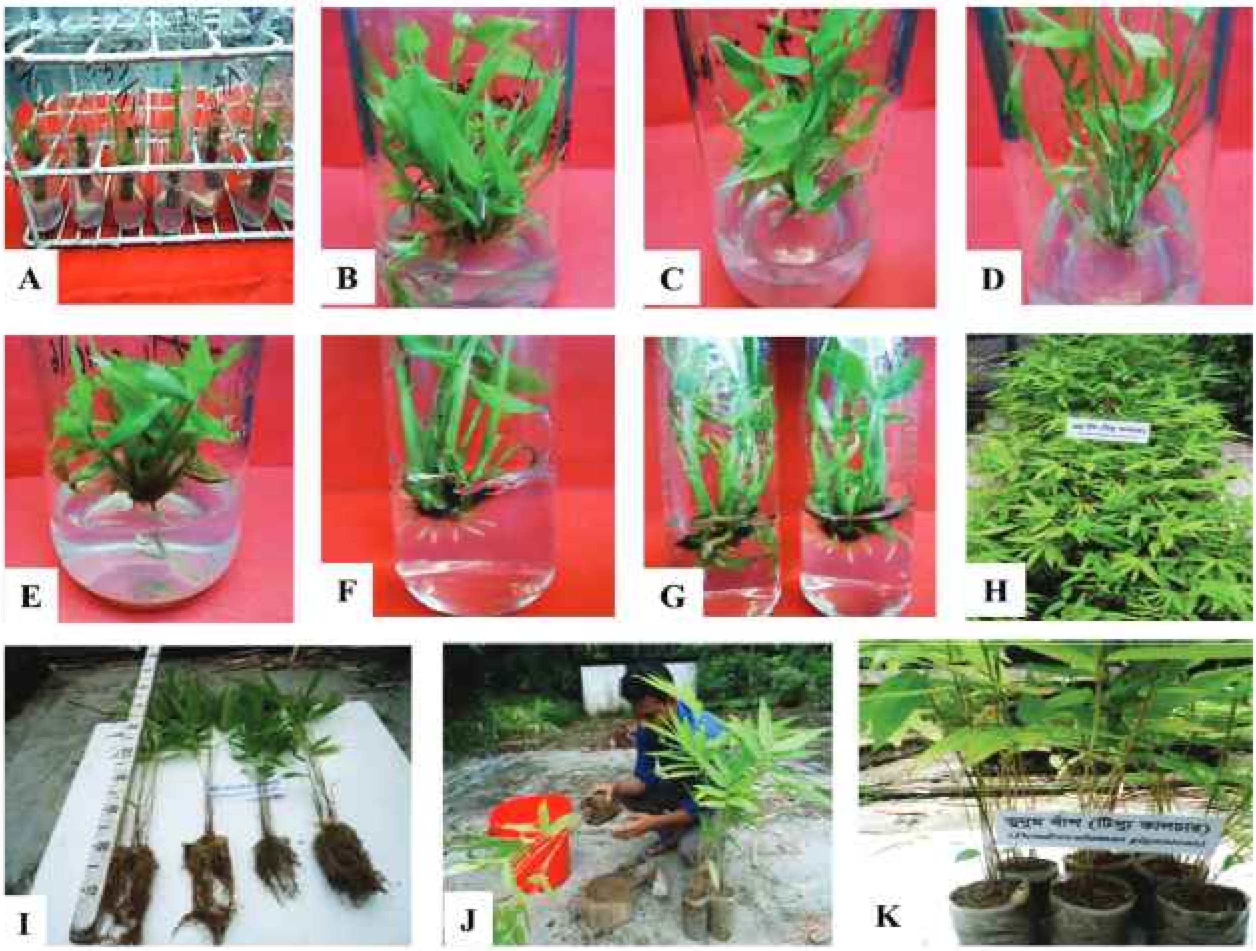

Figure 3. Micro-propagation of *D. longispathas*. Nodal bud breaking and culture initiation in MS + 1.0 mg/L BAP + 3% sugar (A). Multiple shoot production in MS + 3.0 mg/L BAP + 4% sucrose (B&C). Multiple shoot production on MS + 3.0 mg/L Kn + 4% sucrose (D). Combined effect of BAP and Kn in multiple shoot formation, MS + 3.0 mg/L BAP + 1.0 mg/L Kn + 4% sucrose (E). Root induction on the *in vitro* grown shoot. ½ MS + 1.0 mg/L IBA + 2% sucrose (F&G). Transplanted rooted plantlets in the soil hardened in green house (H). Further proliferation of TC seedlings after 3 months old of *D. longispathas* at nursery for mass production (I, J & K).

Table 2. Combined effect of BAP and Kn on shoot multiplication of *D. longispathus* after four weeks of culture.

Hormonal conc. (mg/L)	Mean no. of shoot/culture	Mean no. of shoot length (cm)
3.0 BAP + 0.0 Kn	12.00 ± 0.28	3.30 ± 0.18
3.0 BAP + 1.0 Kn	18.33 ± 0.5	6.28 ± 0.35
3.0 BAP + 2.0 Kn	15.00 ± 0.5	5.56 ± 0.01
3.0 BAP + 3.0 Kn	13.33 ± 0.28	4.00 ± 0.16
3.0 BAP + 4.0 Kn	10.00 ± 0.28	3.95 ± 0.48

Medium: MS+ additives, mean ± SE, n= 3 replicates

Effect of different strength of sucrose on multiple shoot formation

The sucrose in culture media was optimized in MS medium containing 10, 20, 30, 40, and 50g/L. The number of shoots per culture increased in the media having sucrose levels from 10 to 40g/L supplemented with growth regulators. The media having MS+ 3.0 mg/L BAP + 1.0 mg/L Kn + 40g/L sucrose produced the maximum shoots (28.66 per culture) after 6 weeks meanwhile, media containing 50g/L sucrose produced 17.66 shoots per culture after the same period. Among the different concentrations of sucrose, 40g/L produced the highest number of shoots per culture, followed by 30g/L sucrose after 6 weeks. (Fig. 4 & Fig. 3E).

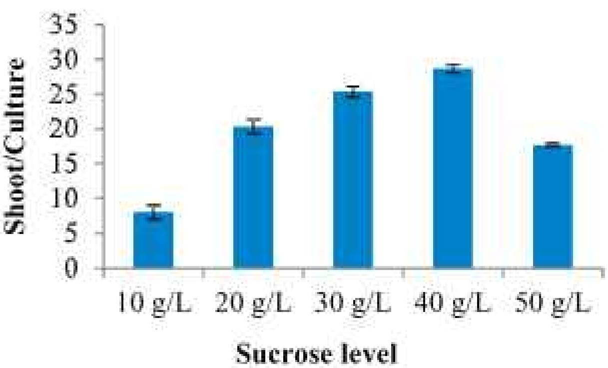

Figure 4. Effect of different strengths of sucrose on multiple shoot production of *D. longispathus* in MS medium. The vertical bar represents the standard error.

Effect of sub culture on multiple shoot production

The effect of subculture on multiple shoot production of *D. longispathus* was evaluated. Every 2 weeks of interval, sub-cultures were maintained for multiple shoot formation. It was observed that shoots regenerated in each subculture without loss of morphogenic changes. In the first sub-culture, the shoot per culture was 10.66, which increased up to the fourth sub-culture as 25.0 shoots/culture. However, in the 5th subculture the shoot number subsequently decreased to 12.33 shoots/ culture (Fig. 5).

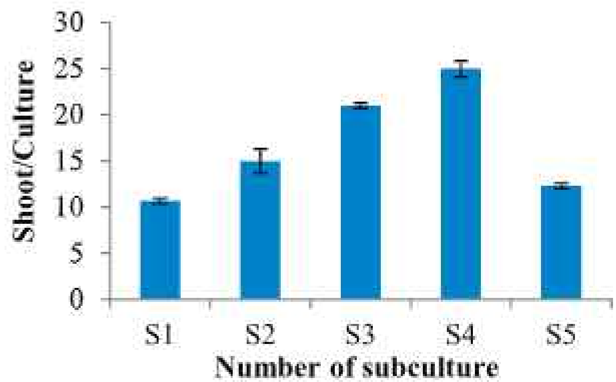

Figure 5. Effect of different subculture on multiple shoot production of *D. longispathus* in MS medium. The vertical bar represents thestandard error.

Effect of different concentrations of auxin on rooting

The optimization of *in vitro* rooting of excised shoots was carried out in ½ MS medium supplemented with different concentrations of IBA, viz. 0.0, 0.5, 1.0, 2.0, 3.0, and 4.0 mg/L. It was observed that no roots were induced in the auxin-free MS medium. The average number of root formations was maximum on hormone supplemented medium. However, medium containing 1.0 mg/L IBA showed quick response in rooting and gained a maximum number of roots per culture. About 90% culture induced roots in this medium. Among the different concentrations of IBA, the maximum number of roots (9.33 per shoot) was recorded in media having 1mg/L after 4 weeks of culture (Fig. 6, Fig. 3F & 3G).

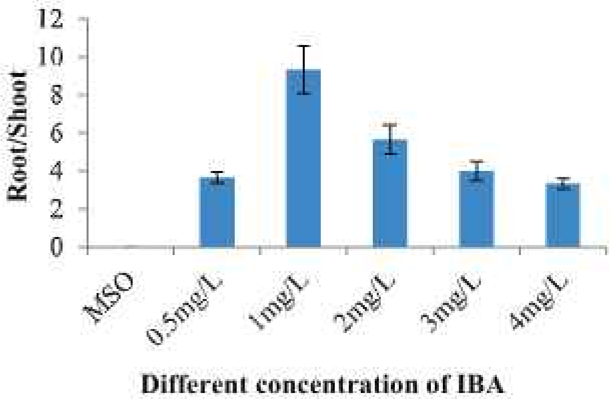

Figure 6. Effect of different concentrations of IBA on root induction of *in vitro* grown excise shoots of *D. longispathus*.

Acclimatization of plantlets

In vitro rooted plantlets with culture bottles were brought to the greenhouse for initial hardening. After 2-3 days, the plantlets were removed from the culture tubes and planted in a small plastic pot/polybag containing forest soil and compost (3:1) and kept in the green house, followed by transfer to the net house after another 2–3 weeks of hardening. Finally, the acclimatized and hardened plants (1–2 feet tall) were transferred to the natural conditions. The survival rate was found to be 95-98% after 60 days of hardening of *D. longispathus* seedlings in the nursery (Fig. 3H).

Morphogenic responses of tissue culture plants under nursery condition

During the growing stage of tissue culture plants in polybag under nursery conditions, each plant produced several numbers of new shoots with healthy roots due to rejuvenality and formed a mini clump. Maximum 22 numbers of new shoots per plant were recorded after 10 weeks of growth in polybag. These mini-clumps were proliferated further and produced more new plants. (Fig. 7, Fig. 3I, 3J & 3K).

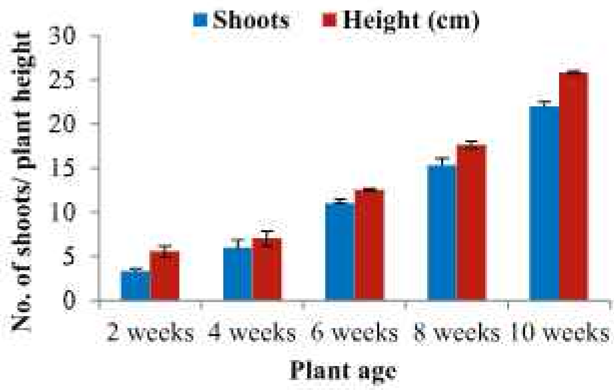

Figure 7. Growth performances of tissue culture derived transplants of *D. longispathus*. The vertical bar represents the standard error.

Discussion

In vitro shoot multiplication and mass production of *D. longispathus* was initiated through nodal bud culture in MS medium supplemented with different concentrations of BAP (0.0, 0.5, 1.0, 1.5, and 2.0 mg/L) and without BAP. The influence of plant growth regulator was evaluated on bud breaking and axillary shoot formation in comparison to the control treatment. It was observed that the explant responded faster to bud breaking and shoot formation in the medium having growth regulators than in the medium devoid of plant growth regulators. This result is also supported by Rahman *et al.* (2018). They suggested that the supplementation of plant growth regulators were positively influenced the shoot proliferation of *Phyllanthus emblica*. The apical shoot tip of *P. emblica* enabled it to produce shoots in MS medium supplemented with different concentrations of BAP to initiate the culture. The germination competence of the seed explants seems to be markedly influenced by different growth regulators in nutrient media (Paudel and Pant 2012). MS with or without growth regulators was found to be effective for the germination of immature seeds (Pant and Swar 2011). BAP with different concentrations significantly affected the seed germination and shoot initiation ($p<0.001$), of *D. giganteus* (Nusrat *et al.* 2020). BAP in combination with Kn at higher concentrations significantly reduced the number of shoots formed per explant. The result is in agreement with the findings in *Opuntia ficusindica* (Garcia – Saucedo *et al.* 2005) and *Zingiber petiolatum* (Prathanturarug *et al.* 2004). The result also supported by Arya *et al.* (1999; 2012), who mentioned that the shoot initiation percentage was greatly influenced by the type and concentrations of BAP in *D. asper* and *D. hamiltonii*, respectively. The requirement of exogenous plant growth regulators for *in vitro* regeneration depended on the endogenous level of the plant tissue, which varied with organs, plant genotype, and the phase of plant growth (Chand and Singh 2004; Rahman *et al.* 2018). The regeneration efficiency depended on plant growth regulator concentrations and combinations (Nodong *et al.* 2006; Popelka *et al.* 2006). Explants cultured on MS medium without cytokinins developed 1-2 shoots, indicating that the explants had enough endogenous cytokinins to induce a limited number of shoots upon culturing. While explants cultured on MS medium supplemented with a higher concentration of BAP induced a number of shoots without roots. This might be due to the enhanced level of cytokinins, and the auxin ratio favors only shoot regeneration in the absence of equivalent level of auxins inside the plant. The micro shoots produced in lower levels of BAP and Kn were green, taller having bigger leaves than those produced at higher concentration of cytokinins. In MS medium containing BAP the plantlets were slightly taller than those produced in MS medium supplemented with Kn. Cytokinin had a strong effect on the quality of the shoots production (Neves *et al.* 2001). The growth of plantlets was retarded at higher concentrations of BAP. It was reported that cytokinins commonly stimulate shoot proliferation in *Capsicum sp.* and *P. emblica*, which inhabit the shoot elongation (Peddabonia *et al.* 2006; Rahman *et al.* 2018). Kalinina and Brown (2007) found that treatments of *Prunus sp.* with BAP concentrations promoted the shoot numbers per explant but decreased the shoot length and negatively affected shoot development. BAP was the most widely used cytokinin for multiple shoot formation (Herath *et al.* 2004). The superiority of BAP over Kn and other cytokinins for multiple shoot formation was also demonstrated in *Salix pseudolasiogyne* (Park *et al.* 2008). The results showed that the addition of lower levels of BAP and Kn to the medium enhanced the shoot regenerative ability in *D. giganteus* (Nusrat *et al.* 2020). However, the number of multiple shoots reduced at higher concentrations of BAP and Kn. *In vitro* grown higher plants are fully autotrophic (Lipavska and Vreugdenhil 1996). During plant tissue culture an exogenous carbon source, is an essential ingredient of all culture media (Kozai 1991b). Debnath (2005) reported that specific carbohydrates may have different effects on morphogenesis *in vitro,* thus the carbohydrate requirements must be defined and optimized for each propagation system. The effect of sugar and concentration on shoot proliferation was genotype dependent.

In the present study, 4% sugar was the optimum carbon source for *in vitro* multiple shoot formation in *D. longispathus*. Pati *et al.* (2006) and Rahman *et al.* (2019) found that sucrose concentration in culture medium had significant effect on shoot and root regeneration. Higher concentrations of sucrose were deleterious to shoot growth and caused a decrease in dry matter accumulation due to a decrease in the osmotic potential of the medium (Lipavska and Vreugdenhil 1996). Increasing sucrose levels by more than 7% in the medium caused osmotic stress, which significantly inhabited the growth of *Parthenium argentatum* (Norton *et al.* 1991). In this study, no shoot proliferation was observed in the sugar free medium. Sub culture exercised an important role in the multiplication of cultures (Debnath and McRae 2001). The duration of culture depended on plant species, growth rate, physical and physiological condition, as well as the development stage of the plant (Moges *et al.* 2004). However, the action of sub-culture at a 2 weeks interval did not enhance the production of multiple shoots but produced a bigger shoot that was dark green in colour. Plant tissue might have a chance to develop mutations due to repeated subculturing, or it might produce callus, become abnormal, and reduce the proliferation rate. The result revealed that *D. longispathus* did not show morphological changes after repeated subculturing. Likewise, it was reported that the long-term culture of *Digitalis obscura* did not affect the genetic stability *in vitro* (Gavidia *et al.* 1996). In this study, the number of shoots and growth declined by repeated sub-culturing after four sessions. Thong (2002) reported that repeated sub-culturing caused shoot reduction in *Zingiber officinale, Curcuma domestica, Alpinia galanga,* and *Kaempferia galangal*. In contrast, repeated sub culturing of *in vitro* shoots of *Spilanthes acmella* increased the multiple shoot formation by threefold (Ang and Chan 2000). *In vitro* shoots was rooted in half-strength MS with different concentrations of IBA and NAA. All media responded positively for root formation, but no rooting was observed in the hormone free medium. However, in the present study, IBA was found to be more effective than NAA of *D. longispathus*. No significant result was found in the media supplemented with different concentrations of NAA. In woody plants, usually a low level of salt concentration is sufficient for rooting of shoots. A similar observation was made by Rai *et al.* (2010). Superiority of IBA over NAA for *in vitro* root induction was reported by Parthiban *et al.* (2013) on *B. balcooa*. *In vitro* developed plantlets have morphological and physiological abnormalities due to the *in vitro* culture conditions (Pospišilova *et al.* 1999). Direct transfer of *in vitro* plantlets to *ex vitro* conditions may result in rapid wilt and death (Lesar *et al.* 2012). Therefore, acclimatization is essential for the survival and successful establishment of plantlets (Deb and Imchen 2010). Plants grown *in vitro* were gradually acclimated to the external environment in the greenhouse and the nursery at Silviculture Genetics Division of BFRI. Addition of compost to the soil increases the porosity, resulting in better aeration of roots which tigger better growth of the plantlets. Season was found to influence the survival rate and growth of the plantlets in the field. At high humidity provides optimum conditions for the survival of delicate *in vitro* plantlets to the field.

Conclusion

The present investigation has been suggested of a protocol for *in vitro* mass propagation of *D. longispathus* from nodal bud culture. MS medium supplemented with 1.0 mg/L BAP with 4.0 g/L sugar might be recommended for maximum multiple shoot production. Half strength of MS medium with 0.5 mg/L IBA was found the best combination for *in vitro* root induction. This protocol can be applied for the large scale propagation of *D. longispathus* which might be a clue for other bamboo species.

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Research Article

Floristic Composition of Ratargul Swamp Forest in Sylhet Region of Bangladesh

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Abstract

Ratargul Swamp Forest (RSF) is a freshwater swamp forest located in Gowainghat upazilla of Sylhet district. The total area of swamp forest is about 204 ha. Approximately118.50 ha was declared reserve forest. It has a unique floral and faunal composition than other forested areas of Bangladesh. The study recorded a total of 69 plant species (tree 09, shrub 13, aquatic shrub 05, herb 36, climber 06) belong to 43 families of the existing plants in the RSF. Among the families, Asteraceae dominated with the highest species number (6 species). A total of 1,414 seedlings of nine species belonging to 07 families were recorded from the 66 sample plots of RSF. The highest tree stem density was found to be Pongamia pinnata (411 stem/ha). While Relative Density (RD) and Importance Value Index (IVI) in the dominant tree were recorded for P. pinnata at 29.55% and 68.96%, respectively. According to the results, P. pinnata is the dominant regenerating species of RSF. It was evident that the majority (56.56%) of seedlings were within the range of 0–50cm height classes, whereas only 5.74% of seedlings were found in 201–250cm height classes. The regeneration rate of P. pinnata (Koroch) and Syzygium fruticosum (Putijam) is higher than that of Barringtonia acutangula (Hijol).

সারসংক্ষেপ

রাতারগুল জলাবন সিলেট জেলার গোয়াইনঘাট উপজেলায় অবস্থিত একটি মিঠাপানির জলাবন। জলাবনের মোট আয়তন প্রায় ২০৪ হেক্টর। এর মধ্যে প্রায় ১১৮.৫০ হেক্টর এলাকাকে সংরক্ষিত বন হিসেবে ঘোষণা করা হয়েছে। বাংলাদেশের অন্যান্য বনাঞ্চলের তুলনায় এর উদ্ভিদ ও প্রাণি জগতের এক অনন্য বৈশিষ্ট্য রয়েছে। গবেষণার মাধ্যমে রাতারগুল জলাবনে ৪৩টি পরিবারের অন্তর্ভুক্ত ৬৯টি (বৃক্ষ-০৯, গুল্ম-১৩, জলজ গুল্ম-০৫, বীরুৎ-৩৬ এবং লতাজাতীয়-০৬) উদ্ভিদ প্রজাতি রেকর্ড করা হয়েছে। অন্যান্য পরিবারের তুলনায় *Asteraceae* পরিবারের আধিক্য ছিল সর্বোচ্চ। রাতারগুল জলাবনের ৬৬টি নমুনাপ্লট হতে ০৭টি পরিবারের অন্তর্ভুক্ত ০৯টি প্রজাতির সর্বমোট ১,৪১৪টি চারা রেকর্ড করা হয়েছে। সবচেয়ে বেশি কাণ্ডের ঘনত্ব পাওয়া গেছে করচের ৪১১ স্টেম/হেক্টর। সর্বোচ্চ আধিক্য ও করচের *Relative Density (RD)* এবং *Importance Value Index (IVI)* যথাক্রমে ২৯.৫৫% এবং ৬৮.৯৬ রেকর্ড করা হয়েছিল। ফলাফল অনুসারে রাতারগুল জলাবনে পুনর্জন্মকৃত উদ্ভিদের মধ্যে করচ সর্বোচ্চ। গবেষণায় দেখা যাচ্ছে যে ০-৫০ সে. মি. উচ্চতার চারার পরিমাণ ছিল সর্বোচ্চ ৫৬.৫৬% আর যেখানে ২০১-২৫০ সে. মি. উচ্চতার চারার পরিমাণ ছিল ৫.৭৪%। করচ এবং পুঁতিজামের পুনর্জন্মের হার হিজলের চেয়ে বেশি পাওয়া গেছে।

Keywords: *Plant diversity, Ratargul Swamp Forest, Regeneration.*

Introduction

Bangladesh is considered the largest delta in the world. The total wetland area of Bangladesh is estimated to be 70,000 to 80,000 km^2. It comprises about 50% of the total national land area of the country (Islam 2010; Khan *et al*. 1994). The wetlands of Bangladesh, located mainly in the north-eastern region, have great ecological, commercial, and socio-economic importance. About 50% of the people of this country are directly dependent on wetland resources for their livelihood (Islam 2010) and 70% of the country'sanimal protein comes from freshwater fish (Bhuiyan 2013). Swamp forests are measured as containing very rich components of biodiversity of local, regional, and national importance (Nabahungu and Visser 2011). Swamp forest plays a vital role in the development of human culture and society (Islam 2010) with the provision of tangible and intangible benefits. Its ecosystem is awonderful source of fish, fiber, fodder, fuel, water supply, water purification, climate regulation, flood regulation, coastal protection, recreational opportunities, tourism, and other services (Lamsal 2015). The freshwater swamps are associated with abundant and often unique plant growth dominated by trees and high shrubs in the tropics (Vijaya and Vasudeva 2011). Although vegetation structure influences productivity and function of forests (Nusslein and Tiedje 1999), until recently relatively less attention has been paid to thevegetation composition of swamp forest ecosystems due to their limited and irregular distribution worldwide. Swamp forests are more complex than other forest types because of the nature of the aquatic vegetation and its tolerance to periodic inundation and its occurrence on the banks of rivers or lakes (Keddy 2010).

Ratargul Swamp Forest is a freshwater swamp forest located in Gowainghat upazilla of Sylhet district. It is the only swamp forest located in Bangladesh and one of the few freshwater swamp forests in the world (Gopal 1999). The forest goes under 20–30 feet of water in the rainy season. The rest of the year, the water level is about 10 feet deep. It is located 45 km away from Sylhet city on the bank of the Goyain river (Banglapedia 2012). The total area of swamp forest is about 204 ha. Approximately 118.50 ha. were declared as a reserve forest (Choudhury *et al.* 2004). It has a unique floral and faunal composition compared to other forested areas of Bangladesh. This forest provides various products and ecosystem services, which play a key role in the livelihood of the local population. Also, ecologically, this forest provides significant habitat for flora and fauna. Swamp forest has experienced rapid degradation due to high population pressure, fuel wood collection, expansion of agriculture, illegal logging, grazing, infrastructure development, tourism activities, collection of medicinal plants and other forest non-wood products, pesticides, and other destruction activities (Islam *et al.* 2016).It is sure that if these disturbances continue for a few years, the wetland resources of this area will be reduced to acritical level. In this case, wetland-dependent people will face serious problems regarding their livelihood and safety. This forest has significant ecological importance. But there has been limited information on the vegetation structure of the RSF. Bangladesh Forest Research Institute is a national forest research institute, but it has little information about swamp forests and botanical specimen collection on RSF. Swam forest area have no proper conservation and management techniques, for which those are declining gradually. Therefore, the study has taken conducted to get information about the floristic composition of RSF and to collect wetland botanical specimens. This information will be helpful for the sustainable management and conservation of wetland resources in the swamp forest.

Materials and Methods

Study area

Ratargul Swamp Forest is located about 45km in the north-west of Sylhet town, is on the south-east bank of the Goyain river (Fig. 1).

Figure 1. The location map of the study area Ratargul Swamp Forest, Sylhet.

Methodology

The vegetation survey was carried out using the random quadrat method to observe the plant diversity of RSF. The optimum quadrat sizes were (10m x 10m) for tree species and (2m x 2m) for shrubs, herbs, and climbers. In each quadrat, the diameter at breast height of each tree (>5 cm dbh) was measured. Seedlings and saplings were included as herbs and shrubs, respectively. The botanical samples were collected from representative sampling plots and identified by ecological characters in the field (Fig. 2). The collected samples were identified with the help of the BFRI Herbarium (BFRIH), Chattogram, and the Bangladesh National Herbarium (BNH), Dhaka. The collected samples were identified through consultation of pertinent literature (Prain 1903; Brandis 1906; Kanjilal *et al.* 1939, 1940 and Ahmed *et al.* 2008). Identified samples were compared with the authentic specimens' samples of the BFRI herbarium. Finally, the samples were preserved in the BFRI herbarium. The family names were adopted according followings Cronquist's system of classification (Cronquist 1981).

Figure 2. Sample plots laying out, collection of regeneration data and botanical samples from Ratargul Swamp Forest.

Statistical analysis

The relative values of density, frequency, dominance, and importance value index (IVI) for each species were calculated according to the methods of Magurran (1988), Dallmeier *et al.* (1992) and Shukla and Chandel (2005). The methods are as follows:

- $\text{Density} = \dfrac{\text{Total number of individual of a species in all quadrats}}{\text{Total number of the quadrats}}$
- $\text{Relative Density} = \dfrac{\text{Total number of individuals of the species}}{\text{Total number of individuals of all species}} \times 100$
- $\text{Frequency} = \dfrac{\text{Total number of quadrat in which the species occurred}}{\text{Total number of the quadrates studied}}$
- $\text{Relative Frequency} = \dfrac{\text{Frequency of one species}}{\text{Total frequency of all species}} \times 100$
- $\text{Abundance} = \dfrac{\text{Total number of individuals of a species in all quadrats}}{\text{Total number of quadrats in which the species occurred}}$
- $\text{Relative Abundance} = \dfrac{\text{The abundance of one species}}{\text{Total abundance of all species}} \times 100$
- Importance Value Index = Relative density+ Relative frequency + Relative abundance

Results

Floristic composition

The study recorded a total of 69 plant species (tree 09, shrub 13, aquatic shrub 05, herb 36, climber 06) belonging to 43 families (Table 1) and Fig. 3 of the existing plants in the RSF.

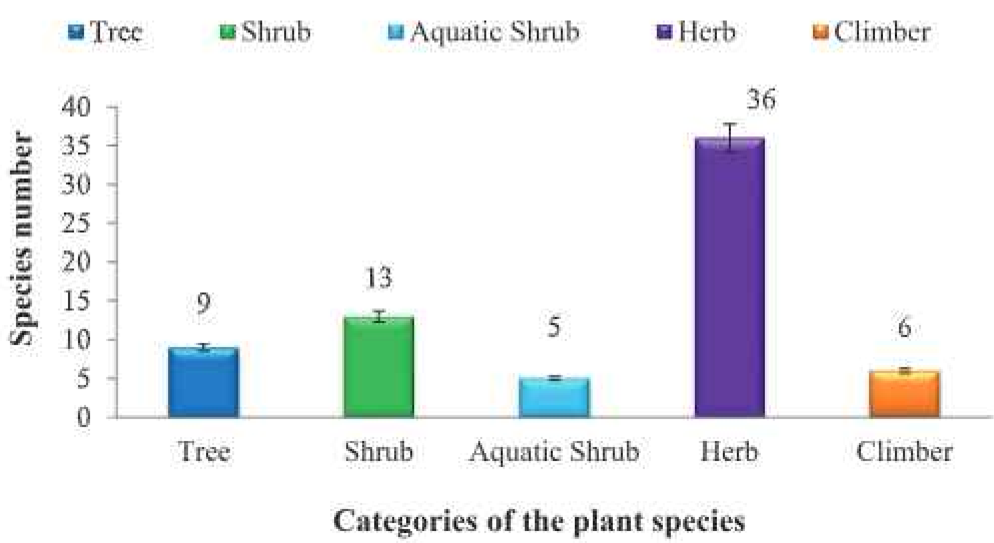

Figure 3. Habit categories of the plant species recorded from Ratargul Swamp Forest.

Table 1. List of the existing plant species in Ratargul swamp forest in the Sylhet region of Bangladesh.

Sl. No.	Local Name	Scientific Name	Family	Habit	Ecosystem value
1.	Ochunti	*Ageratum conyzoides* L.	Asteraceae	Herb	Medicinal
2.	Khetranga	*Alpinia conchigera* Griff.	Zingiberaceae	Herb	Medicinal
3.	Helencha	*Alternanthera philoxeroides* (Mart.) Griseb.	Amaranthaceae	Herb	Wild vegetable
4.	Kakerpantabhat	*Ampelygonum chinense* (L.) Lindley	Polygonaceae	Herb	Unknown
5.	Shialkanta	*Argemone maxicana* L.	Papaveraceae	Herb	Medicinal
6.	Alkushi	*Mucuna pruriens* (L.) DC.	Fabaceae	Climber	Medicinal
7.	Shatomuli	*Asparagus racemosus* Willd.	Liliaceae	Small shrub	Medicinal
8.	Hijol	*Barringtonia acutangula* (L.) Gaertn.	Lecythidaceae	Tree	Unknown
9.	Keshuriya	*Bergia ammannioides* Roxb. *ex* Roth.	Elatinaceae	Aquatic herb	Unknown
10.	Shola	*Blyna octandra* (Roxb.) Planch. *ex* Thw.	Hydrocharitaceae	Stemless herb	Unknown
11.	Bulboden	*Bulbostylis densa* (Wall.) Hand.-Mazz.	Cyperaceae	Herb	Unknown
12.	Jali Bet	*Calamus tenuis* Roxb.	Arecaceae	Shrub	Economic
13.	Thankhuni	*Centella asiatica* (L.) Urban	Apiaceae	Creeping herb	Wild vegetable
14.	Binsowan	*Dopatrium junceum* (Roxb.)Buch.-Ham. *ex* Benth.	Scrophulariaceae	Aquatic herb	Unknown
15.	Assam gach	*Chromolaena odorata* (L.) King & Robinson	Asteraceae	Herb	Medicinal
16.	Kochu	*Colocasia esculenta* (L.)Schott	Araceae	Herb	Wild vegetable
17.	Kanshira	*Commelina benghalensis* L.	Commelinaceae	Herb	Medicinal
18.	Barun	*Crateva magna* (Lour.) DC.	Capparidaceae	Tree	Fuel wood
19.	Joraghasi	*Cyperus articulates* L.	Cyperaceae	Herb	Unknown
20.	Tata ghasi	*Cyperus exaltatus* Retz.	Cyperaceae	Herb	Unknown
21.	DhekiaShak	*Diplazium esculentum* (Retz.) Sw.	Athyriaceae	Creeping herb	Wild vegetable
22.	Gachalu	*Discorea pentaphylla* L.	Dioscoreaceae	Climber	Unknown

Sl. No.	Local Name	Scientific Name	Family	Habit	Ecosystem value
23.	Kalokeshi	*Eclipta prostrate* L.	Asteraceae	Herb	Medicinal
24.	Kachoripana	*Eichhornia crassipes* (Mart.) Solms	Pontederiaceae	Aquatic herb	Unknown
25.	Dumur	*Ficus hispida* L.	Moraceae	Small tree	Wild fruit
26.	Dumur	*Ficus* sp.	Moraceae	Shrub	Fuel
27.	Matkila	*Glycosmis pentaphylla* (Retz.) A.DC.	Rutaceae	Shrub	Medicinal
28.	Hatishur	*Heliotropium indicum* L.	Boraginaceae	Herb	Medicinal
29.	Jhangi	*Hydrilla verticillata* (L.f.) Royle	Hydrocharitaceae	Herb	Unknown
30.	Chhon	*Imperata cylindrica* (L.) P. Beauv.	Poaceae	Herb	Thatching material
31.	Kalmishak	*Ipomoea aquatic* Forssk.	Convolvulaceae	Floating climber	Wild vegetable
32.	Dholkalmi	*Ipomoea fistulosa* Mart. *ex* Choisy	Convolvulaceae	Shrub	Fuel
33.	Ipomoea	*Ipomoea* sp.	Convolvulaceae	Climber	Unknown
34.	Jarul	*Lagerstroemia speciosa* L.	Lythraceae	Tree	Timber
35.	Jialbhadi	*Lannea coromendelica* (Houtt.) Merr.	Anacardiaceae	Tree	Fuel
36.	Lantana	*Lantana camar a* L.	Verbenaceae	Woody shrub	Fuel
37.	Khudipana	*Lemna perpusilla* Torrey	Lemnaceae	Herb	Unknown
38.	Amorkura	*Ludwigia perenni s*L.	Onagraceae	Herb	Unknown
39.	Shayankura	*Ludwigia prostrate* Roxb.	Onagraceae	Herb	Unknown
40.	Datranga	*Melastoma malabathricum* L.	Melastomataceae	Herb	Medicinal
41.	Assam lata	*Mikaniac ordata* (Burm.f.) Robinson	Asteraceae	Climber	Medicinal
42.	Lajjaboti	*Mimosa pudica* L.	Fabaceae	Herb	Medicinal
43.	Bara nukha	*Monochoria hastate* (L.) Solms	Pontederiaceae	Robust herb	Unknown
44.	Sada-shapla	*Nymphaea nouchali* Burm.f.	Nymphaeaceae	Aquatic herb	Wild vegetable
45.	Shapla	*Nymphaea pubescens* Willd.	Nymphaeaceae	Aquatic herb	Wild vegetable
46.	Chandmalla	*Nymphoides indica* (L.) Kuntze	Menyanthaceae	Floating herb	Medicinal

Sl. No.	Local Name	Scientific Name	Family	Habit	Ecosystem value
47.	Bon tulsi	*Ocimum americaneum* L.	Lamiaceae	Small shrub	Medicinal
48.	Amrul	*Oxalis corniculata* L.	Oxalidaceae	Creeping herb	Unknown
49.	Keya-kanta	*Pandanus foetidus* Roxb.	Pandanaceae	Shrub	Fuel
50.	Bishkatali	*Persicaria barbata* (L.) Hara	Polygonaceae	Herb	Unknown
51.	Biskhatali	*Persicaria hydropiper* (L.) Spach	Polygonaceae	Herb	Medicinal
52.	Bishkatali	*Persicaria lapathifolia* (L.) S. F. Gray	Polygonaceae	Herb	Unknown
53.	Bara Panimorich	*Persicaria orientalis* (L.) Spach	Polygonaceae	Herb	Unknown
54.	Nalkhagra	*Phragmites karka* (Retz.) Trin. *ex* Steud.	Poaceae	Small shrub	Thatching material
55.	Citki	*Phyllanthus reticulatus* Poir.	Euphorbiaceae	Shrub	Fuel
56.	Kalocitki	*Phyllanthus urinaria* L.	Euphorbiaceae	Shrub	Fuel
57.	Koroch	*Pongamia pinnata* (L.) Pierre	Fabaceae	Tree	Medicinal
58.	Patipata	*Schumannianthus dichotomus* (Roxb.) Gagnep.	Marantaceae	Shrub	Economic
59.	Bondhoney	*Scoparia dulcis* L.	Plantaginaceae	Herb	Medicinal
60.	Teraj	*Senna tora* (L.) Roxb.	Fabaceae	Herb	Medicinal
61.	Shet-berela	*Sida cordifolia* L.	Malvaceae	Herb	Unknown
62.	Kumarilata	*Smilax perfoliata* Lour.	Smilacaceae	Climber	Medicinal
63.	Marhatitiga	*Spilanthes acmella* (L.) R.K. Janson	Asteraceae	Herb	Medicinal
64.	Shaora	*Streblus asper* Lour.	Moraceae	Small tree	Medicinal, Fuel
65.	Puti jam	*Syzygium fruticosum* (Roxb.) DC.	Myrtaceae	Tree	Wild fruits
66.	Pitali	*Mallotus nudiflora* (L.) Kulju & Welzen.	Euphorbiaceae	Tree	Fuel
67.	Kukshima	*Cyanthillium cinereum* (L.) H.Rob.	Asteraceae	Herb	Medicinal
68.	Binna gash	*Vetiveria zizanioides* (L.) Nash	Poaceae	Herb	Soil binding
69	Bon boroi	*Ziziphu soenoplia* (L.) Mill.	Rhamnaceae	Shrub	Wild fruit

Among the families, with the highest (6 species) number of species, followed by Polygonaceae (5 species), Fabaceae (4 species), Euphorbiaceae, Moraceae, Poaceae, Convolvulaceae, and Cyperaceae each with 3 species, and each of the Hydrocharitaceae, Nymphaeaceae, Pontederiaceae, and Onagraceae family with 2 species. Rest of the families with single species each (Table 2).

Status of saplings

A total of 1,414 seedlings of 9 species belonging to 7 families were recorded from the 66 sample plots of RSF. Among the families, Moraceae was recorded with the highest number of species (3 species), followed by Lythraceae (2 species) and the rest of the families with single species each.

Table 2. The species composition of the plant families recorded in the Ratargul Swamp Forest.

Sl. No.	Family Name	No. of Species	Sl. No.	Family Name	No. of Species
1.	Amaranthaceae	1	23.	Lythraceae	1
2.	Anacardiaceae	1	24.	Malvaceae	1
3.	Apiaceae	1	25.	Marantaceae	1
4.	Araceae	1	26.	Melastomataceae	1
5.	Arecaceae	1	27.	Menyanthaceae	1
6.	Asparagaceae	1	28.	Moraceae	3
7.	Asteraceae	6	29.	Myrtaceae	1
8.	Athyriaceae	1	30.	Nymphaeaceae	2
9.	Boraginaceae	1	31.	Onagraceae	2
10.	Capparidaceae	1	32.	Oxalidaceae	1
11.	Commelinaceae	1	33.	Pandanaceae	1
12.	Convolvulaceae	3	34.	Plantaginaceae	1
13.	Cyperaceae	3	35.	Poaceae	3
14.	Dioscoreaceae	1	36.	Polygonaceae	5
15.	Elatinaceae	1	37.	Pontederiaceae	2
16.	Euphorbiaceae	3	38.	Rhamnaceae	1
17.	Fabaceae	4	39.	Rutaceae	1
18.	Hydrocharitaceae	2	40.	Scrophulariaceae	1
19.	Lamiaceae	1	41.	Smilacaceae	1
20.	Lecythidaceae	1	42.	Verbenaceae	1
21.	Lemnaceae	1	43.	Zingiberaceae	1
22.	Liliaceae	1			

Phyto-sociological characters of the tree species

Tree stem per ha., relative density, relative frequency, relative abundance and importance value index (IVI) of the recorded tree species are shown in Table 3. The highest tree stem density was found to be *Pongamia pinnata* (411 stem/ha). While maximum relative density was recorded in *P. pinnata* (29.55%), followed by *Syzygium fruticosum* (19.62%), *Barringtonia acutangula* (18.97%), *Crateva magna* (8.28%), and *Lagerstroemia speciosa* (6.87%), maximum relative frequency was recorded in *P. pinnata* (16.36%), followed by *S. fruticosum* (15.60%), *B. acutangula* (14.32%), *C. magna* (12.02%), *Streblus asper*

(11.25%), and *L. speciosa* (10.23%). The species with highest relative abundance was *P. pinnata* (23.04%) followed by *B. acutangula* (16.91%), *S. fruticosum* (16.06%), *C. magna* (8.80%), *L. speciosa* (8.57 %) and *S. asper* (7.29%). *P. pinnata* with importance value index of 68.96 was the most dominant tree followed by *S. fruticosum* (51.29), *B. acutangula* (50.20), *C. magna* (29.10), *L. speciosa* (25.67) and *S. asper* (24.98).

Table 3. Tree per hectare, relative density (RD), relative frequency (RF), relative abundance (RA) and importance value index (IVI) of different plant species in Ratargul Swamp Forest.

Sl. No.	Local Name	Scientific Name	Tree stem/ha	RD (%)	RA (%)	R F (%)	IVI
1	Hijol	*Barringtonia acutangula* (L.) Gaertn.	264	18.97	16.91	14.32	50.20
2	Barun	*Crateva magna* (Lour.) DC.	115	8.28	8.80	12.02	29.10
3	Koroch	*Pongamia pinnata* (L.) Pierre	411	29.55	23.04	16.36	68.96
4	Puti jam	*Syzygium fruticosum* (Roxb.) DC.	273	19.62	16.06	15.60	51.29
5	Jarul	*Lagerstroemia speciosa* L.	95	6.87	8.57	10.23	25.67
6	Pitali	*Mallotus nudiflora* (L.) Kulju & Welzen.	45	3.27	6.04	6.90	16.22
7	Sheora	*Streblus asper* Lour	89	6.43	7.29	11.25	24.98
8	Dumur	*Ficus hispida* L.	59	4.25	7.07	7.67	19.00
9	Jialbhadi	*Lannea coromendelica* (Houtt.) Merr.	38	2.72	6.18	5.62	14.53

The importance value index of the seedlings of RSF is shown in Table 4. The highest tree stem density was found to be *P. pinnata* (524 stem/ha). The species with maximum relative density was *P. pinnata* (24.46%), followed by *S. fruticosum* (23.19%), and *B. acutangula* (17.82%). Although maximum relative frequency was found in *P. pinnata* (13.51%), followed by *S. fruticosum* and *B. acutangula* each are (12.88%), *C. magna* (12.47%), but the highest relative abundance was recorded in *P. pinnata* (21.99%), followed by *S. fruticosum* (21.86%)

Table 4. Seedling per hectare, relative density (RD), relative frequency (RF), relative abundance (RA) and importance value index (IVI) of 9 dominant regenerating plants in Ratargul Swamp Forest.

Sl. No	Local Name	Scientific Name	Seedlings/ ha	RD (%)	RA (%)	RF (%)	IVI
1	Hijol	*B. acutangula* (L.) Gaertn.	382	17.82	16.79	12.88	47.50
2	Barun	*C. magna* (Lour.) DC.	168	7.85	7.64	12.47	27.96
3	Koroch	*P. pinnata* (L.) Pierre	524	24.46	21.99	13.51	59.98
4	Puti jam	*S. fruticosum* (Roxb.) DC.	497	23.19	21.86	12.88	57.95
5	Jarul	*L. speciosa* L.	158	7.35	7.16	12.47	26.99
6	Pitali	*M. nudiflora* (L.) Kulju & Welzen.	129	6.01	6.75	10.81	23.57
7	Sheora	*S. asper* Lour	145	6.78	7.77	10.60	25.17
8	Dumur	*F. hispida* L.	118	5.51	5.86	11.43	22.81
9	Jialbhadi	*L. coromendelica* (Houtt.) Merr.	21	0.99	4.13	2.91	8.03

and *B. acutangula* (16.79%). The highest IVI of regenerating tree species was recorded highest in *P. pinnata* (59.98), followed by *S. fruticosum* (57.95), and *B. acutangula* (47.50). According to results, *P. pinnata* is the dominant regenerating species of RSF.

Distribution of seedlings in different height classes

The vertical profile of a forest provides a clear concept of forest stratification. Regenerates below 250 cm in height were considered seedlings. The percentage distribution of all seedlings of all species into different height (cm) classes is provided in Fig.4.

It was evident that majority (56.56%) seedlings were within the range of 0–50cm height classes, whereas only 5.74% seedlings were found 201–250cm height classes. It was found that the number of species decreased regularly with the increase in total height. It indicates the poor survival of seedlings, probably resulting from both biotic and abiotic interferences.

Recruitment of the seedlings

The recruitment of seedlings is important in a natural forest to determine the structure and sustainability of the forest. Comparative recruitment percentages of major dominating seedlings with the corresponding tree stem/ha are shown in Table 5. *P. pinnata* had a maximum 78.29% seedling recruitment percentage, followed by *B. acutangula* (69.11%), *C. magna* (68.45%), and *S. asper* (61.38%). The conservation measures for biological diversity should be based on regeneration potentials of plant species (Verma *et al.* 1999). It is an important indicator for evaluating the overall situation of a forest ecosystem (Rahman *et al.* 2010).

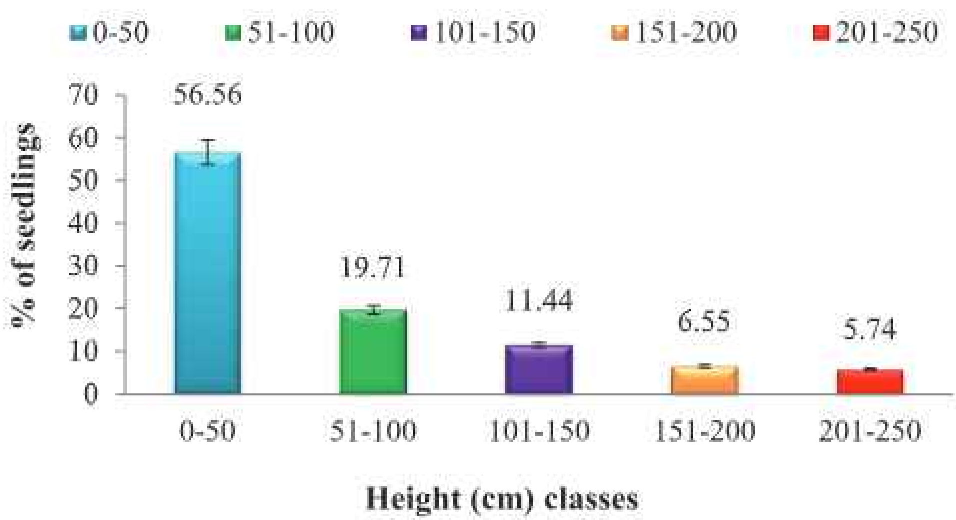

Figure 4. Distribution of all the seedlings into different height (cm) classes.

Table 5. Percentage recruitment of 8 major regenerating tree species in relation to trees/ha and seedlings/ha at Ratargul Swamp Forest.

Sl. No.	Scientific Name	Family	Tree Stem/ha	Seedlings /ha	Recruitment (%)
1.	*B. acutangula* (L.) Gaertn.	Lecythidaceae	264	382	69.11
2.	*C. magna* (Lour.) DC.	Capparidaceae	115	168	68.45
3.	*P. pinnata* (L.) Pierre	Fabaceae	411	525	78.29
4.	*S. fruticosum* (Roxb.) DC.	Myrtaceae	273	497	54.93
5.	*L. speciosa* L.	Lythraceae	95	158	60.13
6.	*M. nudiflora* (L.) Kulju & Welzen.	Euphorbiaceae	45	129	34.88
7.	*S. asper* Lour	Moraceae	89	145	61.38
8.	*F. hispida* L.	Moraceae	59	118	50.00

Discussion

As previously reported by Chowdhury *et al*. (2004), they found 73 species of plants. The number of species in the swamp forests of the south eastern and central Brazil regions ranged mainly from 30 to 60 species (Ivanauskas *et al*. 1997; Marques *et al*. 2003; Guarino and Walter 2005; Scarano 2006). In fresh water swamp forest in Bonny Rivers State, Nigeria, was investigated ninety-four plant species belonging to 40 families (14 shrubs, 26 trees, and 54 herbs) were encountered, which represents 14.89% shrubs, 27.66% trees and 57.45% herbs in the forest (Agbagwa and Chimezie 2011). Agbagwa (2008) reported 39 forest tree species from 19 families within freshwater swamp forests in a confluence area of Delta, Imo, and Rivers States in the Niger Delta. Hossain *et al*. (2016) were recorded 16 plant species were under 16 families indicating a high biological diversity at family-level taxa and *P. pinnata* (Koroch) showed the highest value of importance value index (IVI) (15.62) indicating the dominance of the species in the forest. The present survey has found 68 species of plants in RSF and *P. pinnata* showed the highest importance value index (IVI) (59.98). The results showed that the dominance of *P. pinnata* has increased more than before. The regeneration rate of *P. pinnata* and *S. fruticosum* (Putijam) is higher than that of *B. acutangula* (Hijol). Hijol regeneration is low due to the fact that many mother trees are being attacked by insects and dye-back disease. This may be one of the reasons for the decline in the regeneration of Hijol due to the decline of the mother tree. The present study reveals higher regeneration potentials for many economically and ecologically important tree species. However, there are still many causes thatmay be critical for the occurrence and establishment of natural regeneration. The species that have low IVI should be given priority in conservation programs. Ratargul Swamp Forest is regarded as a reserve forest. According to the definition of a reserve forest (Forest Act 1927), people have no right to do anything without permission (USAID 2005). However, the degradation of forests is increasing day by day. There are several reasons for these disturbances, including a lack of clear boundaries, encroachment, tourism activities, illegal felling, fuel wood collection, grazing, fishing, agricultural land expansion, and other administrative problems. Every day, more than one thousand tourists visit this area. The presence of overloaded tourists all year round has a serious impact on the biodiversity of the forest. Tourists have a full access to all parts of the forest easily they play sounds in mikes at high volume inside the forest; they throw packets, bottles, and papers in the water, which pollutes the water and is a barrier to the living animals and the rare plant species of the forest are minimizing day by day. Many people migrate to this RSF area from outside and they are totally or partly depend on RSF resources. In this case, the participatory forest management approach can be an effective tool to overcome the present problems of RSF.

Conclusion

The diversity of plants was moderately present in RSF. The diversity and richness of RSF might be degraded in near future due to the impacts of continuous threats. There are several reasons for disturbances, including a lack of clear boundaries, encroachment, tourism activities, illegal felling, fuel wood collection, grazing, fishing, agricultural land expansion, and other administrative problems. A proper plan should be taken into account to protect the forest. The RSF has to be divided into a buffer zone and a core zone. All parts of the forest should not be accessible. Only the buffer zone can be entered, but entry into the core zone must be completely prohibited. The specified number of tourists must be allowed to enter. Additional tourists will not be allowed to enter. There should be strict rules the tourists who want to visit the forest. Illegal encroachments should be stopped in the forest. Fishing and grazing inside the forest should be banned. However, the participatory forest management approach (working together with the local community, forest department, national and international NGO's, research organizations and other volunteer organizations) could be an effective tool to overcome the existing problems of RSF. Also awareness urgently needs to be created among the local people about the importance of conservation of biodiversity. Alternative income-generating options need to be provided and promoted to local people to conserve the biodiversity of RSF.

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Research Article

Biological Characteristics of Lappet Moth (*Trabala vishnou*) of Hijol Tree (*Barringtonia acutangula*) in Ratargul Swamp Forest of Bangladesh

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Abstract

Recently Hijol tree (Barringtonia acutangula) at Ratargul swamp forest of Sylhet, Bangladesh was observed to infest by a defoliating caterpillar (Trabala vishnou Le: Lasiocampidae: Lepidoptera). For proper management of the pest its life cycle was studied in the laboratory of Forest Protection Division of Bangladesh Forest Research Institute, Chattogram at 27.76°C temperature and with 81.75% relative humidity. Four generations and six larval instars of the insect were recorded. A total of 299 adults were emerged during the study period among which 182 were female and 117 were male. The eggs of T. vishnou were creamy white in colour and covered with brown hairs. Incubation period was maximum 7 days and minimum 6 days. The larvae were cream colour with brown head and numerous dark brown hairs on the body. Larval period was 33-39 days and pupal period 12-13 days. Pupa was dark brown in colour. The adult was medium sized moth exhibiting sexual dimorphism. The male was pale apple green in colour with brown antennae and the female was yellowish green in colour with a few small spots lined up at the bottom of the front and hind wings. Maximum mating period was 8 days; Pre-egg laying period was 3 days and post laying 6 days. Each female laid a maximum of 262 eggs. Sex ratio of female to male was 1: 0.68. A total lifespan of the moth was 51-59 days. Further study can be done in the natural habitat of the insect in future.

সারসংক্ষেপ

সাম্প্রতিক সময়ে রাতারগুল জলাবনের হিজল গাছ এক প্রকার পাতাভোজী পোকার লার্ভা দ্বারা আক্রান্ত হয়েছে। ক্ষতিকর এ পোকার আক্রমণ থেকে বন রক্ষা করতে পোকার জীবন চক্র বাংলাদেশ বন গবেষণা ইনস্টিটিউটের বন রক্ষণ বিভাগের ল্যাবরেটরিতে ২৭.৭৬ সেলসিয়াস তাপমাত্রায় এবং ৮১.৭৫% আপেক্ষিক আদ্রতায় পর্যবেক্ষণ করা হয়েছে। গবেষণাগারে এ পোকার ছয়টি লার্ভা দশা এবং চারটি প্রজন্ম সনাক্ত করা হয়েছে। গবেষণাকালে মোট ২৯৯টি পূর্ণাঙ্গ পোকা পাওয়া গেছে যার মধ্যে ১৮২টি স্ত্রী পোকা এবং ১১৭টি পুরুষ পোকা। পোকার ডিম হালকা সাদাটে যা বাদামী লোম দ্বারা আবৃত থাকে। ডিম থেকে লার্ভা বের হতে সর্বোচ্চ ৭ দিন এবং সর্বনিম্ন ৬ দিন সময় লাগে। লার্ভা সাদা রঙের, মাথা বাদামী এবং ঘন কালো লোমে আবৃত। পোকার লার্ভা দশা ৩৩-৩৯ দিন এবং পিউপা ১২-১৩ দিন স্থায়ী হয়। পিউপা দেখতে কালো বাদামী রঙের। পূর্ণাঙ্গ পোকা মাঝারি আকারের মথ। স্ত্রী ও পুরুষ পোকা ভিন্ন আকারের হয়। পূর্ণাঙ্গ পুরুষ পোকা দেখতে ফ্যাকাশে আপেল রঙের এবং এন্টিনা বাদামি রঙের। পূর্ণাঙ্গ স্ত্রী পোকা হলদে সবুজ রঙের তবে এর সামনে ও পিছনের পাখার নীচের দিকে ছোট ছোট কয়েকটি দাগ আছে। প্রাপ্ত বয়স্ক পোকা সর্বোচ্চ ৮ দিন মিলন করতে পারে। পূর্ণাঙ্গ পোকার ডিম প্রদানের পূর্বের সময়কাল হলো ৩ দিন এবং ডিম প্রদানের পরের সময়কাল হলো ৬ দিন। একটি স্ত্রী পোকা সর্বোচ্চ ২৬২টি ডিম পাড়তে পারে। ডিম থেকে স্ত্রী ও পুরুষ পোকার হওয়ার হার ১: ০.৬৮। পোকার সম্পূর্ণ জীবনকাল ৫১-৫৯ দিন। ভবিষ্যতে এ পোকার জীবনচক্র আরও বিশদভাবে বনজ পরিবেশে গবেষণা করা প্রয়োজন।

Keywords: *Barringtonia acutangula, Trabala vishnou, Ratargul Swamp Forest, Larva, Pest.*

Introduction

Ratargul swamp forest is one of the most important tourism sites in Bangladesh. The forest is located in Gowainghat upazila of Sylhet, about 23 km from Sylhet City (Jahan and Akhter 2018). The forest remains submerged for six months in a year and dry for the rest six months. Swamp forests around the world play a vital role in maintaining biodiversity, sustaining livelihood and nourishing the ecosystem of wetlands (Agnew *et al.* 2006; Allan *et al.* 2008; Attanasio *et al.* 2012; Burkhard *et al.* 2010; Naiman and Décamps 1997). The Ratargul forest contains around 73 plants species of which 40 species are herbs. 6 species shrubs, 8 species climbers, 3 species epiphytes and 16 species trees. Among the tree species Hijol (*Barringtunia acutangula*) is the second dominant species (Choudhury *et al.* 2004). Relative density, relative frequency, relative dominance and importance value index of Hijol tree are 27.18%, 31.57%, 10.97% and 69.74 respectively. Average diameter and average height of the tree is 19.70 cm and 7.53 meter respectively (Chowdhury *et al.* 2020). Recently Divisional Officer of Sylhet Forest Division informed that Hijol tree of Ratargul swamp forest has been infested by a leaf eating caterpillar. The pest was identified as *Trabala vishnou* Lefebvre (Lasiocampidae: Lepidoptera). Every year this insect pest causes severe attack and make extensive damage of the Hijol tree, causing decreased annual growth and yield loss. Excepting host record, there is little study on the defoliator in Bangladesh. Therefore the present study was undertaken to know the biological characteristics of the pest. Because management of any insect without knowing its biology and ecology is difficult and sometimes impossible. The life cycle of the pest was studied in the laboratory condition. The study period encompassed four generations of the insect.

Materials and Methods

Field visit and sample collection

The study was undertaken during July 2017 to June 2020. Different field visit were conducted during study period in Ratargul swamp forest for the collection of eggs and larvae of Hijol defoliator. Eggs with the leaves of Hijol tree were collected from Garughat area (25°00′665″ and 25°00′688″of North latitudes and in between 091°55′380″and 091°55′382″ of East longitudes) of Ratargul swamp forest. The eggs were kept in small insect collecting box and carried out to the entomology laboratory of Forest Protection Division (FPD) of Bangladesh Forest Research Institute (BFRI), Chattogram.

Larvae rearing in laboratory condition

The larvae were reared in the laboratory to observe different life stages and other biological characteristics under 27.76°C temperature and 81.75% relative humidity (rh). Temperature and relative humidity were recorded regularly by digital hygrometer. Newly hatched larvae were placed separately in petridishes so that the larvae pass the 1st instars of their life stage. After 1st instar the larvae were transferred to rearing jar, both ends of which were enclosed by perforated tin so that fresh air can flow easily (Fig 1a). Petridishes and rearing jars were cleaned and sterilized with cotton soaked in 99% ethyl alcohol. Wet cotton was provided inside the petridish and rearing jar to retain moisture. Fresh and young leaves of Hijal trees were provided to the larvae daily. The length and breadth of larvae of different developmental stages were measured. After last larval instar pupation took place in the rearing jar. A few days later adult moths were emerged. The number of adult based on sex was recorded at one hour interval daily.

Emergence and mating behaviour

Each adult couple was placed in a separate rearing jar (80 x 80 x 40 cm) surrounded by mosquito net. Rangon (*Combretum indicum*) and Korobi flower (*Nerium oleander*) was given inside the jar so that male and female could get vibe of natural environment (Fig 1b).

(a) (b)

Figure 1. Rearing larvae of *T. vishnou* in different jars and mating environment (a) and (b).

The flowers were selected for their availability during study period. The mating period, pre-egg lying and post-egg laying periods, number of eggs laid and sex ratio were observed 8 hours daily during the day time from 9 am to 5 pm and recorded at different time intervals in different generations.

Insect identification

The insect was identified by using the key and description of Browne (1968), Beeson (1941), Asiatic Society of Bangladesh (2009) and Hampson (1892).

Statistical analysis

On different developmental stages such as larva, pupa and adult body measurements were taken in centimetre scale. Average, standard deviation and sex ratio were calculated by MS Excel 2010.

Results

Eggs of T. vishnou

The eggs of the insect collected from Ratargul were creamy-white in colour and covered with numerous brown hairs. The eggs were laid on underside of the leaves arranged in two rows. Each row was arranged like an egg garland and was 2 cm long containing 13-15 semi-ovals eggs. Each egg was 1mm x 1mm in size (Fig. 2).

Figure 2. Eggs of Hijol defoliator (*T. vishnou*)

Hatching of the eggs

In first generation incubation period was 7 days in 25.63°C temperature and 78.17% relative humidity. In second generation incubation period was 6 days in 26.67°C temperature and 78.17% relative humidity. In third and fourth generation incubation period, temperature and relative humidity were 6 and 7 days, 27.50°C and 28.03°C with 86.5% and 85.25% respectively. In first, second, third and fourth generation 38.84, 41.18, 55.99 and 58.78% egg hatched to larvae respectively.

Larval characteristics

During the study period, six distinct larval instars were recorded. At the initial stage larvae were creamy in colour. Body segmentation was very clear. Head is brown. The larvae have numerous light brown hairs on the body

(Fig. 3). Larvae roam and move in groups. In early stage larvae prefer to eat young fresh leaves. When there is a shortage of food larval growth is stranded and they turn yellowish in colour. The maximum length and breadth of 1st instar larvae were found in second generation being 1.71cm and 0.08cm respectively. Minimum length and breadth of 1st instar larvae were found in fourth generation that were 1.01cm and 0.06cm respectively. Similarly in 2nd instar larvae highest length and breadth were found in second generation and lowest length and breadth were found in fourth generation. In case of 3rd instar larvae longest size was found in first generation and smallest size was found in fourth generation being 4.72cm and 2.91cm respectively. In 4th instar larvae though maximum body length 4.98cm was found in second generation but in 5th instar maximum body length 5.72cm was found in first generation and sixth 6.56cm (Fig. 4). Body width was positively correlated (r = 0.916451) with body length. Maximum 6 days for moulting in 1st instar larvae was found in second generation in 27.92°C temperature and 77.30% relative humidity. In 2nd and 3rd instar larvae highest time for changing instars were found in fourth generation being 6 days. Highest and lowest time of stadium for 4th instar larvae were 7 and 5 days in 27.60°C and 28.0°C temperature and 88.0% and 72.25% relative humidity respectively. In 5th instar larvae maximum duration for moulting was found 7 days in fourth generation in 27.90°C temperature and 87.60% relative humidity. In last instar maximum duration for moulting was found 8 days in fourth generation in 27.73°C temperature and 86.70% relative humidity (Table 1).

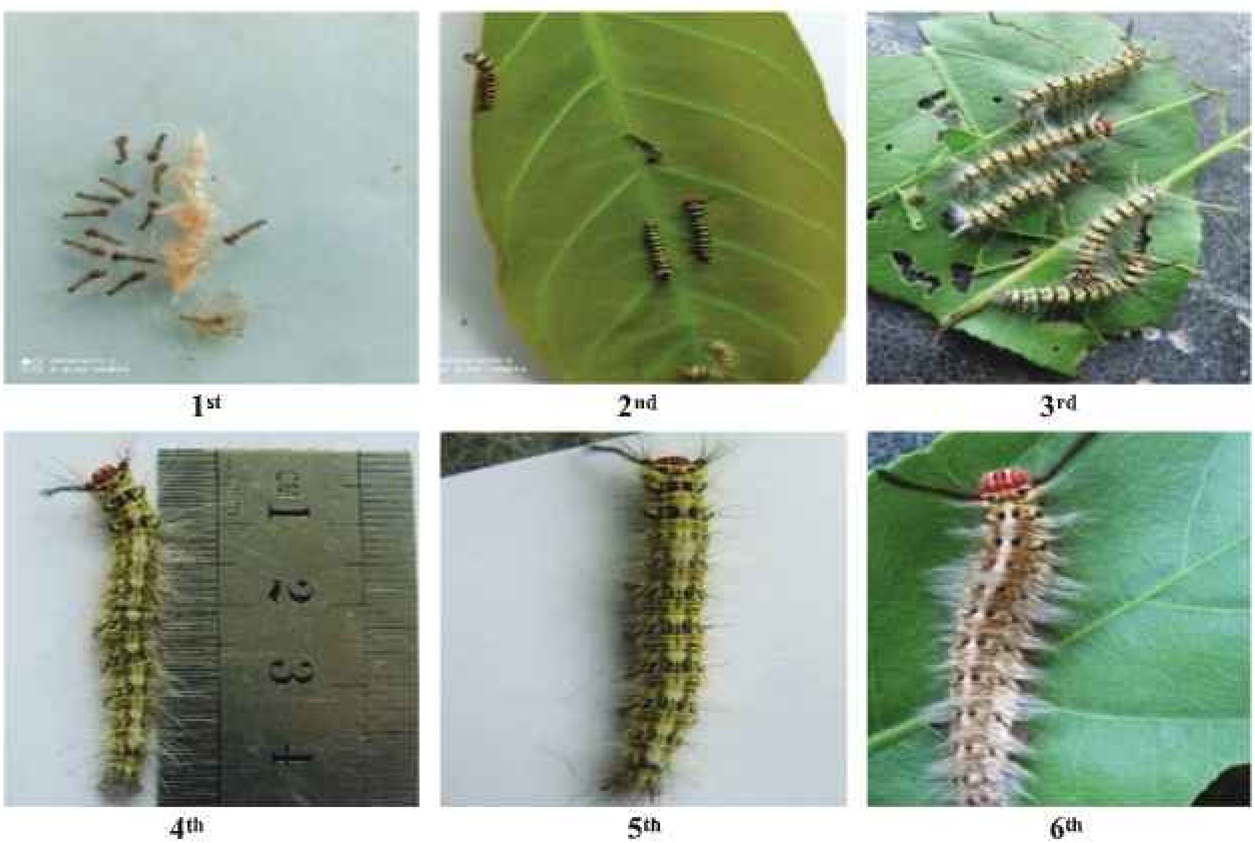


Figure 3. Different larval stages of *T.vishnou* (1st, 2nd, 3rd, 4th, 5th and 6th instars).

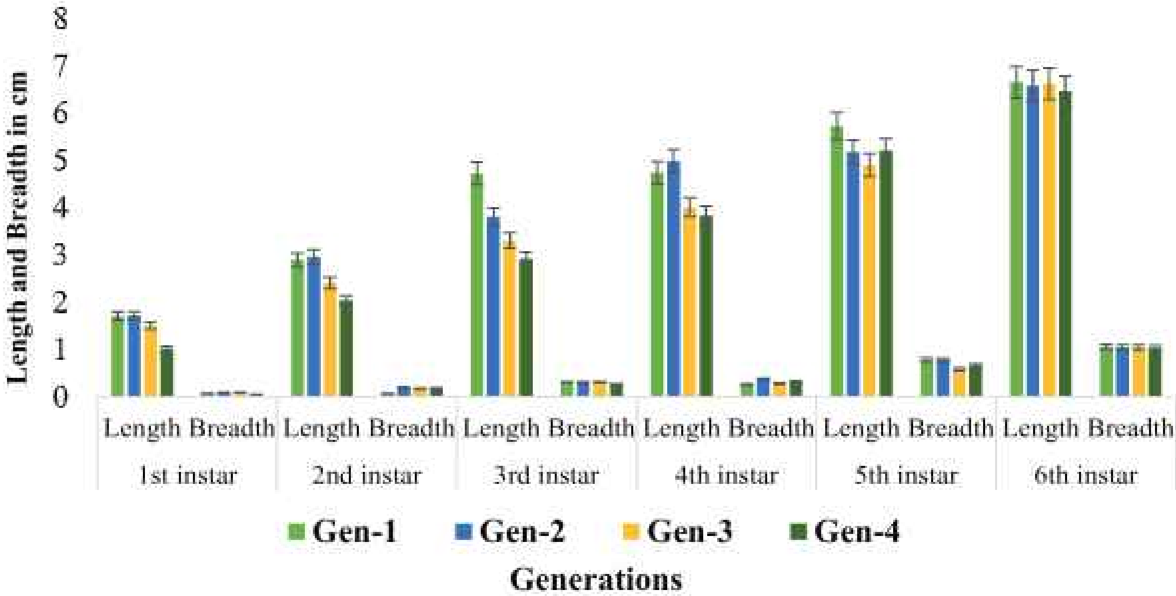


Figure 4. Length and breadth of larvae of *T. vishnou* in different generations.

Pupal characteristics

The full grown larva formed a pupal cocoon interwoven with larval hairs and usually attached to the stem of the host plant. Initially the cocoon was light yellow but later turned to dark brown in colour (Fig. 5a). The larval skin was pushed out from one end of the cocoon and a round hole was made in the hanging part by changing the upper shell of their body (Fig. 5b). From these cocoons, the adults hatched in 12 days. In first generation the length of pupal cocoon was 2.28cm and in second, third and fourth generations, the lengths were 2.29, 2.26 and 2.16cm respectively (Fig. 6). Pupation period in first, second, third and fourth generations were 13, 12, 12 and 13 days respectively in 27.76°C, 28.30°C, 28.20°C, 27.90°C temperature and 76.00%, 84.00%, 86.00% and 86.18% relative humidity (Table 1).

(a) (b) (c)

Figure 5. Pupal stage of *T vishnou*. (a) Pupa with cocoon (b) Pupa with circular hole and (c) Empty pupal case after moth emergence.

Table 1. Duration of larval, pupal and adult life stages of *Trabala vishnou* in different generations.

Stage	Duration in days (Av± SD)				Temperature (Av± SD)				Relative humidity (Av± SD)			
	Gen-1	Gen-2	Gen-3	Gen-4	Gen-1	Gen-2	Gen-3	Gen-4	Gen-1	Gen-2	Gen-3	Gen-4
Incubation period	6.80 ±0.81	5.73 ±0.76	5.60 ±0.80	7.27 ±0.78	25.63 ±0.32	26.67 ±1.66	27.50 ±1.10	28.03 ±1.60	78.17 ±1.24	78.17 ±1.24	86.50 ±0.54	85.25 ±0.78
1st instar	6.16 ±0.48	6.48 ±0.77	5.28 ±0.45	5.48 ±1.00	25.72 ±0.67	27.92 ±0.84	27.70 ±0.64	26.30 ±0.26	58.83 ±3.97	77.30 ±3.67	87.00 ±1.58	89.60 ±0.82
2nd instar	5.92 ±0.81	4.60 ±0.65	4.92 ±0.57	6.24 ±0.88	26.45 ±0.45	28.50 ±0.46	27.62 ±0.22	26.63 ±0.49	58.75 ±3.50	69.75 ±8.18	86.80 ±1.30	89.57 ±1.81
3rd instar	5.24 ±0.78	5.12 ±0.78	5.00 ±0.87	6.12 ±0.67	26.37 ±0.50	29.20 ±0.24	27.70 ±0.17	27.38 ±0.28	64.75 ±7.18	76.00 ±1.15	85.25 ±0.96	88.20 ±2.17
4th instar	5.48 ±1.00	5.80 ±1.29	7.04 ±0.73	6.44 ±1.00	28.00 ±0.50	27.66 ±0.97	27.60 ±0.53	28.48 ±0.45	72.25 ±4.72	80.40 ±4.22	88.00 ±2.65	85.40 ±2.70
5th instar	6.04 ±1.00	6.64 ±1.07	6.12 ±0.97	6.96 ±0.73	28.60 ±0.62	27.77 ±1.01	27.50 ±0.35	27.90 ±0.62	61.60 ±10.74	82.00 ±2.97	89.00 ±0.71	87.60 ±1.90
6th instar	6.64 ±0.95	7.28 ±0.69	5.36 ±0.99	7.56 ±0.77	28.53 ±0.65	27.10 ±0.42	26.90 ±0.47	27.73 ±0.89	75.00 ±2.67	85.90 ±2.12	90.25 ±0.96	86.70 ±2.73
Pupal period	13.36 ±0.90	12.52 ±1.33	12.04 ±1.67	13.28 ±1.28	27.76 ±1.45	28.30 ±0.64	28.20 ±0.90	27.90 ±0.62	76.00 ±7.20	84.00 ±3.07	86.00 ±3.16	86.18 ±1.33
Adult Male	6.52 ±0.96	6.44 ±0.77	6.56 ±1.08	6.48 ±0.77	26.3 ±1.62	27.60 ±1.09	27.10 ±0.88	28.28 ±0.64	82.22 ±4.17	86.38 ±2.09	87.83 ±2.13	84.79 ±2.32
Adult Female	7.60 ±0.71	7.48 ±0.96	7.44 ±1.00	7.90 ±0.99	25.80 ±1.36	27.50 ±1.09	27.20 ±0.84	29.00 ±0.56	81.07 ±3.87	86.58 ±1.51	88.00 ±2.58	84.19 ±2.21

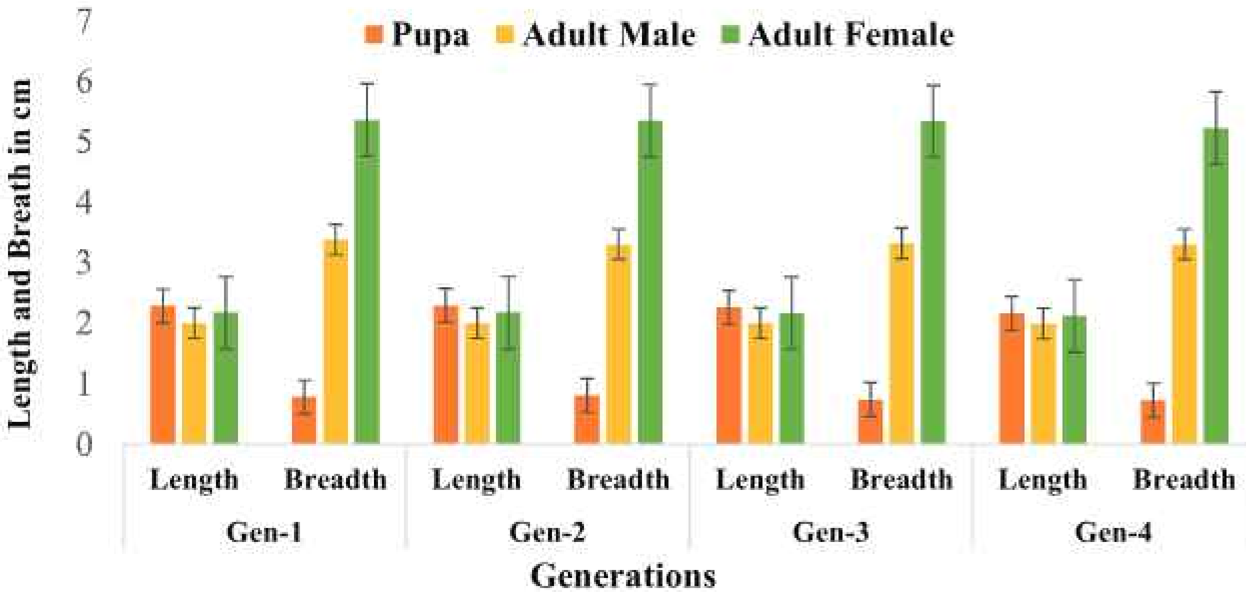


Figure 6. Average length and breadth of pupa and adult of *T. vishnou* in different generations.

Adult characteristics

The adult moths were medium in size and exhibited sexual dimorphisms. Male moths were smaller in size compared to females. Male were pale apple green in colour, antennae brown while the females were yellowish green, with brown spots inner side above the front wing and brown margins on both sides. There were few small spots lined up at the bottom of the front and hind wings in both sexes (Fig.7a & Fig.7b). Bi-pectinate antennae were observed in both sexes but bristles were longer in males. The wing span of male moth at stretched condition was 3.8 cm in size while that of the female was 5.36 cm (Table 1). At the resting time in the front wings of the female, a V-shaped brown mark was observed although this mark is absent in male (Fig. 7b). From larvae to adult maximum survival rate was 71.43% in fourth generation and maximum mortality rate was 57.45% in second generation.

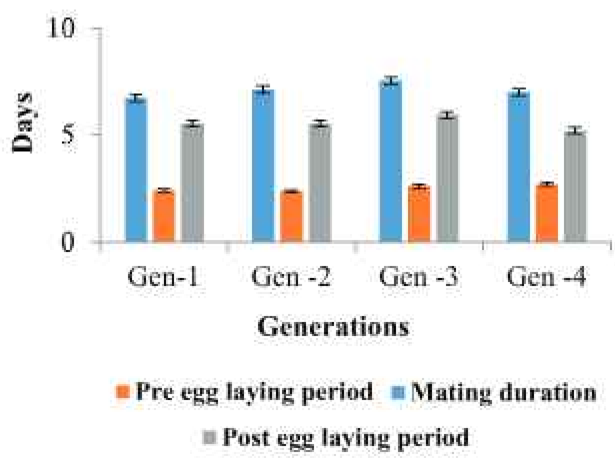
(a) (b) (c)

Figure 7. Sexual dimorphism of adult male, female and ventral side of female *T. vishnou.* (a, b and c).

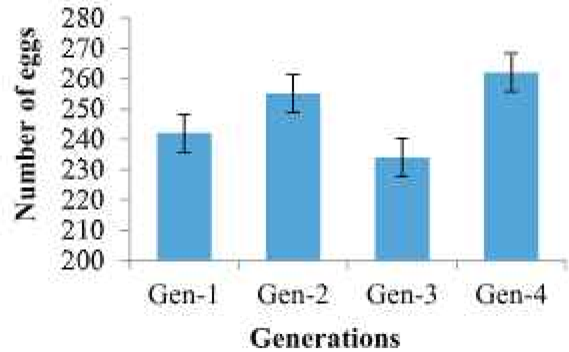
Mating behaviour

Mating rarely occurred during the day time (Fig. 8). Many females laid eggs without mating from which no larvae hatched. Maximum mating duration was up to 7.53 days in third generation. Highest pre egg laying period was found 2.70 days in fourth generation and highest post egg laying period was 5.93 days in third generation (Fig 9a). Female moth laid highest number of eggs (262) in third generation. In first, second and fourth generation female moth laid 255, 157 and 249 eggs respectively (Fig. 9b).

Figure 8. Mating of *T. vishnou.*



(a)



(b)

Figure 9. Reproductive parameters and number of eggs laid by *T. vishnou* in different generations (a & b).

Emergence behaviour

A total of 299 adults emerged in four generations of which were 182 females and 117 males. Male and female emergence percentages were 60 and 40 in first generation, 52.83 and 47.17 in second generation, 39.10 and 60.92 in third generation and 29.10 and 70.90 in fourth generation.

Mortality and survival rate

Survival rate was highest in fourth generation (71.43%) and lowest in first generation (42.55%). On the other hand, the mortality was highest (57.43%) in first generation and lowest (28.57%) in fourth generation (Fig. 10).

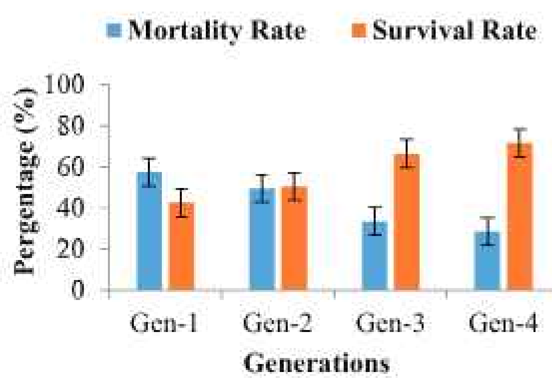


Figure 10. Mortality and survival percentage (%) of *T. vishnou* in different generations.

Sex ratio

Calculated sex ratio of *T. vishnou* was 1: 0.68 (female: male) per population in 4 generations (Table 2).

Table 2. Total number of emerged female and male of *T. vishnou* in different generations and calculated (female: male) sex ratio.

Generations	Female	Male	Sex Ratio (F:M)
1st	16	24	1: 1.5
2nd	25	28	1: 1.12
3rd	53	34	1: 0.64
4th	78	32	1: 0.41
Total	172	118	1: 0.68

Discussion

Trabula vishnou Lefebvre commonly known as rose myrtle lappet moth and tent caterpillars belongs to the family Lasiocampidae of order Lepidoptera. (Tewari and Namgil 1999; Kumer 2013). Every year this pest causes severe attack and make extensive damage to the Hijol tree. The caterpillar is hairy and polyphagous pest feed on a wide range of host plants such as *Acacia confusa, Santalum album, Quercus gomeziana, Quercus spp., Eucalyptus globulus, Anogeissus acuminata, Bischofia javanica, Butea monosperma, Careya arborea, Eugenia jambolana, Lagerstroemia speciose, Lantana camera, Mallotus philippinsis, Psidium guajava, Shorea robusta, Sonneratia apetala, S. caseolaris, Swietenia macroptylla, S. mahagoni, Syzygium cumini, Terminalia bellirica, T. catappa, T. tomentosa*, (Beeson 1941; Browne 1968; Baksha 2008; Baksha and Islam 1997). The insect is very common and well distributed in Bangladesh, India, Pakistan, Myanmar, China, Sri Lanka and Indonesia (Alam 1967; Brown 1968; Hampson 1892 and Asiatic Society of Bangladesh 2009). Kumar *et al.* (2013) studied the biological attributes of *T. vishnou* on *Punica granatum* L. during 2013-14 in monsoon period in an unsprayed experimental orchard of Indian Institute of Horticultural Research, Bangalore, India. They found that eggs of *T. vishnou* were creamy-white and covered with brown hairs laid either on leaves or fruit calyx, and the incubation period varied from 8 to 10 days. The full grown larvae measured on an average 6.06 cm in length with fine network of vertical/horizontal lines, and up to six larval instars were reported with an average larval period of 28.3 days for both the sexes. The result was similar to the findings of this study. Rathore and Verma (1976) & Vishwanath and Visweswara Gowda (1974) found that pupation of *T. vishnou* took place on the host plant. Pupa was reddish brown, and pupation took place inside a saddle like cocoon, usually on the petiole of leaves. The colour of the cocoon was same as that of the larva. Each cocoon had two humps on dorsal side and two openings, one on each side. Male cocoons were smaller in size than those of the female. The total pupal period was 13 to 18 days. This report slightly differs to our findings. The reason may be their study was done in natural condition but this study was carried out in the laboratory. Irungbam *et al.* (2020) made a survey on the assessment of Lasiocampidae fauna of Shirui mountains and surrounding areas of Manipur during 2016 to 2019. They reported that male full grown moth was 40–57 mm and female 68–82 mm. Length of that male forewing was 21–29 mm and female forewing 38–46 mm. Forewing's ground colour is light apple-green in males. The females are significantly larger; their basic colour varies from light green to yellow in all shades. The forewings have a large, brown field with a typical discal spot. Most of these findings are similar to the present study. However, morphometric measurement was slight different. This may be due to the age of full grown adult. Adult moths are lazy in nature and do not move much but they are very fertile. Observations showed that the female moth laid eggs without mating with the male, but the egg did not hatch. Variation in egg hatching rate has been observed in different generations. The larva of *T. vishnou* consumes a large amount of food and moults several times. After the last moulting, it covers its body with strands of thread made of saliva to transform into pupal stage. There are many changes in body composition within the cocoon. When it becomes a full-fledged moth, it cuts the shell and comes out, thus completing the four stages. More than one generation of *T. vishnou* was found in a year, so this insect is multi-voltine.

Conclusion

Hijol (*B. acutangula)* is one of the most important tree species of RSF of Sylhet, Bangladesh. *T. vishnou* is harmful pest of this tree. The insect is polyphagous and spreads very quickly. The current observation on severe defoliation of Hijol by this lasiocampidae shows that it has potential to become serious pest of RSF where no insecticidal sprays are exercised. It is very important to know the life cycle and biological character of this moth for proper management. This study was done in laboratory condition. However, in future detailed life cycle may be carried out in natural conditions.

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Research Article

Growth of Some Mangrove and Mangrove Associate Species inside *Sonneratia apetala* Plantation

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Abstract

The present study aims to investigate the survival and growth performance of eight mangrove and mangrove-associated species at different inundation frequency levels in the western coastal areas of Bangladesh. The study was conducted in the 3-12 months inundated land at Rangabali and Char Kukri-Mukri forest research station. Result showed that the species Thespesia populnea, Calophyllum inophyllum, Ficus rumphii, and Dolichandrone spathacea performed better survival and height growth in the 3-5 months of inundated areas at Rangabali in the years 2019 and 2020 significantly different from Char Kukri-Mukri site. But these species did not survive at 12 months and 9 months of inundated areas at Rangabali, except for D. spathacea in 2017 and 2018. On the other hand, the species Cynometra ramiflora, Aglaia cuculata, T. populnea, and D. spathacea performed better survival 60%, 52%, 50%, 47% and better height performance were observed in T. populnea (0.80m) followed by A. cuculata (0.70m), D. spathacea (0.44m) and C. ramiflora (0.30m) at the 9–12-month inundated area at Char Kukri-Mukri sites respectively. The present study found a significant inundation impact on the survival and growth of these eight mangrove and mangrove associates at the initial stage in western coastal areas. The species T. populnea, C. inophyllum, F. rumphii, and D. spathacea showed signs of growth that suggested it might be suitable for raising under the older keora forest in 3-5 months inundated areas, and A.cuculata and C. ramiflora species also showed signs of growth in 9–12 months inundated areas. The findings reveal that it would be appropriate for enhancing coastal vegetation to generate dense forests.

সারসংক্ষেপ

বাংলাদেশের পশ্চিম উপকূলীয় এলাকায় বিভিন্ন প্লাবন স্তরে ম্যানগ্রোভ ও ম্যানগ্রোভ সহযোগি আটটি প্রজাতির বেঁচে থাকা এবং বৃদ্ধি যাচাই করার জন্য গবেষণা পরিচালনা করা হয়। পরীক্ষাটি বাংলাদেশের পশ্চিম উপকূলীয় এলাকার রাঙ্গাবালী ও চর কুকরী-মুকরী এলাকার কেওড়া বনের অভ্যন্তরে ৩-১২ মাস জোয়ারের পানিতে প্লাবিত স্থানে পরিচালনা করা হয়। পরীক্ষায় ফলাফলে দেখা যায় যে, রাঙ্গাবালী এলাকায় সনবলই, পুনিয়াল, জিরবট এবং পানিকাপিলা প্রজাতির বেঁচে থাকার হার ও বর্ধন ৩-৫ মাস জোয়ারে প্লাবিত স্থানে ভাল হয়েছিল যা তাৎপর্যপূর্ণভাবে চর কুকরী-মুকরী এলাকায় উত্তোলিত পরীক্ষামূলক বাগান হতে পৃথক। কিন্তু পানিকাপিলা প্রজাতিটি ছাড়া ২০১৭ এবং ২০১৮ সালের পরীক্ষামূলক বাগানে অন্য কোনো প্রজাতি ৯ মাস ও ১২ মাস জোয়ারের পানিতে প্লাবিত স্থানে টিকে থাকতে পারেনি। অন্যদিকে চর কুকরী-মুকরী এলাকায় ৯-১২ মাস জোয়ারের পানিতে প্লাবিত স্থানে প্রজাতিগুলোর বেঁচে থাকার হার যথাক্রমে সিংড়া (৬০%), আমুর (৫২%), সনবলই (৫০%) এবং পানি কাপিলা (৪৭%) এবং গড় উচ্চতা যথাক্রমে ০.৮ সে.মি.; ০.৭ সে.মি.; ০.৪৪ সে.মি এবং ০.৩ সে.মি. পাওয়া গিয়েছিল। বর্তমান পরীক্ষায় পশ্চিম উপকূলীয় এলাকায় প্রাথমিক পর্যায়ে এই আটটি ম্যানগ্রোভ এবং ম্যানগ্রোভ সহযোগি প্রজাতির বেঁচে থাকা এবং বর্ধণহারের উপর জোয়ারভাটার প্রভাব পাওয়া গিয়েছে। প্রজাতিগুলোর প্রাথমিক বৃদ্ধির হার ও বেঁচে থাকার হার পরামর্শ দেয় যে, পুরাতন কেওড়া বনের অভ্যন্তরে যেখানে ৩-৫ মাস জোয়ারের পানিতে প্লাবিত হয় এমন স্থানে সনবলই, পুনিয়াল, জিরবট, পানিকাপিলা এবং ৯-১২ মাস জোয়ারের পানিতে প্লাবিত হয় এমন স্থানের জন্য আমুর ও সিংড়া প্রজাতি বাগান সৃজনের জন্য উপযুক্ত হতে পারে। পরীক্ষার এ ফলাফল ঘন বন সৃষ্টির জন্য এবং উপকূলীয় এলাকায় গাছপালা বৃদ্ধির জন্য উপযুক্ত হবে।

Keywords: *Coastal forest, Growth, Inundation, Manmade coastal forest, Mangrove associate, Western coastal region.*

Introduction

Bangladesh is a frontrunner in the afforestation of coastal areas (Siddiqi and Khan 1990; Spalding 1997). Bangladesh's 710 km-long coasts are made up of connections between many natural and economic systems (Hossain 2001; Iftekhar 2006). In recently acquired char lands along the coastal belt, an afforestation effort was launched in 1966 (Rahman and Pramanik 2015). In Bangladesh, mangrove plantations have been expanding daily (Hasan 2013). The Bangladesh Forest Department has planted mangrove species over more than 209,140 hectares of the coastal areas, of which 93% have been established (DoE 2015).

The two most successful mangrove species for planting in the coastal areas are *Sonneratia apetala* Buch. Ham. (keora) and *Avicennia officinalis* L. (baen) respectively (Siddiqi 2001). It is also very common for these species, seedlings to die after being planted in coastal locations (Siddiqi and Das 1988; Miah *et al.* 2014). Due to the demise of planted seedlings, large gaps have formed inside *S. apetala* plantations (Serajuddoula *et al.* 1995). The Bangladesh Forest Research Institute (BFRI) later introduced several notable mangrove species through experimental basis, including *Heritiera fomes, Excoecaria agallocha, Xylocarpus moluccensis, X. granatum, Bruguiera sexangula, Aegiceras corniculatum, Ceriops decandra, Phoenix paludosa* and *Lumnitzera racemosa* (Islam *et al.* 2013). A few mainland species were also trialed on some elevated ground of Char Island's including *Pithocellobium dulce, Samania saman, Casuarina equisetifolia, Acacia nilotica, Thespesia populnea* and *Albizia lebbeck* on small mounds (Islam *et al.* 2014). Additionally, there is insufficient regeneration throughout the keora plantations. Furthermore, Bangladesh's man-made coastal forest productivity is lower than that of other Asian countries. (Islam *et al.* 2015; Howlader 1999). Islam *et al.* (2015) observed that in the various coastal regions of Bangladesh, the density of *S. apetala* was 1201/ha. at the age of 17–42 years. The density of *S. apetala* trees planted in Mirersarai, Chattogram, was determined to be 650 trees per hectare at the ages of 20 to 29 years (Uddin *et al.* 2014).

In contrast, the natural Sundarban has a richer floristic composition than any other mangrove in the world. The Bangladesh Sundarban contains 66 species, according to a list provided by Chaffey and Sandom in 1985. Karim (1994) reported 123 plant species from 22 families and 30 genera in the Bangladesh Sundarban. The Sundarban mangrove forest's 44 undergrowth species were counted by Hossain (2003). It is necessary to introduce several mangrove and mangrove associated species inside the *S. apetala* plantation through underplanting in order to fill up the gaps of the coastal plantation and produce a dense mixed forest. The dense forest can shield against climate change-related extreme weather events that could harm human habitation, lives, property, and agricultural crops. Therefore, a study was carried out to ascertain the viability and growth of eight mangrove and mangrove-associated species in the western coastal region of Bangladesh at different inundation frequency level.

Materials and Methods

In this experiment, the following species namely *Aglaia cucullata* Roxb., *Ficus rumphii* Blume, *Tamarix indica* Wild, *Thespesia populnea* L., *Calophyllum inophyllum* L., *Cynometra ramiflora* L., *Rhizophora mucronata* Lamk and *Dolichandrone spathacea* (L.f.) K. Schum were tried.

Study area

This experiment was conducted by the Plantation Trial Unit Division (PTUD) of BFRI between 2017 and 2020 at two offshore islands, namely Rangabali in Patuakhali district and Char Kukri– Mukri in Bhola district. Rangabali is located at latitude 21^{0}92′ north and longitude 90^{0}92′ east. Char Kukri- Mukri is situated at latitude 21^{0}85′ north and longitude 90^{0}72′ east (Islam *et al.* 2015). There are many similarities between the two sites. The average lowest and highest temperatures are 18°C and 32°C respectively (Siddiqi 2002). The soil is silty clay loam and non-calcareous. In the monsoon and dry seasons, soil salinity ranges from 0.3 to 4.2 DS/m. The pH of the soil is fairly alkaline, ranging from 7.5 to 8.0. (Siddiqi and Khan 2000).

Nursery raising

The seeds gathered from trees with superior phenology were utilized to grow seedlings of species such as: *A. cucullata, T. populnea, C. inophyllum, C. ramiflora, and D. spathacea.* The seedlings of *T. indica* and *F. rumphii* were generated by cutting, and *R. mucronata* from propagules. The polybag, measuring 18cm × 12cm and filled with a 3:1 ratio mixture of loamy soil and cow manure was used to raise seedlings. The seedlings were maintained in the nursery for 8 to 10 months by weeding and watering.

Site selection, site preparation, data collection

The experimental sites were chosen within the 15–30 years-old *S. apetala* plantation at several char land at Rangabali and Char Kukri-Mukri island where flooding occurs three to twelve months in the year. In Rangabali Island experimental plantations were set up in 2017, 2018, 2019 and 2020 with an inundation frequency of 12, 9 and 3 to 5 months, respectively. At Char Kukri-Mukri site, plantations were made in regions with a inundation frequency of 9–12 months. The experimental were prepared through clearing and cutting of bush. Seedlings were planted with three replications at 1.5m ×1.5m spacing in a Randomized Complete Block Design (RCBD). Barbed wire and wooden posts were used to fence the experimental plots to prevent biotic interference. Experimental plantations were maintained through weeding and climber cutting to keep the test plots in good condition twice in year. The data was collected from the experimental plantations twice, in June and December. Data on growth characteristics were collected at these plantations for comparison with experimental plantations.

Statistical analysis

The Minitab statistical software and an excel spreadsheet were used to evaluate all of this data. Growth of experimental species survival, height, and collar diameter were measured using analysis of variance (ANOVA) to determine the effect of inundation frequency of these species.

Results

The results of the experiments are shown in tables 1 and 2. In the experimental year 2020, the highest survival was recorded for T. *populnea* (86%), followed by *F. rumphii* (81%), *D. spathacea* (71%) and *C. inophyllum* (61%) at the age of one year at the Rangabali site. The mean highest height was recorded for *F. rumphii* (1.26m, Fig. 1), followed by *T. populnea* (1.08m), *D. spathacea* (0.99m), and *C. inophyllum* (0.76m, Fig. 1). The highest mean collar girth was found at *F. rumphii* (3.98cm), followed by *D. spathacea* (3.88cm), *C. inophyllum* (3.31cm), and *T. populnea* (3.27cm) at 3-5 months inundation areas of Rangabali site in the plantation year 2020 (Table 1). In the experimental year 2019, the

Table 1. Survival and Growth performance of species planted in 2017, 2018, 2019, and 2020 at Rangabali Forest Research Station.

Name of Species	Plantation year and age									
	2017 (4 years)		2018 (3 years)		2019 (2 years)			2020 (1 year)		
	Inundation Frequency 12 Months		Inundation Frequency 9 Months		Inundation Frequency 3-5 Months			Inundation Frequency 3-5 Months		
	Mean survival %	Mean Height (m)	Mean survival %	Mean Height (m)	Mean survival %	Mean Height (m)	Mean collar girth (cm)	Mean survival %	Mean Height (m)	Mean collar girth (cm)
C. inophyllum	0	0	0	0	4.0± 0.16b	0.61± 0.02c	4.4± 0.12a	61.4± 1.23d	0.76± 0.17c	3.31± 0.15b
A. cucullata	0	0	0	0	35.0± 0.15d	1.05± 0.12b	4.39± 0.11a	-	-	-
T. populnea	0	0	0	0	97.0± 0.16 a	1.71± 0.47 a	4.32± 0.12a	86.0± 0.96a	1.08± 0.03b	3.27± 0.15b
F. rumphii	0	0	0	0	80.0± 0.19c	1.84± 0.09a	4.82± 0.18a	81.0± 1.47b	1.26± 0.03a	3.98± 0.31a
D. spathacea	19.00 ±3.21	1.2 ±0.42	19.85 ±0.58	1.15 ±0.19	32.0± 0.19d	1.10± 0.04b	4.28± 0.23a	71.48± 0.95c	0.99± 0.03b	3.88± 0.32 a
R. mucronata	0	0	0	0	22.0	0	0	0	0	0
C. ramiflora	0	0	0	0	0	0	0	0	0	0
P value					0.000	0.000	0.000	0.000	0.000	0.000

Notes: Means with different letters in a column are significantly different at 5% level (± SE. Mean).

highest survival rate (97%) was recorded for *T. populnea*, followed by *C. inophyllum* (94%), *F. rumphii* (80%), *A. cucullata* (35%), *D. spathacea* (32%) and *R. mucronata* (22%) at the age of two years at the Rangabali site where inundation frequency was 3-5 months. The significantly highest mean height was recorded for *F. rumphii* (1.84m, Fig. 2), followed by *T. populnea* (1.71m, Fig. 2), *D. spathacea* (1.10m), *A. cucullata* (1.05m) and *C. inophyllum* (0.61m). The highest collar girth was recorded 4.82cm for *F. rumphii*, 4.40cm for *C. inophyllum*, 4.39cm for *A. cucullata*, 4.32cm for *T. populnea* and 4.28cm for *D. spathacea*.

At the Char Kukri-Mukri sites, in the experimental plantation of 2020, the highest survival was recorded for *C. ramiflora* (60%) followed by *A. cucullata* (52%), *T. populnea* (50%) and *D. spathacea* (47%), *C. inophyllum* (30%) and *T. indica* (22%) at the age of one year. The highest mean height was recorded for *T. populnea* (0.80m), followed by *A. cucullata* (0.70m), *C. inophyllum* (0.70m), *D. spathacea* (0.44m), *C. ramiflora* (0.30m) and *T. indica* (0.20m). The highest mean collar girth was found in *T. indica* (4.73cm), followed by *A. cucullata* (3.47cm), *T. populnea* (2.29cm), C. inophyllum (2.12cm), *D. spathacea* (1.78cm), and *C. ramiflora* (1.36cm) (Table 2). In the experimental plantation of 2019, the highest survival was found for *D. spathacea* (32%) followed by *T. indica* (22%), *T. populnea* (21%) and *A. cucullata* (11%). The highest mean height was recorded for *T. populnea*

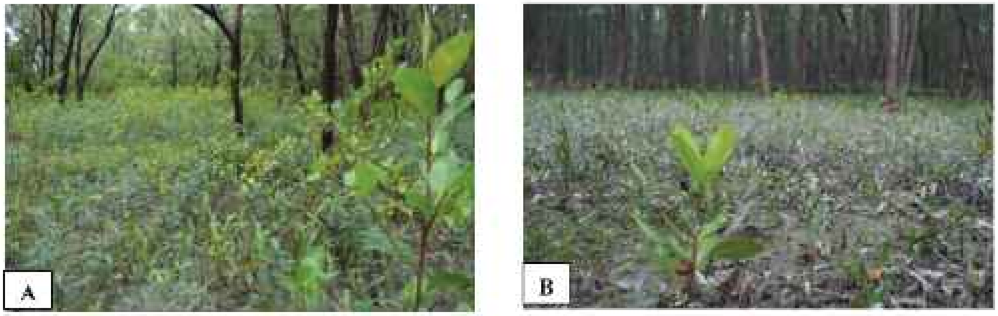

Figure 1. Understoried experimental plantation of *F. rumphii* and *C. inophyllum* at Char Nazir, Rangabali, Patuakhali (1 Year) (A&B).

Figure 2. Experimental plantation of *T. populnea* and *F. rumphii* under the *S. apetala* forest at Char Nazir (3-5 months inundation area), Rangabali, patuakhali (2 years) (A&B).

Table 2. Survival and growth performance of mangrove and mangrove associated species planted in 2018, 2019 and 2020 at Char Kukri-Mukri Forest Research Station under the *S. apetala* forest.

Name of species	2018 (age 2.5 years)			2019 (age 2 years)			2020 (age 1 year)		
	Mean survival %	Mean height (m)	Mean collar girth (cm)	Mean survival %	Mean height(m)	Mean collar girth (cm)	Mean survival %	Mean height(m)	Mean collar girth (cm)
C. inophyllum	12.0± 0.01b	0.78± 0.26a	3.44± 0.17c	10.00± 0.16c	0.65± 0.12b	2.58± 0.14c	30.0± 0.90d	0.47± 0.19b	2.12± 0.10c
A. cucullata	8.50± 0.02c	0.98± 0.56a	4.33± 0.11b	11.00± 0.03c	0.73± 0.46b	3.72± 0.12b	52.0± 1.28b	0.70± 0.18a	3.47 ±0.15b
T. populnea	-	-	-	21.00± 0.09b	0.95± 0.53a	2.6± 0.02c	50.0± 2.14b	0.80± 0.03a	2.29 ±0.13c
F. rumphii	-	-	-	-	-	-	-	-	-
D. spathacea	30.0± 0.02a	0.65± 0.02b	3.80± 0.20c	32.00± 0.65a	0.54± 0.02c	2.58± 0.14c	47.5± 1.32b	0.44± 0.02b	1.78± 0.08c
C. decandra	0	0	0	0	0	0	0	0	0
R. mucronata	-	-	-	-	-	-	-	-	-
C. ramiflora	0	0	-	-	-	-	60.0± 1.90a	0.30± 0.00c	1.36 ±0.05c
T. indica	15.0± 0.16b	0.56± 0.09bc	5.75± 0.16a	22.00± 0.10b	0.35± 0.12d	4.92± 0.11a	22.0± 0.27d	0.20± 0.00d	4.73± 0.15a
P value		0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000

Notes: Means with different letters in a column are significantly different at a 5% level

(0.95m), followed by *A. cucullata* (0.73m), *D. spathacea* (0.54m), and *T. indica* (0.35m). The highest mean collar girth was recorded for *T. indica* (4.92cm), followed by *A. cucullata* (3.72cm), *D. spathacea* (2.58cm) and *T. populnea* (2.6cm) at the age of two years (Table 2). The growth performance of the species was found to be better at the Rangabali site than at the Char Kukri-Mukri site in respect of survival, height, and collar girth.

Discussion

Results of experimental plantations raised in 2020 indicated a significant differencesin survival, height growth and collar girth of the species at the Rangabali locations and shows disparities in height growth and survival in 2019 plantation. Survival, height growth, and collar girth of various species raised in 2020 at Char Kukri-Mukri site also revealed a significant differences. The growth performance of the species *T. populnea*, *C. innophyllum*, *D. spathacea* and *F. rumphii* was shown to be superior in terms of survival, height, and collar girth at the Rangabali site, where inundation occurs for 3-5 months than at the Char Kukri-Mukri site, where inundation occurs for 9-12 months of the year. Difference in the performance of the species seems to be due to the frequency and duration of *C. ramiflora*, *A. cuculata*, *T. populnea* and D. *spathacea* species performed better in the 9–12 month inundated area at Char Kukri-Mukri areas than in Rangabali sites. It was noted that the plantation years 2017 and 2018 were more negatively impacted by grazing and caused damage. For that reason the results may be different from Char Kukri-Mukri site. The species *C. ramiflora* totally failed at Rangabali areas having 9 and 12 months inundation.The growth performance of these species was found to be better at the Rangabali site than at the Char Kukri-Mukri site in respect of survival, height, and collar girth could be due to the inundation frequency. Severe disturbance was noticed at the Char Kukri-Mukri site also. The species *T. populnea*, *C. innophyllum*, and *F. rumphiiare* usually grown in coastal raised land areas. Meepol *et al.* (2020) found *A. cucullata* measuring 30 cm in dbh and 15-20 m in height on the banks of the Kraburi River in Ranong Province, Thailand. According to Ahmed *et al.* (2009) and Hossain (2015), the species *F. rumphii* can grow as tall as 20 meters. *Serajuddoula et al.* (1995) was found *T. populnea* had a mean survival rate of 98.67%, a mean height of 3.67 m, and a mean diameter at breast height of (DBH) 3.8cm at Rangabali research station. Islam *et al.* (2014) found that at the Rangabali location in 17-year-old plantations had a mean survival rate of 52%, a mean height of 7.19m, and a mean DBH of 13.77cm. On homogeneous peat near Buntai in Indonesia, Leksono *et al.* (2021) identified 81.4% mean survival, 1.74m mean height, and 3.97 cm DBH at the age of two years in *C. inophyllum*. At the age of two years, *C. ramiflora* showed 67% mean survival and 1.02 m height at the Rangabali site and 71% mean survival and 0.96 m height at the Char Kukri-Mukri site, according to Siddiqi *et al.* (1992). Rahman (2016) observed that *R. mucronata* at the age of eight years in Sundarbans had a 74% mean survival rate, 5.23 m mean height, and 4.83 cm DBH. The height of *D. spathacea* is 4–10m (Weereesa and Chatchai 2021).

Conclusion

Making a choice about which species to use in an evaluation program based on tree growth performance may be helpful. To improve the density and biodiversity of manmade coastal forests, trials were initiated in the coastal areas to select suitable mangrove and mangrove associate species. Some of the species, like *T. populnea*, *C. innophullum*, *D. spathacea* and *F. rumphii*, were found promising at the ages of

2 and 1 years old in the 3-5 month inundation frequency level at Rangabali research station. The species *C. ramiflora* and *A.cuculata* performed better in 9–12 months-old inundated areas of Char Kukri-Mukri research station. According to the initial results of the study, *T. populnea, C. innophullum, D. spathacea,* and *F. rumphii* should be planted under the Keora forest, where the inundation frequency is 3-5 months. In 3–12 months inundated areas, the species *C. ramiflora* and *A. cuculata* can be performed. These species can be used to create a dense coastal forest to protect against natural calamities. This is, however, an interim report. The experimental trials will be maintained and the comprehensive ones will be available after a few year.

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Research Article

Elemental Chlorine Free Bleaching of Oxygen-delignified Kraft Pulp of Rubber Tree Species

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Abstract

Elemental Chlorine Free (ECF) pulp bleaching is now the dominant pulp bleaching process in the world to reduce the environmental pollution. The possibility of producing easy bleachable pulp from rubber stem and branches by oxygen delignification was studied in this study. Delignification of rubber wood was carried out by conventional Kraft pulping under varying conditions. Kraft pulp from rubber tree was bleached by $D_0E_pD_1$ (where D_0 represents 2% chlorine dioxide, Ep represents peroxide reinforced alkaline extraction and D_1 represents 1% chlorine dioxide) sequences. Kappa number and pulp yield of both stem and branch of rubber wood were comparable to other hardwood species before oxygen delignification. Oxygen delignification reduced kappa numbers 24.51% and 23.41% and increased brightness 21.12% and 26.51% in branch and stem of rubber wood pulp, respectively at 20% active alkali (AA). Branch pulp obtained brightness 77.57% and for stem 79.50%. After oxygen delignification branch pulp showed higher bleachability than stem pulp. The Kraft controls pulp could not reach target brightness of 80% using only $D_0E_pD_1$ in stem and branch pulp. But oxygen delignified Kraft pulp reached brightness 83% for branch and for stem 81.3%. Paper making properties of the bleached pulps did not show significant variation after oxygen delignification, apart from tear index in oxygen pre-bleached pulp. Considering bleachability and papermaking properties, oxygen was the best pre-bleaching option for attaining standard ISO brightness (80%) of stem and branch of pulp. The hand sheets were made and the physical strength properties of pre-bleached and final bleached pulp likely tear, tensile and burst were evaluated at 250 and 450 CSF (Canadian Standard Freeness) freeness level. The pulps produced from stem and branches of rubber tree possessed moderate strength properties. These could be used for producing moderate quality writing, printing and wrapping papers.

সারসংক্ষেপ

পরিবেশ দূষণ কমাতে এলিমেন্টাল ক্লোরিন ফ্রি (ইসিএফ) পাল্প ব্লিচিং এখন বিশ্বে সর্বাধিক প্রচলিত প্রক্রিয়া। এই স্টাডিতে অক্সিজেন ডিলিগনিফিকেশনের মাধ্যমে রাবার কাণ্ড এবং শাখা থেকে সহজে বিরঞ্জনযোগ্য মণ্ড উৎপাদনের সম্ভাবনা স্টাডি করা হয়েছে। বিভিন্ন অবস্থার অধীনে প্রচলিত ক্রাফট পাল্পিং পদ্ধতি দ্বারা রাবার কাঠের মণ্ড তৈরি করা হয়েছে। রাবার গাছ থেকে প্রাপ্ত ক্রাফট পাল্প $D_0E_pD_1$ সিকোয়েন্সের মাধ্যমে ব্লিচিং করা হয়েছে। কাণ্ড ও শাখা হতে প্রাপ্ত মণ্ডের কাপ্পা নাম্বার ও মণ্ডের হার অন্যান্য হার্ডউডের প্রজাতির সাথে তুলনীয় ছিল। রাবার গাছের শাখা এবং কাণ্ডের মণ্ডের অক্সিজেন ডিলিগনিফিকেশন দ্বারা কাপ্পা সংখ্যা ২৪.৫১% এবং ২৩.৪১% হ্রাস করেছে এবং উজ্জ্বলতা ২১.১২% এবং ২৬.৫১% বৃদ্ধি করা হয়েছে। শাখা এবং কাণ্ড হতে প্রাপ্ত মণ্ডের উজ্জ্বলতা যথাক্রমে ৭৭.৫৭ এবং ৭৯.৫০% বৃদ্ধি পেয়েছে। অক্সিজেন ডিলিগনিফিকেশনের পরে শাখা পাল্প, স্টেম পাল্পের চেয়ে অধিকতর উজ্জ্বল দেখায়। রাবার কাণ্ড ও শাখার মণ্ড অক্সিজেন ডিলিগনিফিকেশন ছাড়া কেবলমাত্র $D_0E_pD_1$ সিকুয়েন্স ব্যবহার করে টার্গেট উজ্জ্বলতা ৮০% এ পৌঁছাতে পারেনি। কিন্তু অক্সিজেন ডিলিগনিফিকেশন করা ক্রাফট পাল্প শাখার জন্য ৮৩.০% এবং স্টেম এর জন্য ৮১.৩% উজ্জ্বলতা অর্জন করেছে। অক্সিজেন প্রাকবিরঞ্জিত মণ্ডের টিয়ারসূচক ব্যতীত বিরঞ্জিত মণ্ডের কাগজ তৈরির অন্যান্য ধর্মেও উল্লেখযোগ্য কোন বৈচিত্র্য পরিলক্ষিত হয়নি। বিরঞ্জিতকরণ এবং কাগজ তৈরির ভৌত বৈশিষ্ট্য বিবেচনায় রাবার কাণ্ড এবং শাখা মণ্ডের আদর্শ উজ্জ্বলতায় পৌঁছাতে অক্সিজেন প্রাক ব্লিচিং ছিল ভালো উপায়। প্রাকবিরঞ্জিত ও চূড়ান্ত বিরঞ্জিত মণ্ডের তৈরি কাগজের ভৌত শক্তি ধর্ম যেমন টিয়ার, টেনসাইল এবং বার্স্ট ২৫০-৪৫০ সিএসএফ ফ্রীনেস লেভেলে মূল্যায়ন করা হয়েছিল। রাবার গাছের কাণ্ড এবং শাখা থেকে উৎপাদিত পাল্পগুলো মাঝারি শক্তির বৈশিষ্ট্য ধারণ করে। এগুলো লেখা, মুদ্রণ এবং কাগজ মোড়ক তৈরিতে ব্যবহার করা যেতে পারে।

Keywords: *Brighiness, Bleaching sequences, Chlorine dioxide, Kappa number, Latex, Rubber tree.*

Introduction

The use of paper, board and newsprint has been growing at a robust rate of 20% annually in the last five years (Anon 2010). The per capita consumption of paper is about 6 kg/year for 150 million people. Bangladesh Forest Industries Development Corporation, Chattogram Hill Tract Development Board and other private organizations planted rubber trees [*Hevea brasiliensis* (Willd. ex A. Juss.) Muell.-Arg.] on a large scale for latex production. The present rubber plantation of the corporation is 32,665 acres in the fallow, hilly and semi-hilly areas of greater Chattogram, Sylhet and Mymensingh districts having in all 41,00,000 rubber trees. The private planters have raised about 33,000 acres of rubber gardens having over 4 million rubber trees (Anon 2006b). The trees are harvested at the age of 30 years when tapping becomes uneconomical. The tree is light yellowish white on fresh cut, but turns into reddish brown on exposure. The sapwood and heartwood are indistinguishable by color (Mohiuddin 1993). The rubber wood contains 76.6% holocellulose and 42.7% alpha cellulose which are suitable for pulping (Das *et al.* 1995). There is no information on the use of rubber stem and branches as pulping raw material when the trees are harvested for replanting. One of the biggest state-owned mills in Bangladesh, Karnaphuli Paper Mills (KPM), uses bamboo and mixed hardwood as its main raw materials, and pulping is done by Kraft process (Biswas *et al.* 2017). Pulping conditions can affect residual lignin nature, which may play a key role in the development of pulp brightness.

Environmental pollution is now one of the greatest concerns of the worldwide pulp and paper industry. In Bangladesh's industrial classification system, pulp and paper mills fall under the "red" category, which designates them as highly polluting industries (Anon 1995). The bleaching sector of a pulp mill is one of the harmful areas from an environmental point of view. Conventional bleaching practices are generating large quantities of highly toxic organic halides (AOX); however, the substitution of chlorine dioxide (ClO_2) for bleaching reduces AOX production substantially. Elemental chlorine for Kraft pulp bleaching was stopped globally (Anon 1992). As a result of global trends and customer demand for cleaner bleach pulp, interest in elemental chlorine-free (ECF) and total chlorine free (TCF) bleaching is increasing. Pre-bleaching reduces kappa number and chemical consumption in bleaching stages, which reduces the entire effluent load (Viikari 1986; Ikeda *et al.* 1999a, 1999b, 1999c; Jahan *et al.* 2006). To reduce effluent load, sulfuric acid is used for removing the lignin from the pulp after Kraft pulping. Removal of lignin from Kraft pulp by acid treatment improved bleaching performance (Siddhartha *et al.* 2010) but reduced the paper strength. Both TCF and ECF bleaching sequences have been utilized mostly for bleaching of wood chemical pulps with low kappa number (Jahan *et al.* 2010; Tutus 2004). ECF bleaching is currently in general used to bleach wood chemical pulp (Latibari *et al.* 2012).

Oxygen delignification was very flexible, and was viewed as a bleaching mechanism between cooking and final bleaching (Rahmati *et al.* 2016). Oxygen delignification was a modern and environmentally friendly process which was normally used before elemental chlorine free bleaching sequences to run delignification reducing lignin in the pulp 35-55% prior to bleaching (Samuelson 1994). Oxygen delignification process reduced the kappa number of the pulp up to 40-45 (Rahmati *et al.* 2010). Pre-bleaching of Kraft pulp, using oxygen the production cost of high grade bleached pulp and strength properties of paper were higher. To increase 1% pulp yield, decrease the wood consumption 2.4% (Danielewicz and Surma-Ślusarska 2006). And thus lowers the raw material cost. Oxygen delignification is a more selective process to remove residual lignin from pulp (MeCubbin 1997). Oxygen selectivity is a very attractive research objective that has recently attracted the attention of several research groups (Colodetto1993; Magnotta 1998). The tensile strength of oxygen delignification pulp increased slightly with lignin removed which was probably due to the improvement of bonding between fibers after oxygen delignification (Rallming 2003).

The utmost of the lignin is removed during pulping, but a small amount of highly colored residue is outstanding in the unbleached pulp (Sixta *et al.* 2006). There are also some colored particles as well as foreign matter that contribute to the residual lignin is the main cause of color. Bleaching goal of removing the residual lignin by destroying the colored compound in lignin and other pulp components (Fogelholm 2000). In modern chemical pulp bleaching chlorine dioxide is used as the primary bleaching agent. ECF pulp, using ClO_2 as the primary bleaching chemical, had about 85% world market share in 2005 (Anon 2006a). The percentage is likely to have increased during the last 10 years. Due to the high selectivity and low environmental impact, use of ClO_2 is highly popular in the world (Sixta *et al.* 2006). ClO_2 is highly significant in practical pulp bleaching both today and in the near future. In this study, stems and branches of rubber wood pulp were delignified with oxygen and then delignified pulp was evaluated. Bleaching response of oxygen delignified Kraft on D_0EpD_1 bleaching sequences were also investigated.

Materials and Methods

Raw material

The stem and branches of freshly cut rubber trees, age was 35 years and diameter was 16 inches, were collected from Datmara Rubber Estate, Fatikchari, Chattogram (22.71° N, 91.70° E) with bark on. It was kept in open air to reduce moisture content. These were debarked and converted to plank whose size was 4'x4"x3". Chips were prepared separately using a laboratory chipper. The chips of stems and branches were screened to remove oversized and pin chips. Finally, the screened chips were hand sorted to remove all pieces of knots, barks and decayed wood. The accepted chips were about 20 mm in length, 10 mm in width and 3 mm in thickness. The chips were then air dried and stored in a sealed polythene bag for pulping.

Kraft pulping

Air dry (AD) chips of 2 kg were charged in the 5 liter stainless steel valley digester placed in steam heated. Analytical grades of Na_2S and NaOH (Merk, Germany) were used as cooking chemicals. The cooking time was 150min. at 170°C. The time required to raise this temperature from room temperature was 90 min. The liquor to wood ratio was 4:1 in all the cooks (L/kg). Two doses of active alkali were used to obtain different levels of delignification. A sulphidity of 25% was used in all the Kraft cooks. The cooked fibers were taken in a screen box and washed overnight under running water to wash out the residual liquor. These were stirred slightly with water in a bucket by a slow speed electric mixture. The pulp slurry was then screened in a Johnson vibratory screen to separate any uncooked material from the pulp. The wet pulp was passed through a screw press to remove excess water, and then samples were taken for dry matter content. The pulp yield was determined according to T-208 om-88 (Anon 1992). The screening rejects were collected and dried for calculating total pulp yield. The kappa number was determined using (Anon 1992) T-236 cm-85.

Oxygen delignification

The weighted portion of pulp (150g OD) was placed in a polyethylene bag and then the following chemicals were added: 0.4% magnesium sulfate and then 2.5% of sodium hydroxide on relative to oven dry (OD) pulp. The bagged content was hand-mixed and then transferred in quantity to an electrically heated digester. The auto-clave was closed and filled with oxygen with 110 pound per square inch (psi); the rotating mechanism was switched on, heated to a temperature of 95°C within 60 min. and then heating was continued at this temperature for 60 min. At the end of the delignification time, the digester was degassed and emptied. After delignification, the pulp was washed with distilled water and filtered, and its moisture and yield were determined.

D_0EpD_1 bleaching

The pulp of the stem and branch of rubber were bleached by D_0EpD_1 bleaching sequences. The chlorine dioxide was prepared in the laboratory by reacting sodium chlorite with hydrochloric acid. The delignification is Do stage was done by 2% ClO_2 at 70°C for 60 min. The consistency of pulp in all stages was 10%. The pH was adjusted to 2.5 by adding dilute H_2SO_4 (20%). Peroxide reinforced alkaline extraction was carried out with 2% NaOH and 0.5% H_2O_2 (on OD 150 g pulp) at 70°C for 60 min. In the final D_1 brightening stage 1% ClO_2 was used with a small addition of NaOH to maintain final pH 4.5. The brightness of the bleach pulp was determined in accordance with the T-236 cm-85 (Anon 1992) method.

Hand sheet making and physical testing

The oxygen delignified and final bleached pulp samples were beaten in a PFI mill to achieve a Canadian Standard Freeness (CSF) of 450 and 250 ± 3 mL (SCAN-C 21:65) and hand sheets were made. These were then conditioned at 23±1°C temperature and 50±2% relative humidity and tested according to SCAN-C 28:69 for determining the physical strength properties.

Statistical analysis

The physical strength properties were evaluated from five sheets for each beating. Then the mean and standard deviation were calculated. The graphical extrapolated values at 250 and 450 CSF were represented by regression.

Results

Pulping

Pulp yield of rubber stem at 16, 18 and 20% is 48.7, 48.8 and 46.8% respectively. On the other hand pulp yield of rubber branch at 16, 18 and 20% is 49.5, 51.7 and 50.6% respectively. With the increase of alkali doses from 16 to 20% both the branch and stem cooked well and pulp yield becomes 51.7% for branch and 48.8% for stem (Table 1). The chips were cooked well with 20% alkali doses. It was found that the pulp yield of both stem and branches of rubber wood was comparable to other hardwood wood species widely used in Karnaphuli Paper Mill. The yield of Kraft pulp from rubber wood with

Table 1. Yield and kappa number of unbleached and bleached Kraft pulp of rubber stem and branch at 25% sulphidity.

Portion of rubber tree	AA (%)	Yield (%)		Kappa No.	
		Before oxygen delignification	After oxygen delignification	Before oxygen delignification	After oxygen delignification
Stem	16	48.7±0.20	40.2±0.53	44.4±0.30	30.7±0.40
Branch		49.5±0.60	41.1±0.50	43.3±0.30	30.3±0.70
Stem	18	48.8±0.20	45.3±1.00	35.3±0.10	20.6±0.50
Branch		51.7±0.90	48.1±0.80	29.8±0.60	15.1±1.22
Stem	20	46.8±0.70	42.8±0.50	20.5±1.20	15.7±1.10
Branch		50.6±0.60	45.5±0.60	15.5±0.20	11.7±1.47

16-20% active alkali were (48.8-46.8) for stem and for branch (49.5-51.7) respectively. The kappa number of pulp was (42.4-20.5) for stem and for branch (40.3-15.5) respectively. Kappa numbers of the unbleached and oxygen delignified pulps were plotted against active alkali doses in Fig. 1 and Fig. 2. Pulp yield unbleached and oxygen delignified pulp of both stem and branches were decreased with the increase of active alkali concentration (Fig. 3 & Fig. 4)

Oxygen delignification

Kappa number of rubber stem unbleached pulp at 16, 18 and 20% is 44.4, 35.3 and 20.5 respectively. Kappa number of rubber branch unbleached pulp at 16, 18 and 20% is 43.3, 29.8 and 15.5 respectively. After oxygen delignification kappa number of rubber stem pulp at 16, 18 and 20% is 30.7, 20.6 and 15.7 respectively. However, after oxygen delignification kappa number of rubber branch pulp at 16, 18 and 20% is 30.3, 15.1and 11.7 respectively. The kappa number was reduced by oxygen delignification of the Kraft pulp and increased brightness. The kappa number reduced for stem 26.34% and for branch 24.38% which pulp produced at 20% active alkali. Oxygen delignification values the yield, kappa number after oxygen delignification given in the Table 1. The delignification was found easier in case of branches compared to the stem. Yield of branch and stem were decreased were increasing active alkali (Fig. 5). After delignification the kappa number reduced for stem 30.5% and for branch 30.2% which pulp were produced at 16% active alkali. The kappa number reduced for stem 41.6% and for branch 49.3% which pulp were produced at 18% active alkali. After delignification the kappa number reduced from 20.6 to 15.7 for stem and that reduced from 15.5 to 11.7 for branch at 20% active alkali. In this work, the Kraft pulp of high-kappa number was delignified in the single stage medium consistency oxygen delignification to decrease the lignin content to 11.7-15.5 kappa number units for branch and for stem 15.7-20.5, which would enable the pulp to be bleached fully with a reasonable amount of bleaching agent.

Bleaching ($DoEpD_1$)

Brightness of unbleached rubber stem pulp at 16%, 18% and 20% is 25.33, 26.88 and 28.40 ISO respectively. On the other hand brightness of unbleached rubber branch pulp at 16, 18 and 20% is 26.72, 27.50 and 28.85 ISO respectively. Brightness of oxygen-delignified rubber stem pulp at 16%, 18% and 20% is 32.65, 34.40 and 38.50 ISO respectively. Brightness of oxygen-delignified rubber

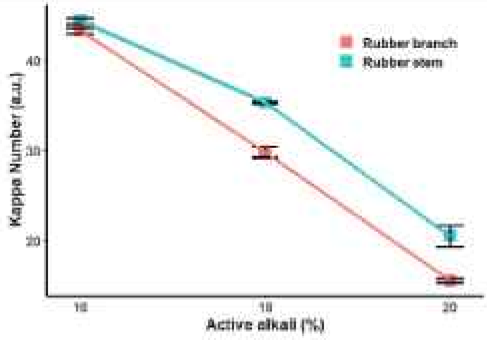

Figure 1. Effect of active alkali on kappa number after pulping.

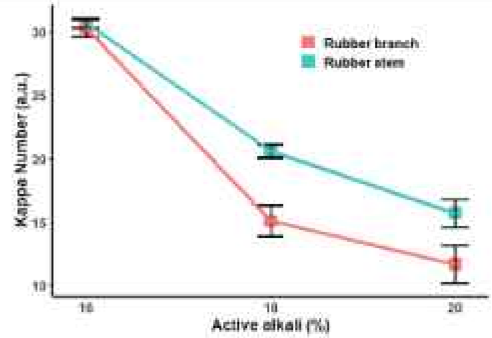

Figure 2. Effect of kappa number after o-delignification.

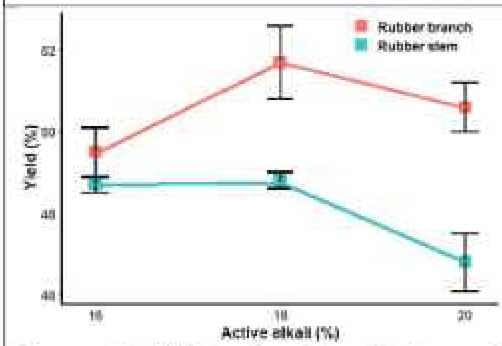

Figure 3. Effect of active alkali on yield before oxygen delignification.

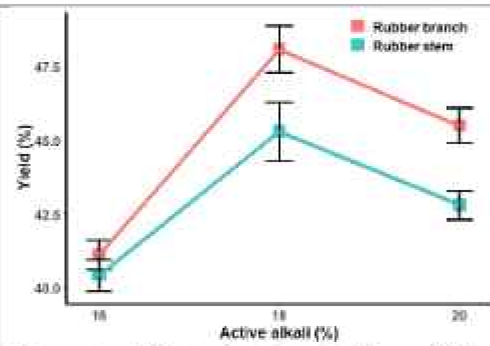

Figure 4. Effect of active alkali on yield after oxygen delignification.

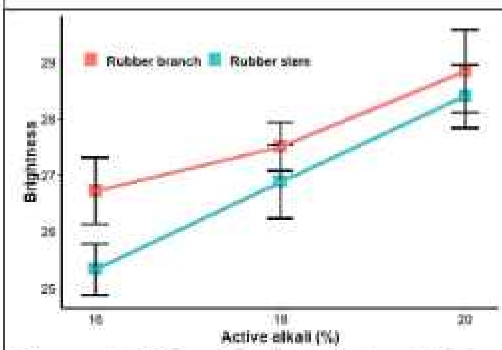

Figure 5. Effect of active alkali on brightness before oxygen delignification.

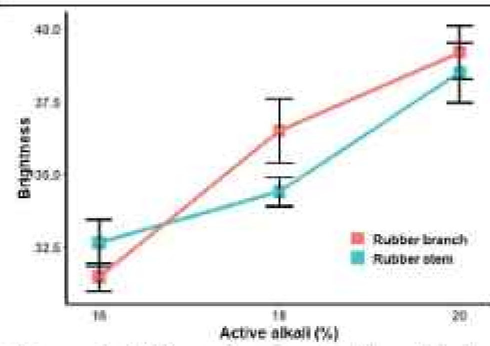

Figure 6. Effect of active alkali on brightness after oxygen delignification.

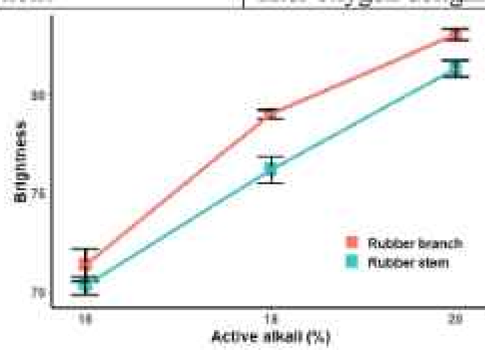

Figure 7. Effect of brightness on active alkali after final bleaching

branch pulp is 31.47, 35.50 and 39.20 ISO respectively. Brightness of bleached rubber stem pulp at 16%, 18% and 20% is 70.34, 76.20 and 81.30 ISO respectively. Brightness of bleached rubber branch pulp at 16%, 18% and 20% is 71.37, 79.00 and 83.00 ISO respectively. Brightness of pulp was increased with increasing active alkali (Fig. 5 & Fig. 6). After final bleaching it was found that branch pulp obtained higher brightness than that of stem pulp (Table 2). This might be attributed to a higher initial kappa number of unbleached stem pulp. The highest brightness (83.1%) was observed for branch pulp while the same for stem pulp was 81.3% (Fig. 7) after final bleaching.

Physical strength properties

The pulp-making characteristics of bleached branch and stem pulp of rubber were determined after beating in a PFI mill (Table 3). Tear strength decreased and, both tensile and burst strength increased with the decreasing CSF which are shown in Table 3 & 4. The tear, tensile and burst strength properties at 450 and 250 CSF of bleached pulp is given in Table 4. It showed that tear strength

Table 2. Comparison of brightness of unbleached, oxygen- delignified and bleach pulp.

Portion of rubber tree	Active Alkali (%)	Tear mNm²/g		Tensile mN/g		Burst kPa.m²/g	
		450 CSF	250 CSF	450 CSF	250 CSF	450 CSF	250 CSF
Stem	16	8.95±0.03	7.95±0.40	60.0±0.90	61.4±1.17	4.25±0.70	5.79±0.01
Branch		8.61±0.04	7.40±0.20	55.6±0.30	63.6±0.90	4.22±0.32	6.13±0.12
Stem	18	7.69±0.50	7.63±0.71	59.6±0.20	72.8±1.87	4.18±0.52	5.78±0.02
Branch		7.14±0.90	6.72±0.60	62.2±0.20	74.9±0.66	3.84±0.35	5.51±0.10
Stem	20	6.46±0.70	6.20±0.30	66.0±1.10	72.3±1.00	4.64±0.70	5.60±0.30
Branch		6.16±0.30	6.12±0.02	60.1±0.90	77.1±3.10	4.25±0.50	5.63±0.41

Table 3. Strength properties at 450 mL and 250 mL CSF of bleached (Oxygen delignified) Kraft pulp of rubber stem and branch at 25% sulphidity.

Portion of rubber tree		Active Alkali (%)	Tear (mNm²/g)		Tensile (mN/g)		Burst (kPa.m²/g)	
			450 CSF	250 CSF	450 CSF	250 CSF	450 CSF	250 CSF
Stem		16	5.55±0.32	4.99±0.22	46.2±0.96	65.0±050	3.34±063	4.11±0.02
Branch			7.88±0.24	6.97±0.17	65.9±0.70	70.1±2.40	4.55±0.42	4.99±0.23
Stem		18	5.40±0.13	5.02±0.10	45.8±0.12	62.1±0.58	3.15±0.63	4.15±0.05
Branch			7.52±0.50	7.47±0.48	65.8±0.23	69.8±0.50	4.26±025	5.12±0.20
Stem		20	6.88±0.35	6.72±0.39	63.2±0.35	72.7±0.20	4.02±0.20	5.02±0.64
Branch			7.05±0.54	6.69±0.30	66.8±0.10	75.0±0.20	4.31±1.12	5.33±0.32
Control	Stem	20	6.62±1.12	6.42±14	66.37±0.25	72.35±0.54	4.62±1.23	4.62±0.41
	Branch		7.13±0.90	6.23±.32	67.40±0.87	73.15±0.25	4.73±0.20	4.73±0.23

Table 4. Strength properties at 450 mL and 250 mL of bleached (D_oEpD_1) Kraft pulp of rubber stem and branch 25% sulphidity.

Portion of rubber tree		Active Alkali (%)	Tear (mNm^2/g)		Tensile (mN/g)		Burst ($kPa.m^2/g$)	
			450 CSF	250 CSF	450 CSF	250 CSF	450 CSF	250 CSF
Stem		16	5.55±0.32	4.99±0.22	46.2±0.96	65.0±050	3.34±063	4.11±0.02
Branch		16	7.88±0.24	6.97±0.17	65.9±0.70	70.1±2.40	4.55±0.42	4.99±0.23
Stem		18	5.40±0.13	5.02±0.10	45.8±0.12	62.1±0.58	3.15±0.63	4.15±0.05
Branch		18	7.52±0.50	7.47±0.48	65.8±0.23	69.8±0.50	4.26±025	5.12±0.20
Stem		20	6.88±0.35	6.72±0.39	63.2±0.35	72.7±0.20	4.02±0.20	5.02±0.64
Branch		20	7.05±0.54	6.69±0.30	66.8±0.10	75.0±0.20	4.31±1.12	5.33±0.32
Control	Stem	20	6.62±1.12	6.42±14	66.37±0.25	72.35±0.54	4.62±1.23	4.62±0.41
Control	Branch	20	7.13±0.90	6.23±.32	67.40±0.87	73.15±0.25	4.73±0.20	4.73±0.23

Table 5. Comparison of strength properties of final bleached Kraft pulps of stem and branches of rubber tree with other wood species.

Wood Species	Yield (%)	Process	Freenes s/°SR	Brightness (ISO)	Tear index mNm^2/g	Burst index $kPa.m^2/g$	Tensile index mN/g
Rubber stem[a]	46.8	D_0EpD_1	250 CSF	81.3	6.72	5.02	72.7
Rubber Branch[a]	51.6	D_0EpD_1	250 CSF	83.0	6.69	5.33	75.0
Prebleach Gamar[b]	46.0	DEDED	-	87.2	-	-	-
Prebleach Hardwood[c]	---	$D_oE_oD_1$	40°SR	83.2	15.0	3.9	38.4
Prebleach Muli bamboo[c]	---	$D_oE_oD_1$	41°SR	82.2	21.8	4.7	38.5
Rapeseed[d]	---	$D_oE_oD_1$	-	87.0	-	-	-
White straw[e]	48.1	$D_oE_oD_1$	-	60.0	10.71	2.26	34.1
Mixed hardwood[f] (SADL)		SEDED	-	76.0	4.0	5.31	55.23

a- Present work, b- Jahan *et al.* 2017, c- Jahan *et al.* 2013, d- POTŮČEK and RIHOVA 2017, e- Latibari *et al.* 2014, f- Siddharta 2010.

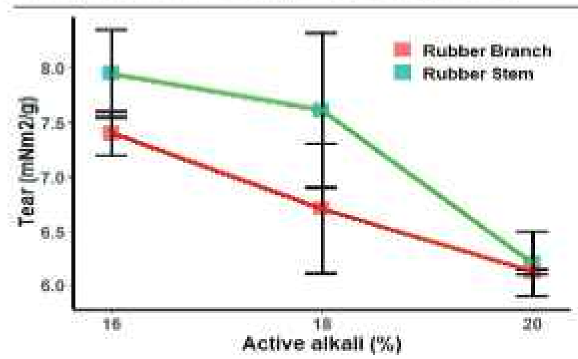

Figure 8. Effect of active alkali on tear index after oxygen delignification.

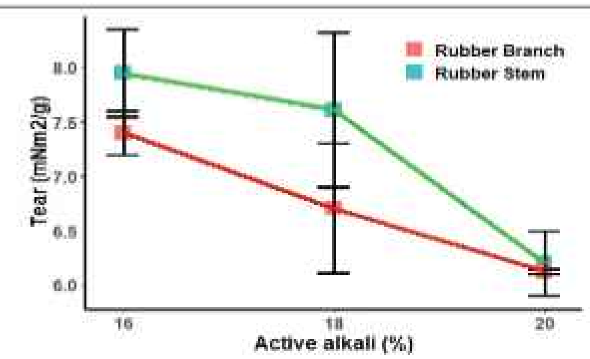

Figure 9. Effect of active alkali on tear index after final bleaching.

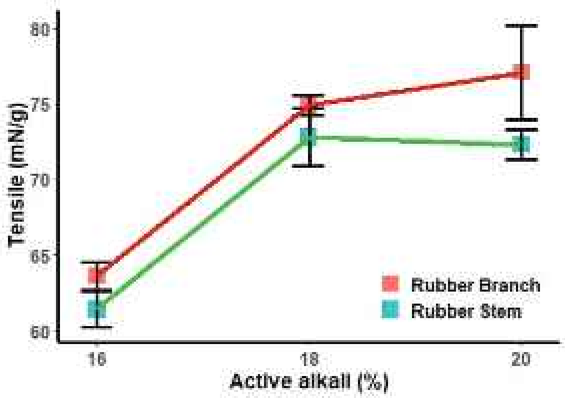

Figure 10. Effect of active alkali on tensile strength after oxygen delignification.

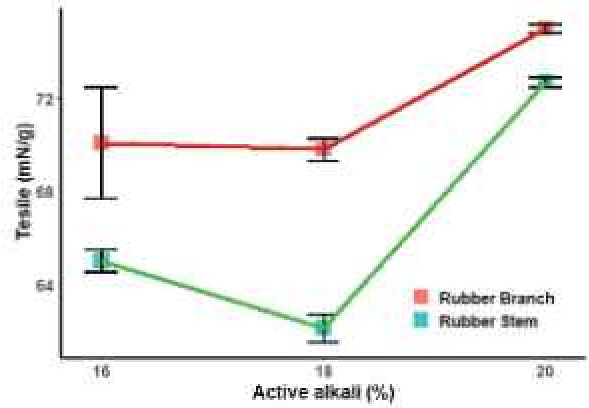

Figure 11. Effect of active alkali on tensile strength after bleaching.

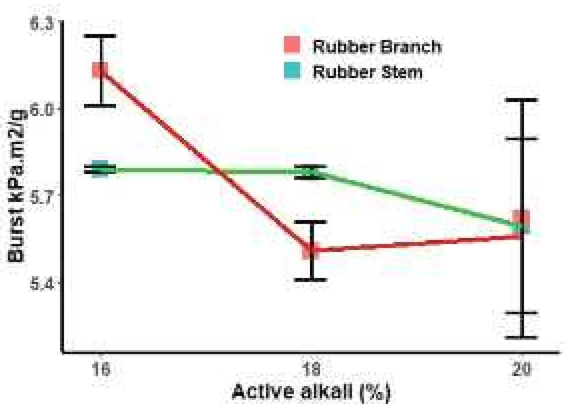

Figure 12. Effect of active alkali on burst index on after oxygen delignification.

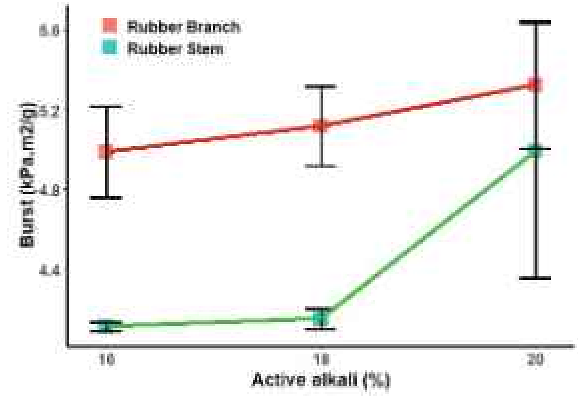

Figure 13. Effect of active alkali on burst index after final bleaching.

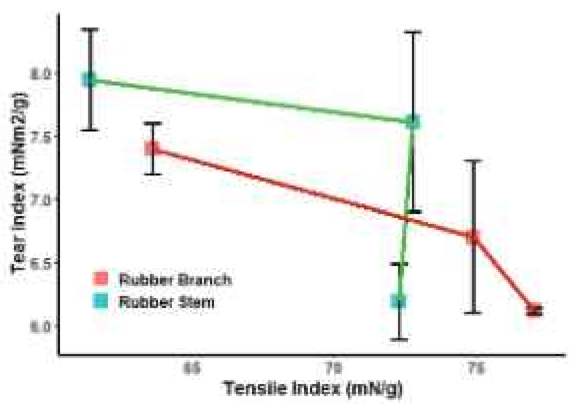

Figure 14. Tear tensile relationship after oxygen delignification.

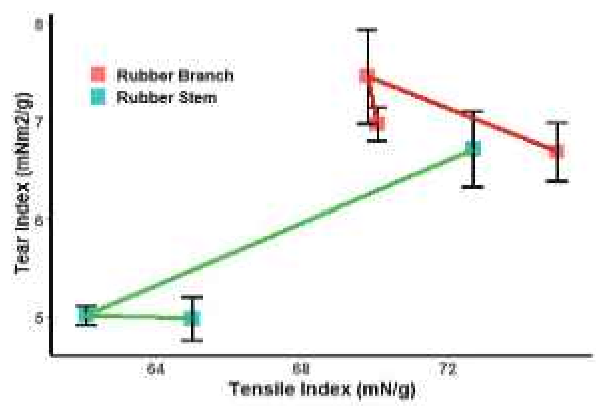

Figure 15. Tear tensile relationship after final bleaching.

decreased and, both tensile and burst strength increased with the decrease of CSF. Tear, tensile and burst strength were decreasing (Fig. 8, Fig. 10 & Fig. 12) after oxygen delignification. The tear, tensile and burst strength of rubber stem and branches were lower than that of pre bleach hardwood muli bamboo and white straw (Table 5). After final bleaching, between stem and branches, tear, tensile and burst index of stem superior to branch pulp which was shown in Fig. 9, Fig. 11 and Fig. 13. Relationship between tear and tensile was shown in Fig. 14 and Fig. 15.

Discussion

In previous studies many hardwood species were found suitable for pulping with an alkali charge of 14% maintaining 25% sulphidity (Akhtaruzzaman and Chowdhury 1991; Bose *et al.* 1995). It seems that for pulping of rubber stem and branches, a high alkali dose was required. The rubber wood stem was characterized by the lower lignin, higher alpha cellulose and longer fiber length than those of the branch. But the stem was wounded at the time of latex collection, so pulp of branch was easier to rubber stem. At 16% and 18% active alkali stem and branch did not produce bleachable grade pulp. Both stem and branches produced bleachable grade pulp at 20% active alkali dose for 150 min cooking time and for longer cooking time the alkali requirement was reduced. In Kraft pulp the C_6H_5OH units were generated from the β-aryl ether cleavage reaction. Phenolic compound content of residual pulp lignin increased steadily with decreasing the pulp kappa number. The degree of delignification depends on the initial kappa number (Vu *et al.* 2004). This trend was consistent with earlier observations (Yang and Lai 2009). Oxygen delignification processes removed 50% of the phenolic unit from unbleached Kraft pulp (Yang and Lai 2009). In case of kadam wood needed 19% active alkali (Misbahuddin *et al.* 2019). So, effluent would be more environmental friendly of pre bleach pulp than direct bleaching chlorine dioxide by active alkali. After oxygen delignification, the tear tensile relation at 250 CSF was 448.26 for the stem and for branch was 471.85 of rubber trees at 20% active alkali. Brightness was high for the stem at 20% active alkali. Oxygen delignification becomes especially significant in the case of rubber Kraft pulps with higher kappa numbers, because such pulps were not qualified directly for bleaching, especially in sequences where the elemental chlorine was completely substituted by chlorine dioxide. Oxygen delignified pulp showed promising results in the both stem and branch of rubber wood. Oxygen delignification was essential for attaining 83% ISO brightness. Chlorine dioxide was able to depolymerize both phenolic and non-phenolic lignin structure (Lindgren 1971; Brage *et al.* 1991). The pulp brightness was 80% ISO at 16% and 18% active alkali. On the other hand the brightness got 83% (ISO) for 20% active alkali. Higher brightness level was got by using same amount of bleaching chemicals of oxygen delignified bleachery agent. In the case of control pulp, the brightness level was lower than standard level (80 ISO). To increase brightness level bleachery chemicals would be increased. In case of oxygen delignified pulp reduced the bleached effluent load (Gustavsson *et al.* 1999). The tear index of the branch was lower while the tensile and burst index was higher for the stem of rubber wood at 250 CSF in this study. This was due to the longer fiber length of rubber stem (Jahan 2011). This result correlates well with the nalita (*Trema orentalis*) wood species (Jahan *et al.* 2010). Tear, tensile and burst strength properties of pre bleach pulp was lower than that of control pulp after final bleaching. This was because the tear strength depends on the strength of individual fiber cells, which decreases with beating. On the other hand, the tensile and burst strength depend on strong fiber to fiber bonding which result in the increase of bond potential with the progress of beating. In the present study the tear and burst index of stem pulp were more or less like to branch pulp however the tensile index of pulps made from stem was found slightly higher than that of branch pulp. This was due to the longer fiber length of rubber stem (Jahan 2010). These results correlate well with the nalita (*T. orientalis*) wood species (Jahan et al. 2010). With the increase of active alkali the strength properties decreased for both stem and branch. All physical properties of paper sheets of rubber stem and branch are higher than that of sulphuric acid delignified mixed hardwood pulp (Siddharta 2010). The properties of the pulp were interdependent. So, the quality of the pulp was determined by tear-tensile relationship. In this study tear-tensile relationship proved that stem pulp was a little bit superior in all cases except brightness. Brightness of steam was more or less similar with branches.

Conclusion

Rubber pulp was produced with Kraft process. Unbleached pulp was delignified with oxygen then bleaching was done by D_0EpD_1 sequences. The delignification, between rubber stem and branches, was found easier in case of branches. The pulp and paper quality of the branch was better than the stem. Oxygen delignified pulp obtained standard brightness whose were 81.3% for stem and 83% for branches. On the other hand, control or unbleached pulp could not attain standard level of brightness after final bleaching. At a certain consumption of 3% chlorine dioxide, branch pulp produces 2% higher brightness than that of rubber stem. Oxygen delignification was helpful for the environment due to the lower bleaching chemicals was needed at the time of bleaching. The paper-making properties of final bleached pulp of rubber wood was equivalent to other hardwood. This pulp can be used with other imported virgin pulp. Piercing of ClO_2 doses, reduced over consumption of ClO_2 through eliminating like mucomic acid resulted better delignification and higher brightness of the bleached pulp.

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Research Article

Conspectus the Vascular Flora of Hazarikhil Wildlife Sanctuary in Chattogram, Bangladesh

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Abstract

This paper presents the vascular plants (Angiosperms, Gymnosperms and Pteridophyta) of Hazarikhil Wildlife Sanctuary (HWS) in Bangladesh, which is managed by the Chattogram North Forest Division, have been rediscovered. A total of 462 species belonging to 313 genera under 100 families has been documented from the HWS of about 1177.53 ha. Habit analysis of vascular plants that, 184 are trees (40%), 69 shrubs (15%), 148 herbs (32%) and 61 species are climbers (13%) and two epiphytes. Euphorbiaceae is the dominant family represented by 29 taxa, followed by Fabaceae, Rubiaceae and Poaceae (24 taxa each), Asteraceae and Moraceae (16 taxa each), Acanthaceae (15 taxa), Convolvulaceae, Mimosaceae, and Verbenaceae (13 taxa each), Caesalpiniaceae (10 taxa) Lamiaceae, Sterculiaceae and Arecaceae (9 taxa each), Malvaceae and Anacardiaceae (8 taxa each), Amaranthaceae, Apocynaceae, Lauraceae, Araceae Meliaceae, Myrtaceae, Cyperaceae (7 taxa each) and Vitaceae (6 taxa). The Most common species was found the Ficus genera from this sanctuary. The Gymnosperm species of Taxodium distichum (L.) Rich was first recorded in Bangladesh from the study area. Nineteen rare species have been found whereas their plant genetic resources of this sanctuary. The native and tall tree species of the stratum has been described. A list of native trees suitable for reforestation in the HWS has been provided. The species are enumerated with scientific name, family name, bangla name(s), habit and habitat. The HWS is conserved by management plan for execution of National Conservation Strategy.

সারসংক্ষেপ

চট্টগ্রাম উত্তর বন বিভাগের আওতাধীন হাজারিখীল বন্যপ্রাণী অভয়ারণ্য এলাকার ভাস্কুলার উদ্ভিদ (আবৃতবীজী, নগ্নবীজী ও টেরিডোফাইট) এর পুন:আবিষ্কার সম্পর্কে এই প্রবন্ধে উপস্থাপন করা হয়েছে। প্রায় ১১৭৭.৫৩ হে. আয়তনের বন্যপ্রাণী এলাকা হতে ১০০টি পরিবার ও ৩১৩ গণের অন্তর্গত ৪৬২টি প্রজাতির উদ্ভিদ লিপিবদ্ধ করা হয়েছে। উক্ত বন্যপ্রাণী অভয়ারণ্য এর উদ্ভিদ বৈচিত্র্য হতে দেখা যায়, ১৮৪টি বৃক্ষ প্রজাতি (৪০%), গুল্ম ৬৯টি (১৫%), বীরুৎ ১৪৮টি (৩২%) এবং ৬১টি (১৩%) আরোহী জাতীয় প্রজাতি। ইউফরবিয়েসি পরিবারে সবচেয়ে বেশি প্রজাতি (২৯টি) রয়েছে। একইভাবে, ফেবাসি, রুবিয়েসি ও পোয়েসি পরিবার (২৪টি করে প্রজাতি), এসটেরাসি ও মোরেসি (১৬টি করে প্রজাতি), একানথেসি (১৫টি প্রজাতি), কনভলভুলাসি, মাইমোসাসি ও ভারবিনেসি (১৩টি করে প্রজাতি), সিসালপিনিয়াসি (১০টি প্রজাতি), লেমিয়াসি, স্টারকিউলিয়াসি ও এরিকাসি (৯টি করে প্রজাতি), মালভেসি ও এনাকারডিয়েসি (৮টি করে প্রজাতি), এমারেনথেসি, এপোসাইনেসি, লরেসি, এরাসি, মিলিয়েসি, মাইরটাসি, সাইপিরাসি (৭টি করে প্রজাতি) এবং ভাইটেসি (৬টি প্রজাতি) ধারণ করে। অভয়ারণ্যে ডুমুর জাতীয় উদ্ভিদ সবচেয়ে বেশী পরিলক্ষিত হয়। গবেষণা এলাকা হতে *Taxodium distichum (L.) Rich* নামক নগ্নবীজী উদ্ভিদটি বাংলাদেশে প্রথম রেকর্ড করা হয়েছে। ১৯টি দুর্লভ প্রজাতির উদ্ভিদ পাওয়া গেছে, যাদের জেনেটিক রিসোর্স উক্ত অভয়ারণ্যে আছে। দেশীয় উচু বৃক্ষ প্রজাতির শাহাড়ের আনুভূমিক স্তর অনুযায়ী বর্ণনা দেয়া হয়েছে। তাছাড়া উক্ত অভয়ারণ্যে দেশীয় উদ্ভিদ প্রজাতি পুন:বনায়নের জন্য একটি তালিকা সরবরাহ করা হয়েছে। উদ্ভিদ প্রজাতিসমূহের বৈজ্ঞানিক নাম, পরিবার, বাংলা নাম, বাসস্থান ও স্বভাব উপস্থাপন করা হয়েছে। জাতীয় সংরক্ষণ কৌশল পরিকল্পনা অনুযায়ী হাজারিখীল বন্যপ্রাণী অভয়ারণ্যটির ব্যবস্থাপনা ও সংরক্ষণ করা হচ্ছে।

Keywords: Assessment, Habit diversity, Hazarikhil Wildlife Sanctuary, Vascular flora.

Introduction

Bangladesh is a small country of about 14.757 million hectares of land area with a large population. Out of the total land area 2.53 million hectares (17.5%) is forest land cover (BFD 2017). Bangladesh has a rich biological heritage containing about 3,723 species of angiosperms (Hossain *et al.* 2017). It is estimated that the forest cover is reducing at an annual rate of 3.3 percent (Hossain 2001). The rapid loss and degradation of forests in Bangladesh has brought about an alarming rate of forest biodiversity depletion. Because of the reduction in the total forest area and also the country's overall demand for timber, fuel, food and fodder and maintaining ecological balance of the country. Biodiversity in this country has been heavily disturbed during the past several decades due to rapid population growth, energy deficit, resource shortage, myopic planning, poor management and lack of motivation on the needs of biodiversity conservation, which has resulted in the loss of wild biodiversity (Hassan 1995). Bangladesh government has implemented and explored some alternative forest management strategies for the conservation of forests as well as biodiversity of the country (Abdullah *et al.* 2007). In the present, Bangladesh possesses a total of 55 Protected Areas (PAs) cover about 6,18,254 hectares covering 4.19% forest land of Bangladesh (BFD 2017).

The Hazarikhil Wildlife Sanctuary (HWS) is situated the 45 km north of Chattogram port in south-east Bangladesh. It has been declared as a Wildlife Sanctuary in 2010 for taking proper protection and biodiversity conservation management.The major aim of establishing HWS as PA was to strengthen the conservation of the existing flora and fauna of the area. It comprises an area of about 1177.53 ha and lies between $22^{0}40$- $22^{0}46$ North latitude and $91^{0}38$- $91^{0}42$ East longitude. It is located to Fatikchari Upazila of Chattogram district, under Ramgarh- Sitakundu forests of Chattogram North Forest Division. It is covered bytropical moist evergreen and semi-evergreen forest comprising of hills, hillocks and plain lands. HWS hills are made up of sand-storms and shale (Rahman 2017). The hilly forest of Hazarikhill is floristically and geographically more related to Indo-China than to any other part of the Indian sub-continent (Khan 1977). The vascular flora of this wildlife sanctuary is mostly evergreen and mixed evergreen type except some areas of deciduous type composed of *Tectona grandis* plantations. Natural patch mostly with indigenous trees are on the sporadic hills of low, medium and high elevations. Some of natural forest areas have been converted to *T. grandis* and recent *Acacia auriculiformis* plantations. Some perennial streams flow along the bottom of the ravines meeting in single larger stream as a *Kalapainna chara* and form the main water source of the sanctuary. The bank of the main stream, lying almost entirely in the Hazarikhill range has more well-preserved natural vegetation. It has a unique territory with mountains and beautiful landscapes. It also helps offers feeding, nesting sites and breeding ground of a large number of wild animals for the human being. A wildlife sanctuary is providing various opportunities of education, research, tourism and associates employment. But there is no systematic taxonomic study on the vascular flora of this sanctuary. The present investigation was explored to assess vascular plant diversity in the HWS aimed at justifying the declaration of WS in this natural forest. Also, it is comparable with government managed other protected areas vascular flora in the country. The present findings of the study will provide valuable information for the preparation of taxonomic report and the monitoring of vegetation dynamics of HWS.

Materials and Methods

A systematic qualitative survey through transect walk followed by the field trips during July 2016- June 2019 in different seasons were conducted to cover the whole study area. Plant material and data were collected from study area on habit, habitat, ecology, occurrence and distribution of the vascular plant for identification. Plant species with fertile material were documented and identified in the field. Herbarium specimens of fertile plant materials were prepared for preservation at the Bangladesh Forest Research Institute Herbarium (BFRIH). Identification of unknown species has been made in the Herbarium of Bangladesh Forest Research Institute specimens and by consulting the pertinent literatures *viz.* Hooker (1872-1897); Prain (1903); Heinig (1925); Huq (1986); Das and Alam (2001); Kanjilal *et al.* (1934, 1938, 1940); Dey (1995) and Dey *et al.* (1999). An update nomenclature determination with current names and synonyms have been made consulting relevant literature, such as, Ahmed *et al.* (2009); Rashid and Rahman (2011, 2012) and Rahman (2013). The family names adapted followings Cronquist system of classification (Cronquist 1981). The present vascular floralist of this HWS is provided in the result. The plant families, genera and species under each family have been arranged alphabetically. Each species entry provides the scientific name, bangla name (s) and diversity of habit and habitat.

Results

Taxonomic diversity

The present investigation is carried out for collection, identification, update nomenclature and assessment of vascular plants (Angiosperms, Gymnosperms and Pteridophyta) for HWS in Chattogram. The present rediscovery records a total of 462 (Angiosperms, Gymnosperms and Pteridophyta) species belonging to 313 genera under 100 families (Table 1) within an area of 1177.53 ha.

Table 1. List of present record of the vascular plants of the Hazarikhil Wildlife Sanctuary.

(A) Angiospermae (Dicotyledoneae)

Family	Botanical name	Local name	Habit	Habitat
Acanthaceae	*Andrographis paniculata* (Burm. f.) Wall. *ex* Nees	Kalomegh	Herb	FM
	Barleria cristata L.	Janti	Shrub	FM
	B. prionitis L.	Kantajati	Shrub	FFr
	Eranthemum pulchellum Andrews	Shukhmurali	Shrub	FF
	Hygrophila polysperma (Roxb.) T. Anders	Alai kalai	Herb	FF
	Justicia adhatoda L.	Basak	Shrub	P
	J. japonica Thunb.	Jagotmadan	Herb	FM
	Lepidagathis incurve Buch.-Ham. *ex* D. Don	Karoggathis	Herb	MP
	Nelsonia canescens (Lam.) Spreng.	Paramul	Herb	FF
	Rungia pectinata (L.) Nees	Punakapundu	Herb	LS
	Staurogyne angustifolia T. Anders.	Angutigyne	Herb	MP
	S. argentea Wall.	Cheimdima	Herb	MP
	Strobilanthes auriculatus (Wall.) Nees	Kara	Herb	LS
	Thunbergia erecta (Benth.) T. Anders.	Nil ghanta	Climber	MS
	*T. grandiflora*Roxb.	Neel lata	Climber	MS
	Achyranthes aspera L.	Apang	Herb	FF
	Alternanthera philoxeroides (Mart.) Griseb.	Helencha	Herb	MP

Family	Botanical name	Local name	Habit	Habitat
Amaranthaceae	*A. sessilis* (L.) R. Br. *ex* Roem. &Schuil.	Chanchi	Herb	OP
	Amaranthus spinosus L.	kantamarish	Herb	OP
	A. viridis L.	Noteyshak	Herb	OP
	Celosia argentea L.	Moragh phul	Herb	P
	Cyathula prostrata (L.) Blume	Shyontula	Herb	MP
Anacardiaceae	*Anacardium occidentale* L.	Kajubadam	Tree	P
	Bouea oppositifolia (Roxb.) Maessn.	Maila aam	Tree	MS
	Holigarna longifolia Roxb.	Barola	Tree	MS
	Lannea coromandelica (Houtt.) Merr	Jiolbhadi, Jiga	Tree	LS
	Mangifera indica L.	Aam	Tree	P
	M. longipes Griff.	JongliAam	Tree	MS
	Spondias pinnata (L.f.) Kurz	Bon amra	Tree	HB
	Swintonia floribunda Griff.	Civit, Aamchundul	LT	HB
Annonaceae	*Desmos chinensis* Lour.	Epeyharang	WC	MS
	Fissistigma rubiginosum (A. DC.) Merr.	Rubi bheduli	WC	MS
	Uvaria cordata (Dunal) Alston	Bagh-ranga	WC	MS
Apiaceae	*Centella asiatica* (L.) Urban in Mart.	Thankuni	CR	
Apocynaceae	*Alstonia nerifolia* D.Don	Chatim	ST	US
	A. scholaris (L.) R. Br.	Chhatim, Chatian	Tree	LS
	Holarrhena antidysenterica (L.) Wall. *ex* Decne	Kurchi,Kuruj	Tree	MS
	Ichnocarpus frutescens (L.) R. Br.	Dudhilata	Climber	MS
	Rauvolfia serpentina (L.) Benth. *ex* Kurz	Sarpagandha	Shrub	HB
	Tabernaemontana crispa Roxb. *ex* Wall.	Bon togar	Shrub	MS
	Wrightia arborea (Dennst.) Mabb.	Dudh-korach	Tree	MS
Aralliaceae	*Brassaiopsis glomerulata* (Blume) Regel	Kurila	ST	LS
	Macropanax oreophillum Miq.	Pani- kesuri	Tree	LS
	Trevesia palmata Vis.	Bon pepe	Tree	LS
Aristolociaceae	*Aristolochia indica* L.	Ishwarmul	Climber	LS
	A. tagala Cham.	Ishwarmul	Climber	MS
	Gymnema acuminatum (Roxb.) Wall.	Khara lata	WC	US
Asclepiadaceae	*Calotropis gigantea* (L.) R. Br.	Akanda	Shrub	LS
	Hoya globusa Hook. f.	Golahoya	Herb	E
	Tylophora indica (Burm. f.) Merr.	Antamul	Climber	MS
Asteraceae	*Ageratum conyzoides* L.	Fulkuri	Herb	MP
	Blumea lacera (Burm. f.) DC.	Kukurshunga	Herb	FF
	B. lanceolaria (Roxb.) Druce	Barotoragaas	Herb	FF
	Chromolaena odorata (L.) King & Robinson	Assamlata	Herb	LS
	Eclipta alba (L.) Hassk.	Bhimraj	Herb	MP
	Elephantopus scaber L.	Gejiashak	Herb	FF
	Emilia sonchifolia (L.) DC.	Sadushi	Herb	FF
	Mikania cordata (Burm. f.) Robinson	Assamlata	Climber	LS
	Pseudoelephantopus spicatus (B. Juss. *ex* Aubl.) Gleason	Kukur gihba	Herb	FF
	Sonchus wightianus DC.	Ban palang	Herb	FF
	Spilanthes calva DC.	Marhatitiga	Herb	MP
	Synedrella nodiflora (L.) Gaertn.	Relanodi	Herb	FF
	Tridax procumbens L.	Tridhara	Herb	FF
	Vernonia cinerea (L.) Less.	Kukshima	Herb	LS
	Wedelia chinensis (Osbeck) Merr.	Mahabhringaraj, Bhimraj	Herb	MS
	Xanthium indicum Koenig *ex* Roxb.	Ghagra	Herb	LS
Bignoniaceae	*Fernandoa adenophylla* (Wall. *ex* G. Don) Blume	Barapata	Tree	MS
	Oroxylum indicum (L.) Kurz	Kanaidinga, Khona	ST	MS
	Stereospermum colais (Buch.- Ham. *ex* Dillw.) Mabberely	Dharmara	Tree	MS

Family	Botanical name	Local name	Habit	Habitat
Bombacaceae	*Bombax ceiba* L.	Simul	LT	P
	B. insigne Wall.	Bon simul	LT	HB
Boraginaceae	*Cordia serrata* Roxb.	Koratsora	ST	HB
	Heliotropium indicum L.	Hatisur	Herb	LS
	Ehretia serrata Roxb.	Kaluza	ST	HB
Brassicaceae	*Lepidium sativum* L.	Halimshak	Herb	MP
Buddlejaceae	*Buddleja asiatica* Lour.	Neemda	Shrub	LS
Burseraceae	*Canarium resiniferum* Brace *ex* King	Dhup	ST	HB
	Protium serratum (Wall. *ex* Colebr.) Engl.	Guitguitta	Tree	MS
Caesalpiniaceae	*Caesalpinia digyna* Rotter	Kochi	WC	MS
	Cassia fistula L.	Sonalu	Tree	MS
	C.nodosa Buch. – Ham. *ex* Roxb.	Bon sonalu	MT	MS
	Saraca asoca (Roxb.) de Wild.	Ashok	ST	MS
	Senna alata (L.) Roxb.	Dadmordan	Shrub	LS
	S. occidentalis (L.) Link	Bara-Kalkasunda	Herb	MP
	S. siamea (Lamk.) Irwin & Barneby	Minjiri	Tree	P
	S. sophera (L.) Roxb.	Choottokolkasunde	Shrub	LS
	S. tora (L.) Roxb.	Hurhurey	Shrub	LS
	Tamarindus indica L.	Tentul	Tree	P
Capparaceae	*Cleome gynandra* DC.	Sadahurhurey	Herb	FF
	C. rutidosperma DC.	Hurhurey	Herb	FF
	Crateva manga (Lour.) DC.	Barun, Gota baruna	ST	LS
Casuarinaceae	*Casuarina equisetifolia* Forst.	Jhau	ST	P
Chenopodiaceae	*Chenopodium album* L.	Betuashak, Vathua-shak	Herb	LS
Clusiaceae	*Calophyllum inophyllum* L.	Puinal	MT	HB
	Mesua ferrea L.	Nageshwar	Tree	HB
	*Garcinia cowa*Roxb. *ex* DC.	Kaogola	ST	HB
	*G. lanceaefolia*Roxb.	Ban kao	MT	MS
	G. xanthocymens Hook. f. *ex* T. Anders.	Tamal	ST	MS
Combretaceae	*Anogeissus acuminate* (Roxb. *ex* DC.) Guill. & Perr.	Itchri	MT	US
	Calycopteris floribunda (Roxb.) Lamk.	Goichalata	WC	MS
	Terminalia bellirica (Gaertn.) Roxb.	Boyra, Bohera	Tree	MS
	T. chebula Retz	Horitaki	ST	MS
Convolvulaceae	*Argyria argentea* (Roxb.) Chosy.	Chotto-biztarak	Climber	FF
	Evolvulus nummularius (L.) L.	Buiokra	CH	FF
	Hewittia sublobata (L. f.) Kuntze	Jarad kalmi	Climber	OP
	Ipomoea alba L.	Dhudikalmi	Climber	FFr
	I. attenua Forsk.	Kalmishak	Herb	MP
	I. batatas (L.) Lamk.	Misti Aloo	Climber	OP
	I. fistulosa Mart. *ex* Choisy	Dholkalmi	Shrub	FFr
	I. hederifolia L.	Neela kalmi	Climber	FFr
	I. pestigridis L.	Langulilata	Climber	FFr
	Merremia attenuata (L.) Halleer	Sada kalmi	Herb	MP
	M. emarginata (Burm. f.) Hallier. f.	Indurkanipana	Climber	FF
	M. umbellata (L.) Hallier. f.	Kommolata	Climber	FF
	Operculina turpethum (L.) S. Marso.	DudhKalmi	Herb	FF
Cucurbitaceae	*Citrullus colocynthis* (L.) Schrad.	Indrayan	Climber	OP
	Coccinia grandis (L.) Voigt	Telakucha	Climber	LS
	Hodgsonia macrocarpa (Blume) Cogn.	Gular, Pathligular	Climber	FF
	Trichosanthes cordata Roxb.	Bhuikakra	Climber	FFr
Cuscutaceae	*Cuscuta reflexa* Roxb.	Swarnalata	Climber	MS
Crypteroniaceae	*Crypteronia paniculata* Blume	Goru mara	Tree	US
Datiscaceae	*Tetrameles nodiflora* R. Br.	Chundul	Tree	HB
Dilleniaceae	*Dillenia indica* L.	Chalta	Tree	MS

Family	Botanical name	Local name	Habit	Habitat
	D. pentagyna Roxb.	Hargeja	Tree	LS
Dipterocarpaceae	*Anisoptera scaphula* (Roxb.) Pierre	Boilam	Tree	US
	Dipterocarpus alatus Roxb. *ex* G. Don.	Dholi Garjon	Tree	HB
	D. costatus Gaertn.	BaittyaGarjon	Tree	HB
	D. turbinatus Gaertn.	TellyaGarjon	Tree	HB
	Hopea odorata Roxb.	Telsur	Tree	HB
	Shorea robusta Roxb. *ex* Gaertn. f.	Shal	Tree	MS
Ebenaceae	*Diospyros malabarica* (Desr.) Koste.	Gab, Deshi gab	Tree	LS
	D. peregrina Guerke	Deshi gab	ST	LS
	D. pilosula Wall.	Khalta	ST	MS
Elaeocarpaceae	*Elaeocarpus floribundus* Blume	Jolpai	Tree	HB
	Elaeocarpus rugusus Roxb. *ex* G.Don	Belpoi	LT	HB
Euphorbiaceae	*Antidesma bunius* (L.) Spreng	Elena	ST	US
	A. ghaesembilla Gaertn.	Chotkigola	ST	US
	Aporosa dioica (Roxb.) Muell.- Arg.	Kechua	ST	US
	A. oblanga Muell.- Arg.	Kastoma, Kharulla	ST	MS
	A. wallichii Hook.f.	Kakra	ST	MS
	Baccaurea ramiflora Lour.	Latkon	Tree	MS
	Bischofia javanica Blume	Kanjolbhadi	Tree	LS
	Breynia retusa (Dennst.) Alston.	Silpati	Shrub	LS
	Bridelia stipularis (L.) Blume	Pat koi	Shrub	LS
	Chaetocarpus castanicarpa (Roxb.) Thw.	Atthalia	ST	MS
	Croton bonplandianus Baill.	Bondhone	Herb	FF
	C. caudatus Geisel.	Nanbhanti	Shrub	LS
	C. lobetus L.	Crotongach	Herb	FFr
	Euphorbia hirta L.	Dudiya	Herb	FF
	Glochidion multiloculare (Roxb. *ex* Willd.) Muell.-Arg.	Keotomi	Shrub	MS
	Glochidion sp.	----	Shrub	MS
	Macaranga denticulata (Blume) Muell.Arg.	Bura, Burna	ST	LS
	Mallotus tetracoccus (Roxb.) Kurz	Moin bura	ST	LS
	M. philippensis (Lamk.) Muell. – Arg.	Sinduri	Tree	MS
	M. repandus (Willd.) Muell.- Arg.	Gunti	WS	MS
	M. roxburghianus Muell. - Arg.	Nimputeli	Tree	FFr
	Phyllanthus emblica L.	Amloki	ST	MS
	P. niruri L.	Bhuiamla	Herb	MP
	P. reticulatus Poir.	Citki	Shrub	FFr
	Ricinus communis L.	Bherenda	Shrub	OF
	Sapium baccatum Roxb.	Campata, boloch	Tree	HB
	Suregada multiflora (A. Juss.) Baill.	Moricha	ST	MS
	Tragia involucrata L.	Bichuti	Herb	S
	Trewia nudiflora L.	Pitali, pitagola	Tree	LS
Fabaceae	*Abrus precatorius* L.	Kunch	Climber	HS
	Butea monosperma (Lam.) Kuntze	Palash	Tree	P
	Crotalaria acicularis Buch.-Ham. *ex* Benth.	Kata jhunjhuni	Herb	FF
	C. pallida Aiton	Jhun jhuni	Herb	FFr
	C. tetragona Roxb. *ex* Anders.	Gona jhunjhuni	Herb	FF
	C. verrucosa L.	Jhanjhana	Shrub	FFr
	Dalbergia confertiflora Benth.	Toloarsheem	Climber	FFr
	D.lanceolaria L. f.	Chakemdia	ST	MS
	D. sissoo Roxb.	Sisoogace	Tree	MS
	D. spinosa Roxb.	Chulikanta, Anantakanta	Shrub	FFr
	D. stipulacea Roxb.	Dadbari	Shrub	FFr
	D. volubilis Roxb.	Ankilata	Climber	US
	Derris robusta (Roxb. *ex* DC.) Benth.	Jamarjakoroi	Tree	US

Family	Botanical name	Local name	Habit	Habitat
	Desmodium gangeticum (L.) DC.	Salpani	Shrub	OF
	D. heterocarpon (L.) DC.	Karpo modi	Shrub	OF
	D. motorium (Houtt.) Merr.	Gorachan	Shrub	OF
	D. pulchellum (L.) Benth.	Jat -salpani	Shrub	OF
	D. triflorum (L.) DC.	Kadaliya	Herb	OF
	D. triquetrum (L.) DC.	Kalaliya	Herb	OF
	Erythrina indica L.	Mandar	Tree	LS
	E. stricta Roxb.	Pahari mandar	ST	LS
	Flemingia macrophylla (Willd.) O. Kuntze *ex* Merr.	Bara salphan	Shrub	OF
	F. strobilifera (L.) R. Br.	Bon sim	Shrub	FFr.
	Mucuna monosperma DC.	Nata alkushi	Climber	US
	M. pruriens (L.) DC.	Al-kushi	Climber	US
	Psophocarpus tetragonolobus (L.) DC.	Kamranga shim	Climber	US
	Pterocarpus indicus Willd.	Padauk, Padak	LT	P
	Tephrosia purpurea (L.) Pers.	Bon-neel	Herb	FFr.
	Uraria sp.	Belai leja	Shrub	FF
Fagaceae	*Castanopsis lancifolia* (Kurz) Hickel & A. Camus	Jat Batna	Tree	US
	Lithocarpus elegens (Blume) Hatus	Rai batna	Tree	MS
Flacourtiaceae	*Flacourtia jangomus* (Lour.) Racusch	Painnagota, lukluki	ST	MS
	Hydnocarpus kurzii (King.) Warb.	Chaulmugra	ST	HB
Gesneriaceae	*Rhynchotechum ellipticum* (Diet.) DC.	Dub mormoijja	Shrub	LS
Juglandaceae	*Engelhardtia spicata* Lesch *ex* Blume	Kaichrabhadi, Jhumkabhadi	ST	MS
	Anisomeles indica (L.) Kuntze	Gubura	Herb	LS
	Hyptis brevipes Poir.	Gol tokma	Shrub	FFr
	H. suaveolens Poir.	Tokma	Shrub	FFr
Lamiaceae	*Leonurus sibiricus* L.	Roktodron	Herb	MP
	Leucas aspera (Willd) Link	Choto halkusa	Herb	FFr.
	L. indica (L.) R. Br. *ex* Vatke	Shetodron	Herb	FFr.
	Ocimum americanum L.	Bon-tulshi	Herb	FF
	O. sanctum L.	Tulshi	Herb	FF
	Pogostemon auricularius (L.) Hassk.	Aripachuli	Herb	OF
	Actinodaphne angustifolia Nees	Modonmosta	Tree	MS
	Cinnamomum iners Reinw. *ex* Blume	Tejbohu	ST	MS
	Cryptocarya amygdalina Nees	Bhuiya gachh	Tree	HB
Lauraceae	*Litsea glutinosa* (Lour.) Robinson	Karjiukimenda	ST	MS
	L. monopetala (Roxb.) Pers.	Menda	Tree	LS
	Persea bombycina (K. & H.) Kosterm.	Nalaomshi	ST	MS
	Phoebe pallida (Nees) Nees	Dulia	ST	MS
Lecythidaceae	*Baringtonia acutangula* (L.) Gaertn.	Hijal	Tree	LS
	Leea aequata L.	Kakjangha	Shrub	LS
Leeaceae	*L. crispa* L.	Banchalita	Shrub	LS
	L. indica (Burm. f.) Merr.	Kurkurjihwa	S. tree	MS
Loranthaceae	*Dendrophthoe pentandra* (L.) Miq.	Pharulla	Shrub	E
	Scurrula parasitica L.	Parula	Shrub	E
	Lagerstroemia parviflora Roxb.	Sidhalarul	Tree	P
Lythraceae	*L. speciosa* (L.) Pers.	Jarul	Tree	P
	Woodfordia fruticosa (L.) Kurz	Dhaiphul	Shrub	FFr
Magnoliaceae	*Michelia champaca* L.	Champa	Tree	P
	Abelmoschus moschatus Medic.	Mushakdana	Shrub	LS
	Hibiscus surattensis L.	Ram bhindi	Herb	OP
	Sida acuta Burm.	Kureta	Shrub	OP
Malvaceae	*S. cordata* (Burm.f.) Borss.	Pitberela, Junka	Herb	OP
	S. cordifolia L.	Berela	Shrub	OP
	S.mysorensis Wight & Arn.	Chatchata	Shrub	OP

Family	Botanical name	Local name	Habit	Habitat
	S. rhombifolia L.	Lal berela	Shrub	OP
	Urena lobata L.	Ban-okhra	Shrub	OP
Melastomataceae	*Melastoma malabathricum* L.	Datranga, Lutki	Shrub	FFr.
	Osbeckia chinensis L.	Choigachi	Shrub	FF
Meliaceae	*Aphanamixi spolystachya* (Wallich) R.N. Parker	Pitraj, royna	Tree	P
	Azadirachta indica A. Juss.	Neem gacch	Tree	P
	Chukrasia tabularis A. Juss.	Chikrassi	Tree	P
	Dysoxylum binectariferum (Roxb.) Hook.f. *ex* Beddome	Rata, rangirata	Tree	HB
	Melia azadirachta L.	Gora nim	Tree	P
	Swietenia mahagoni (L.) Jacq.	Mehogoni	Tree	P
	Toona ciliata J. Roem.	Toon	Tree	P
Menispermaceae	*Stephania japonica* (Thunb.) Miers	Raj Pathda	Climber	MS
	Tinospora crispa (L.) Hook. f. & Thom.	Gulancha	Climber	US
	T. cordifolia (Willd.) Hook. f.	Gulonchalata	Climber	US
Menyanthaceae	*Nymphoides hydrophylla* (Lour.) O. Kuntze	Panchulli	Herb	A
Mimosaceae	*Acacia auriculiformis* A. Cunn. *ex* Benth.	Akasmoni	Tree	P
	A. caesia (L.) Willd.	Ailai	Tree	P
	A. mangium Willd.	Mangium	Tree	P
	Albizia lucidior (Steud.) Nielson. *ex* Hara	Sil koroi	Tree	P
	A. chinensis (Osb.) Merr.	Chakuakoroi	Tree	P
	A. lebbeck (L.) Benth.	Kala koroi,Sirish	Tree	P
	A. odorssima (L. f.) Benth.	Tetuyakoroi	Tree	P
	A. procera (Roxb.) Benth.	Jat koroi	Tree	P
	Calliandra umbrosa (Wall.) Benth.	ChottoBetmara	ST	MS
	Entada rheedii Spreng.	Gila lata	WC	US
	Mimosa pudica L.	Lajja bati	Herb	FF
	Samanea saman (Jacq.) Merr.	Rain tree	Tree	LS
	Xylia xylocarpa (Roxb.) Taub.	Lohakat	LT	HB
Moraceae	*Artocarpus chama* Buch. - Ham. *ex* Wall.	Chapalish	LT	LS
	A. heterophyllus Lamk.	Khanthal	Tree	P
	A. lacucha Buch. -Ham.	Barta, dewa	Tree	LS
	Ficus auriculata Lour.	Bara dumur	Tree	MS
	F. benghalensis L.	Bot gacch	Tree	HB
	F. benjamina L.	Dumur	Tree	HB
	F. fistulosa Reinw. *ex* Blume	Fapa- dumur	Tree	LS
	F. gibbosa Blume	Bot	Tree	HB
	F. hispida L. f.	Kakdumur	ST	LS
	Ficusheteropleura Blume	Paraboha	ST	HB
	F. laevis Blume	Dumurlata	Climber	FF
	F. nervosa Heyne *ex* Roth	Panidumur	ST	MS
	F. racemosa L.	Jogyadumur	Tree	HB
	F. religiosa L.	Panibot,Ashwath	MT	MS
	F. semicordata Buch.-Ham. *ex* Smith.	Jaggyadumur	Tree	HS
	Streblus asper Lour.	Sheora, harba	Tree	HB
Myristicaceae	*Knema clarkeana* Warburg	Kina barala	ST	AS
	Myristica linifolia Roxb.	Barella	ST	MS
Myrsinaceae	*Ardisia solanacea* Roxb.	Ban-jam	Shrub	LS
	Maesa attenua A. DC.	Narichagach	Shrub	MS
	M. indica (Roxb.) DC.	Sirkhi	ST	HB
	M. ramantacea Wall.	Noa moricha	ST	US
Myrtaceae	*Cleistocalyx nervosum* (DC.) Kosterm	Bhutijam,Godajam	Tree	MS
	Euclalyptus citrodora Hook.	Eucalyptus	Tree	P
	Syzygium cumini (L.) Skeels	Kalajam	Tree	P
	S. formosum (Wall.) Masamune	Paniya jam	Tree	P

Family	Botanical name	Local name	Habit	Habitat
	S. fruticosum DC.	Puti jam,Kakjam	Tree	FFr
	S. jambos (L.) Alston	Gulab jam	Tree	P
	S. praecox (Roxb.) Rathakr. & N. C. Nair	Kharkarajam	Tree	P
Nympheaceae	*Nymphaea nouchali* Brum. f.	Sada Sapla	Herb	A
Oleaceae	*Jasminum sambac* (L.) Aiton	Beli	WC	MS
	J. scandens Vahl.	Jongli jui	WC	MS
	Ligustrum robustum (Roxb.) Blume	Ligubus	WC	MS
	Myxopyrum smilacifolium (Wall.) Blume	Chiknabizi	Shrub	HS
Onagraceae	*Ludwigia hyssopifolia* (G. Don) ex A. & R. Fem.	Mulsi	Herb	MP
	L. prostrate Roxb.	Shayan kura	Herb	MP
Oxalidaceae	*Oxalis corniculata* L.	Amrul	Herb	MP
Passifloraceae	*Adenia trilobata* (Roxb.) Eng.	Akandaphal	Climber	FF
	Passiflora foetida L.	Jomkalata	Climber	FF
Piperaceae	*Peperomia attenuata* (L.) Kunth.	Peperomea	Herb	LS
	Piper longum L.	Pipul	Herb	LS
	*P. sylvaticum*Roxb.	Ban Pan	CH	MP
Polygalaceae	*Salomonia ciliata* (L.) DC.	Salmonisil	Herb	LS
Polygonaceae	*Ampelygonum chinense* (L.) Lindl.	Mohicharanshak	Herb	LS
	Persicaria orientalis (L.) Spach.	Bara panimarich	Herb	LS
	P. hydropiper (L.) Spach.	Pakurmul	Herb	LS
	P. viscosa (Buch. – Ham. *ex* D. Don) Nakai	Biskatali	Herb	LS
Rhamnaceae	*Ziziphus mauritiana* Lamk.	Boroi, Kul	Tree	HB
	Z. oenoplia (L.) Mill.	Bon boroi	Shrub	MS
Rubiaceae	*Aidia micrantha* (K. Schum.) Bullock *ex* F. white	Aimira	Shrub	MS
	Canthium angustifolium Roxb.	Katalichapa	Shrub	HB
	Chasalia curviflora Thw. *var. ophioxyloodes* (Wall. *ex*Roxb.) Deb. & Krishna	Hel gaas	Shrub	MS
	Dentella repens (L.) Forst. & G. Frost.	Bhuipat	Herb	OP
	Gardenia coronaria Buch.- Ham.	Konnayri	Tree	MS
	Hedyotis corymbosa (L.) Lamk.	Panki	Herb	OP
	H. scandens Roxb. - Roxb.	Pankiraj	Shrub	OP
	Hymenodictyon orixensis (Roxb.) Mabberley	Bhui kadam	ST	US
	Ixora cuneifolia Roxb.	Beophul	Shrub	FF
	I. nigricans R. Br. *ex* Wight & Arn.	Nikrangachuillya	ST	MS
	Knoxia sumatrensis (Retz) DC.	Sumatra noxi	Herb	LS
	Mitracarpus hirtus (L.) DC.	Tupi kadam	Herb	FF
	Morinda angustifolia Roxb.	Banamali	ST	LS
	M. citrifolia L.	Banach	Shrub	LS
	M. umbellate L.	Gassalata	Shrub	MS
	Mussaenda roxburghii Hook.f.	Silchauri	Shrub	HB
	Ophiorrhiza mungos L.	Gandhanakuli	Herb	MP
	Paederia foetida L.	Gandha-badali	Climber	FF
	Pavetta indica L.	Banamali	Shrub	LS
	Psychotria adenophylla Wall.	Baro sudma	Shrub	LS
	P. symplocifolia Kurz	Sim bhuta	Shrub	LS
	Spermacoce articularis L. f.	Ahtharogia	Herb	Ffr.
	Wendlandia tinctoria ssp.*Orientalis* Cowan	Rong ghitya	ST	MS
Rutaceae	*Clausena excavata* Burm. f.	Dulia maricha	ST	MS
	C. heptaphylla (Roxb.) Wight & Arn.	Karanphul	Shrub	MS
	Glycosmis pentaphylla (Retz.) Corr.	Motkila	ST	HB
Sapindaceae	*Allophylus cobbe* (L.) Raeuschel var. *serratus* (Roxb.) Prain	Chita	ST	LS
	Allophylus cobbe (L.) Raeuschel var. *villosus* (Roxb.) Prain	Rakhalchita	ST	LS
	Cardiospermum helicacabum L.	Phutka	Climber	FF

Family	Botanical name	Local name	Habit	Habitat
	Lepisanthes rubiginosa (Roxb.) Leenh.	Barohorina	ST	MS
	Palaquium polyanthum Engl.	Tali	MT	P
Sapotaceae	*Mimusops elengi* L.	Bakul	ST	P
Scrophulariaceae	*Adenosma indianum* (Lour.) Merr.	Kesuti	Herb	MP
	Lindernia antipoda (L.) Alston	Choto helencha	Herb	MP
	Scoparia dulcis L.	Bandhaney	Herb	FF
	Torenia asiatica L.	Asiantoren	Herb	MP
	T. diffusa D. Don	Ushatoren	Herb	MP
Solanaceae	*Physalis minima* L.	Futka	Herb	OP
	Solanum nigrum L.	Gurkhi begun	Herb	FF
	S. sisymbrifolium Lamk.	Kanta begun	Herb	FF
	S. torvum Sw.	Gott begun	Shrub	LS
	S. virginianum L.	Kantakari	Herb	LS
Sonneratiaceae	*Duabunga grandiflora* (Roxb. *ex* DC.) Walp.	Bandarhulla	Tree	AS
Sphenocleaceae	*Sphenoclea zeylanica* Gaertn.	Jhillmarich	Herb	AS
Sterculiaceae	*Abroma augusta* (L.) L. f.	Ulatkambal	ST	HB
	Byttneria aspera Colebr.	Nil bhutta	WC	US
	B. pilosa Roxb.	Harbanga-lata	WC	US
	Firmiana colorata (Roxb.) R. Br.	Jongliudal, Naichichaudal	Tree	HB
	Pterospermum acerifolium (L.) Willd.	Muskanda, Kanakchampa	ST	US
	P. semisagittatum Buch.-Ham.	Laonaassar	ST	MS
	Sterculia foetida L.	Jonglibadam	Tree	US
	*S. villosa*Roxb. *ex* Smith.	Udal	Tree	US
	Harpullia cupanoides Roxb.	Har pulli	Tree	MS
Styracaceae	*Styrax serrulatus* Roxb.	Fulkat	Tree	US
Theaceae	*Eurya attenuata* DC.	Sagolerbori	ST	HB
	Schima wallichii (DC.) Korth.	Kanak	Tree	MS
Tiliaceae	*Corchorus aestuans* L.	Titapat	Herb	LS
	Grewia nervosa (Lour.) Panigr.	Assar	ST	MS
	Triumfetta rhomboidea Jacq.	Ban-okra	Herb	LS
Ulmaceae	*Trema orientalis* (L.) Blume	Jibon	ST	LS
Urticaceae	*Boehmeria glomerulifera* Miq.	Borthurthuri	ST	LS
	Pouzolzia zeylanica (L.) Benn.	Kullaruki	Herb	MP
Verbenaceae	*Callicarpa arborea* Roxb.	Barmala	Tree	MS
	C. macrophylla Vahl.	Khoja	ST	MS
	Clerodendrum indicum (L.) Kuntze	Bamunhati	Shrub	MS
	C. viscosum Vent.	Bhant	Shrub	LS
	Gmelina arborea Roxb.	Gamari	Tree	P
	Lantana camara L.	Lantana	Shrub	MS
	Lippia alba Mill. N. E. Br. *ex* Brit. & Wilson	Pichas-lakr	Shrub	LS
	Phyla nodiflora (L.) Greene	Bhuiokra	Herb	LS
	Premna esculenta Roxb.	Lalana	Shrub	LS
	Tectona grandis L. f.	Shegun	Tree	P
	Vitex negundo L.	Nishinda	ST	LS
	V. peduncularis Wall. *ex* Schauer	Goda	Tree	MS
	Vitex pinnata L.	Awal	Tree	HB
Vitaceae	*Ampelocissus barbata* (Wall.) Planch.	Jarila-lahari	Climber	FFr.
	Cayratia japonica (Thunb.) Gagnep.	Japanigoalilata	Climber	FFr.
	Cissus assamica (Laws.) Craib	Amasha lata	Climber	FFr.
	C. elongate Roxb.	Dhemna	Climber	LS
	Tetrastigma angustifolia (Roxb.) Deb	Nekungriubi	Climber	MS
	T. leucostaphylum (Dennst.) Alston	Jarul lata	WC	MS

(B) Monocotyledonae

Family	Botanical name	Local name	Habit	Habitat
Amaryllidaceae	*Curculigo orchioides* Gaertn.	Talamuli	Herb	OM
Araceae	*Alocasia cucullata* (Lour.) G. Don	Bish kachu	Herb	SP
	A. macrorrhizos (L.) G. Don	Mankachu	Herb	LS
	Caladium bicolor Vent.	Diranga kachu	Herb	SP
	Colocasia esculenta (L.) Schott	Kachu	Herb	LS
	C. oresbia A. Hay	Sada kachu	Herb	FH
	Pothos scandens L.	Hatilata, sundad	CH	OT
	Typhonium trilobatum (L.) Schott	Ghet -kachu	Herb	FR
Arecaceae	*Calamus erectus* Roxb.	Kadam bet	WC	MS
	C. flagellum Griff.	Bhudum bet	WC	MS
	C. floribundus Griff.	Fuli bet	WC	LS
	C. gracilis Roxb.	Mapuri, kiring bet	WC	LS
	C. latifolius Roxb.	Karak, budum bet	WC	MS
	C. viminalis Willd.	Bara bet	WC	MS
	Caryota urens L.	Bansupari, chaur	Tree	US
	Daemonorops jenkinsiana (Griff.) Martius	Golla bet	Shrub	HB
	Phoenix sylvestris Roxb.	Khejur	Tree	US
Commelinaceae	*Commelina benghalensis* L.	Kanchira	Herb	FF
	C. diffusa Burm.f.	Monaynakanchira	Herb	FF
	C. sikkimensis C.B. Clarke	Batbaithia shak	Herb	FF
	Murdannia nudiflora (L.) Brenan	Kureli, kanduli	Herb	FF
Cyperaceae	*Cyperus compressus* L.	Chanca	Herb	FF
	C. cuspidatus Kunth in Humb.	Sagarmukhimethi	Herb	FT
	C. cyperoides (L.) O.Ktze.	Kusha, kucha	Herb	FM
	C. rotundus L.	Mutha grass	Herb	SP
	Kyllinga brevifolia Rottb.	Bindimuthi	Herb	R
	K. nemoralis (J.R.Forst.) Dandy *ex* Hut	Nirbishi	Herb	HS
	Scleria levis Retz.	Chas gashi	Herb	MP
Dioscoreaceae	*Dioscorea bulbifera* L. var. *sativa* (Hook.f.) Prain	Amdalata, Rata alu	Climber	FFr.
	Dioscorea pentaphylla L.	Ban alu, jhum	Climber	FFr.
	D. prazeri Prain &Burkill	Jhum alu	Climber	FFr.
Musaceae	*Musa paradisiaca* L.	Aitta kola	Herb	FF
Pandanaceae	*Pandanus foetidus* Roxb.	Keyakanta	Shrub	FFr.
Poaceae	*Bambusa tulda* Roxb.	Mitinga, Talla	Tree	HB
	B. vulgaris Schrad. *ex* Wendl.	Bajjya bans	Tree	HB
	Cynodon dactylon (L.) Pers.	Durbaghas	Herb	FF
	Cyrtococcum accrescens (Trin.) Stapf	Cyrtococcum	Herb	FF
	C. oxyphyllum (Steud.) Stapf	Oxycocca ghas	Herb	FFr.
	C. patens (L.) A. Camus	Pat coccaghas	Herb	FFr.
	Dactyloctenium aegyptium (L.) P. Beauv.	Makra		HB
	Digitaria setigera Roth *ex* Roem. & Schult.	Shetighas	Herb	FF
	Eleusine indica (L.) Gaertn.	Malanga kuri	Herb	HS
	Eragrostis ciliaris (L.) R. Br.	Lomkoni	Herb	US
	E. tenella (L.) P. Beauv. *ex* Roem.	Koni ghas	Herb	FFr.
	E. unioloides (Retz.) Nees *ex* Steud.	Kuni ghas	Herb	FFr.
	Gigantochloa andamanica (Kurz) Kurz	Kali bans	Tree	MS
	Imperata cylindrica (L.) Beauv.	Ulu, Chon	Herb	OP
	Melocanna baccifera (Roxb.) Kurz	Muli bans	Tree	MS
	Oplismenus burmanni (Retz.) P. Beauv.	Gohur	Herb	OP
	O. compositus (L.) P. Beauv.	Gohur	Herb	OP
	Panicum brevifolium L.	Panibrevighas	Herb	LS
	P. notatum Retz.	Panita ghas	Herb	LS
	Paspalum scrobiculatum L.	Goicha, kedoadhan	Herb	MS
	Pogonatherum crinitum (Thunb.) Kunth	Nitu bansh	Herb	HS
	P. paniceum (Lamk.) Hack.	Khudibansh	Herb	HS
	Schizostachyum dullooa (Gamble) R. Majumdar	Dolu bans	Tree	FF
	Thysanolaena maxima (Roxb.) O. Kuntze	Phuljharu	Herb	HS

(C) Gymnosperms

Family	Botanical name	Local name	Habit	Habitat
Podocarpaceae	*Podocarpus nerifolius* D. Don	Banspata	Tree	P
Cupressaceae	*Taxodium distichum* (L.) Rich	Swamp cypress (Eng)	Tree	P

(D) Pteridophyta

Family	Botanical name	Local name	Habit	Habitat
Acrostichaceae	*Pteris vittata* L.	Dhakia	Herb	MP
Athyriaceae	*Diplazium esculentum* (Retz.) Sw.	Dhekiashak	Herb	MP
	D. polypodioides Bl.	Dhekia	Herb	MP
Acrostichaceae	*Pteris vittata* L.	Dhekia	Herb	MP
Cyatheaceae	*Cyathea gigantea* (Wall. *ex* Hook.) Holtt.	Gach dhekia	ST	AS
Helminthostachyaceae	*Helminthostachys zeylanica* (L.) Hook.	Sada dhekia	Herb	LS
Lygodiaceae	*Lygodium flexuosum* (L.) Sw.	Latadhekia	CH	LS
Polypodiaceae	*Drynaria quercifolia* (L.) J. Sm.	Pankhiraj	EH	E
	Microsorum pteropus (Bl.) Copel.	Tripatradhekia	Herb	FF
	Pyrrosia nuda (Gies.) Ching	Nudarossi	Herb	FF
Pteridaceae	*Pteris quadriaurtia* Retz.	Dhekia	Herb	FFr
Schizaeaceae	*Dicranopteris linearis* (Burm.f.) Underw.	Lomba dhekia	Herb	HB
Thelypteriaceae	*Ampelopteris prolifera* (Retz.) Copel.	Dhekiashak	Herb	SP

[Here, LT- Large tree, MT- Medium tree, ST- Small tree, CR- Creeping herb, EH- Erect herb, WC- Woody climber, FM- Forest mergin, FFr- Forest frindge, FF- Forest floor, MP- Moist places, SP- Shady places, HB- Hill Base, MS- Middle slope, LS- Lower slope, P- Planted, HS- Hill slope, US – Upper slope, R-Road side, AS- Along the stream, E- Epiphyte, OF- Open fallows, A- Aquatic, FT- Foot trail, OP- Open places, S- Scrubs]

The Gymnosperms are represented by only 2 species under 2 genera in 2 families (according to Boerhost 1971). The Pteridophytes are represented by 13 species in twelve genera distributed under ten families (according to Siddiqui *et al.* 2007). The analysis of the taxa revealed that 11 families are represented by more than 5 species. Among the taxa, Euphorbiaceae having 29 species ranks top followed by Fabaceae (28 spp.), Rubiaceae and Poaceae (24 spp.), Moraceae and Asteraceae (16 spp.), Acanthaceae (15 spp.), Convolvulaceae and Verbenaceae (13 spp.) and Caesalpiniaceae (10 spp.). Other families are belonging to 2-9 species in the study area. Thirty- two families are represented by single genus having single species each in the study area. Out of 313 genera enumerated, *Ficus* is the largest genus having 12 species. *Ipomoea, Dalbergia, Desmodium* and *Calamus* are represented by 6 species. The genus of *Senna, Sida, Albizia* and *Syzygium* are represented by 5 species. The rest of genera come to the next position having 2 to 4 species. All species in Araceae, Zingiberaceae, Gesneriaceae, Lecythidaceae, Polygalaceae, Polygonaceae, Ulmaceae and Urticaceae families are growing the moist places with herbaceous in nature. The rest of species are occurring the forest floor, forest margin, forest frindge, hill slope and hill

Table 2. Synopsis of vascular plant taxa enumerated in the Sanctuary.

Plant group	Family	Genus	Species
Angiosperms	88	299	447
Pteridophyta	10	12	13
Gymnosperms	2	2	2
Total	100	313	462

base of the study area. The synopsis of the vascular plants taxa has been enumerated in the following table (Table 2).

Habit diversity

The vascular plants of the HWS are classified as trees, shrubs, herbs and climber on the basis of habit. According to the habit diversity, trees occupy the highest position, comprising 184 species which constitutes 40% of taxa, followed by shrubs comprising 69 species (15%), herb comprises 149 species (32%) and 61 (13%) are climberspecies. In 2017, flowers of *Elaeocarpus rugosus* and fruits of *Aphanamixis polystachya* were collected from HWS as a threatened species and preserved at Bangladesh Forest research Institute Herbarium shown in Fig. 1 & Fig. 2.

Figure 1. *Elaeocarpus rugosus* is a lagre native tree in HWS.

Figure 2. Fruits of *Aphanamixis polystachya*.

Occurrence of the species according to stratum

Hazarikhil Wildlife Sanctuary presents diverse habitat including hills and hills base, valleys, gullies, some water streams and covered mainly by secondary degreded forests. Along the beginning forest hill base are planted with *Xylia xylocarpa* (Lohakat), *Calophyllum inophyllum* (Kamdev), *Palaquium polyanthum* (Tali) and *Pterocarpus indicus* (Padok) etc. A few individuals of *Anisoptera scaphula* (Boilam), *Swintonia floribunda* (Civit), *Mangifera longipes* (Jongli Aam), *Pterospermum acerifolium* (Lana Assar) are still as characteristic elements of the forest. One of the unique features of this forest is the occurrence of three indigenous angiosperm species, *Firmiana colorata*, *Elaeocarpus rugosus* and *Cryptocarya amygdalina*. The forest has occufied the tall trees like *Dipterocarpus turbinatus, D. alatus, Vitex peduncularis, Anoguesus acuminata, Stereospermum colais, Bombax insigne, Artocarpus lacucha, A. chama, Spondias pinnata, Protium serratum, Tetramelesn odiflora*. The second storey consists of *Holarrhena antidysenterica, Hymenodictyono rixensis, Glochidion multiloculare, Trevesia palmata, Streblus asper, Macropanax oreophilum, Fernandoa adenophylla, Cordia serrata, Dillenia indica, D. pentagyna, Shorea robusta, Aporosa dioica, Hydnocarpus kurzii, Ficus spp., Podocarpus nerifolia, Palaquium polyanthum, Aphanamixis polystachya*, Some denuded and abandoned areas are covered with *Globba marantina, Staurogyne angustifolia, Ixora cuneifolia* and various species of rattan, bamboos and grasses. The other barren areas of the lower hill slopes are mostly covered with *Impreta cylindrica* and *Thysanolaena maximas* species. The present

Table 3. List of rare species are native inHazarikhil Wildlife Sanctuary

Family	Endangered species	Local name	Occurrence
Anacardiaceae	*Mangifera sylvatica*	Jongliaam	MS
	Swintonia floribunda	Civit	HS
Apocynaceae	*Alstonia nerifolia*	Chatim	US
Araliaceae	*Macropanex oreophillum*	Pani-kesuri	AS
Bueseraceae	*Protium serratum*	Gutguti	MS
Clausiaceae	*Calophyllum inophyllum*	Kamdev, Puinal	HB
Ebenaceae	*Diospyros pilosula*	Khalta	MS
Elaeocarpaceae	*Elaeocarpus rugosus*	Belpoi	HB
Fabaceae	*Pterocarpus indicus*	Padauk, Padak	Planted
Fagaceae	*Castanopsis castanicarpa*	Kanta batna	US
Lauraceae	*Cryptocarya amygdalina*	Bhuiya gachh	HB
Meliaceae	*Dysoxylum binectariferum*	Rata, rangirata	LS
Sapindaceae	*Palaquium polyanthum*	Tali	Planted
Sterculiaceae	*Firmiana colorata*	NaichichaUdal	HB
	Pterospermum semisagittatum	Laonaassar	MS
	Sterculia foetida	Jonglibadam	US
Styracaceae	*Styrax serrulatus*	Fulkat	US
Vitaceae	*Cissus assamica*	Amasha lata	FFr.
	Tetrastigma angustifolia	Nekungriubi	MS

[Here, FFr- Forest Frindge, HS- Hill slope, HB- Hill Base, US- Upper slope, MS- Middle slope, LS Lower slope, AS- Along the stream]

study reveales that the Fatikchari forest beat has fairly some natural forest cover rich species diversity with native tall trees occur in the HWS. And some patches are composed of native plant with a good vegetation structure.

These threatened species in this wildlife sanctuary are likely to be under conservation management. The present study also resulted with the while exploring in HWS under Chattogram district, Bangladesh for collection of plant genetic resources, the scientists of Forest Botany Division, BFRI collected a Gymnosperm specimen, which was previously not recorded for Bangladesh. After critical study at Bangladesh Forest Research Institute (BFRI) Herbarium the specimen was identified as *T. distichum* (L.) Rich by referring to the details of the specimen can be seen online in Kew's Herbarium Catalogue. This taxon was not reported from the area now falling under the political boundaries of Bangladesh by any of the previous literature of this region viz. Ahmed *et al.* (2008); Backer (1976); Kurz (1877); Prain (1897, 1903); Brandis (1906); Heinig (1925), Hooker (1980), Cowan (1926), Kanjilal *et al.* (1938); Raizada (1941); Sinclair (1955); Mia and Khan (1995) being recorded here for the first time from Bangladesh.

Discussion

It has been reported that in Bangladesh there are a total of 3,611 species of angiosperms belonging to 198 families. Vascular plants species composition of HWS revealed in this study that a total of 462 species belonging to 313 genera under 100 families recorded covering the study area. It seems to be very encouraging. It was found that the number of the species composition of 1177.53 ha. is higher than that of same area, e.g. 478 plant species under 305 genera with in an area of 2908.5 ha. reported by Rahman (2017). Also, 184 tree species were found in this study and higher in composition to other greater Chattogram forest areas, i. e. 179 tree species in Barayadhala National Park area by Rashid *et al.* (2018), 183 tree species reported from the Dudhpukuria- Dhopachari Wildlife Sanctuary (Hossain *et al.* 2013), 36 tree species in Sitakunda area by Heinig (1925) and 38 tree species in Ukhiarange of Cox'sBazar (Ahmed and Haque 1993). On the other hand, the tree species composition is comparatively lower than 189 tree species reported from the same area (Rahman 2017) and 238 tree species reported from the Bangladesh Forest Research Institute Campus (Alam *et al.* 2015). However, considering the results of these related studies, it can be attendant that the Hazarikhil area possesses moderately well diversified with higher number of indigenous tree species in comparison to other natural forests of the country. A very few plant taxonomists were done on herb and shruby flora richness in the HWS. It was found that, the herbaceous and shruby vegetation on the natural patches were showed good diversity in the hill slope and hill base of the study area. As a result, the vascular flora has been changed the HWS after over the time. There are some proposals recommended here may be classified as meant for long term planning for sustainable utilization of the natural resources of the forest. There are restore the natural environment and reforestation should be undertaken by planting the native trees to the HWS, instead of planting the exotic species viz: *Alstonia nerifolia* , *Anisoptera scaphula, Bouea oppositifolia, Canarium resiniferum, Castanopsis lancifolia, Dipterocarpus costatus, D. turbinatus, Dysoxylumbi nectariferum, Elaeocarpus rugosus, Engelhardtia spicata, Fernandoa adenophylla, Garcinia xanthocymens, Pterospermum acerifolium, Pterospermum semisagittatum, Swintonia floribunda, Vitex peduncularis* and *Wrightia arborea*. These native to forest whose flowers and fruits will provide fodder for the birds and mammals. And native trees should be planted expansively in the forest to attack wildlife which in revolvebrings about cross pollination, effective seed spreading, increased yields and sustainable development. The dead and hollow trees will not be removed from the sanctuary as the trees are suitable for biodiversity conservation of Moraceae family.

Conclusion

The HWS exists still remnant of natural forest of the Chottogram north forest division. It is one of the important habitat key places for *in situ* conservation of Bangladesh. The plant diversity of HWS has been changed after its establishment in 2010. The vascular plant species from an area of about 1177.53 ha WS at Hazarikhil seems to be in comparison to other protected areas from the region. A large number of indigenous plants are naturally growing in this sanctuary. Occurrence of 462 species in this area seems to have a good number of vascular species diversity which is comparable with other protected area in the country. The present findings will provide the valuable information on vascular plant distribution and vegetation structure, which will helpful the future conservation and in developing a conservation management plan of this sanctuary. One day this result will also work as a seed source. It is included that the present investigation more possible the way for further study to investigate of regeneration behavior in the study area. More particularly, the rare and threatened species along with their degraded habitats to be protected by taking proper conservation management programme. Local enthusiasts have to be involved in the conservation programmes and to create public awareness regarding the sustainable development through posters, photographs, graphics and pamphlets.

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Research Article

Survival and Growth Performance of Four Native Palm Species in the Central Coastal Belt of Bangladesh

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Abstract

Plantation Trial Unit Division of Bangladesh Forest Research Institute (BFRI) carried out a research in the central coastal belt (Noakhali area) of Bangladesh with Areca catechu L., Cocos nucifera L., Phoenix sylvestris Roxb., and Borassus flabellifer L. from 2019 to 2021 in order to assess the growth performance of these four native palm species. Seedlings of these species, except C. nucifera, were raised in polybags, and 10–12-months-old seedlings were planted in the field in June of every year. The study was laid out in a Randomized Complete Block Design (RCBD) with 3 replications and the spacing was 1.82 m for A. catechu and 5.48 m for other three species. A. catechu had the highest survivability (96.67 and 70.33%) after 0.5 and 2.5 years of plantation, and C. nucifera had the highest (86.67%) survivability after 1.5 years of plantation. On the other hand, B. flabellifer had the lowest survivability (77.78%) after 0.5 years of plantation and P. sylvestris had the lowest (58.87 and 40.07%) after 1.5 years and 2.5 years. After 0.5, 1.5, and 2.5 years of plantation, C. nucifera had the highest (1.13, 1.67, and 6.62 m) and B. flabellifer had the lowest (0.51, 0.75, and 1.08 m) height. After 0.5, 1.5, and 2.5 years of plantation, the highest numbers of new fonds were found for C. nucifera (3.51 nos.), A. catechu (3.69 nos.), and P. sylvestris (4.67 nos.), respectively. But the lowest numbers (2.04, 3.34, and 3.33 nos.) of new fonds were found for B. flabellifer. This result will be helpful for raising large-scale plantations with these four palm species in the Noakhali coastal belt areas of Bangladesh.

সারসংক্ষেপ

বাংলাদেশ বন গবেষণা ইনস্টিটিউট এর অধীন প্লান্টেশান ট্রায়েল ইউনিট বিভাগ, বাংলাদেশের মধ্য উপকূলীয় অঞ্চলে (নোয়াখালী এলাকায়) ২০১৯ থেকে ২০২১ সাল পর্যন্ত *Areca catechu* (সুপারি), *Cocos nucifera* (নারিকেল), *Phoenix sylvestris* (খেজুর) এবং *Borassus flabellifer* (তাল) এই ৪টি দেশীয় পাম প্রজাতির বৃদ্ধি পারফরম্যান্স নির্ধারণের জন্য একটি গবেষণা চালায়। *Cocos nucifera* ছাড়া অন্য প্রজাতির চারাগুলো পলিব্যাগে তোলা হয় এবং ১০-১২ মাস বয়সী চারা প্রতি বছরের জুন মাসে রোপণ করা হয়। গবেষণাটি ৩টি প্রতিলিপিসহ র‍্যান্ডমাইজড কমপ্লিট ব্লক ডিজাইনে (আরসিবিডি) করা হয় যেখানে *A. catechu* এর জন্য রোপনের ব্যবধান ছিল ১.৮২ মিটার এবং অন্যান্য ৩টি প্রজাতির জন্য ৫.৪৮ মিটার। *Areca catechu* রোপনের ০.৫ এবং ২.৫ বছর পরে সর্বোচ্চ (৯৬.৬৭ এবং ৭০.৩৩%) বেঁচে ছিল, কিন্তু *C. nucifera* রোপনের ১.৫ বছর পর সর্বোচ্চ (৮৬.৬৭%) বেঁচে ছিল। অন্যদিকে, *B. flabellifer* রোপনের ০.৫ বছর পর সর্বনিম্ন (৭৭.৭৮%) এবং *P. sylvestris* রোপনের ১.৫ এবং ২.৫ বছর পর সর্বনিম্ন (৫৮.৮৭ এবং ৪০.০৭%) বেঁচে ছিল। রোপনের ০.৫, ১.৫ এবং ২.৫ বছর পর *C. nucifera* এর উচ্চতা সর্বোচ্চ (১.১৩, ১.৬৭, এবং ৬.৬২ মি.) এবং *B. flabellifer* উচ্চতা সর্বনিম্ন (০.৫১, ০.৭৫, এবং ১.০৮মি.) ছিল। রোপনের ০.৫, ১.৫ এবং ২.৫ বছর পর যথাক্রমে *C. nucifera* (৩.৫১টি), *A. catechu* (৩.৬৯টি), এবং *P. sylvestris* এ সর্বাধিক সংখ্যক (৪.৬৭টি) নতুন পাতা পাওয়া গেছে, তবে প্রতিক্ষেত্রেই *B. flabellifer* এ সর্বনিম্ন (২.০৪, ৩.৩৪, এবং ৩.৩৩টি) সংখ্যক নতুন পাতা পাওয়া গেছে। গবেষণার এই ফলাফল, বাংলাদেশের নোয়াখালী উপকূলীয় অঞ্চলে, এই চারটি পাম প্রজাতি দিয়ে বৃহৎ পরিসরে বনায়নের ক্ষেত্রে বিশেষ ভূমিকা পালন করবে।

Keywords: *Areca catechu, Borassus flabellifer, Central coastal belt, Cocos nucifera, Growth performance, Phoenix sylvestris.*

Introduction

Palms (family Palmae or, more recently, Arecaceae) commonly dominate the rural landscape in tropical countries (Mogea *et al.* 1991). Palms are one of the most important horticultural crops in many countries (Rahman *et al.* 2021; Rana and Islam 2010; James 1980; Kamal 1969) and provide most of the necessities of life for humans in the tropics for centuries (Nath *et al.* 2002). There are around 230 genera and 2,700 palm species, most of which are found in tropical and subtropical climates (Pasha 2006) being an essential and fundamental feature of tropical forests (Johnson 1995). Bangladesh being in the tropics, has a diverse range of palm trees, ranging from hilly topography to plain areas to muddy mangrove forests (Blatter 1978; Hussain 2001). At least 20 kinds of native palm trees occur in Bangladesh, while at least five foreign species are planted as avenue or garden plants (Pasha 2006). The most common palm tree species found in Bangladesh are Palmyra palm (*Borassus flabellifer*), Coconut (*Cocos nucifera*), date palm (*Phoenix sylvestris*), and betel nut (*Areca catechu*) (Rana and Islam 2010). Palm cultivation can provide a considerable financial return (Dowson 1982). The fruit, beverage, leaf, fiber, and stem of the palm tree are highly prized as food, thatching material, lumber, fuelwood, weaving mat, windbreak, raw material for oil production, canoe making etc. (Zaid 1999; Chan and Elevitch 2006; Mitchell and Ahmad 2006; Calzada *et al.* 2007; Rahman *et al.* 2011; Al-Adhroey 2011).

Borassus fiabellifer (Palmyra palm) is considered one of the principal sugar-yielding palm among the 3000 multifunctional palms of the tropics and subtropics (Johnson 1983; Mogea *et al.* 1991). In the southern part of the Bangladesh, it is widely planted for juice production (Nath *et al.* 2002) and it has medicinal benefits in all of its sections (Blatter 1978; CISRO 1985; Morton 1988). Another prominent economic palm in Bangladesh is *C. nucifera* (coconut), which is one of the country's most important homestead plantation crops (Pasha 2006; Rahman 2005, Dissanayake 1977). It is an important fruit tree in the globe, supplying sustenance for millions of people, particularly in tropical and subtropical countries, and it is often referred to as the "tree of life" because of its various uses (Chan and Elevitch 2006). *Areca catechu*, locally known as supari (Rashid *et al.* 2015), originated in the Philippines, is now widely grown throughout Bangladesh (Nandi *et al.*, 2019). This plant, which is primarily grown for the production of nuts or seeds and is an important component of betel pepper, has important medicinal properties (Nath and Karmakar 2001; Staples and Bevacqua 2006). *Phoenix sylvestris* is one of the most common popular palms ever found in Bangladesh and a well-known source of sugar (Blatter 1978; Hussain 2007) and it's juice has been used to make traditional sweeteners (Ahmed, 2007). It provides food, ornament, material for shelter, fiber and fuel in a hard environment where relatively few other plants can grow (Zaid 1999), and frequently utilized in brick kilns (Sait *et al.* 2012; El May *et al.* 2012). Around 72.4 million people in Bangladesh live in rural areas and rely on agriculture and tree-based economic activities for their survival (BBS 2012), and the palm-based manufacturing system is one of the most essential ways to improve the economic, social, and environmental standards in Bangladesh's rural areas (Nandi *et al.* 2019). Palm tree species are one of the most important plantation trees in Bangladesh's Southeastern region for their fruits and sap collection (Pasha 2006; Nandi *et al.* 2019), and many rural farmers in this region rely on palm husbandry for their seasonal livelihoods (Rana and Islam 2010). Because of the systematic cultivation of palm for better yield, it has received little attention in Bangladesh (Rana and Islam 2010; Rahman *et al.* 2011); Policymakers should pay close attention to assessing the potentials of palm (Nandi *et al.* 2019). A study was carried out in the western coastal areas of Bangladesh with these four native palm species and found promising. But no systematic study has been carried out with these four native palm species in the central coastal belt areas (Noakhali areas). Therefore, a research was carried out with four palm species (*B. flabellifer*, *C. nucifera*, *P. sylvestris*, and *A. catechu*) to assess their survival and growth performance in the central coastal belt of Bangladesh. This result will be helpful to improve the cultivation of palm, enrich palm biodiversity, and standardize the plantation techniques for large-scale plantations with these native palm species in Noakhali areas of Bangladesh.

Materials and Methods

Study area

The research was conducted at the Subarnachar upazila of Noakhali district of Bangladesh. Subarnachar upazila is situated between latitudes 22°23' and 22°45' north and longitudes 90°54' and 91°20' east (Miah *et al.* 2015; Prosun *et al.* 2018). It has a tropical climate with heavy rainfall for the majority of the year and a short dry season (Barua *et al.* 2019). The highest average annual temperature is 34.3°C and the lowest at 14.4°C, and the average annual rainfall is 3302 mm (BBS 2013). Soil pH ranges from 6.7 to 8.0, with soil salinity ranging from 6.6 to 13.9 dS/m during the rainy and dry seasons (SRDI 2010). With only 8 mm of precipitation, January is the coldest and driest month of the year (Hussain 2008).

Raising experimental plantation

In this research, four native palms, namely *C. nucifera* (coconut), *B. flabellifer* (palmyra palm), *P. sylvestris* (date palm) and *A. catechu* (betel nut) were used. The seeds collected from phenotypically superior trees and seedlings of these species, except *C. nucifera*, were raised in polybags. For raising *C. nucifera* seedlings, mature *C. nucifera* is directly put up in the seedbeds. Seedlings of all species are kept in the nursery for about 10–12 months. *B. flabellifer* seedlings were raised by the detached germ tube method. Ten to twelve-months old seedlings were planted in the field in a Randomized Complete Block Design (RCBD) with three replications. The plantation was carried out in the raised land and the embankment of the study area. The spacing was 5.48 m from seedling to seedling for *B. flabellifer*, *C. nucifera*, and *P. sylvestris* and 1.82 m for *A. catechu*. The experimental plantation for research was carried out during the months of June for 3 subsequent years of 2019, 2020 and 2021.

Data collection

Data was collected in December, 2021 after 0.5, 1.5, and 2.5 years of plantation planted in the years of 2021, 2020 and 2019 respectively.

Statistical analysis

The Excel spreadsheet and the R-Studio (version 3.3.0) were used to compute and analyze the data.

Results

Comparison of survivability

Survival performance of four species was found to decrease with the age of the plantation. The mean survivability of *A. catechu*, *C. nucifera*, *P. sylvestris*, and *B. flabellifer* was 96.67, 93.00, 78.53, and 77.78% respectively, after 0.5 years of planting in the plantation year of 2021 (Fig.1 & Table 1).

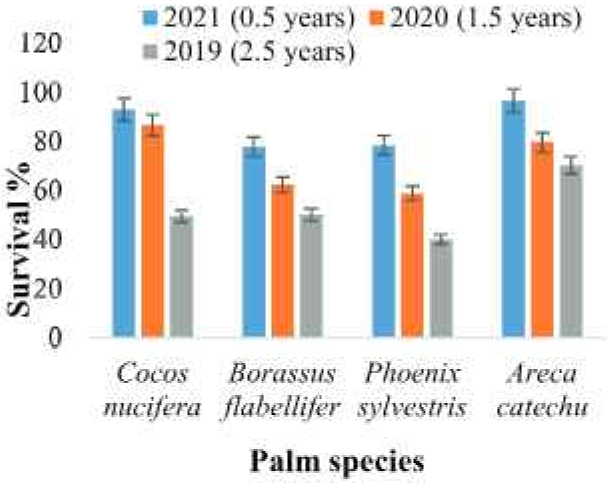

Figure 1. Survivability of four native palm species after 0.5, 1.5, and 2.5 years of plantation.

On the other hand, the mean survivability of *C. nucifera*, *A. catechu*, *B. flabellifer* and *P. sylvestris* was 86.67, 79.60, 62.40 and 58.87% respectively after 1.5 years of planting in the plantation year of 2020. The mean survivability of *A. catechu*, *B. flabellifer*, *C. nucifera*, and *P. sylvestris* was 70.33, 50.16, 49.59 and 40.07% respectively after 2.5 years of planting in the plantation year of 2019 (Fig. 1 & Table 1).

Comparison of height growth

The mean height of *C. nucifera*, *A. catechu*, *P. sylvestris* and *B. flabellifer* was 1.13, 0.61, 0.60 and 0.51m respectively after 0.5 years of planting (Fig. 2 & Table 2). On the other hand, the mean height of *C. nucifera, A. catechu, P. sylvestris* and *B. flabellifer* was 1.67, 1.40, 0.82 and 0.75m respectively after 1.5 years of planting. The mean height of *C. nucifera*, *A. catechu*, *P. sylvestris* and *B. flabellifer* was 6.62, 6.02, 1.19 and 1.08m, respectively after 2.5 years of planting (Fig. 2 & Table 2).

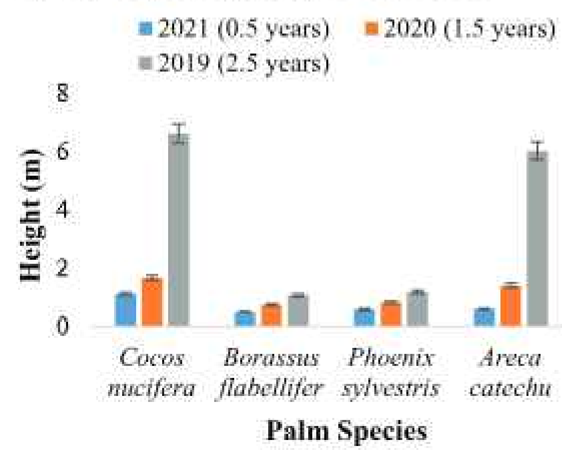

Figure 2. Height of four native palm species after 0.5, 1.5, and 2.5 years of plantation.

Table 1. Comparison of the survivability of four native palm species after 0.5, 1.5, and 2.5 years of planting in the central coastal belt of Bangladesh.

Plantation year	Age (Years)	Vernacular name	Scientific name	Survivability (%)
2021	0.5	Betel-nut	*A. catechu*	96.67 ± 0.45 [a]
		Coconut	*C. nucifera*	93.00 ± 3.60 [a]
		Date palm	*P. sylvestris*	78.53 ± 3.42 [b]
		Palmyra palm	*B. flabellifer*	77.78 ± 2.22 [b]
2020	1.5	Betel-nut	*A. catechu*	79.60 ± 3.20 [a]
		Coconut	*C. nucifera*	86.67 ± 1.66 [a]
		Date palm	*P. sylvestris*	58.87 ± 4.17 [b]
		Palmyra palm	*B. flabellifer*	62.40 ± 3.82 [b]
2019	2.5	Betel-nut	*A. catechu*	70.33 ± 2.90 [a]
		Coconut	*C. nucifera*	49.59 ± 3.60 [b]
		Date palm	*P. sylvestris*	40.07 ± 2.54 [b]
		Palmyra palm	*B. flabellifer*	50.16 ± 3.79 [b]

Note: Treatment values followed by different letters (like a, b, etc.) significantly differ at the 5% significance level.

Table 2. Comparison of the height of four native palm species after 0.5, 1.5, and 2.5 years of planting in the central coastal belt of Bangladesh.

Plantation year	Age (Years)	Vernacular name	Scientific name	Height (m)
2021	0.5	Betel-nut	*A. catechu*	0.61 ± 0.05 [b]
		Coconut	*C. nucifera*	1.13 ± 0.06 [a]
		Date palm	*P. sylvestris*	0.60 ± 0.03 [b]
		Palmyra palm	*B. flabellifer*	0.51 ± 0.02 [b]
2020	1.5	Betel-nut	*A. catechu*	1.40 ± 0.11 [a]
		Coconut	*C. nucifera*	1.67 ± 0.13 [a]
		Date palm	*P. sylvestris*	0.82 ± 0.10 [b]
		Palmyra palm	*B. flabellifer*	0.75 ± 0.04 [b]
2019	2.5	Betel-nut	*A. catechu*	6.02 ± 0.08 [b]
		Coconut	*C. nucifera*	6.62 ± 0.17 [a]
		Date palm	*P. sylvestris*	1.19 ± 0.07 [c]
		Palmyra palm	*B. flabellifer*	1.08 ± 0.05 [c]

Note: Treatment values followed by different letters significantly differ at the 5% significance level.

Comparison of new fonds production

The mean number of new fonds of *C. nucifera*, *A. catechu*, *P. sylvestris* and *B. flabellifer* was about 3.51, 3.42, 2.08, and 2.04 nos., respectively, after 0.5 years of planting (Fig. 3 & Table 3). On the other hand, the mean number of new fonds of *A. catechu*, *P. sylvestris*, *C. nucifera*, and *B. flabellifer* was about 3.69, 3.67, 3.60, and 3.34 nos. respectively after 2.5 years of planting. The mean number of new fonds of *P. sylvestris*, *A. catechu*, *C. nucifera* and *B. flabellifer* was about 4.67, 4.45, 3.67 and 3.33 nos. respectively after 2.5 years of planting (Fig. 3 & Table 3).

Mean annual increment of height

The mean annual height increment of *C. nucifera*, *A. catechu*, *P. sylvestris*, and *B. flabellifer* was 2.65, 2.41, 0.48, and 0.43 m, respectively, after 2.5 years of planting (Table 4).

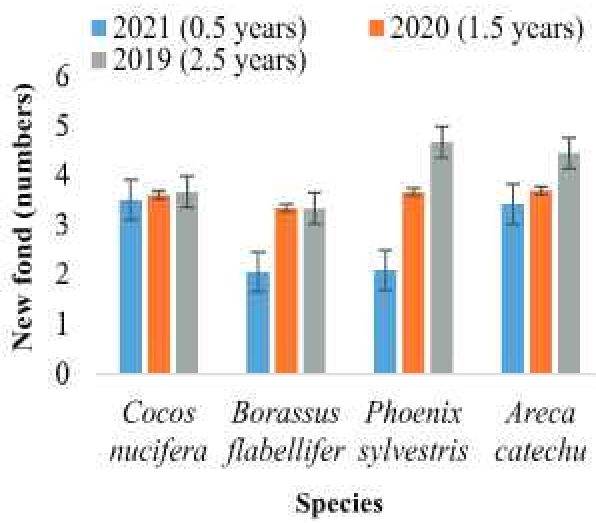

Figure 3. Number of new fonds of four native palm species after 0.5, 1.5, and 2.5 years of plantation

Table 3. Comparison of the new fonds of four native palm species after 0.5, 1.5, and 2.5 years of planting in the central coastal belt of Bangladesh.

Plantation year	Age (Years)	Vernacular name	Scientific name	New fond (nos.)
2021	0.5	Betel-nut	*A. catechu*	3.42 ± 0.15 [a]
		Coconut	*C. nucifera*	3.51 ± 0.36 [a]
		Date palm	*P. sylvestris*	2.08 ± 0.34 [b]
		Palmyra palm	*B. flabellifer*	2.04 ± 0.18 [b]
2020	1.5	Betel-nut	*A. catechu*	3.69 ± 0.66 [a]
		Coconut	*C. nucifera*	3.60 ± 0.22 [a]
		Date palm	*P. sylvestris*	3.67 ± 0.33 [a]
		Palmyra palm	*B. flabellifer*	3.34 ± 0.37 [a]
2019	2.5	Betel-nut	*A. catechu*	4.45 ± 0.27 [a]
		Coconut	*C. nucifera*	3.67 ± 0.33 [ab]
		Date palm	*P. sylvestris*	4.67 ± 0.33 [a]
		Palmyra palm	*B. flabellifer*	3.33 ± 0.30 [b]

Note: Treatment values followed by different letters (like a, b, etc.) significantly differ at the 5% significance level.

Table 4. Mean Annual Increment (MAI) of height of four native palm species after 2.5 years of plantation in the central coastal belt of Bangladesh.

Name of species	Age	Height (m)	MAI of height (m)
A. catechu	2.5	6.02 ± 0.08	2.41 ± 0.03
C. nucifera	2.5	6.62 ± 0.17	2.65 ± 0.07
P. sylvestris	2.5	1.19 ± 0.07	0.48 ± 0.03
B. flabellifer	2.5	1.08 ± 0.05	0.43 ± 0.01

Discussion

A significant difference was found among *A. catechu*, *C. nucifera*, *P. sylvestris* and *B. flabellifer* for survivability after 0.5, 1.5, and 2.5 years of plantation. After 0.5 years of planting, *A. catechu* had the highest (96.67%) and *B. flabellifer* had the lowest survivability (77.78%). However, after 1.5 years of planting, *C. nucifera* had the highest (86.67%) survivability, while *P. sylvestris* had the lowest (58.87%). Finally, after 2.5 years of planting, the maximum survivability (70.33%) was found for *A. catechu* and the lowest (40.07%) for *P. sylvestris*. In consideration of survivability after 2.5 years *A. catechu* showed the most promising species than others. Survivability of these four native palm species was found promising after 0.5 years of plantation but gradually reduced after 1.5 and 2.5 years of plantation due to disturbances mainly by humans and cattle. Islam *et al.* (2014) found the survivability of *P. sylvestris*, *A. catechu*, *C. nucifera*, and *B. flabellifer* was 82%, 60%, 81%, and 65%, respectively, after 12 years of plantation in the western coastal belt of Bangladesh. A significant difference was also found among the four native palm species for height growth after 0.5, 1.5 and 2.5 years of plantation. For 0.5, 1.5 and 2.5 years of plantation, *C. nucifera* had the highest height (1.13, 1.67 and 6.62m) and *B. flabellifer* had the lowest height (0.51, 0.75 and 1.08m) in this study. Islam *et al.* (2014) found the height of *P. sylvestris*, *A. catechu*, *C. nucifera*, and *B. flabellifer* was 7.74m, 10.07m, 10.98m and

8.38m respectively after 12 years of plantation in the western coastal belt of Bangladesh. Generally, *C. nucifera* trees are found to grow 10 to 30 meters, *B. flabellifer* up to 30 meters, *P. sylvestris* 10 to 14 meters, and *A. catechu* 10 to 30 meters tall. Besides height, *P. sylvestris* was found to grow up to 50cm in diameter and *A. catechu* up to 15cm in diameter (Siddiqui *et al.* 2007). Moreover, a significant difference was found among the four palm species for the production of new fonds after 0.5, 1.5 and 2.5 years of plantation. The highest numbers of new fonds were found for *C. nucifera* 3.51nos., *A. catechu* 3.69 nos., and *P. sylvestris* 4.67 nos., respectively, among the four species, after 0.5, 1.5 and 2.5 years of plantation. But in all cases (0.5, 1.5 and 2.5 years), the lowest number (2.04, 3.34, and 3.33 nos.) of new fonds was found for *B. flabellifer*. After 2.5 years of planting, the highest MAI was found for *A. catechu* (2.41m) and the lowest for *B. flabellifer* (0.43m). During the first 40 years of growth, *C. nucifera* grows at a moderate rate of about 30–50cm (12–20 inch) per year (Chan and Elevitch 2006), while *A. catechu* grows at a rate of 0.5m/year (20 inch/year) (Staples and Bevacqua 2006). The growth and yield of the palms are negatively affected by periods with mean daily temperatures below 21^{0}C (700F) (Chan and Elevitch 2006). Palm growth is also depending on the soil's ability to drain well during the rainy season and be rich in organic matters (Staples and Bevacqua 2006).

Conclusion

A significant difference found among *A. catechu, C. nucifera, P. sylvestris*, and *B. flabellifer* for survivability, height, and number of new fonds after 0.5, 1.5, and 2.5 years of plantation. The survivability of these four native species is promising after 0.5 years of plantation but gradually reduces after 1.5 and 2.5 years of plantation due to disturbances mainly by humans and cattle. In consideration of survivability, the height growth, number of new fonds, and MAI, all the four native palm species were found promising. These palms are economically and ecologically important species in Bangladesh and serve as a strong shelterbelt against cyclonic storms. This result will be helpful for raising large-scale plantations with these four palm species in the Noakhali coastal belt areas of Bangladesh. This study should continue for a few years, and future research could be conducted by covering broad geographical ranges and highlighting the soil variables.

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Research Article

Preparation of Quality Pulp from Sugarcane Bagasse with Different Chemical Pulping Processes

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Abstract

Bagasse are available in sugar mills of Bangladesh. Some of them are used as fuel in sugar mills and the rest of them are discarded into environment without any commercial return. Bagasse is used in the pulp and paper mill as alternative raw materials. Production of pulp from bagasse was studied in various processes to increase pulp and paper quality. Pulping was done at 0.1M NH4OH solution with the variation of KOH concentation viz. 11, 13, 15 and 17% and 0.1% methyl anthraquinone (MAQ) at 165°C temperature. Pulps were also made from the Kraft and soda process. 12% active alkali, 25% sulphidity and 0.1% MAQ were used for the Kraft process and 12% active alkali was used for the soda process, where MAQ concentration was 0.05 and 0.1%. Cooking time was 120 min. maintained at 170°C temperature. The yield varied from 53-62.34%. Kappa numbers were reduced with the increase of KOH. At 17% of KOH concentration the Kappa number was reached to 20.1. When a physical strength property of KOH-MAQ process was compared with the Kraft and soda, the tear strength was found to be slightly lower but tensile and burst strength was higher. Tissue products, boxes, wrapping paper, and newspaper can be prepared from bagasse pulp. Black liquor is rich in nutrients elements so it can be used as a fertilizer for agricultural production.

সারসংক্ষেপ

বাংলাদেশের চিনিকলগুলোতে প্রচুর আখের ছোবড়া পাওয়া যায়। এর মধ্যে কিছু চিনিকল আখের ছোবড়া জ্বালানী হিসাবে ব্যবহার করে এবং বাকিগুলো কোন বাণিজ্যিক রিটার্ন ছাড়াই পরিবেশে পরিত্যক্ত হয়। পাল্প এবং পেপার এর গুণগত মান বৃদ্ধি করতে বিভিন্ন পদ্ধতিতে মণ্ড তৈরির উপর গবেষণা করা হয়েছে। ০.১ M NH_4OH দ্রবণ ব্যবহার করে ১১, ১৩, ১৫ এবং ১৭% KOH ও ০.১% মিথাইল অ্যান্থ্রাকুইনোন (MAQ) যোগ করে মণ্ড তৈরি করা হয়েছে। ক্রাফট এবং সোডা প্রক্রিয়ায়ও মণ্ড তৈরি করা হয়েছে। ক্রাফট প্রক্রিয়ার জন্য জন্য ১২% সক্রিয় ক্ষার, ২৫% সালফিডিটি এবং ০.১% মিথাইল অ্যানথ্রাকুইনোন (MAQ) ব্যবহার করা হয়েছিল এবং ১২% সক্রিয় ক্ষার ব্যবহার করা হয়েছিল সোডা প্রক্রিয়ার জন্য, যেখানে MAQ ডোজ ছিল ০.০৫ এবং ০.১%। ১৭০ ডিগ্রি সেন্টিগ্রেড তাপমাত্রায় ১২০ মিনিট সময় ধরে কুকিং করা হয়েছে। মণ্ডের উৎপাদন হার ৫৩ থেকে ৬২.৩৪% এ পরিবর্তিত হয়। KOH এর মাত্রা বৃদ্ধির সাথে কাপ্পা নম্বর হ্রাস পেয়েছে। KOH এর ১৫% ডোজে এ কাপ্পা সংখ্যা ২৩.৯% এ পৌঁছেছে। ক্রাফট এবং সোডা প্রক্রিয়ায় উৎপাদিত মণ্ডের ভৌত শক্তির সাথে তুলনা করলে টিয়ার শক্তি কিছুটা কম ছিল তবে বার্স্ট এবং টেনসাইল শক্তি বেশি ছিল। টিস্যু, বক্স, রেপিং পেপার এবং নিউজ প্রিন্ট আখের ছোবড়ার মণ্ড হতে তৈরি করা যাবে। আখের ছোবড়ার মণ্ডীকরণের সময় প্রাপ্ত তরল বর্জ্য কৃষিজ দ্রব্য উৎপাদনে সার হিসেবে ব্যবহার করা যাবে।

Keywords: *KOH-MAQ, Kraft process, NH_4OH, Soda process, Yield.*

Introduction

The global demand for paper continues to escalate at an alarming rate, raising concerns about the sustainability of forest resources that serve as the primary raw material for paper production. While paper, paperboard, and newsprint consumption has experienced robust growth, with net consumption increasing from 0.611 to 0.779 MT between 2014 and 2018 (FAO 2018) production levels have stagnated at 0.058 MT during the same period. In Bangladesh, per capita paper and paperboard consumption stands at a mere 5 kg/year/person, significantly lower than advanced countries (~300kg/capita), the world average (~50 kg/capita) and the Asian average (~50 kg/capita) (Quder 2011). Consequently, Bangladesh's demand for paper and paperboard necessitates importing 0.736 MT (FAO 2018), as domestic paper mills struggle to meet targeted daily production levels due to inadequate raw material supply. This predicament underscores the urgent need to explore alternative sources of raw materials for pulp and paper mills to ensure self-sufficiency in paper production while mitigating the environmental impact of excessive forest exploitation.

Bagasse, the fibrous residue obtained after extracting sugar from sugarcane, emerges as a promising alternative source of raw material for paper production. Its low cost, longer fiber length (1.9mm) compared to straw (Yousefi 2009), satisfactory α-cellulose and pentosan content and milder pulping requirements (Jahan *et al.* 2009) make bagasse an attractive option. Additionally, its low refining energy consumption and ability to produce good sheet formation and paper smoothness enable it to meet the quality standards for newsprint and paper manufacturing (Rajesh and Rao Mohan 1998). Composed of approximately 40-50% cellulose, 20-30% hemicellulose, and 18-25% lignin (Ariningsih 2014), bagasse's hemicellulose fraction is primarily comprised of xylose, accounting for about 80% of the total sugars (Aguilar *et al.* 2002; Mosier *et al.* 2005). Furthermore, with its low ash content (1-3%), bagasse offers advantages over other plant sources like rice straw and wheat straw, which contain 17% and 11% ash, respectively (Pandey *et al.* 2000). Consequently, bagasse presents itself as a promising lignocellulosic feedstock for pulp production (Hilares *et al.* 2017) offering a viable solution to meet the growing demand for paper while mitigating the environmental impact of excessive forest exploitation.

Bangladesh's sugar industry presents a significant opportunity for utilizing bagasse as a raw material for paper production. The country's sole bagasse-based pulp mill, the state-owned North-Bengal Pulp and Paper Mills (NBPM), underscores the potential of this agricultural residue. With 16 sugar mills operating on sugarcane in Bangladesh, a substantial amount of bagasse is readily available. According to a study by Mahamud *et al.* (2012) approximately 425,000 acres of land are dedicated to sugarcane cultivation, yielding an annual production of about 7.5 million tons. However, only 2.28 million tons are processed in sugar mills, while the remainder is used for molasses production. Consequently, Bangladesh currently generates around 150,000 tons of sugar, 100,000 tons of molasses, and a staggering 800,000 tons of bagasse annually. This abundance of bagasse, a natural agro-waste material obtained at a relatively low cost, energy, and time investment, presents a promising opportunity for domestic paper mills to diversify their raw material sources and alleviate the strain on forest resources. While bagasse has traditionally been utilized as a fuel source in sugar mills (Habibullah *et al.* 2014), its unique chemical composition offers advantages for pulp production. Bagasse lignin is considerably more reactive than wood lignin, allowing for milder pulping conditions. For instance, soda pulping requires only 12-16% sodium hydroxide at 170-175°C, while Kraft pulping demands 11-13% active alkali with 15-20% sulfidity (Thomas *et al.* 2016). Interestingly, the pulp produced by the Kraft process offers little advantage over that obtained through the soda process, as the resulting pulps are virtually identical. Numerous agricultural wastes, such as dhaincha (*Sesbania bispinosa*), jute stick (*Corchorus capsularis*), wheat straw (*Triticum aestivum*), corn stalks (*Zea mays*) (Sutradhar *et al.* 2018), rice straw (Jahan *et al.* 2016), and kash (*Saccharum sponteneum*) (Jahan *et al.* 2016a), have been successfully pulped using potassium hydroxide (KOH). While bagasse has proven suitable for the production of Kraft and soda pulp, there remains a lack of research on the potential of KOH-MAQ (monoamine oxidase) pulping to enhance pulp yield and paper quality. This study aims to bridge this gap by investigating the feasibility of KOH-MAQ pulping of bagasse, as KOH pulping is well-suited for small-scale operations, and the resulting black liquor can be utilized as a fertilizer in agriculture (Huang *et al.* 2007; Jahan *et al.* 2016).

Materials and Methods

Raw materials

Bagasses sample were collected from Faridpur Sugar Mills Ltd., Modhukhali, Faridpur (23°37' N, 89°29' E). It was processed in a hydropulper for 2 min. for depithing. The depithed bagasse was then air dried. Dry matter content (DMC) was determined after air-drying (AD). Tappi test methods T236 cm-85 (Anon 1992) was used for dry matter determination.

Pulping and pulp evaluation

The pulping experiments were carried out with 200g of oven dried (OD) bagasse in 2-liter autoclaves heated in a temperature-controlled air bath. Pulping was done at 0.1M NH_4OH with the variation of KOH concentration viz. 11, 13, 15 and 17%. The methyl anthraquinone was 0.1% based on OD material. The temperature was maintained at 165°C. Pulps were also produced in the Kraft and soda process for comparison. Analytical grades of Na_2S and NaOH were used as cooking chemicals for Kraft pulping. Cooking time was 120 min. maintained at 170°C for Kraft and soda pulping. The time required to raise this temperature from room temperature was 90 min. The liquor to bagasse ratio was 9:1 in all the cooks (L/kg). A sulphidity of 25% was used in all the Kraft cooks. After cooking, the bagasse was discharged and the black liquor was collected for residual alkali determination. The cooked fibers were taken in a screen box and washed overnight under running water to wash out the residual liquor. These were stirred slightly with water in a bucket by a slow speed electric mixture. The pulp slurry was then screened in a Johnson vibratory screen to separate any uncooked material from the pulp. The wet pulp was passed through a screw press to remove excess water, and then samples were taken to poly bag for preservation. The pulp yield was determined according to Tappi test method. The screening rejects were collected dried and then weighted. The kappa number of pulp was determined using Tappi test method.

Physical strength properties

The pulps samples were beaten in a PFI mill (a laboratory scale device used to beat or grind pulp sample for the preparation offhand sheet) to achieve a Canadian Standard Freeness (CSF) of 450 and 250 mL (SCAN-C 21:65) and hand sheets were made. These were then conditioned at 23±1°C temperature and 50±2% relative humidity and tested according to SCAN-C 28: 69 for determining the physical strength properties.

Statistical analysis

The physical strength properties were evaluated from five sheets for each beating. Then the mean and standard deviation were calculated. The graphical extrapolated values at 250 and 450 CSF were represented by regression.

Results

Raw materials processing

The data on the depithing process of bagasse using two different methods: hydropulper and stirrer was presented in Table 1. The yield of depithed bagasse obtained using the stirrer method was 92.3%. The table compares the depithing process and yields obtained using two different methods, hydropulper and stirrer, for processing bagasse. The hydropulper method was performed on a larger scale (6500g of bagasse), while the stirrer method was conducted on a smaller scale (300g of bagasse).

The material yield on depithing was 81.71%. After depithing by hydropulper the bagasse yield was 88.8%. And the yield was 92.3% after depithed by stirrer. The percentage of fine particle in bagasse was 11.2% after hydropulper depithing and 7.7% after depithing by stirrer.

Pulping and pulp evaluation

Yield and kappa number of bagasse pulp were determined. The value of yield and kappa were presented in Table 2. Effect of alkali ratio, alkali charge and MAQ concentration in different pulping method of bagasse were shown in Fig.1. The pulp yield was found 62% at 17% of KOH-MAQ chemicals and lower yield was 53.93% at 11% cooking chemicals with 0.1% MAQ. In Kraft process yield of pulp was 61.28%. There were influences in soda

Table 1. Depithing loss of bagasse.

Depithed by hydropulper						
Bagasse (AD) g	DMC (%)	Bagasse (OD) g	Depithed bagasse (OD) g			Yield (%)
			Coarse	Fine	Total	
6500	81.71	5311.15	3982.56	734.15	4716.71	88.8
Depithed by stirrer						
300	81.71	245.13	204.53	21.7	226.23	92.3

Table 2. Results of chemical pulping of bagasse in 1 M NH_3 solution with MAQ.

Pulping Process	Cooking Chemicals (%)	MAQ (%)	Yield (%)	Kappa No	Reject (%)
KOH-MAQ with 1M NH_4OH	11	0.1	53.93±2.24	61.2±10	13.64±1.90
	13	0.1	61.03±2.13	47.0±0.95	5.96±3.72
	15	0.1	60.75±2.37	23.9±0.80	Nil
	17	0.1	62.34±0.57	20.1±0.40	Nil
Kraft	12	---	61.28±0.53	35.4±0.90	0.63±0.21
Soda	12	0.05	60.30±0.82	27.8±2.08	0.40±0.03
	12	0.1	62.28±0.88	24.0±0.79	0.48±0.05

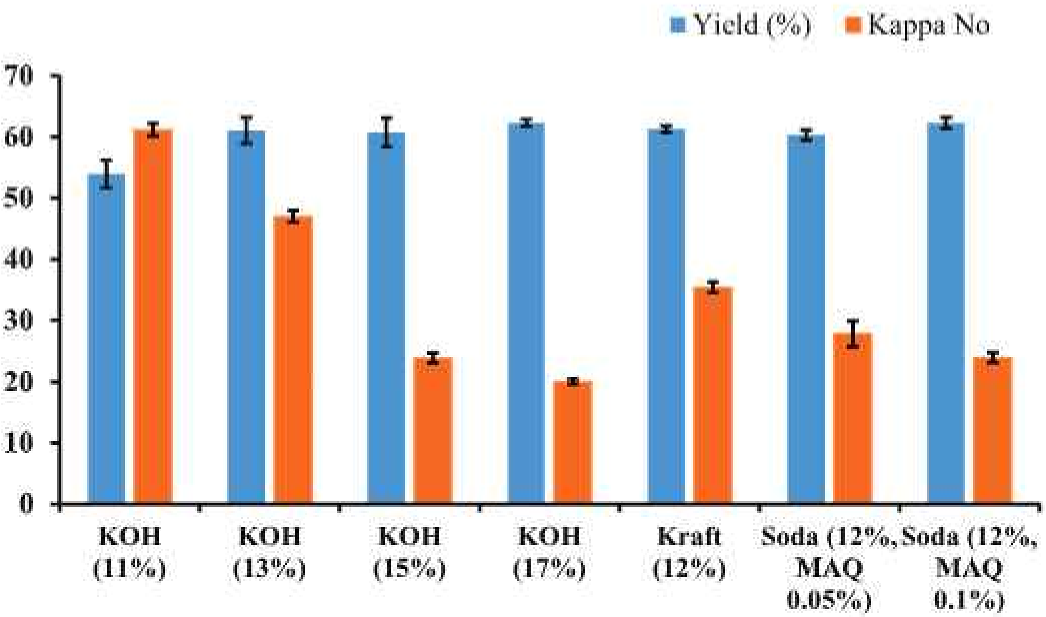

Figure 1. Compares of yield and kappa number of prepared pulp in various pulp.

process and yield varies from 60.30 - 62.28%. Highest yield was found at 12% chemical doses with 0.1% MAQ.

Physical strength properties

The tear, tensile and burst strength properties at particular freeness at 450 and 250 CSF which were shown in Table 3. It was found that the tear strength decreased and both tensile and burst strength increased with the decrease of CSF as usual. With regard to physical strength properties this verifies that burst index, tensile index, and tear index at particular freeness at 250 and 450 CSF of KOH pulp at 15% dose was better than other doses. It is also notable that compared with the Kraft and soda process the tear strength was slightly lower but tensile and burst strength was higher. Tensile strength is higher for KOH-MAQ process among the all chemical process and about similar in KOH-MAQ with 1M NH_4OH. At 15% KOH doses tensile strength was higher which was 70.45 Nm/g (Fig. 2) and lower (51.90%) at 12% active alkali with 0.05% MAQ in 250 CSF. Tear strength gradually were increased in all chemical process from 4.92 to 6.35

Table 3. Strength properties of the paper sheets made from bagasse.

Process	Cooking Chemicals (%)	MAQ (%)	Tear index (mNm^2/g) CSF (mL)		Tensile index (Nm/g) CSF (mL)		Burst index ($kPa.m^2/g$) CSF (mL)	
			450	250	450	250	450	250
KOH-MAQ with1.0 M NH_4OH	11	0.1	5.23	4.92	55.87	62.47	3.70	4.92
	13	0.1	6.20	5.80	58.25	65.20	4.05	5.20
	15	0.1	5.85	5.54	65.50	70.45	4.60	5.33
	17	0.1	5.94	5.90	59.54	67.88	4.50	5.75
Kraft	12	--	6.65	6.35	52.09	51.90	4.20	4.80
Soda	12	0.05	6.95	6.01	51.90	50.15	4.15	5.03
	12	0.1	6.71	6.31	52.51	52.80	4.37	5.82

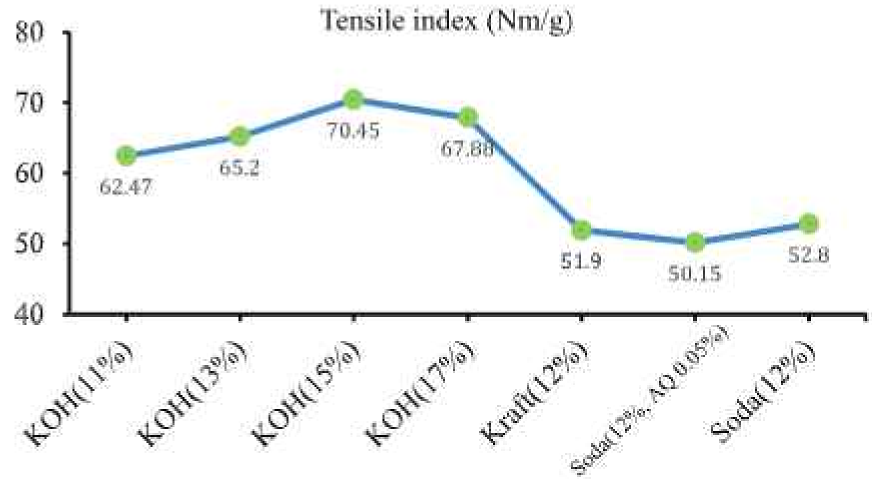

Figure 2. Pulping process and tensile strength with varying alkali doses at 250 CSF.

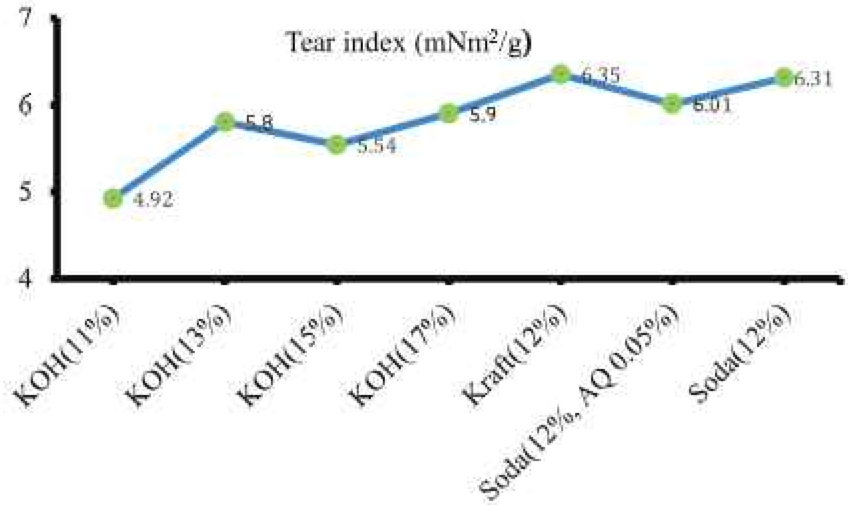

Figure 3. Pulping process and tear strength with varying alkali doses at 250 CSF.

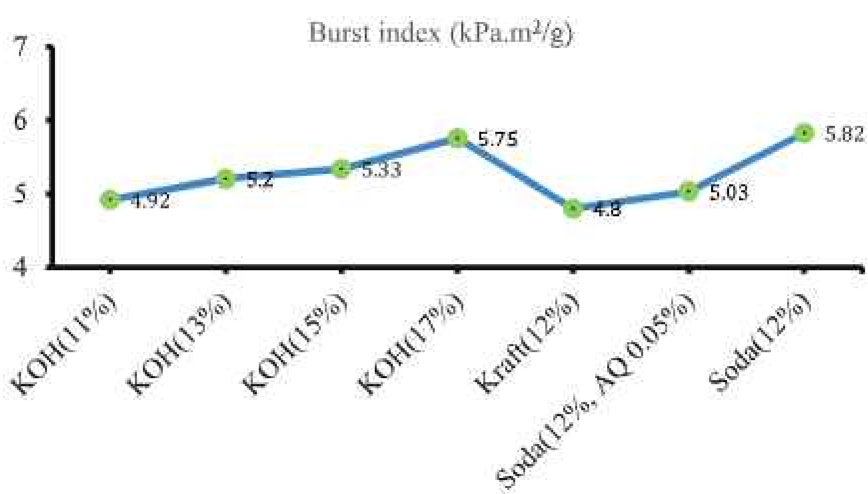

Figure 4. Pulping process and burst strength with varying alkali doses at 250 CSF.

mNm²/g. at 250 CSF (Fig. 3). Burst index in different chemical process varied from 4.92 to 5.82 kPa.m²/g. The burst index value was highest for soda process at 12% active alkali doses (Fig. 4).

Discussion

Bagasse is characterized by a high percentage of pith (35-40%) interspersed with fiber, primarily composed of parenchyma material. This non-fibrous pith is rich in juice. On a dry, water-insoluble basis, bagasse consists of "pith" from the center of the plant (30%), "fiber bundles" (65%; 50% from the rind and 15% from the internal material), and the epidermis (5%) (Rao 1997). The fiber bundles in bagasse are mostly sclerenchyma cells bound together, typically measuring 1.0-1.2mm in length and 20μm in diameter (Paul and Kasi Viswanathan 1998; Rainey *et al.* 2010), with a wall thickness of 5μm and a resulting lumen diameter of 10μm (Rainey *et al.* 2010). In contrast, the "pith" parenchyma material originates from the vascular bundles (Giertz and Varma 1979) and is composed of thin-walled, squarer cells with a lower aspect ratio, reaching a maximum length of 0.52mm (Rainey *et al.* 2009) and a diameter of 140μm (Paul and Kasi Viswanathan 1998). It is widely accepted that for producing acceptable quality pulp, approximately 30% of the shortest bagasse fibers must be removed (Atchison 1962; Giertz and Varma 1979; Paul and Kasi Viswanathan 1998; Covey *et al.* 2005; Rainey *et al.* 2010). The presence of pith creates challenges during pulping, such as increased cooking chemical requirements, inferior pulp quality, and poor black liquor properties. Depithing, the process of removing pith from bagasse, is crucial for reducing cooking chemical usage, foaming, handling and storage costs, dirt count in the paper, and improving pulp drainage in the pulp washers and paper machine, tensile properties, and black liquor quality (Rao 1997; Lois-Correa 2012). Therefore, depithing is a prerequisite step prior to pulping for producing high-quality paper from bagasse. The pulp yield ranged from 54 to 63%, with kappa numbers varying between 20 and 61, as presented in this study. The chemical dose (%) had no significant impact on pulp yield, except for the low cooking chemical dose of 11% KOH, where the yield was 53.93%. Notably, the screened yield of 60.75% was higher than other non-wood sources such as dhaincha (48.6%), jute stick (48.4%), wheat straw (44.7%) and corn stalk (45.8%) when pulped using the KOH process (Sutradhar *et al.* 2018). The kappa number decreased significantly as the KOH chemical dose increased, while the reject was high at lower chemical percentages. However, at 15% alkali dose of KOH, the kappa number reduced to 23.9%. The chemical composition of bagasse, being comparatively rich in carbohydrates and having a fairly low content of easily accessible lignin, makes it easier to pulp with good yield when properly cooked (Huang *et al.* 2007). Hossain *et al.* (1970) demonstrated that the tear strength of ekra, nal and khagra grasses were 0.84, 0.71 and 0.80 mNm²/g respectively, indicating that the tear strength index of bagasse is higher than these different grasses. Regarding burst strength, the KOH-MAQ, Kraft, and soda processes yielded varying results. The soda-MAQ process at 12% active alkali exhibited the highest burst strength of 5.82 kPa.m²/g, while the Kraft process showed a lower value of 4.8 kPa.m²/g, as depicted in this study. In the KOH-MAQ process, at 17% active alkali dose, the burst strength reached 5.75 kPa.m²/g. Shafi *et al.* (1994) reported that the burst strength of jute stick is 4.80 kPa.m²/g at 250 CSF, indicating that the burst strength of bagasse pulp is higher. Burst strength values for other species, such as corn stick (5.4), kash (3.2), rice straw (3.8), wheat straw (3.9), and daincha (4.5), further highlight the superior burst strength of bagasse pulp. Additionally, Hossain *et al.* (1970) showed that the burst strength values for ekra, nal and khagra grasses were 20.1, 17.1 and 20.0 kPa.m^2/g, respectively.

Conclusion

Bagasse, a renewable biomass by-product of the cash crop sugarcane, presents sustainable reasons for its utilization in pulp making. Although lower chemical doses resulted in higher kappa numbers and a higher percentage of rejects, the kappa number was effectively lowered to 23.9% at 15% alkali doses of KOH. The pulp yield obtained was comparable to that of soda and Kraft pulps. Considering the tear-tensile relationship, there was no significant variation among the pulping processes. The bagasse pulp can find utility in producing tissue products, boxes, wrapping paper, and newspaper. However, incorporating long-fibered wood or bamboo pulp could enhance the paper quality. Notably, pulping bagasse with aqueous ammonia containing small amounts of KOH effectively removed lignin, resulting in a black liquor rich in nutrient elements such as nitrogen, potassium, and ammoniacal lignin. This presents a promising prospect for utilizing the black liquor as a fertilizer for agricultural production, although further investigation into its potential is warranted. Overall, bagasse's renewable nature and the potential valorization of its by-products make it an attractive feedstock for sustainable pulp and paper production.

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Research Article

Biomass and Carbon Stock of Mangrove Arboretum in the Sundarbans, Bangladesh

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Abstract

Mangrove forests are known for their ability to sequester and store large amounts of carbon. Carbon is stored in the biomass of the trees and the soil, helping mitigate climate change by removing carbon dioxide from the atmosphere. Sundarbans, being the largest mangrove ecosystem, is expected to have a substantial carbon stock. Carbon storage capacity is influenced by factors such as the types of mangrove species, soil conditions, and the overall health of the ecosystem. Carbon stock assessments involve measuring the carbon content in above-ground biomass, below-ground biomass, and soil. In this study, we assessed the biomass and carbon stock of mangrove arboretum in the Sundarbans, established by the Mangrove Silviculture Division, Bangladesh Forest Research Institute. A total of sixty experimental plots (8248 m^2 area) were surveyed to calculate DBH, height, biomass, and carbon stock. Avicennia marina, Rhizophora mucronata, Lumnitzera racemosa and Aegiceras corniculatum showed their suitability for coastal and barren char land plantations with higher height and DBH growth. The average above-ground, below-ground, and total biomass ranged from 1.61 – 248.64 $Mgha^{-1}$; 0.97 – 117.64 $Mgha^{-1}$; and 2.59 – 366.28 $Mgha^{-1}$ respectively. The average carbon stock and carbon-di-oxide equivalence of mangrove arboretum was 15.83 $Mgha^{-1}$ and 58.09 $Mgha^{-1}$ ranging from 1.29 – 183.14 $Mgha^{-1}$ and 4.75 – 672.12 $Mgha^{-1}$ respectively. The mean annual DBH, height, biomass, and carbon stock increment of mangrove arboretum ranged 0.5-1.1$cmyr^{-1}$, 0.6-1.1$m yr^{-1}$, 0.99- 13.74 $Mgha^{-1}yr^{-1}$ and 0.5-7 $Mgha^{-1}yr^{-1}$ respectively. The study expressed the necessity of mangrove arboretum in the barren areas within the Sundarbans.

সারসংক্ষেপ

প্রচুর পরিমাণে কার্বন সংগ্রাহক ও সঞ্চায়ক হিসাবে ম্যানগ্রোভ বনগুলো পরিচিত হয়ে উঠেছে। কার্বন সাধারণত গাছে এবং মাটিতে সঞ্চিত হয়ে থাকে। গাছপালা বায়ুমণ্ডল থেকে কার্বন ডাই অক্সাইড অপসারণ করে জলবায়ুর পরিবর্তন প্রশমিত করে। সুন্দরবন, পৃথিবীর সবচেয়ে বড় একক ম্যানগ্রোভ ইকোসিস্টেম হওয়ায় এখানে যথেষ্ট কার্বন মজুদ আছে বলে মনে করা হয় যা ম্যানগ্রোভ প্রজাতিভেদে, মাটির অবস্থাভেদে এবং বাস্তুতন্ত্রের সামগ্রিক অবস্থার পরিপ্রেক্ষিতে পরিবর্তিত হয়ে থাকে। ম্যানগ্রোভ সিলভিকালচার বিভাগ, বাংলাদেশ বন গবেষণা ইনস্টিটিউট সুন্দরবনের বিলুপ্তপ্রায় প্রজাতি সংরক্ষণের জন্য ২০০৪ সাল থেকে বনায়ন কার্যক্রম পরিচালনা করছে। ২০০৪ থেকে ২০১২ পর্যন্ত মোট ৪.২৫ হেক্টর এলাকায় ম্যানগ্রোভ আরবোরেটাম তৈরি করা হয়েছিল। এই গবেষণায় ডিবিএইচ (DBH), উচ্চতা, বায়োমাস এবং কার্বন স্টক সম্ভাব্যতার পরিপ্রেক্ষিতে সুন্দরবনে ম্যানগ্রোভ আরবোরেটামের প্রয়োজনীয়তা তুলে ধরা হয়েছে। উপকূলীয় এলাকাতে এবং নতুন চরের জন্য Avicennia marina (বাইন), Rhizophora mucronata (কাঁদা), Lumnitzera racemosa (কিরপা) এবং Aegiceras corniculatum (খলসি) উপযুক্ত এবং এই এলাকাতে এই চারটি প্রজাতির ডিবিএইচ (DBH) এবং উচ্চতা বৃদ্ধি অনেক বেশি। মাটির উপরে, নিচে এবং মোট বায়োমাস হচ্ছে যথাক্রমে ১.৬১ থেকে ২৪৮.৬৪ মেগাগ্রাম প্রতি হেক্টরে, ০.৯৭ থেকে ১১৭.৬৪ মেগাগ্রাম প্রতি হেক্টরে এবং ২.৫৯ থেকে ৩৬৬.২৮ মেগাগ্রাম প্রতি হেক্টরে। ম্যানগ্রোভ আরবোরেটামের গড় কার্বন এবং গড় কার্বন-ডাই-অক্সাইড সমতা হলো প্রতি হেক্টরে ১৫.৮৩ মেগাগ্রাম এবং ৫৮.০৯ মেগাগ্রাম যার পরিসীমা যথাক্রমে প্রতি হেক্টরে ১.২৯ থেকে ১৮৩.১৪ মেগাগ্রাম এবং ৪.৭৫ থেকে ৬৭২.১২ মেগাগ্রাম। ম্যানগ্রোভ আরবোরেটামের বাৎসরিক গড় ডিবিএইচ (DBH), উচ্চতা, বায়োমাস এবং কার্বন বৃদ্ধির পরিসীমা হচ্ছে যথাক্রমে ০.৫-১.১ সে.মি; ০.৬-১.১ মি; ০.৯৯-১৩.৭৪ মেগাগ্রাম প্রতি হেক্টর এবং ০.৫-৭ মেগাগ্রাম প্রতি হেক্টর। সুন্দরবনের অভ্যন্তরে অনুর্বর এলাকায় ম্যানগ্রোভ আরবোরেটাম কতটা গুরুত্বপূর্ণ তা এই ফলাফল থেকে বুঝতে পারা যায়।

Keywords: *Afforestation, Arboretum, Biomass, Carbon, Climate change, Endangered.*

Introduction

Mangrove forests, a primary tropical and subtropical ecosystem, play a crucial role in delivering various essential functions and services. These habitats serve as coastal protectors, providing shelter, breeding, and nursery grounds for numerous fish, crustaceans, and other sea and terrestrial fauna. Notably, mangrove forests are vital contributors to carbon storage, yet the quantification of this storage has been somewhat overlooked despite its significance. Mangrove forests can exhibit an impressive total carbon storage, averaging around 1023 Mg ha^{-1} (Donato *et al.* 2011). This substantial carbon reservoir is attributed to factors such as the high density of large trees, with some reaching diameters of up to 2 meters, organic-rich peat soils, and generally deep growth exceeding 5 meters (Murdiyarso *et al.* 2011). Unfortunately, human activities have severely impacted mangrove ecosystems, resulting in the loss of approximately one-third of these forests globally over the past 50 years (Alongi 2002). This degradation contributes significantly to greenhouse gas (GHG) emissions, emphasizing the urgent need for conservation efforts.

Sundarbans, a UNESCO World Heritage Site and a RAMSAR wetland ecosystem, covering about one million hectares extended between Bangladesh and India (between 21°27′ and 22°30′ N, and 89°00′ and 89°55′E) (Alongi 2002). It contains one-third of the global mangrove plant species (Ghosh *et al.* 2016) and serves as a habitat for numerous globally endangered plant and animal species (Iftekhar and Islam 2004). It also serves diverse human needs such as fuel-wood, hogla, grass, fruit, malia, goran stick, molasses, medicinal plants, honey, fish, prawn, crabs, and more (Azad *et al.* 2020). Regrettably, despite its status as a vital biodiversity hotspot, the Sundarbans is now one of the most vulnerable areas globally and is undergoing rapid degradation (IPCC 2007) due to the loss of many native species (Sarker *et al.* 2019) and less productive due to the environmental, climatic and anthropogenic drivers (Ahmed *et al.* 2022). Sarker *et al.* (2019) observed a shift in the Sundarbans mangrove composition, with dominance by a few species e.g. *Excoecaria agallocha* (59.69% of total trees), *Heritiera fomes* (30.89%), *Ceriops decandra* (6.12%), and *Xylocarpus mekongensis* (0.82%). Some species showed habitat expansion and local invasiveness, and some species faced local extinction (Sarker *et al.* 2019). In response, the Mangrove Silviculture Division of Bangladesh Forest Research Institute has been implementing afforestation programs (mangrove arboretum) since 2004 to conserve the locally endangered species and enhance Sundarbans diversity. Increasing the number of regionally threatened species (IUCN regional species red list) in the Sundarbans was the primary objective of establishing the mangrove arboretums in the Sundarbans. These arboretums will be used as the seed bank for these species.

Afforestation emerges as a potent strategy for the conservation of endangered species and the prevention of soil degradation by mitigating soil erosion, enhancing soil organic matter, improving soil structure, and functioning as a carbon sink (Jackson *et al.* 2002). Additionally, afforestation contributes to nutrient cycling and provides habitat for wildlife by refining lands (Franco *et al.* 2003). Over recent decades, widespread afforestation initiatives have been undertaken to restore degraded habitats (Pincetl *et al.* 2013). While natural regeneration is integral for conserving and sustaining biological diversity, artificial regeneration remains crucial depending on specific management objectives. Mangrove forests, on the other hand, can become carbon sources through deforestation (Baccini *et al.* 2017), releasing additional carbon into the atmosphere and contributing to climate change (Pan *et al.* 2011). The quantification of biomass and carbon within such ecosystems poses a challenge but is indispensable for global efforts to address climate change, exemplified by initiatives like "Reduce emissions from deforestation and forest degradation in developing countries" (REDD+). REDD+ serves as an international framework incentivizing developing countries to reduce emissions from forested lands by preserving existing carbon stocks and incorporating sustainable forest management practices (Edwards *et al.* 2010). In this study, the leverage allometric models and vegetation plot data to estimate above and belowground vegetation biomass and carbon stocks in 4.25 ha of mangrove arboretum of seven threatened species namely Kirpa (*Lumnitzera racemosa*), Jhana (*Rhizophora mucronata*), Khalshi (*Aegiceras corniculatum*), Amoor (*Aglaia cuculata*), Baen (*Avicennia marina*), Kankra (*Bruguiera sexangula*) and Vathkathi (*Kandelia candel*) in Sundarbans created by the Mangrove Silviculture Division, Bangladesh Forest Research Institute from 2004 to 2012.

Materials and Methods

Study area

The Sundarbans Reserve Forest (between 21°30' and 22°30' N and 89°00' and 89°55' E) is the largest continuous expanse of tidal halophytic mangrove forest globally (Fig. 1). The Sundarbans, covering 10,000 km² of land and water, is part of the world's largest delta (80,000 km²) formed from sediments deposited by three great rivers, the Ganges, Brahmaputra, and Meghna, which converge on the Bengal Basin that transports about 2.4 billion tons of sediments (Mitra and Zaman 2016). The soil salinity level has increased by 60% since 1980 due to the drop in freshwater supplies (Aziz and Paul 2015). The projected sea level rise ranges from 30 to 100cm by 2100 which is higher than the global range (26–59cm). The Sundarbans have already lost 10–23% of its present area (Karim and Mimura 2008; Payo *et al.* 2016). Rainfall is heavy and humidity is high (80%) due to the proximity of the Bay of Bengal. About 80% of the rainfall occurs in the monsoon season, spanning from June to October. The mean annual rainfall varies from 1474 to 2265 mm (Chowdhury *et al.* 2016). The Rhizophoraceae have minor importance while the dominant species are Sundri (*H. fomes*) and Gewa (*E. agallocha*).

Figure 1. Geographic locations of the established arboretum sites.

Plantations in the mangrove arboretum

The Mangrove Silviculture Division of the Bangladesh Forest Research Institute has been actively implementing afforestation initiatives since 2004 to restore the biodiversity of the Sundarbans and conserve its endangered species. A list of regionally threatened species was prepared following the IUCN red list of plants and conducting comprehensive surveys of the Sundarbans. Seeds and propagules were collected and cultivated in the nurseries of the Mangrove Silviculture Division to produce seedlings, which were then transplanted to carefully selected sites in the Sundarbans based on survey data. Plantations were established with spacing intervals of 1m, 1.5m, 1.75 m, 2m, and 2.5m between species to optimize growth. Between 2004 and 2012, a total of 4.25 hectares of plantation was created (Table 1, Fig. 2A & 2B). The plantation area varied depending on the availability of seedlings and suitable land.

Table 1. Plantation year, species name and area of created mangrove arboretum

Plantation Year	Species (Local Name)	Scientific Name	Total Area
2004	Kirpa	*Lumnitzera racemosa*	0.85 ha
2006	Kirpa	*L. racemosa*	0.85 ha
2008	Kirpa	*L. racemosa*	0.28 ha
	Jhana	*Rhizophora mucronata*	0.28 ha
	Khalshi	*Aegiceras corniculatum*	0.28 ha
2009	Amoor	*Aglaia cuculata*	0.28 ha
	Baen	*Avicennia marina*	0.28 ha
	Kirpa	*L. racemosa*	0.28 ha
2012	Kankra	*Bruguiera sexangula*	0.43 ha
	Vathkathi	*Kandelia candel*	0.44 ha
		Total	**4.25 ha**

(A) **(B)**

Figure 2. Mangrove arboretum established in 2004 (A) and 2006 (B)

Sample design and size

A total of sixty (60) sample plots of varying ages and sizes were selected for the study. The dimensions of the sampling plots included 8m × 8m, 12m × 12m, 14m × 14m, 16m × 16m, and 20m × 20m, covering a combined area of 8,248 m^2. This represented 19.4% of the total plantation area. Within these plots, the diameter (in cm) and height (in m) of each tree were measured. Variations in sample plot size were primarily influenced by differences in plantation techniques and the presence of natural obstacles. Spacing was considered to maximize area coverage during plantation, and no standardized plot size was consistently applied.

Biomass and carbon measurement

The most preferable method for estimating biomass involves harvesting from trees. However, the most cost-effective, less time-consuming, and environment-friendly non-destructive method was used (allometry equations) (Komiyama *et al.* 2008). In allometry equations, DBH (Diameter at Breast Height) and height are the most commonly measured variables from other variables for biomass accretion in the forest sector. Numerous developed allometric equations can be found for estimating the mangrove biomass of Sundarbans (eg. Hossain *et al.* 2019; Pitol and Hossian 2023). The model developed by Hossain *et al.* (2019) was more convenient for the Sundarbans. The model developed by Hossain *et al.* (2019) to determine the above-ground biomass (AGB) of Sundarbans trees was used. The below-ground biomass (BGB) was estimated by using the common method recommended by Cairns *et al.* (1997). Most of the body parts of the tree contain 50% carbon on a dry basis. The estimated biomass by 0.5 (Chave *et al.* 2005) to get the carbon stock Above Ground Carbon (AGC), Bellow Ground Carbon (BGC) and Total Carbon (TC) has been multiplied. The carbon-di-oxide equivalence (CO_2e) was calculated by multiplying the total carbon stock by 3.67 (Kauffman and Donato 2012).

Statistical analysis

The data were first tested for normality using the Shapiro–Wilk goodness-of-fit test. Biomass and carbon stock for each individual tree were calculated and aggregated to obtain plot-wise data for all species. Descriptive statistics, including maximum, minimum, mean, standard deviation (SD), and standard error (SE), were computed. To assess differences in diameter at breast height (DBH), height, above-ground biomass (AGB), below-ground biomass (BGB), total biomass (TB), above-ground carbon (AGC), below-ground carbon (BGC), total carbon (TC), and carbon dioxide equivalent (CO_2e) among species, a one-way analysis of variance (ANOVA) was performed. All statistical analyses were conducted using Microsoft Excel 2019 and SPSS 20 software.

Results

DBH and height of seven species in the mangrove arboretum

A statistically significant variation in diameter at breast height (DBH) was identified among the seven species (df = 58; F = 34.86; $P < 0.001$). *Avicennia marina* exhibited the highest mean DBH of 11.67cm, ranging from 4.6cm to 20.5 cm, followed by *Rhizophora mucronata* (mean DBH = 7.71cm), *Lumnitzera racemosa* (7.35cm), and *Aglaia cucullata* (5.46cm) (Table 2). Similarly, a significant difference in height was observed across the species (df = 58; F = 10.47; $P < 0.001$). *A. marina* and *R. mucronata* recorded the highest mean heights of 11.62m and 11.24m, respectively, followed by *L. racemosa* (8.35m), *Aegiceras corniculatum* (6.76m), and *A. cucullata* (6.49m) (Table 2).

Table 2. Minimum, maximum, mean ± SE and standard deviation (SD) of DBH (cm) and height (m) of seven mangrove species in mangrove arboretum.

Species	DBH (cm)				Height (m)			
	Minimum	Maximum	Mean ± SE	SD	Minimum	Maximum	Mean ± SE	SD
Aglaia cuculata	4.4	7.8	5.46 ± 0.12	0.73	5	8	6.49 ± 0.06	0.88
Avicennia marina	4.6	20.5	12.24 ± 0.69	3.39	5.5	19	11.78 ± 0.26	2
Rhizophora mucronata	4.5	12	7.71 ± 0.30	1.88	6	12.6	11.24 ± 0.37	1.01
Bruguiera sexangula	3.7	7.5	4.72 ± 0.17	0.85	4	7	5.2 ± 0.06	0.64
Aegiceras corniculatum	4	8.3	5.47 ± 0.14	0.89	2.2	9	6.38 ± 0.29	1.1
Lumnitzera racemosa	3.5	11.9	7.15 ± 0.21	1.59	4	12	7.95 ± 0.42	2.37
Kandelia candel	3.8	7.2	5.23 ± 0.07	0.85	4	6.6	5.71 ± 0.12	0.54

Table 3. Above-ground biomass (AGB), below-ground biomass (BGB), total biomass (TB), above-ground carbon stock (AGC), below-ground carbon stock (BGC) total carbon stock (TC), Carbon-di-oxide equivalence (CO2e), and Bangladeshi taka (BDT) of seven mangrove species in mangrove arboretum.

Species	AGB (Mg ha^{-1})	BGB (Mg ha^{-1})	TB (Mg ha^{-1})	AGC (Mg ha^{-1})	BGC (Mg ha^{-1})	TC (Mg ha^{-1})	CO_{2e} (Mg ha^{-1})	BDT/ha
A. cuculata	7.9 ± 0.4	4.8 ± 0.2	12.8 ± 0.7	4.0 ± 0.2	2.4 ± 0.1	6.4 ± 0.3	23.5 ± 1.2	25967 ± 1351
A. marina	102.9 ± 37.8	48.2 ± 17.9	151.1 ± 55.8	51.5 ± 18.9	24.1 ± 8.9	75.6 ± 27.9	277.3 ± 102.4	306654 ± 113194
R. mucronata	30.3 ± 11.9	15.8 ± 6.0	46.1 ± 17.9	15.1 ± 5.9	7.9 ± 3.0	23.1 ± 8.9	84.5 ± 32.9	93460 ± 36338
B. sexangula	6.2 ± 0.5	3.9 ± 0.3	10.1 ± 0.8	3.1 ± 0.3	1.9 ± 0.2	5.1 ± 0.4	18.6 ± 1.5	20532 ± 1654
A.corniculatum	20.8 ± 6.7	12.4 ± 3.9	33.2 ± 10.7	10.4 ± 3.4	6.2 ± 1.9	16.6 ± 5.4	60.9 ± 19.6	67306 ± 21682
L. racemosa	12.9 ± 1.4	6.9 ± 0.7	19.9 ± 2.1	6.5 ± 0.7	3.5 ± 0.5	9.9 ± 1.1	36.5 ± 3.7	40317 ± 4269
K. candel	8.0 ± 0.2	4.9 ± 0.1	12.9 ± 0.4	4.0 ± 0.1	2.5 ± 0.1	6.5 ± 0.2	23.7 ± 0.7	26151 ± 732
Mean	**20.8 ± 4.6**	**10.9 ± 2.2**	**31.7 ± 6.7**	**10.4 ± 2.3**	**5.4 ± 1.1**	**15.8 ± 3.4**	**58.1 ± 12.3**	**64242 ± 13589**

Biomass and carbon stock of seven species in the mangrove arboretum

A statistically significant difference in total biomass (TB) was observed among the seven species (df = 58; F = 9.95; P < 0.001). *A. marina* exhibited the highest total biomass (151.11 Mg ha^{-1}), comprising above-ground biomass (AGB) of 102.92 Mg ha^{-1} and below-ground biomass (BGB) of 48.19 Mg ha^{-1}, outperforming the other species (Table 3). The total biomass for *R. mucronata*, *A. corniculatum* and *L. racemosa* was 46.05 Mg ha^{-1}, 33.17 Mg ha^{-1}, and 19.87 Mg ha^{-1}, respectively. Across all species, the mean values for AGB, BGB, and TB were 20.8 Mg ha^{-1}, 10.86 Mg ha^{-1} and 31.66 Mg ha^{-1}, respectively, with observed minimum values of 1.61 Mg ha^{-1} (AGB), 0.97 Mg ha^{-1} (BGB), and 2.59 Mg ha^{-1} (TB), and maximum values of 248.64 Mg ha^{-1} (AGB), 117.64 Mg ha^{-1} (BGB) and 266.28 Mg ha^{-1} (TB). A statistically significant variation in total carbon stock was observed among the seven species (df = 58; F = 9.95; P < 0.001). A. marina demonstrated the highest total carbon stock (75.56 Mg ha^{-1}), comprising above-ground carbon (51.46 Mg ha^{-1}) and below-ground carbon (24.1 Mg ha^{-1}) (Table 3). The total carbon stocks for *R. mucronata*, *A. corniculatum*, and *L. racemosa* were 23.03 Mg ha^{-1}, 16.58 Mg ha^{-1}, and 9.93 Mg ha^{-1}, respectively (Table 3). The mean carbon stock across the mangrove arboretum was 15.83 Mg ha^{-1}, with a range of 1.29 Mg ha^{-1} to 183.14 Mg ha^{-1}. The total carbon

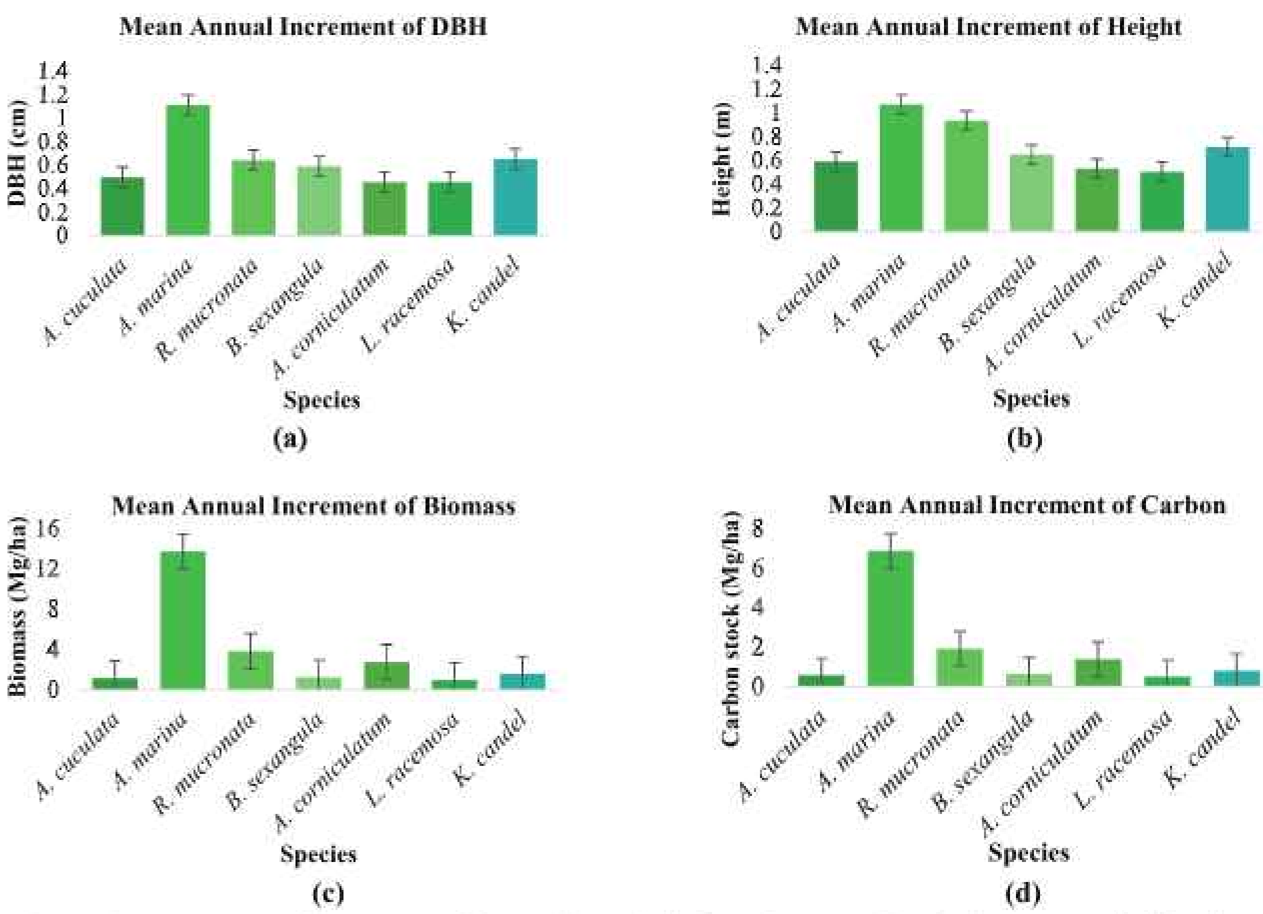

Figure 3. Mean annual increment of DBH (a), Height (b), Biomass (c) and Carbon stock of various mangrove species (d).

dioxide equivalents (CO_2e) were as follows: *A. marina* (277.29 Mg ha^{-1}), *R. mucronata* (84.51 Mg ha^{-1}), *A. corniculatum* (60.46 Mg ha^{-1}), *L. racemosa* (36.46 Mg ha^{-1}), *K. candel* (23.65 Mg ha^{-1}), *A. cucullata* (23.48 Mg ha^{-1}), and *B. sexangula* (18.57 Mg ha^{-1}) (Table 3). The mean CO_2e was 58.09 Mg ha^{-1}, with values ranging from a minimum of 4.75 Mg ha^{-1} to a maximum of 672.12 Mg ha^{-1}.

Mean annual growth of seven species in the mangrove arboretum

A. marina demonstrated the highest mean annual growth in diameter at breast height (DBH) (1.1 cm) and height (1.07 m), followed by *R. mucronata* (0.64 cm DBH, 0.93 m height) and *K. candel* (0.65 cm DBH, 0.71 m height), which were comparable to *A. marina*. The mean annual growth for DBH and height for *B. sexangula* (0.59cm, 0.64m), *A. cucullata* (0.49cm, 0.59m), *A. corniculatum* (0.46cm, 0.53m) and *L. racemosa* (0.46cm, 0.50m) was lower (Fig. 3a & 3b). Additionally, *A. marina* exhibited the highest biomass growth rate (13.74 Mg ha^{-1} yr^{-1}) compared to the other species. The biomass growth rates for *R. mucronata, A. corniculatum, K. candel, B. sexangula, A. cucullata*, and *L. racemosa* were 3.84 Mg ha^{-1} yr^{-1}, 2.76 Mg ha^{-1} yr^{-1}, 1.61 Mg ha^{-1} yr^{-1}, 1.26 Mg ha^{-1} yr^{-1}, 1.16 Mg ha^{-1} yr^{-1}, and 0.99 Mg ha^{-1} yr^{-1}, respectively (Fig. 3c). Moreover, *A. marina* also showed the highest carbon stock increment (6.87 Mg ha^{-1} yr^{-1}), followed by *R. mucronata* (1.92 Mg ha^{-1} yr^{-1}), *A. corniculatum* (1.38 Mg ha^{-1} yr^{-1}), *K. candel* (0.81 Mg ha^{-1} yr^{-1}), *B. sexangula* (0.63 Mg ha^{-1} yr^{-1}), *A. cucullata* (0.58 Mg ha^{-1} yr^{-1}), and *L. racemosa* (0.50 Mg ha^{-1} yr^{-1}) (Fig. 3d).

Discussion

The plant species of the Sundarbans are experiencing a gradual decline due to climatic changes, edaphic factors, and a combination of natural and anthropogenic influences. This decline is particularly pronounced in areas of the Sundarbans adjacent to human settlements (Siddiqui *et al.* 2021). The degradation of stabilized mangrove plantations, estimated at 3%, is attributed to activities such as shrimp farming, salt cultivation, industrialization, and ship recycling (Hossain 2013). Consequently, the conservation of these stabilized plantations is critical for maintaining the ecological integrity of the region. To restore and sustain the biodiversity of the Sundarbans, mangrove species should be preserved within their native habitats. In pursuit of this goal, the Mangrove Silviculture Division has been conducting annual sapling plantations in barren areas of the Sundarbans since 2004. While artificial plantations near natural forests can reduce species diversity (Rahman *et al.* 2020), they also sequester significant carbon stocks (Pitol *et al.* 2019; Azad *et al.* 2021) and release substantial amounts of oxygen (Pitol and Mian 2022). Variations in diameter at breast height (DBH) and height among species were observed, influenced by species differences, salinity gradients, and the age of the plantations. *A. marina, R. mucronata, L. racemosa*, and *A. corniculatum* showed exceptional growth in both height and diameter at breast height (DBH) which indicate that these plants might be well-suited for afforestation in the barren regions of the Sundarbans. Similarly, *R. mucronata* and *K. candel* showed high performance (Rahman 2018). The mean height of seven mangrove species ranged from 2.2m to 19m, with *A. marina* exhibiting the highest mean DBH (11.67cm) and height (11.62m), ranging from 4.6cm to 20.5cm and 5.5m to 19m, respectively. These findings are consistent with observations of *R. apiculata* in Sri Lanka, which demonstrated a mean height of 10.3m (Amarasinghe and Balasubrananiam 1992). In this study, the mean above-ground biomass (AGB), below-ground biomass (BGB), and total biomass (TB) of the mangrove arboretum were estimated at 20.8 Mg ha^{-1}, 10.86 Mg ha^{-1}, and 31.66 Mg ha^{-1}, respectively, with ranges of 6.21–102.92 Mg ha^{-1} for AGB, 3.9–48.19 Mg ha^{-1} for BGB, and 10.12–151.11 Mg ha^{-1} for TB. *A. marina* exhibited the highest total biomass (151.11 Mg ha^{-1}), comprising 102.92 Mg ha^{-1} in AGB and 48.19 Mg ha^{-1} in BGB. These values surpass those reported for young mangrove plantations in Asia and Australia, such as *A. marina* (6.8 Mg ha^{-1}; Woodroffe 1985) and *B. gymnorrhiza* (5.8 Mg ha^{-1}; Choudhuri 1991). Previous studies have shown that AGB can range from 31 Mg ha^{-1} in pioneer mangroves to 315 Mg ha^{-1} in mature coastal mangroves (Fromard *et al.* 1998). The mean annual biomass increments in this study ranged from 0.99 to 13.74 Mg ha^{-1} yr^{-1}, indicating substantial growth. Comparatively, the mean below-ground biomass in the riverine mangrove forests of Sukkur, Sindh, Pakistan, was reported as 2.57 Mg ha^{-1} (Anwar *et al.* 2018), emphasizing the high productivity of the studied arboretum. The mean above-ground carbon stock (AGC), below-ground carbon stock (BGC), and total carbon stock (TC) of the mangrove arboretum were estimated at 10.4 Mg ha^{-1}, 5.43 Mg ha^{-1}, and 15.83 Mg ha^{-1}, respectively, with ranges of 3.11–51.46 Mg ha^{-1} for AGC, 1.95–24.1 Mg ha^{-1} for BGC, and 5.06–75.56 Mg ha^{-1} for TC in this study. The carbon stock increment of *R. mucronata* was the highest (1.92 Mg ha^{-1} yr^{-1}), followed by *A. corniculatum* (1.38 Mg ha^{-1} yr^{-1}), *K. candel* (0.81 Mg ha^{-1} yr^{-1}), *B. sexangula* (0.63 Mg ha^{-1} yr^{-1}), *A. cuculata* (0.58 Mg ha^{-1} yr^{-1}), and *L. racemosa* (0.50 Mg ha^{-1} yr^{-1}). Factors such as stand structure and composition, age, and stand density significantly influence carbon storage in mangroves (Cheng *et al.* 2013). Additionally, carbon sequestration potential can reach up to 20 Mg ha^{-1} yr^{-1} in highly productive riverine forests, such as those in Sukkur, Sindh, Pakistan (Anwar *et al.* 2018). These findings underscore the variability in carbon stock across species, locations, areas, and environmental conditions. Understanding the structural characteristics of plantations is essential for accurately comparing biomass and carbon stock values.

Conclusion

This study provides a comprehensive analysis of biomass and carbon stock within the mangrove arboretum in the Sundarbans, established by the Mangrove Silviculture Division, Bangladesh Forest Research Institute. The average biomass values, encompassing above-ground, below-ground, and total biomass, were found to range between 1.61 and 248.64 Mg ha^{-1}, 0.97 and 117.64 Mg ha^{-1}, and 2.59 and 366.28 Mg ha^{-1}, respectively. Similarly, the average carbon stock and carbon dioxide equivalence were estimated at 15.83 Mg ha^{-1} and 58.09 Mg ha^{-1}, with ranges of 1.29–183.14 Mg ha^{-1} and 4.75–672.12 Mg ha^{-1}, respectively. The annual increments in DBH, height, biomass, and carbon stock varied between 0.5–1.1 cm yr^{-1}, 0.6–1.1 m yr^{-1}, 0.99–13.74 Mg ha^{-1} yr^{-1}, and 0.5–7 Mg ha^{-1} yr^{-1}, respectively. These findings underscore the significant role of arboretums in conserving biodiversity and sequestering carbon within the Sundarbans. Establishing additional arboretums is imperative for safeguarding this critical ecosystem and ensuring its resilience against environmental threats. The outcomes of this study offer valuable insights for policymakers, particularly in advocating for equitable participation in global carbon trading mechanisms. Furthermore, these results emphasize the need to expand arboretum initiatives in the Sundarbans and other coastal regions to enhance biodiversity conservation and carbon sequestration.

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Acknowledgements

People, who contributed to the work but are not authors, should be listed in the acknowledgements part, along with their contributions. Authors have to ensure that everyone whose name is included in the acknowledgements does not have any objection to include their name in the acknowledgement part of that particular manuscript.

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1. Journal Publication (one, two & more than two authors)

(a) Alam, M.K. 1991. Additional Hosts for Some species of Loranthaceae from Bangladesh. *Bangladesh Journal of Forest science* 20 (1&2): 62-64.

(b) Akhtaruzzaman, A.F.M. and Shafi, M. 1995. Pulping of jute. *Tappi Journal* 78 (2): 106-112.

(c) Parvin, W.; Govender, N.; Othman, R.; Jaafar, H.; Rahman, M.M. and Wong, M.Y. 2020. Phenazine from *Pseudomonas aeruginosa* UPMP3 induced the host resistance in oil palm (*Elaeis guineensis* Jacq.)-*Ganoderma boninense* pathosystem. *Scientific Reports* 10(15621): 1-12.

2. Reference to same author(s) publish several articles in the same year

(a) Baksha, M.W. and Crawley, M.J. 1998a. Population dynamics of teak defoliator, *Hyblaea puera* Cram. (Lep., Hyblaeidae) in teak plantations of Bangladesh. *Journal of Applied Entomology* 122: 79-83.

(b) Baksha, M.W. and Crawley, M.J. 1998b. Effect of defoliation on the growth of teak. *Journal of Tropical Forest Science* 10(3): 312-317.

3. Reference to a journal publication with a DOI

Rahman, M.M., Parvin, W., Sultana, N. and Tareq, S.A.M. 2018. *Ex-situ* conservation of threatened forest tree species for sustainable use of forest genetic resources in Bangladesh. *Journal of Biodiversity Conservation and Bio-resource Management* 4(2): 89-98.

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5. Reference to an article/chapter in an edited book

(a) If the reference is made from an article in a book, the style should be: author, year, title of the article, followed by editor(s), book title (italics), publisher, place of publication and pages, eg. Siddiqi, N.A. and Khan, M.A.S. 1996. Planting techniques for mangroves on new accretions in the coastal areas of Bangladesh. In: Field, C.D. (ed.). Restoration of Mangrove Ecosystems. International Society for Mangrove Ecosystems, Okinawa, Japan.143-159 pp.

(b) If the reference is made from a chapter in a book, the style should be: Surname(s) of Author(s) than Author(s) name(s) initial(s). Year of publication. Title of chapter (small letters). Chapter page number(s). In: "Title of Book" (Editor(s) of the book containing the contribution, ed.(s). Publisher name. Place of Publication, full number of book pages. DOI number if any.

eg. Pradhan S.K. 2000. Integrated pest management. p. 463-469. In: "IPM System in Agriculture. Volume 6- Cash Crop" (R.K. Upadhyaya, K.G. Mukerji, O.P. Dubey, eds.). Aditya Books Pvt. Ltd. New Delhi, India. 710 pp.

6. Reference to a website

If the information is cited from website, the style should be:

(a) If there is author(s):

Alam, A.B.M.S; Chowdhury, M.S.M; and Istiak, S. 2012. Biodiversity of Tanguar Haor: a Ramsar site of Bangladesh: Vol. 1: wildlife (Amphibians, Reptiles, birds and Mammals) (www.iucn.org/knowledge/ publication_ doc/publications/) retrieved on 05 June 2012.

(b) If there is no author(s):

Banglapedia 2006. National Encyclopedia of Bangladesh.(www.markoseb.com/ww/banglapedia.org) Retrieved on 7 June 2012.

7. For encyclopedia entries (with no author or editor)

Title of Encyclopedia (year) "Title of entry", volume, edition, Title of Encyclopedia, Publisher, Place of publication, pages.

Encyclopaedia Britannica (1926) "Psychology of culture contact", Vol. 1, 13th ed., Encyclopaedia Britannica, London and New York, NY, pp. 765-771.

8. Internet Source

Faizah, Abdul Majid, Zalizan Jelas & Norzaini Azman. 2002. *Selected Malaysian Adult Learners' Academic Reading Strategies: A Case Study*. Retrieved August 16, 2005 from http://face.stir.ac.uk/ Majidp61.htm

9. For newspaper articles (non-authored)

Newspaper (year), "Article title", date, pages. e.g. *The Daily Star*. 2018. "The Grace of Tallest Grass" 16 March. p.16

10. Proceedings

Siddiqi, N.A. 2011. Changing trends in biodiversity of the mangroves of Bangladesh. In: Roskaft, E. and Chivers, D.J.(eds). *Proceedings of the International Conference on Biodiversity- Present State, Problems and Prospects of its Conservation*. Norwegian University of Science and Technology, Trondheim, Norway. 77-82 pp.

11. Reference to a conference paper

Waheeda, P.; Radziah, O.; Hawa, J. and Wong M.Y. 2013. *Detection and Optimization of Indole -3 Acetic Acid in Rhizo-bacterial strains Pseudomonas aeruginosa* UPMP3 and *Burkholderia cepacia* UPMB3 *Isolated from Oil Palm Rhizosphere in vitro*. Poster session presentation at the 25th the Annual Meeting of the Thai Society for Biotechnology and International Conference,16-19 October, 2013, Emerald Hotel, Bangkok, Thailand. pp 403 – 410.

12. Thesis or Dissertation

Rahman, M.M. 2014. *Development of Improved Protocols for Plant Regeneration and Genetic Transformation of Rubber (Hevea brasiliensis* Muell.Arg.) Ph.D. Dissertation, Universiti Putra Malaysia, Selangor, Malaysia. 194 p.

13. Bulletin

Banik, R.L.; Islam, S.A.M.N.; Mannan, M.A. and Das, S. 1997. *A manual for clonal propagation of Hybrid Acacia and Eucalytus camaldulensis*. Bulletin 2, Tree Propagation Series, Bangladesh Forest Research Institute, Chittagong. 18 pp.

14. Title of a paper is in a language other than English

If the title of a paper is in a language other than English, the English translation of the title is to be shown in parenthesis.

Baksha, M.W. 1996. Ashbabpatrer Ghoon Poka O Tar Neontron Babostha (Powderpost beetles of furnitures and their management). Krishikatha 56 (8): 253-254.

Short Communications

These should not exceed four journal pages including graphs, tables and figures. The manuscript should be without sub-heads, such as, Abstract, Introduction, Materials and Methods, etc. but with Keywords and References.

Originality and Plagiarism

Authors should submit only original work that is not plagiarized, and has not been published or being considered elsewhere. Appropriate softwares may be used by the editorial office to check for similarities of submitted manuscripts with existing literature. Work and/or words of others, that this has been appropriately cited or quoted.

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