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CONTENTS

Survival, Growth and Nutrient Distribution in Seedling Parts of *Aglaia Cucullata* (Roxb.) Pellegr. Along the Salinity Gradient of Sundarban

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Abstract

Aglaia cucullata (Roxb.) Pellegr. is a less salt-tolerant tree species of Sundarban mangrove ecosystem. The present study was conducted to investigate the influence of salinity on the survival and growth of *A. cucullata* seedlings and nutrient distribution in seedling parts. All (100%) the seedlings of *A. cucullata* was found to survive at non-saline to slightly saline (0 to 5 PSU) condition and no seedlings were survived beyond 15 PSU salinity. Seedling growth in terms of biomass, height and collar diameter showed a significant ($p<0.05$) negative relationship with the salinity gradient. The highest concentration of nitrogen (42 to 25 mg/g) and potassium (34 to 30 mg/g) was found at leaves. While roots contained the highest phosphorous (4 to 3 mg/g) and sodium (34 to 13 mg/g). However, nitrogen, phosphorous and potassium in different parts of seedlings showed significant ($p < 0.05$) negative correlations with the salinity gradient, while sodium showed a significant ($p < 0.05$) positive correlation. In conclusion, *A. cucullata* is very sensitive to salinity for survival, growth and nutrient distribution in their parts, and that the distribution of this species may be confined only in the less saline areas of Sundarban.

সারসংক্ষেপ

Aglaia cucullata (Roxb.) Pellegr সুন্দরবনের একটি অল্প লবণ-সহনশীল বৃক্ষ প্রজাতি। এই গবেষণাটি *A. cucullata* বৃক্ষের চারা বেঁচে থাকা, বৃদ্ধি ও বিভিন্ন অংশে খাদ্যপ্রাণের উপস্থিতির উপর লবণাক্ততার মাত্রার প্রভাব অনুসন্ধানের জন্য করা হয়েছিল। *Aglaia cucullata* চারা লবণাক্ত শূন্য থেকে সামান্য (০-৫ পিএসইউ) লবণাক্ততায় শতভাগ বেঁচে থাকতে পারে। তবে ১৫ পিএসইউ লবণাক্ত মাত্রার পরে কোনো চারাই জীবিত থাকতে দেখা যায়নি। চারার উচ্চতা এবং কাণ্ড ও শেকড়ের সংযোগ স্থলের ব্যাসের বৃদ্ধির সাথে লবণাক্ততার একটি ঋণাত্মক (p<০.০৫) সম্পর্ক পাওয়া যায়। সর্বোচ্চ পরিমাণ নাইট্রোজেন (৪২ থেকে ২৫ মিলিগ্রাম/গ্রাম), পটাসিয়াম (৩৪ থেকে ৩০ মিলিগ্রাম/ গ্রাম) পাতায় পাওয়া যায় এবং শেকড়গুলিতে সর্বাধিক পরিমাণ ফসফরাস (৪ থেকে ৩ মিলিগ্রাম/ গ্রাম) এবং সোডিয়ামের (৩৪ থেকে ১৩ মিলিগ্রাম/ গ্রাম) উপস্থিতি লক্ষ্য করা যায়। তবে চারাগুলির বিভিন্ন অংশে নাইট্রোজেন, ফসফরাস এবং পটাসিয়াম লবণাক্ত মাত্রার সাথে (p<০.০৫) নেতিবাচক পারস্পারিক সম্পর্ক দেখিয়েছে, কিন্তু সোডিয়াম উল্লেখযোগ্য ইতিবাচক সম্পর্ক (p<০.০৫) দেখিয়েছে। পরিশেষে বলা যায় যে, *A. cucullata* এর বেঁচে থাকা, বৃদ্ধি এবং বিভিন্ন অংশের পুষ্টির বিতরণের জন্য লবণাক্ততা অত্যন্ত সংবেদনশীল এবং এই প্রজাতির ব্যাপ্তি কেবল সুন্দরবনের কম লবণাক্ত অঞ্চলে সীমাবদ্ধ থাকতে পারে।

Keywords: *Aglaia cucullata,* Growth, Nutrient, Sundarban, Survival.

Introduction

Mangrove forests are the most productive coastal ecosystems of the tropical and sub-tropical areas (Hutchings and Sanger 1987). Mangroves play a crucial role in protecting the life and properties of the coastal communities from the cyclone and tidal surges. It provides habitats for many crustaceans, fishes and marine animals and deliver plant species that can produce both the timber and non-timber forest products that supports the livelihood of the coastal people (Tomlinson 1986; Hellier 1988; Pemadasa 1996; Kathiresan and Qasim 2005).

Salt is an important regulatory factor in the mangrove ecosystems (Waisel 1972). Salt concentration influences seed germination, sprouting of propagules, survival, growth, reproduction and distribution of mangroves plant species (Lovelock *et al.* 2004; Naidoo 2006; Elumalai and Manikandan 2013; Mahmood *et al.* 2014a, b; Alam *et al.* 2017). Higher salt content in a habitat influences to accumulate higher amount of sodium in plant tissues which ultimately disrupts the nutrient uptake mechanism and thus affect negatively in the plant growth and development (Mahmood *et al.* 2014a; Alam *et al.* 2018). In most cases, a higher salt content leads to an increased Na^+ and Cl^- ions in plant tissue and results in decreased concentration of N, P, K^+, and Ca^{2+} (Karimi *et al.* 2005; Tuna *et al.* 2007; Navarro *et al.* 2008). This phenomenon also found to affect the nutrient distribution within the plant parts (Fernández-García *et al.* 2004; Mahmood *et al.* 2014a).

The salt adaptive capacity of mangroves varies with the species. However, the exclusive mangrove species are more salt-tolerant compared to the mangrove associates (Tomlinson 1986; Hogarth 2015). Many researchers studied the threshold limit of salinity for survival and growth of mangrove seedlings of the Sundarban, for example *Heritiera fomes* (Mahmood *et al.* 2014a), *Millettia pinnata* (Nasrin *et al.* 2016), *Xylocarpus granatum* (Siddique *et al.* 2017), *Avicennia officinalis* (Alam *et al.* 2018), *Xylocarpus mekongensis* (Saha *et al.* 2020), *Sonneratia apetala* (Narsin *et al.* 2021) etc. Among these species, some showed better survival and seedling growth at lower salinity (up to 10 PSU). However, up to a certain limit of further increases in salinity inevitably decreased the survival and growth of mangrove plants (Chen and Ye 2014) through disrupting the nutrient uptake (Musyimi *et al.* 2007).

Aglaia cucullata is a small to medium-sized mangrove associates of the Sundarban of Bangladesh and found to grow in the less and moderate saline zone (Mahmood 2015). Comparatively higher regeneration (85%) of this species was observed at less saline (5 PSU) condition, while no seed was germinated beyond 20 PSU salinity (Mahmood *et al.* 2014b). This species is a component of Sundarban biodiversity and has important uses (Mahmood 2015). It is evident that the salinity of Sundarban is increasing due to the changes in rainfall pattern and distribution and reduced flow of freshwater from the upstream (Islam and Gnauck 2011; IWM 2010). The increased salinity in Sundarban is believed to detrimental for the total ecosystem as a whole or may cause losses of certain biota from this ecosystem (IUCN 2012). *Aglaia cucullata*, being a less to moderate salt tolerant associate species, requires attention to evaluate its threshold level of salinity for its survival and growth. This will help us to take interventions for the conservation of this species in Sundarban. Therefore, this study was conducted to investigate, a) the effect of salinity on the survival and growth of *A. cucullata* seedling in hydroponic media, b) nutrient and sodium distribution in seedling parts (roots, stem, and leaves).

Materials and Methods

Seed collection and seedling raising

The mature seeds were collected from healthy *A. cucullata* trees during March-April from Bhodra (22^0 14′ 6″ N, 89^0 32′ 43″ E) and Patakata (22^0 2′ 1″ N, 89^0 29′ 52″ E) forest areas, which belong to the moderate saline (10-25 PSU) water zone of Sundarban (Fig. 1). The collected seeds were sorted manually to avoid damage/defective ones. The sorted seeds were sown on germination bed (1m × 5 m) of the forest nursery of Forestry and Wood Technology Discipline, Khulna University, Khulna, Bangladesh. The seedlings were maintained in the nursery for six months for this study.

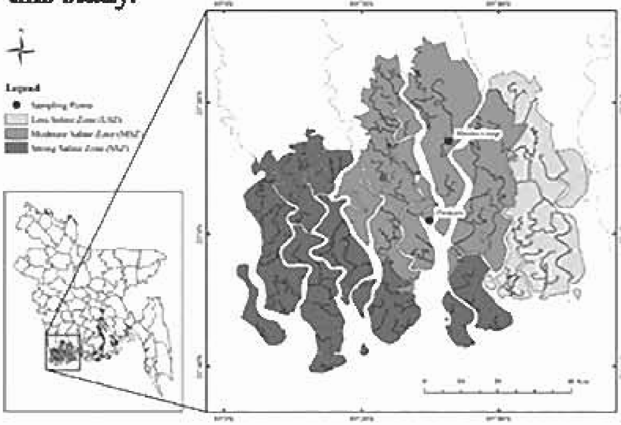


Figure 1. Map of Sundarban showing the seed collection areas.

Experiment setup

Six-month-old seedlings which were 9 cm in diameter and 20 cm in height was placed in a filled with coarse sand polyethylene terephthalate (PET) bottle. A total of 96 experimental unites were prepared (Fig. 2) for the study. For this study collar diameter, total height and green biomass of all the seedlings used in this experiment were measured before transplant to the PET bottle. However, ten of such seedlings were taken to the laboratory and oven-dried at 80°C until constant weight to get the green weight to oven-dry weight conversion ratio.

A total of 12 experimental units was placed in a plastic box (46 cm x 30 cm x 24 cm). Thus a total of 8 boxes was prepared for 8 salinity treatments (0, 5, 10, 15, 20, 25, 30, and 35 PSU). Here, full-strength modified Hogland solution (Siddique *et al.* 2017; Saha *et al.* 2020) was used as growth media. The modified Hogland solution was adopted to avoid the interruption of Na and Cl salts with the salinity treatments. Distilled water was used for 0 PSU treatment, while crud sea salt was used to prepare the desired salinity treatments (5, 10, 15, 20, 25, 30, and 35 PSU). Crude sea salt was used to get the natural salinity condition with all the nutrients that are available in seawater. The salinity of all treatments was 0 PSU during the 1st week of the experiment. The salinity of all the treatments (except 0 PSU) were then raised to 2.5 PSU at the 2nd week. Thus, a gradual increase in salinity was adopted for the treatments to avoid the sudden shock of high saline conditions as described by Mahmood *et al.* (2014a) and Siddique *et al.* (2017) (Table 1). The nutrient solution was changed weekly and salinity level was checked regularly throughout the experiment. A portable hand salinity refractometer (RHS-4/ATC) was used to check the salinity level. The pH of the nutrient solution was maintained at 7.5-8.0 for all the treatments. This experiment was conducted for 25 weeks in a glass house with ambient temperature (32 to 35°C) and light.

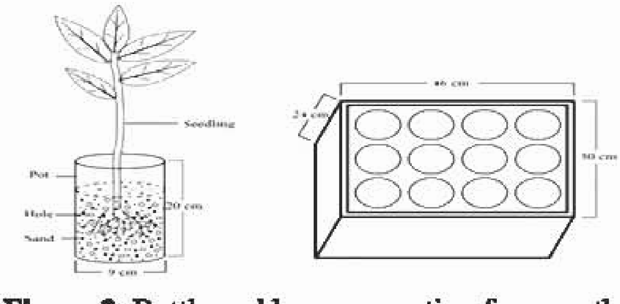


Figure 2. Bottle and box preparation for growth experiment. (Saha *et al.* 2020).

Table 1. Temporal diagram of the gradual change in salinity (Saha *et al.* 2020).

	Salinity (PSU)							
Week	0	5	10	15	20	25	30	35
1	0	0	0	0	0	0	0	0
2	.	2.5	2.5	2.5	2.5	2.5	2.5	2.5
3	.	5	5	5	5	5	5	5
4	.	.	7.5	7.5	7.5	7.5	7.5	7.5
5	.	.	10	10	10	10	10	10
6	.	.	.	12.5	12.5	12.5	12.5	12.5
7	.	.	.	15	15	15	15	15
8	.	.	.	.	17.5	17.5	17.5	17.5
9	.	.	.	.	20	20	20	20
10	.	.	.	.	.	22.5	22.5	22.5
11	.	.	.	.	.	25	25	25
12	.	.	.	.	.	.	27.5	27.5
13	.	.	.	.	.	.	30	30
14	.	.	.	.	.	.	.	32.5
15	.	.	.	.	.	.	.	35
.	.	.	.	.	.	.	.	.
.	.	.	.	.	.	.	.	.
.	.	.	.	.	.	.	.	.
25	0	5	10	15	20	25	30	35

Survival and growth of seedlings

The seedling number under each treatment was counted to get survival percentage. Collar diameter and height of the lived seedlings were measured at the end of the experiment. Finally, the lived seedlings of each treatment were harvested and oven-dried separately at 80°C until constant weight to get final dry weight. The increment in collar diameter, height and biomass was calculated from the initial and final values of the respective treatments. These oven-dried seedlings were separated into different parts (leaf, stem, bark and root) according to the treatments. Then they were grinded and sieved by 2 mm mesh and stored in airtight container for further analysis.

Nutrients (N, P, K) and sodium in seedling parts

The grinded and sieved samples were acid digested to get sample extract. Micro Kjeldahl digestion for Nitrogen (N) and tri-acid (H_2SO_4, $HClO_4$ and HNO_3) digestion for Phosphorus (P) and Potassium (K) were adopted for seedling parts according to Allen (1989). Nitrogen and Phosphorus in the sample extract were measured calorimetrically according to the Baethgen and Alley (1989) and Timothy *et al.* (1984) list respectively, using UV–visible Recording Spectrophotometer (HITACHI, U-2910, Japan). Potassium concentration in sample's extract was measured by Flame Photometer (PFP7, Jenway LTD, England).

Statistical analysis

The survival percentage value of each salinity treatment was transformed to arcsine and a one-way analysis of variance (ANOVA) followed by Duncan Multiple Range Test (DMRT) was conducted to compare the survival percentages among the salinity treatments. Biomass increment (oven-dried) in different salinity treatments was also compared by one-way ANOVA followed by DMRT. The ANOVA analysis was conducted by using SAS 6.12 statistical software. In addition, correlation analysis was conducted among salinity treatments with survival, growth of seedlings, nutrients and sodium by using SAS 6.12.

Results

Survival seedlings

The highest survival (100%) of *A. cucullata* seedlings was observed up to 5 PSU, which significantly ($p < 0.05$) declined to 75% at 15 PSU salinity and no seedling was found to survive beyond this salinity end (Fig. 3). The survival percentage of this species showed a significant ($p<0.05$) strong negative correlation ($r = -0.91$) with increase of salinity.

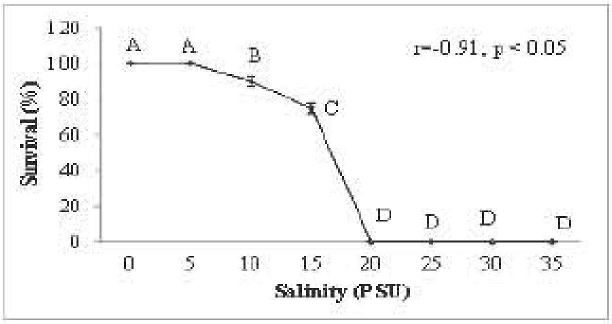
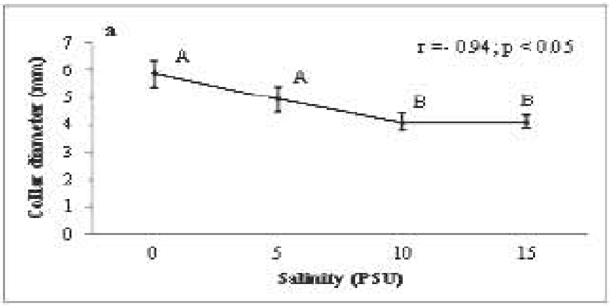


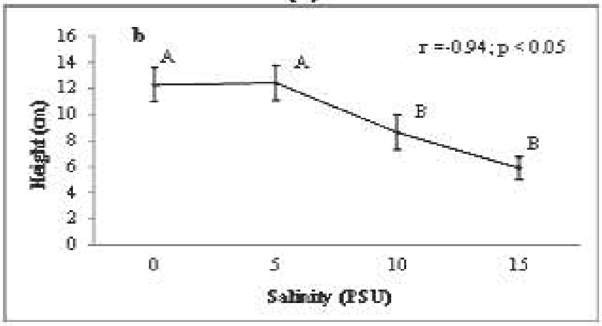
Figure 3. Effect of salinity on survival of *A. cucullata* seedlings. Similar alphabet on the line indicates no significant ($p>0.05$) difference.

Growth of Seedlings

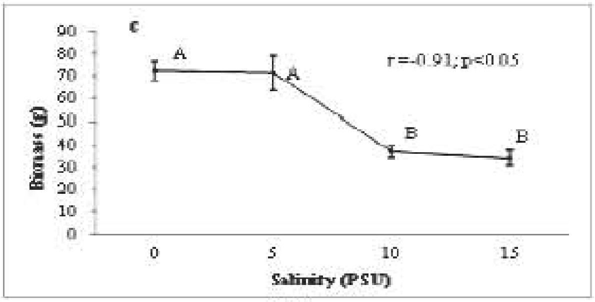
Comparatively higher growth in collar diameter (5.88 mm) was observed at non-saline (0 PSU) condition, while the highest height growth (12.42 cm) was reported at slightly saline (5 PSU) treatment. The diameter and height growth of the seedlings were not varied significantly ($p < 0.05$) at non-saline to slightly saline conditions. The lowest growth (diameter and height) was observed at 15 PSU salinity. However, the collar diameter and height growth showed a significant ($p < 0.05$) strong negative correlation with the increase of salinity (Fig. 4 a and b). Similar to diameter and height growth, comparatively ($p<0.05$) higher biomass (72.38 -71.41 g) growth was recorded at the non-saline to slightly saline conditions which significantly ($p<0.05$) declined at higher saline (15 PSU) treatment. The biomass growth also showed a significant ($p<0.05$) strong negative correlation with the increase salinity (Fig. 4c).



(a)



(b)



(c)

Figure 4. Effects of salinity on seedlings of *A. cucullata* (a) collar diameter growth (b) height increment and (c) biomass growth. Similar alphabet on the line indicates no significant ($p > 0.05$) difference.

Nutrients (N, P, K) and sodium in seedling parts

Comparatively ($p<0.05$) the highest concentration of nitrogen (42 mg/g) was recorded in leaves and the lowest in roots (20 mg/g) at non-saline (0 PSU) condition (Fig. 5a). Similarly, the highest concentration of potassium was found in leaves (34 mg/g) followed by root and stem (Fig. 5c). Where as, a comparatively higher concentration of phosphorous was detected in the root (4 mg/g) followed by the stem at the non-saline condition (Fig. 5b). Conversely, significantly ($p<0.05$) higher concentration (34 mg/g) of sodium was recorded in root and the lowest concentration (10 mg/g) in the stem at the high saline (15 PSU) treatments (Fig. 5d). Collectively, significant ($p<0.05$) variation in nitrogen, phosphorus, potassium and sodium concentration was observed for different parts of seedlings at different saline treatments with the exception of nitrogen in bark and stem, and phosphorous in bark (Fig 5 a, b, c, and d). Nitrogen and potassium concentration in different parts of seedlings showed significant ($p<0.05$) negative correlation with salinity except for nitrogen in the bark. Though phosphorous concentration in bark and stem showed a significant ($p<0.05$) negative correlation with salinity but in leaf showed a significant ($p<0.05$) positive correlation and in root showed no significant ($p<0.05$) correlation. Conversely, sodium concentration in different plant parts showed significant ($p < 0.05$) positive correlation ($r = 0.81$ to 0.93) with salinity treatments (Table 2).

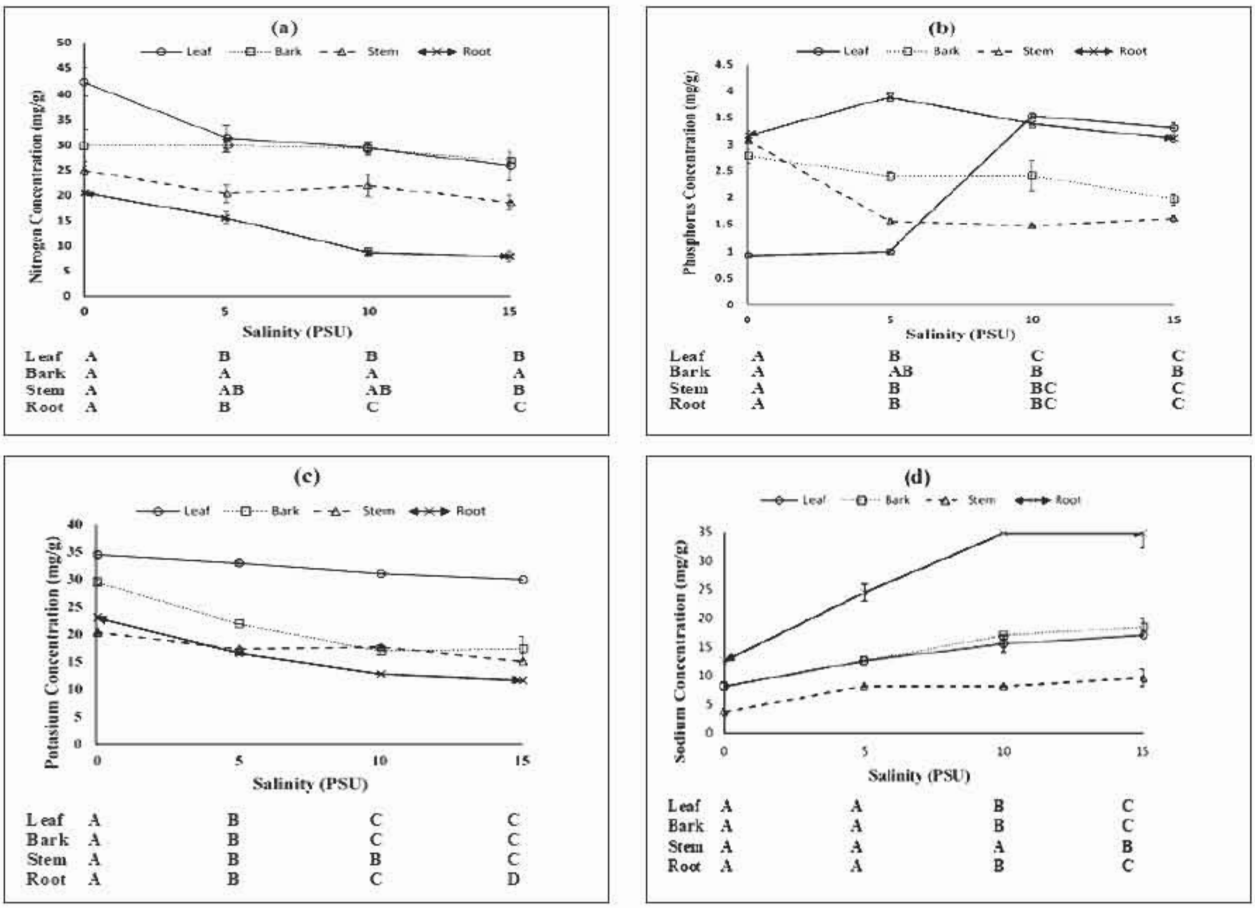


Figure 5. Effects of salinity in nutrients concentration in seedling parts of *Aglaia cucullata* (a) Nitrogen; (b) Phosphorus; (c) Potassium and (d) Sodium. Treatments sharing the similar alphabet are not varied significant ($p>0.05$).

Table 2. Correlation among salinity treatment and nutrient (nitrogen, phosphorus, potassium and sodium concentration) in parts of *Aglaia cucullata* seedlings.

Nutrients	Parameters			
	Leaf	Bark	Stem	Root
Nitrogen	- 0.82	- 0.36*	- 0.58	- 0.93
Phosphorus	0.88	- 0.72	- 0.75	- 0.23*
Potassium	- 0.95	- 0.87	- 0.90	- 0.95
Sodium	0.93	0.95	0.81	0.92

* Values are not significant at 95% level.

Discussion

Salinity is one of the important driving factors that influence the productivity of the mangroves ecosystem. It also plays an important role to regulate the physiological processes, growth, height, survival and zonation of mangroves (Snedaker 1982; Ball and Farquhar 1984; Tomlinson 1986; Hutchings and Saenger 1987; Ball 1988; Lin and Sternberg 1992). However, mangrove plants are not salt lovers but they can tolerate salt, which is an adaptation to salinity. This adaptation capacity is very much species-specific (Alam *et al*. 2018; Mahmood *et al*. 2014a; Nasrin *et al*. 2016, 2021).

Most of the energy of mangrove plants participate in their survival at the high saline condition, conversely low saline atmosphere facilitates high growth (Lopez-Hoffman *et al.* 2006). This could be the reason to high survival and growth at non-saline (0 PSU) to slightly saline (5 PSU) treatments of the species studied. This phenomenon indicates that *A. cucullata* seedlings are very sensitive to higher salinity. Similar to the present study, higher growth of *Acanthus ilicifolius*, *Aegiceras corniculatum* and *Avicennia marina* seedlings was observed at the non-saline to slightly saline condition (Ye *et al.* 2005). A high level of salinity is a barrier to the growth of mangrove seedlings (Smith 1992), through the low potential of soil solution triggering physiological drought, imbalance of nutrient, toxicity or an amalgamation of all factors (Noor *et al.* 2015; Khan *et al.* 2000; Lauchli and Grattan 2007). In addition, higher salinity decreases the rate of water uptake (Clough 1984) affecting leaves intercellular CO_2 concentration (Andrews and Muller 1985), decrease the rate of photosynthesis and results the lower growth (Pezeshki *et al.* 1990; Sobrado 1999).

Plant uptake nutrients from the soil and translocate to leaves and synthesized food thereafter is distributed to different parts. Nutrients are essential for plant growth and different physiological process (Jones *et al.* 1991; Marschner 1995). The present study showed a higher concentration of nitrogen and potassium in leaves, while roots contained higher content of phosphorous. In high saline conditions, phosphorus is responsible to increase the root growth for generating greater surface area to uptake more nutrients (Okusanya and Fawole 1985). This could be the reason to accumulate the highest amount of phosphorus in the root of *A. cucullata.* Many studies have demonstrated that the nutrient concentration varies with species and plant parts (Jones *et al.* 1991; Mahmood *et al.* 2006). Comparatively higher concentration of nutrients usually observed in the physiological active parts of plant-like leaves and roots (Mahmood 2004). Salinity stress reduces the uptake of nutrients and affecting the nutrient distribution within the plant parts (Grattan and Grieve 1994; Mahmood *et al.* 2014a). This could be the reason to observe a lower concentration of nutrients (N, P, K) in seedling parts of the studied species at higher saline treatments. In conclusion, salinity is a critical factor for the survival and growth of mangrove seedlings and the salt-tolerant capacity is species-specific which also supported by the Houle *et al.* (2001) and Nandy *et al.* (2007). Moreover, most of the energy is utilized for survival at high saline conditions (Suarez and Medina 2005) that enable to development of salinity-induced physiological changes in plants (Munns and Tester 2008). *Aglaia cucullta* may not have the capacity to develop salinity-induced physiological changes beyond 15 PSU salinity, which may cause the death of seedling which was found in the present study.

Conclusion

Survival, growth, and nutrient in distribution in different parts of mangrove species are chiefly controlled by salinity. Though, *A. cucullata* is known as a less saline tolerant species of the Sundarbans but can also tolerate moderate saline conditions. The anthropogenic and natural causes are responsible for increasing salinity in Sundarban. This increased salinity in Sundarban may restrict the survival, growth and distribution of *A. cucullata*.

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Raising of *Calamus erectus* Roxb. Seedlings and their Performance at Nursery and Field Conditions

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Abstract

The paper deals with seed germination and seedlings growth performance of *Calamus erectus* in the nursery and field conditions. Clean seeds were sown in the seed bed filled with soil and decomposed cow dung at 3:1 ratio. Seeds started germination after 52 days of sowing and completed within 76 days with maximum 78% germination. The survival performance of the seedlings was determined by transferring the seedlings from germination bed to the polybags from 10-80 days after germination with 10 days interval. Optimum survival (100%) was found significant ($p \leq 0.05$) transferring after 30-40 days of germination from seedbed to polybag. Plantation in the field was made with one year old seedling at 2.0 m x 2.0 m spacing. Average seedlings survival was 94% after one year of plantation in the field. Mean seedling height was recorded 94.6 cm after two years of planting. Survival of seedlings and growth performance in the field were satisfactory when one year old seedlings were out-planted. Clean or decoated seeds for nursery raising and one year old seedlings were found suitable for successful plantation raising of *Calamus erectus*.

সারসংক্ষেপ

বর্ণিত প্রবন্ধে *Calamus erectus* এর বীজের অঙ্কুরোদগমের হার নির্ণয়, নার্সারি ও মাঠে চারার বৃদ্ধি পর্যবেক্ষণ করা হয়। মাটি ও গোবর ৩ঃ১ অনুপাতে মেশানো বেডে পরিষ্কার বীজ বপন করা হয়। বীজ বপনের ৫২ দিনের পরে অঙ্কুরোদগম শুরু হয় এবং ৭৬ দিনে সম্পূর্ণ হয় এবং সবচাইতে বেশী ৭৮% অঙ্কুরোদগম পাওয়া যায়। ১০-৮০ দিন বয়সের চারা ১০ দিন অন্তর অন্তর সীডবেড থেকে পলিব্যাগে স্থানান্তর করে বেঁচে থাকার হার নির্ণয় করা হয় এবং ৩০-৪০ দিন বয়সের চারা বীজ তলা থেকে পলিব্যাগে স্থানান্তর করলে চারার বেঁচে থাকার হার সবচেয়ে বেশী (১০০%) এবং এটি তাৎপর্যপূর্ণ (p≤০.০৫)। এক বছর বয়সী চারা ২.০ মি. x ২.০ মি. দূরত্বে মাঠে লাগিয়ে বৃদ্ধি পর্যবেক্ষণ করা হয়। মাঠে লাগানোর এক বছর পর চারার গড় বেঁচে থাকার হার ৯৪%। দুই বছর পর চারার গড় উচ্চতা ৯৪.৬ সে.মি.পাওয়া যায়। এক বছর বয়সের চারা মাঠে রোপণের পর চারার বেঁচে থাকার হার এবং বৃদ্ধি সন্তোষজনক। নার্সারি উত্তোলনের জন্য পরিষ্কার বা ত্বকবিহীন বীজ এবং সফল বাগান উত্তোলনের জন্য এক বছর বয়সী চারা উপযুক্ত বলে প্রতীয়মান হয়।

Key words: *Calamus erectus*, Germination percentage, Seedling growth, Survival percentage.

Introduction

Calamus erectus L. commonly known as rattan, is the largest genus of the family Arecaceae (Palmae) with about 520 species worldwide, mostly distributed in the Asia-Pacific region and Africa (Dransfield *et al.* 2008; Baker 2015; Baker and Dransfield 2016). Out of these, 15 species were recorded in Bangladesh (Wong 1984; Alam 1990, 1991; Basu 1991, 1992; Ali 2003). Recent investigation provided a list of 10 species under two genera growing in the country (Ara 2008, 2011). Rattan is the second most important non timber forest products after bamboo in the tropical and sub-tropical countries of Asia and Africa (Uhl and Dransfield 1987; Sunderland 2002; Ogunwusi 2012; Haider *et al.* 2014; Wan *et al.* 2018). The ethnic communities and the settlers heavily depend on the natural resources for their subsistence as well as for cash income (Chauhan *et al.* 2004). The rattan resource has exhausted recklessly in recent years due to over exploitation and poor management (Siddiqi 1995). To coup with ever increasing global demand, it is an imperative for sustainable management of rattan resources. To achieve this goal, immediate attention is needed for establishing rattan plantations and also management of existing rattans properly in their natural habitats.

Calamus erectus is a non-climbing species of rattan. It is locally known as sita bet, occurs naturally in sloppy pockets of hills, mixed with scrub vegetation, found in the Sitapahar (Chattogram), Khadimnagar (Sylhet), Ampupara (Bandarban) and BFRI (Chattogram) in Bangladesh (Alam 1990; Ara 2008). *C. erectus* is globally distributed in the region of China, Bangladesh, Bhutan, India, Laos, Myanmar, Nepal and Thailand (Flora of China 2010). It is a non climbing species with hairy young shoots. Stem with leaf sheath 3.5-4 cm in diameter; exposed part of the stem green and smooth; internodes 10-12 cm long. Leaves ecirrate, 3-5 m long; leaf sheath without flagellum, armed with black, flattened spines; ocrea conspicuously auriculate; petiole 1.5 m long, subterete, covered with irregular, whorled spines. Leaflets linear-ensiform, equidistant, green on both sides; rachis armed below with irregular to whorled straight spines. Inflorescence 1m long, compact, non-flagelli form; primary bract elongate, tubular, lacerate in upper part; peduncle strongly armed with black, flattened comb-like spines; male rachillae slender, sterile basal part of rachillae enclosed within the basal bracts. Male flowers bifarious, narrowly oblong, obscurely 3-angled at base. Calyx campanulate, 3-lobed, lobes apiculate, corolla with 3 distinct petals. In female inflorescence rachillae without sterile basal part. Fruit ellipsoid, 3 cm x 2 cm, with distinct conical beak. Seed oblong to ovoid, terete in cross section; endosperm ruminate; embryo basal. Flowering twice in a year: April-May and August-September. Fruting time is October to February. Fruits are about 2 cm long, roundish, with a thin scaly pattern cover which turn reddish brown when ripe. The fleshy aril covered the seed (Fig.1).

The plant has medicinal uses (Basu 1992). The fruits are edible, stems are used for making baskets, chair, etc. (Angami *et al.* 2006). It is also used for making houses for chicken, making strings of the bows for teasing cotton. *C. erectus* is mostly used for garden fencing, making animal shades, structural material for making furniture (Alam 1990). Young shoots are eaten as vegetables; the fruits are also eaten by rural people. Seeds can be used as a substitute of betel nut. *C. erectus* is an important member of the family palmae in Bangladesh with limited occurrence. The population of the species is declining gradually. To stop the declining trend it is important to know its germination pattern, seedling raising technique and also plantation technique etc. for future plantation program. Considering the facts the study has been undertaken to develop nursery and plantation techniques.

Figure 1. *Calamus erectus* clump (A), Stem (B), Inflorescence (C), Fruits in the clumps (D), Whole fruits (E) and Clean seeds (F).

Materials and Methods

The study was carried out in the nursery of Bangladesh Forest Research Institute (BFRI), Chattogram, Bangladesh over a period of three years from June 2014 to May 2017. Geographic position of the study area is situated between 22⁰22.27″ and 22⁰29.0″ North latitude and 91⁰ 46.30″ and 91⁰46.30″ East 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 28.3 to 31.9⁰ C and from 15.2 to 25.2⁰ C (Hossain and Arefin, 2012). Mean annual rainfall is around 3000 mm mainly occurred from June to September.

Collection of seeds and germination trials

Ripen fruits of *Calamus erectus* were collected from natural forest of Sitakunda, under Chattogram district of Bangladesh in the first week of June 2014. The numbers of whole fruits and cleaned seeds per kg were 120 - 150 and 250 - 350 respectively. Clean seeds were obtained by removing the scale and pulp through rubbing. For germination trials clean seeds of *C. erectus* were sown in the seed bed filled with soil and decomposed cow dung mixture at a ratio of 3:1 by volume. Completely Randomized Design (CRD) was adopted for the experiment with three replications. Hundred seeds were sown in each replication and total of 300 seeds were sown for germination trial. Germination was recorded at 3 days interval till the end of the germinations.

Determination of optimum transplanting time of the seedlings

To determine the optimum transplanting time of seedlings from seedbed to polybag an experiment was conducted. Seedlings were transplanted to 23 cm x 15 cm size polybag filled with soil and cow-dung at 3:1 ratio. Transferring of seedlings started at 10 days of its germination and continued up to 80 days with 10 days interval. Survival percentages of the transplanted seedlings were recorded one month after transplanting.

Seedlings growth performance in the nursery and field condition

To determine the seedlings growth performance in the nursery and the field, the seedlings of *Calamus erectus* about 30-40 days old (with 1-2 leaves), were transferred to the polybags (23 cm x 15 cm in size) filled with soil mixed with cow dung (3:1). The polybags were kept under full shade for one week and then placed under direct sunlight and allowed them to grow there. Data on survival percentage shoot length, root length and leaf numbers of seedlings were also recorded at 3 months, 6 months, 12 months and 24 months after transferring in polybags. On the other hand, when the seedlings were about one year old, 125 seedlings were out planted in the field at the beginning of the monsoon (June-July). Seedlings were planted in the field at 2.0 m x 2.0 m spacing at Bangladesh Forest Research Institute campus, Chattogram, Bangladesh. Weeding was done at every three months in the first year and at every six months in second year in the field. Survival percentage of the planted seedlings in the field was determined one year after planting and heights of each plant were recorded at 6 months, 12 months and 24 months after planting.

Data analysis

Data were analyzed with computer software IBM SPSS ver. 21 to determine the significant ($p \leq 0.05$) variations among the treatments. Analysis of variance (ANOVA) and Duncan Multiple Range Test (DMRT) were carried out to analyze the data.

Results

Germination success

Germination of *C. erectus* seeds showed the similar trends like other members of Palmae. Germination of seeds started after 52 days from sowing and continued up to 76 days. Germination was recorded 78 % (Fig. 2).

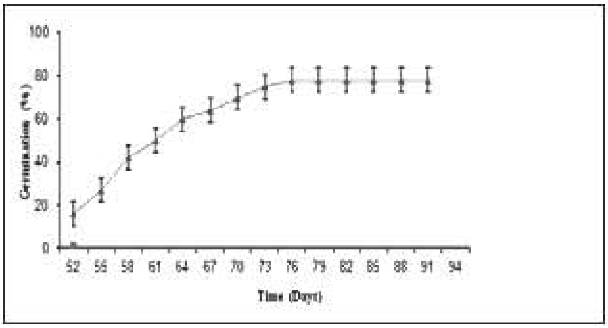

Figure 2. Germination of *Calamus erectus* over time.

Determination of optimum time for transferring of seedlings from seed bed to polybag

Ten days after germination, seedlings were transferred to polybags resulted 60% survival. Rest of the 40% seedlings were died. Seedlings transferring after 20 days of germination, survival were found 80%. Seedlings transferred after 30 days of germination, survival was recorded 100%. Similarly 100% seedlings survival was also recorded after 40 days of transferring from seed bed to polybag. Transferring of seedlings after 50 days of germination, survivality was noticed (90%). Transferring of seedlings after 80 days of germination, survivality was recorded 60% (Table 1). Survival percentage transferring after 30-40 days of germination was found significantly ($p \leq 0.05$) higher than other treatment. However, no significant variation was observed among 20, 50, 60 and 70 days after transferring.

Table 1. Seedling survival and performance of *C. erectus* after transferring to polybag over the time.

Days of transfer after germination	Survival percentage (%)	Average height of roots (cm)	Average length of shoots (cm)	Avg. no. of leaves per seedlings
10	60 ± 0.71^{d}	3.40 ± 0.18^{g}	2.75 ± 0.15^{f}	1.0 ± 0.0^{d}
20	80 ± 0.95^{c}	5.0 ± 0.14^{f}	4.15 ± 0.10^{e}	1.2 ± 0.13^{cd}
30	100 ± 0.0^{a}	8.10 ± 0.20^{e}	7.50 ± 0.22^{d}	1.5 ± 0.17^{bc}
40	100 ± 0.0^{a}	$8.5\ 0 \pm 0.16^{de}$	7.70 ± 0.19^{cd}	$1.6 \pm 0.\ 16^{b}$
50	90 ± 0.45^{b}	8.90 ± 0.12^{d}	8.15 ± 0.11^{bc}	1.7 ± 0.15^{ab}
60	80 ± 1.30^{c}	10.0 ± 0.22^{c}	8.5 ± 0.15^{ab}	1.8 ± 0.13^{ab}
70	80 ± 1.41^{c}	11.20 ± 0.19^{b}	8.75 ± 0.15^{a}	2.0 ± 0.0^{a}
80	60 ± 1.14^{d}	13.15 ± 0.21^{a}	8.90 ± 0.19^{a}	2.0 ± 0.0^{a}

Seedlings growth performance in nursery condition

Based on the findings of the previous experiment 30 to 40 days old seedlings having 1-2 leaves were transferred to the polybags filled with soil - cow dung media and allowed them for growing there (Fig. 3). After one year of transferring the seedlings in the polybags, 125 seedlings were out planted in the field. Rests of the seedlings were grown in the nursery for one more year. Seedlings growth performance recorded in the nursery bed at different age shown in Table 2. Seedlings attained 15.6 cm height (above ground) with average length of root 13.2 cm and 2.4 leaves in 3 months. After 6 months the seedlings became quite tough and attained average height of 22.4 cm with 15.6 cm root and 4.8 leaves. The average height of the seedlings was 30.2 cm with 19.6 cm root and 6.8 leaves were recorded at 12 months. The seedlings attained a height of 62.4 cm with 25.4 cm long root and 10.4 leaves at 24 months (Table 2).

(A) (B) (C)

Figure 3. Different stages of seedlings of *C. erectus*. One-month old seedlings of *C. erectus* in nursery bed (A) an individual seedling prior to transfer into the polybag (B) and six-months old seedlings in the nursery (C).

Table 2. Seedling growth and survival performance of *Calamus erectus* at different age (up to 24 months) in the nursery.

Age of seedlings (months)	Survival (%)	Average height (cm)	Average length of roots (cm)	Average no. of leaves per seedlings
3	100 ± 0.0[a]	15.6 ± 0.51[d]	13.2 ± 0.37[d]	2.4 ± 0.24[d]
6	100 ± 0.0[a]	22.4 ± 0.74[c]	15.6 ± 0.50[c]	4.8 ± 0.37[c]
12	98 ± 1.58[b]	30.2 ± 1.01[b]	19.6 ± 0.67[b]	6.8 ± 0.49[b]
24	98 ± 1.0[b]	62.4 ± 1.28[a]	25.4 ± 0.74[a]	10.4 ±0.50[a]

Note: The figure in each column mean followed by standard error (SE) of means.

Seedlings survival and growth performance in the field

One-year old seedlings of *C. erectus* were planted in the field. Survival was recorded after one year of out planting and seedlings growth performance was recorded at 6, 12 and 24 months after planting in the field (Table 3). Survival percentage varied from 92 - 96 with an average of 94 among the plots. The seedlings height varied from 44.1 - 48.5 cm at six months; 61.0 - 70.3 cm in one year and 90.0 to 102.2 cm in two years after planting in the field (Table 3).

Table 3. Survival percentage and seedling growth performance of *Calamus erectus* after out planting.

Plots	Survival % at 12 month	Average Height (cm)		
		6 months	12 months	24 months
Plot-1	94 ± 0.71[ab]	44.1 ±1.49[b]	63.6 ±1.36 [bc]	93 ±1.0 [bc]
Plot-2	92 ± 0.45 [b]	46.9 ±1.0[ab]	68.2 ±1.56 [ab]	97.4 ±2.18[ab]
Plot-3	96 ± 0.95 [a]	48.5 ±0.92[a]	70.3 ±1.70[a]	102.2 ±1.96 [a]
Plot-4	96 ± 1.58 [a]	44.1 ±1.46[b]	61.4 ±2.01 [c]	90.2 ±1.85 [c]
Plot-5	92 ± 1.26 [b]	44.0 ±1.29[b]	61.0 ±1.52[c]	90.0 ±1.58 [c]

Discussion

Similar to other members of the family Palmae, the species *Calamus* required long time to germinate. Generalao (1980) reported that cane seeds take weeks to six months to germinate depending on the species and method of treatment. Sumantakul (1989) reported that *C. longisetus* seed starts to germinate from 30 days and continues till 60 days in different media. Banik and Nabi (1979) mentioned that the seeds sown with intact sarcotesta require two or three months to start germination and give poor germination percentage (10-26 only). Haider *et al.* (2014) reported that clean seeds of *Calamus longisetus* started germination after 56 days of sowing (DAS) and continued up to 106 DAS, and showed 60% germination. Alam *et al.* (2020) also reported that *Calamus latifolius* seeds started germination after 54 days of sowing and continued until 74 days and showed maximum germination (70%) with scarified seeds by wire net. Ara (2008) reported that *Calamus erectus* showed 55% germination from seeds collected during May. The study revealed that *C. erectus* started germination after 52 days of sowing and continued up to 76 days with maximum 78% germination. Germination trends showed the resemblance to other findings mentioned here. However, germination percentage of present study was recorded higher (78%) in comparison to Ara (2008), which may be due to seed collection time.

Age of seedlings is an important factor for its survival after transferring from seed bed to polybag. It was noticed from the experiment that 30 - 40 days after germination pricking of seedlings showed 100% survival. It means that 30-40 days after germination is optimum time for pricking out the seedlings from seed bed and transferring to polybag. After 50 days gradually mortality of the seedlings was noticed. Eighty days after germination and transfer of the germinated seeds to polybag 40% seedling mortality was noticed. Feaw (1994) reported that when the first leaves are fully expanded, rattans seedlings are generally ready for transferring in the polybags which is similar to the present study findings. Mohiuddin *et al*. (1986) reported that gradual increase in survival with delayed transferring after sprouting for *Calamus tenuis*. Siddiqi *et al*. (1998) reported that seedlings of *Calamus viminalis* transfer to polybag in 90 days after germination, seedlings mortality was noticed. Haider *et al*. (2014) reported that delayed pricking, 100-120 days after sowing the seeds from nursery bed to polybag ensures least or no mortality. The variation among the rattan species may be due to nature of the species. Initial growth performance of the seedlings in the nursery showed that progressive growth in root and shoot length and number of leaves with the age of seedlings. Outcomes of the present study are analogous to findings of Haider *et al*. (2014) in case of *Calamus longisetus* and Alam *et al*. (2020) in case of *Calamus latiflolius.*

The height growth of seedlings in the field was found higher in plot 4 than the other plots and lowest in plot 5. This variation of the seedlings height growth was probably due to the microclimatic conditions of the plots. Since the survival percentage of the seedlings in the field was quite satisfactory (92-96%), outplanting of one-year old seedlings may be considered for the planting of the species in the field. The finding is like to the report of Alam *et al*. (2020) in case of *Calamus latifolius* and report made by Siddiqi *et al*. (1998) for *Calamus viminalis* in Bangladesh. Kerala Forest Research Institute, India also made similar report and mentioned that rattan seedlings were outplanted at the age of one year.

Conclusion

Germination behavior of *Calamus erectus* is similar to other members of the family Palmae and needs longer time to germinate. *C. erectus* seeds started to germination after 52 days of sowing and completed within 76 days. Pricking of seedlings at 30-40 days old from nursery bed to polybags ensures least or no mortality of the seedling. Survival of seedlings and growth performance in the field was satisfactory when one year old seedlings were out-planted at 2.0 m x 2.0 m spacing. Therefore, clean seeds are suitable for nursery raising and one year old seedlings of *Calamus erectus* may be recommended for plantation program.

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In vitro Micro-propagation of *Acacia* Hybrid through Shoot Tip Culture

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Abstract

Propagation and conservation by vegetative means were attempted for better preservation of true-to-type genetic characteristics with higher yield planting materials of *Acacia* hybrid. In this regard, *in vitro* micro propagation of *Acacia* hybrid through shoot tip culture was initiated from outdoor mature plant on MS basal medium supplemented with 1.0 mg/L BAP. The shoot tip cultures produced axillary shoot bud and used for multiple shoot production. The multiple shoot production rate was optimized on MS medium supplemented with different concentrations of cytokinins. The highest number (20) of multiple shoots per culture was recorded on MS medium augmented with 2.0 mg/L BAP after 8 weeks of culture. The rooting was initiated on ½ MS medium enriched with different concentrations of IBA. The best rooting rate 90% was obtained on medium having 2.0 mg/L IBA after 28 days of culture. The well-developed rooted plantlets were transferred to *in vivo* condition for further growth and acclimatization. More than 95% of transplanted plantlets survived and grew well in polybag under natural condition.

সারসংক্ষেপ

একাশিয়া হাইব্রিড এর সঠিক কৌলিক বৈশিষ্ট্য ও উচ্চতর উৎপাদনশীল চারা উৎপাদনের উদ্দেশ্যে অঙ্গজ প্রক্রিয়ায় বংশবিস্তার ও সংরক্ষণের পরীক্ষা করা হয়। এ লক্ষ্যে বাইরে জম্মানো একাশিয়া হাইব্রিডের একটি পূর্ণ বয়স্ক গাছের শাখার শীর্ষাগ্র এম এস খাদ্য মিডিয়ামে ১.০ মিলিগ্রাম/লি. হারে BAP প্রয়োগ করে ইন ভিট্রো মাইক্রোপ্রোপাগেশন প্রক্রিয়ার সূচনা করা হয়। প্রাথমিকভাবে গজানো নতুন বিটপ (shoot) কে নতুন খাদ্য মিডিয়ামে স্থানান্তরের মাধ্যমে পুনরায় আরো বিটপ জন্মানো হয়। বিটপ জন্মানোর হারকে সর্বোচ্চ মাত্রায় নেবার জন্য বিভিন্ন ঘন মাত্রায় সাইটোকাইনিন খাদ্য মিডিয়ামে প্রয়োগ করা হয়। এ পর্যায়ে ৮ সপ্তাহ পর ২.০ মি.গ্রাম/লি. BAP এবং ৩% সুগার সম্বলিত এমএস মিডিয়াম থেকে প্রতি কালচার প্রতি সর্বোচ্চ সংখ্যক ২০টি বিটপ পাওয়া যায়। উৎপাদিত বিটপগুলিতে শিকড় গজানোর জন্য অর্ধ শক্তির এমএস মিডিয়ামে বিভিন্ন মাত্রার IBA প্রয়োগ করা হয়। দুই (২.০) মি.গ্রাম/লি. IBA যুক্ত মিডিয়ামে ২৮ দিন পর শতকরা ৯০ ভাগ বিটপে শিকড় উৎপাদন হয়। শিকড়যুক্ত বিটপগুলিকে হার্ডেনিং করার জন্য পলিব্যাগের মাটিতে স্থানান্তর করা হয়। এভাবে শতকরা ৯৫ ভাগ উৎপাদিত চারা বেঁচে থাকে এবং পলিব্যাগে ভালভাবে প্রাকৃতিক পরিবেশে বেড়ে ওঠে।

Key words: Micro propagation, Multiplication, *Acacia* hybrid, Shoot tip, MS medium, Plantlets.

Introduction

The *Acacia* hybrid, a cross between *Acacia mangium* and *Acacia auriculiformis*, grows in Indonesia, Malaysia, Thailand, Vietnam, and China (Kha 1996). It is a medium-sized tree that looks similar to *A. mangium*. The tree can reach 8 to 10 m and 7.5 to 9.0 cm diameter within 2 years. It has been gained an increasing interest in reforestation programs under the humid tropical conditions. The species grows on sandy loam or sandy clay loam soils; however, it also thrives on lateritic crude soils.

A. mangium, being one of the selected fast growing species has become an important choice of species in agroforestry. It originates from the humid tropics of Northern Australia, Papua New Guinea, Eastern Indonesia and Malaysia (Ahmad and Kamis 1999). It is potentially an important timber where the wood being suitable for furniture, and cabinet making as well as particleboard and pulp production. Also used as firewood and occasionally planted as an ornamental, for erosion control or as a fire-break or wind-break. The pulp is readily bleached to high brightness levels for making paper. While the *A. auriculiformis* found in Australia, southwestern Papua New Guinea and Indonesia is planted widely in tropical Asia. It has been established in western Malaysia.

A. auriculiformis has become a major source of firewood; its dense wood and high energy (calorific value of 4500 to 4900 kcal/kg) contribute to its popularity. It provides very good charcoal that glows well with little smoke and does not spark. The wood is extensively used for paper pulp and is excellent for turnery articles, toys, carom coins, chessmen and handicrafts. It is also used for furniture, joinery, tool handles, and for construction if trees of suitable girth are available. However, the *A.* hybrid differs from *A. auriculiformis* and *A. mangium* in several ways. When *A.* hybrid is young, the bark is greenish white, similar to the bark of *A. auriculiformi*s. As it ages, the bark turns greenish brown or brown. It is as smooth as the bark of *A. auriculiformis*, with slightly scalely and shallow furrows at the foot of the tree (Kha 1996).

The hybrid's branching behavior differs from *A. mangium* and *A. auriculiformis*. The tree has many small and light branches that can be easily pruned. Its main stem, though not as straight as that of *A. mangium*, is much straighter than the main stem of *A. auriculiformis*. Unlike the stem of *A. mangium,* that of *Acacia* hybrid has no angles or ribs (Kijkar 1992). Its phyllode is about 4 to 6 cm wide and 15 to 20 cm long with four veins similar to those of *A. mangium*, but the vein on the outer edge of the crescent is not easy to see. Its seeds are similar in appearance to those of *A. auriculiformis* except that the funicles of the hybrid are lighter and are only partly attached to the seeds (Kijkar 1992). The hybrids tend to grow vigorously, have better form than *A. auriculiformis* and have lighter branching than *A. mangium* which is self-prune (Rufelds and Lapongan 1986). It has a slightly higher wood density, is good for producing chipwood, pulp, paper production, medium density fiber board, oriented-strand board, for general construction and furniture.

Seed collected from *Acacia* hybrid trees yields highly variable and poorly performing offspring and are not commonly used in regeneration. *A*. hybrid seeds are not commonly used in regeneration programs because they may produce *A. auriculiformis* (52%) or *A. mangium* (2-3%) (Kijkar 1992). Propagation and conservation by vegetative means are desirable for better preservation of true-to-type genetic characteristics with higher yield planting materials can be obtained within minimum time period.

Plant tissue culture technology has a potential to overcome this problem where it allows efficient and rapid clonal propagation of many economically important species. However, the low survival percent of *in vitro* plantlets during the *ex vitro* acclimatization and delivery to the field poses many problems to make tissue culture technology a viable alternative proposition. Germplasm conservation has become necessary for future sustainable harvesting systems and as a means of maintaining species diversity to prevent genetic erosion. *In vitro* micro propagation technique may be reliable method for long-term storage of plant genetic resources without apparent risk of genetic instability using minimum space and with lower labour and maintenance costs. Tissue culture techniques have also been successfully developed using aseptic emerging seedlings as multiplication materials (Darus 1993). Monteuuis *et al.* (2012) reported the organogenic capacity for shoot multiplication by axillary budding, with average multiplication rates of 3–5 every 2 months, as well as for adventitious rooting of *Acacia* hybrid.

The present study described the *in vitro* response of shoot tip explant collected from mature outdoor *Acacia* hybrid plant on the medium with different concentrations of plant growth regulator and the subsequent plant production.

Materials and Methods

Plant materials

Shoot tip explants were collected from outdoor mature *Acacia* hybrid plant and brought to the tissue culture laboratory for *in vitro* culture establishment. The experiments were carried out at the tissue culture laboratory and the nursery of Silviculture Genetics Division of Bangladesh Forest Research Institute, Chattogram, Bangladesh.

Explants preparation and surface sterilization

The collected shoot tips were cut about 10 cm length, sealed in plastic bags, and brought back to the laboratory. The shoot tip explants were rinsed under running tap water for 30 minutes. After that explants were carried under laminar air flow. The surface sterilization was started with one drop of tween 20 for 7-10 minutes with frequent shaking and washed with sterilized distilled water for 2-3 times. Then the explants were immersed in 70% ethanol for 1 minute and sterilized with 20% Clorox® for 15 minutes, and rinsed with sterilized distilled water for 3-4 times. Again sterilization was done for 10 minutes and rinsed with sterilized distilled water. The shoot tips were then dissected into 1.0-1.5 cm length for culture initiation.

Culture media preparation

The surface sterilized shoot tips were inoculated onto Murashige and Skoog (1962) medium comprising 3% sucrose as carbon source and 2.8 gm/L gelrite as solidifying agent for initial growth. Various plant growth regulators such as; cytokinins (BAP & Kn) and auxins (IBA & NAA) were used to prepare MS medium for explant establishment, multiple shoots production and root induction of the regenerated new shoots. MS medium devoid of growth regulators used as control treatment. The pH of the medium was adjusted to 5.8 using 0.1 N NaOH or 0.1 N HCl before addition of gelrite and sterilized by autoclaving at 1.08 kg/cm^2 pressure and 121^{0} C for 20 minutes.

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 tabulated.

Multiple shoots production and optimization

The aseptic shoot tips were cultured on MS medium supplemented with 0.0 (MS 0/control), 0.5, 1.0, 1.5 and 2.0 mg/L of BAP. Number of shoots per explants and their morphology were observed periodically. To optimize the shoot production, effect of sub culturing and the strength of sucrose level in culture medium were evaluated. Rate of multiplication of shoots and their growth were recorded up to 3-8 weeks of culture.

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

In vitro elongated shoots (6-7 cm) were taken from the 5th cycles of multiplication stages. Treatments used for induction of rooting were ½ MS medium supplemented with different concentrations (0.0, 0.5, 1.0, 2.0 mg/L) of IBA with control. One-month *in vitro* rooted shoots were used for acclimatization in the greenhouse. When the plantlets developed few leaves and roots on the rooting medium, they were taken out from the culture vessels, washed thoroughly running tap water to remove the debris gelling agent with care and transferred to polybag (20 cm × 40 cm). Potted shoots were kept in greenhouse covered with black netting to maintain low temperature and high humidity. The temperature was in the range of 25–30° C and relative humidity was approximately 80% with 50% shade. After 7 days, the covering bags were finally removed. Sudden removal of covering bags had adverse effect on establishment. The potted plants were brought out from the green house and kept under full sunlight for 2-3 hours per day. The plants were successfully acclimatized in natural conditions under sunlight and they eventually became suitable for final plantation. About 90% potted plants established successfully.

Statistical analysis

All experiments were performed as Completely Randomized Design (CRD). Data were analyzed using statistical analysis system (SAS v 9.3) 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 thrice.

Results

In vitro explant establishment

In vitro culture established from shoot tip explants collected from outdoor mature plant. The single shoot tips (1.0-2.0 cm) were cultured on MS basal medium supplemented with lower concentrations of cytokinin BAP (0, 0.5, 1.0, 1.5 and 2.0 mg/L) as well as with control. It was observed that MS basal medium devoid of plant growth regulators (PGR) did not support enough to response the culture for further growth. Besides, the cultures supplemented with different concentrations of BAP attained for quick response. Best response (100%) was recorded in MS basal medium supplemented with 1.0 mg/L BAP after 2 weeks of culture (Fig.1, Fig. 3A.). The explants with new shoots were transferred for regeneration of multiple shoots and optimization of shoot growth.

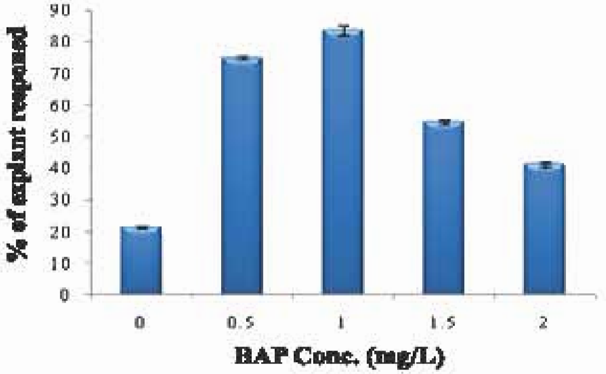

Figure 1. Effect of different concentrations of BAP on shoot induction from shoot tip explant of *Acacia* hybrid .

Optimization of multiple shoot production

Effect of BAP and Kn on multiple shoot formation

The effect of two cytokinins BAP and Kn were evaluated for multiple shoot formation and optimization. There were significant differences at different levels of BAP and Kn on shoot induction in terms of the percentage of shoot regeneration and the mean number of shoots produced. MS medium supplemented with different concentrations (MS 0, 1.0, 2.0, 3.0, 4.0 mg/L) of BAP and Kn alone or in combination. The results showed that MS medium without plant growth regulators induced a very little number of shoots whereas the supplementation of plant growth regulators enhanced shoot formation rate. The highest percentage of shoot regeneration (100%) was in MS medium with 2.0 BAP along with the highest mean number of shoots (20) and mean length of shoots (8 cm) (Fig.2, Fig.3C & 3D) followed by 2.0 mg/L Kn (12.66 number of shoots and mean length of shoots 6 cm) after 8 weeks of culture (Fig. 2, Fig. 3E).

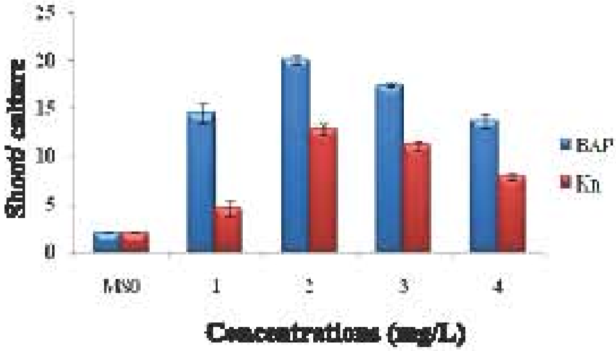

Figure 2. Effect of different concentrations of cytokinin on shoot multiplication of *Acacia* hybrid after 8 weeks of culture. Each value is the mean of three replications. Vertical bars indicated standard errors.

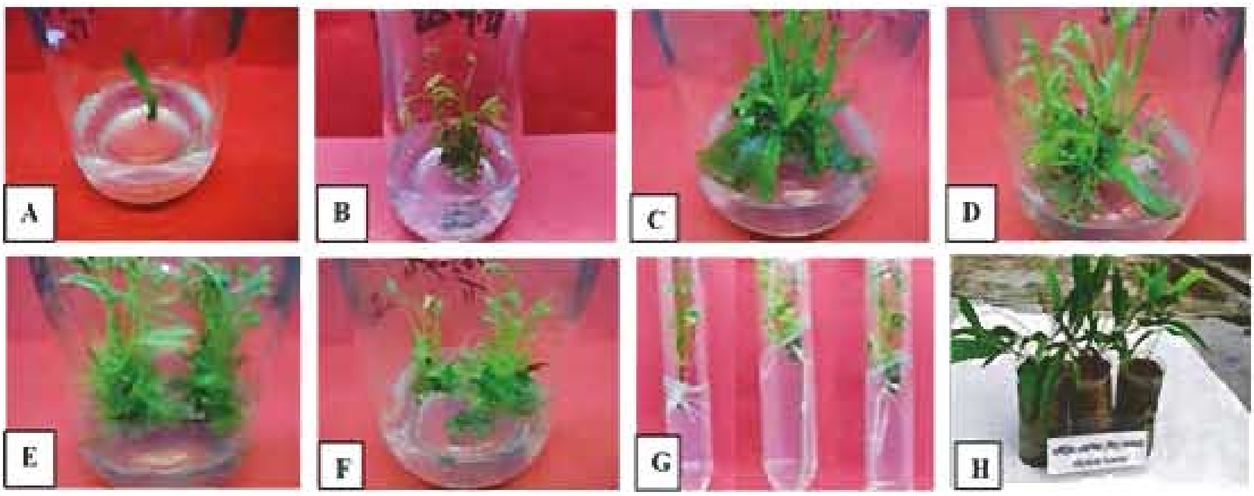

Figure 3. Effect of different concentrations of BAP and Kn in MS medium on culture establishment, multiple shoot production and optimization of *A.* hybrid (A-F). (A) Shoot tip culture on MS medium with 1.0 mg/L BAP, (B) Shoot multiplication control (MS0), (C&D) MS + 2.0 mg/L BAP + 3% Sugar, (E) MS + 2.0 mg/L Kn + 3% Sugar, (F) MS + 2.0 mg/L BAP + 2.0 mg/L Kn, (G) Root induced on excised in vitro grown shoots, (H) *Acacia* hybrid tissue cultured plants in polybags after hardening.

Qualitative observation of the shoots showed that shoots in 2.0 BAP were greener and more vigorous compared to shoots cultured in higher concentrations of BAP such as 4.0 mg/L which were pale green and fragile. Shoots in MS medium without any plant growth regulators were less elongated and did not produce any multiple shoots, but remained healthy. In compare the two cytokinins BAP was found more potential than Kn for new shoot regeneration of *Acacia* hybrid. A combined effect of BAP with different concentrations of Kn was also evaluated for the optimization of multiple shoot production. However, both the cytokinins BAP and Kn alone enhanced the shoot proliferation *of Aca*cia hybrid. When BAP was combined with different concentrations of Kn (0.0, 1.0, 2.0, 3.0 and 4.0 mg/L), the best response for shoot production (12.00) and shoot length (6.28 cm) was recorded on medium containing 2.0 mg/L BAP + 2.0 mg/L Kn + 3% sugar after 8 weeks of culture. (Table 1, Fig. 3F).

Table 1. Combined effect of BAP and Kn on shoot multiplication of *Acacia* hybrid.

Hormonal concentration (mg/L)	Number of shoot/explants	Shoot length (cm)
2.0 BAP + 1.0 Kn	10.33 ± 2.00	2.30 ± 0.08
2.0 BAP + 2.0 Kn	12.00 ± 3.00	6.28 ± 0.38
2.0 BAP + 3.0 Kn	10.33 ± 2.00	4.45 ± 0.28
2.0 BAP + 4.0 Kn	8.00 ± 2.50	3.49 ± 0.26

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

Effect of subculture on multiple shoot production

The effect of sub culturing on multiple shoot production of *Acacia* hybrid was evaluated. Every 2 weeks of interval sub-cultures were maintained for multiple shoot formation. It was observed that the shoots regenerated in each sub-culture without loss of morphological responses. In the first sub-culture, the mean of shoots per culture was 6.0 and it increased up to the 4th sub-culture as 20.0 shoots/culture. After excision of the multiple shoots, when the mother explants was cultured on the fresh shoot multiplication medium then the shoot numbers were increased significantly for the next 4 repeated transfers and reduced thereafter. Incorporation of Kn into MS medium supported shoot multiplication. However, BAP proved to be a better choice than Kn because the maximum mean number of shoots 20.0 per culture was obtained on 2.0 mg/L BAP after 8 weeks of culture (Fig. 2, Fig. 3C & 3D). In the fifth sub-culture the shoot number decreased as 14.0 shoots/culture which trend to the subsequent sub culture (Fig. 4).

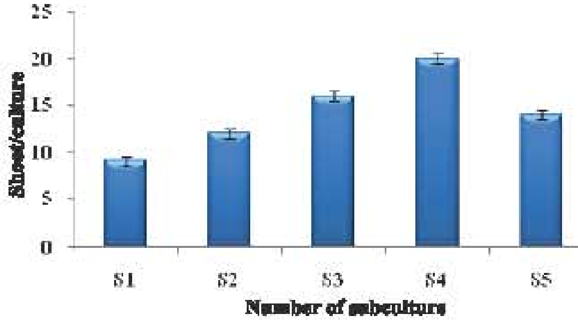

Figure 4. Effect of subculture on multiple shoot production of *Acacia* hybrid. The vertical bar represents the standard error.

Effect of different sucrose level on multiple shoot production

The sucrose level of cultures was optimized in respect to multiple shoot production on MS medium containing 10, 20, 30, 40 and 50g/L. The number of shoots per culture increased in the media having sucrose level from 10 to 30g/L. The culture media supplemented with 30g/L sucrose produced the maximum shoots with a mean of 20.33 per culture after 8 weeks. Meanwhile 50g/L sucrose induced lowest 9 shoots/culture respectively (Fig. 5 & Fig. 3C). Shoots in 50g/L sucrose were small and less elongated compared to shoots in other concentrations of sucrose (Fig. 3D).

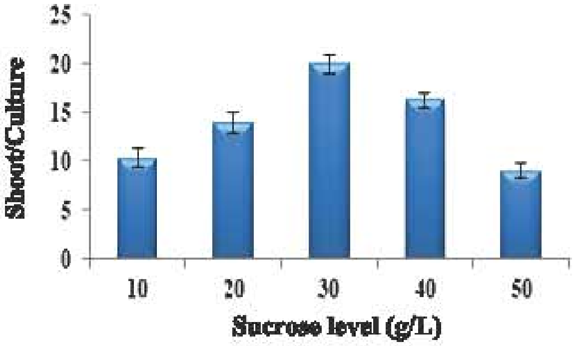

Figure 5. Effect of different sucrose concentrations supplemented with MS medium on multiple shoot production from shoot tip explants of *Acacia* hybrid. The vertical bar represents the standard error.

Effect of different concentrations of auxin on *in vitro* rooting of excised shoots

Optimization of *in vitro* rooting of excised shoots were carried out in ½ MS medium supplemented with different concentrations of IBA viz. 0.0, 1.0, 2.0 and 3.0 mg/L. It was observed that no roots produced in the auxin free MS medium. The highest percentage of shoots was rooted (90%) in MS medium supplemented with auxin IBA. The average number of root formation was significantly higher on hormone containing medium. Among the different concentrations of IBA, the maximum mean number of roots per shoot was 5.0 produced in media supplemented with 2.0 mg/L IBA after 4 weeks of culture. The average number of roots reduced to 3.33 roots/shoot at 3.0 mg/L IBA with the subsequent higher concentrations of IBA (Fig. 6, Fig. 3G).

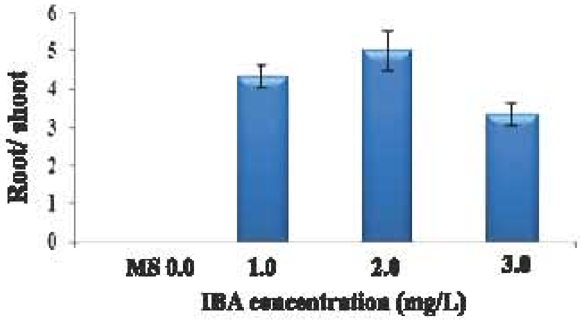

Figure 6. Effect of different concentrations of auxin, IBA supplemented with MS medium on root induction of *Acacia* hybird from *in vitro* regenerated shoots after 4 weeks of culture. The vertical bar represents the standard error.

There were significant differences on the percentage of shoots rooted, mean number of roots, mean length of roots, mean number of axillary roots, mean length of axillary roots, and mean height of shoots from the different concentrations of IBA tested.

Transfer of rooted plant in soil and hardening

In vitro rooted plantlets were initially hardened in culture room conditions where leaves expanded. After 2 weeks, the plantlets were shifted to green house and mist house subsequently. About 90% plantlets were successfully acclimatized in small poly bag containing sterilized soil (Fig. 3H).

Discussion

Rapid shoot multiplication and mass production of *Acacia* hybrid was initiated through shoot tip culture collected from outdoor growing mature plant. However, most of the reports on micro propagation of *Acacia* have used explant from aseptically grown seedlings. Full strength MS medium supplemented with different concentrations of BAP and Kn as well as the devoid of phytohormones were evaluated for culture initiation, multiple shoot production and optimization. It was observed that the shoot tip culture of *Acacia* hybrid proliferated faster with the addition of cytokinins than the medium devoid of plant growth regulators. The supplementation of plant growth regulators were positively influenced the shoot proliferation of *Acacia* hybrid. Rahman *et al.* (2018) stated that shoot proliferation of *Phylanthus emblica* were faster with the addition of cytokinins than the medium devoid of plant growth regulators. *In vitro* grown single shoot was able to produce multiple shoots in MS medium supplemented with different concentrations of cytokinins BAP and Kn. MS medium has also been used in most work on micro propagation of *Acacia* species (Nangia and Singh 1996; Ismail *et al.* 2012; Griffin *et al.* 2014).

Experiment conducted for shoot production and optimization on MS medium supplemented with different concentrations of BAP and Kn singly or in combination. The shooting variation due to cytokinin BAP concentrations revealed that low concentration of BAP (2.0 mg/L) were sufficient for shoot initiation in terms of the mean number of shoots and shoot elongation for *in vitro* grown shoots of *A.* hybrid. According to Darus (1991b) and Galiana *et al.* (1991), low level of BAP (2.22 μ M) was good for shoot multiplication and elongation of *A. mangium*. Higher rates of cytokinin have caused production of many small shoots which typically fail to elongate and/or induce shoots to become hyperhydric (George 1993). For instance, in this study, shoots produced in higher concentration of BAP (4mg/L) exhibited characteristics less vigorous shoots with small stunted shoots at the base.

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). The regeneration efficiency depended on plant growth regulator concentrations and combinations (Nodong *et al.* 2006; Popelka *et al.* 2006). 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 plantlet formed were slightly taller than those produced in MS medium supplemented with Kn. Cytokinin types had a strong effect on the quality of the shoots produced (Rahman *et al.* 2018). The growth of plantlets was retarded at higher concentration of BAP. Kalinina and Brown (2007) found that treatments of *Prunus* sp. with elevated BAP concentrations promoted the shoot numbers per explants but decreased the shoot length and negatively affected shoot development.

In this study, all the formulations of BAP combined with Kn regenerated and produced multiple shoots. The results showed that the addition of lower level of BAP and Kn to the medium enhanced the shoot regenerative ability in *Acacia* hybrid. However, the number of multiple shoot reduced at higher concentration of BAP and Kn. The combined effect of BAP and Kn on multiple shoot production was observed. All the combinations produced new shoots in the culture medium and elongated the shoots. Similar results were observed in *P. emblica* (Rahman *et al*. 2018). Sub-culture exercised an important role on the shoot 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). Plant tissue might have a chance to develop mutation due to repeated sub culturing, or it might produce callus, became abnormal and reduced the proliferation rate. The result revealed that *A.* hybrid did not show morphological changes after repeated sub-culturing. The number of shoots increased up to the 4th subculture then decreased by the repeated sub-culturing. Likewise, it was reported that the long term culture of *Digitalis obscura* did not affect the genetic stability *in vitro* (Gavidia *et al*. 1996). The shoot production ability varied greatly among different species. Thong (2002) reported that repeated sub-culturing caused shoots reduction in *Zingiber officinale*, *Curcuma domestica*, *Alpinia galanga*, and *Kaempferia galanga* In contrast, repeated sub-culturing of *in vitro* shoot of *Spilanthes acmella* increased the multiple shoots formation by three hold (Ang and Chan 2000). Romano *et al*. (1995) found 30 g/L sucrose was the best carbon source for proliferation of *Quercus robur* (English Oak) which favored shoot elongation. In this study, the quality of *Acacia* hybrid shoots was observed to be good in 20 to 30 g/L sucrose. The shoots produced in 40-50 g/L sucrose were less elongated compared to others and had the lowest number of shoots per explant. This effect might be a result of due to the carbohydrate concentration (sucrose) modifying the osmotic strength of the medium. At a high osmotic strength the medium was shown to reduce plant height and slow growth (Short *et al*. 1987). Maretzki *et al*. (1972) also found that when the concentration of sucrose in a high salt medium such as MS medium was increased above 4-5% (40-50 g/L), there would be a progressive inhibition of cell growth in many types of cultures. This appears to be an osmotic effect because addition of other osmotically active substances (such as mannitol and polyethylene glycol) to the medium also caused similar responses.

Higher plants grown *in vitro* were fully autotrophic (Lipavska and Vreugdenhil 1996). Therefore plant tissues culture required an exogenous carbon source and generally sucrose, is an essential ingredient of all culture media (Kozai 1991b). This is because in the culture vessels, photosynthesis was insufficient due to growth taking place in conditions unsuitable for photosynthesis or without photosynthesis (in darkness) and the concentration of carbon dioxide (CO_2) was limited for photosynthesis. Debnath (2005) reported that specific carbohydrate may have different effects on morphogenesis *in vitro*, thus the carbohydrate requirements must be defined and optimized for each propagation system. The effect of carbohydrate type and concentration on shoot proliferation were genotype dependent. In this study 3% sucrose was a most optimum carbon source for *in vitro* multiple shoot formation in *Acacia* hybrid. Pati *et al*. (2006) found that sucrose concentration in culture medium had significant effect on shoot and root regeneration. High concentration of sucrose was deleterious to shoot growth and caused decrease in dry matter accumulation due to decrease in osmotic potential of the medium (Lipavska and Vreugdenhil 1996). Increasing sucrose levels 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 medium without carbohydrate.

Initially it was difficult to induce roots of the excised shoots. Systemic experiments were needed to carry out to define the condition for root induction. Excised shoots were cultured on both hormone free and with different concentrations of IBA viz. 0.0, 1.0, 2.0, and 3.0 mg/L. No rooting was observed in the hormone free medium. Only root induced when half strength MS medium supplemented with auxin. Media having ½ MS with IBA 2.0 mg/L significantly supported the highest number of roots of *A*. hybrid. Comparatively the lower concentration of IBA induced maximum roots on excised shoots. Similar observation was found by Rahman *et al* (2018). In woody trees, usually low level of salt concentration is sufficient for rooting of shoots.

Conclusion

In conclusion, our present investigation, describes a regeneration method for *A*. hybrid from the shoot tip explants of outdoor mature plant. MS medium supplemented with 2.0 mg/L BAP may be recommended for maximum multiple shoot production. Half strength of MS medium with 2.0 mg/L IBA found the best combination for *in vitro* root induction on the micro shoots. Therefore, the method can be used for large-scale commercial production of *A*. hybrid.

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Volume Equations and Tables for Planted and Natural Stands of *Sonneratia apetala* Buch.-Ham. in the Coastal Areas of Bangladesh

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Abstract

Keora (*Sonneratia apetala* Buch.-Ham.) is one of the most important tree species for large scale plantations in the coastal areas of Bangladesh. The aim of this study was to generate a common volume equation and table for predicting the total and merchantable volume of planted and natural stand of *S. apetala* in the coastal areas of Bangladesh. A total of 430 sample trees having different girth classes were sampled from the plantation stands of Chattogram, Noakhali, Bhola and Patuakhali. Twenty one (21) models were tested to derive best-fit models for the volume over bark and under bark. The best fit models were selected based on the highest value of R^2 (co-efficient of determination), the lowest value of Akaike Information Criterion (AIC) and Root Mean Square Error (RMSE). The selected models were validated by Chi-square test of goodness of fit, Paired t-test, Percent Absolute Deviation (% AD) and 45 degree line test. The best-fit one-variable and two-variable basic models were and respectively. The best-fit models showed the highest efficiency in volume estimation compared to previous developed model in terms of Model Prediction Error (MPE), Model Efficiency (ME) and Root Mean Square Error (RMSE).

সারসংক্ষেপ

বাংলাদেশের উপকূলীয় অঞ্চলে ব্যাপক আকারে বৃক্ষরোপণের জন্য কেওড়া একটি গুরুত্বপূর্ণ বৃক্ষ প্রজাতি। এই গবেষণার উদ্দেশ্য হলো সৃজিত ও প্রাকৃতিকভাবে জন্মানো কেওড়া গাছের মোট আয়তন ও বিক্রয়যোগ্য আয়তনের সাধারণ গাণিতিক সমীকরণ নির্ণয় ও সারণী তৈরী করা। এই উদ্দেশ্য বাস্তবায়নের জন্য চট্টগ্রাম, নোয়াখালী, ভোলা এবং পটুয়াখালী উপকূলীয় বনাঞ্চল হতে বিভিন্ন বেড় শ্রেণির ৪৩০ টি দাঁড়ানো গাছের উপাত্ত সংগ্রহ করা হয়। বাকলসহ এবং বাকলছাড়া আয়তন নির্ণয়ের সেরা মডেল বের করার জন্য একুশটি (২১) মডেল পরীক্ষা করা হয়েছে। সর্বোচ্চ R^2 (coefficients of determination) মান, সর্বনিম্ন AIC (Akaike Information Criterion) Ges RMSE (Root Mean Square Error) দ্বারা সেরা-যথাযথ মডেল নির্বাচন করা হয়েছে। নির্বাচিত মডেলগুলি কাই-বর্গ, জোড়া টি-টেস্ট, Percent Absolute Deviation (%AD) এবং ৪৫ ডিগ্রি লাইন পরীক্ষা দ্বারা বৈধতা পরীক্ষা করা হয়েছে। একমূখী আয়তন নির্ণয়ে এবং দ্বিমূখী আয়তন নির্ণয়ে মৌলিক মডেলদ্বয় সেরা মডেল নির্বাচিত হয়েছে। সেরা ফিট আয়তন নির্ণয়ের মডেলগুলি, মডেল পূর্বাভাস ত্রুটি (MPE), মডেল দক্ষতা (ME) এবং রুট মিন স্কয়ার ত্রুটি (RMSE) বিবেচনায় পূর্ববর্তী উন্নয়নকৃত মডেলের তুলনায় আয়তন অনুমানের সর্বোচ্চ দক্ষতা দেখিয়েছে।

Key words: *Sonneratia apetala*, Total volume, Volume model, Volume table.

Introduction

Keora (*Sonneratia apetala* Buch.-Ham, Family-Lythraceae) is the pioneer mangrove species that can attain a height of about 20 m and a diameter of about 80 cm (Siddiqi 2001, Mahmood 2015). *Sonneratia apetala* is a fast growing compared to other mangrove species. It is a strong light demanding species. The tree occurs on newly accreted soil in moderately to strongly saline areas and is considered as a pioneer species in ecological succession (Mahmood 2015). Afforestation Programme along the coastal belt was initiated in 1966 with the primary objective to protect the lives and properties of coastal communities from cyclone and tidal surges by creating mangrove forest cover in the exposed 710 km coastal belt (Das and Siddiqi 1985; Mahmood *et al.* 2020). *Sonneratia apetala* was the most successful tree species in all along the coastal belt and *Avicennia officinalis* was the second most successful species in coastal plantation. A total of 0.192 million hectares of accreted lands were afforested with *S. apetala* that constitutes about 95% of the total coastal plantations.

Volume equations have been used to estimate tree and stand volume, have played a significant role in forest management. The inherent morphological differences among tree species recommend to develop species-specific volume (Burkhart and Gregoire 1994). The volume equations and tables have been developed for more than forty three important tree species in Bangladesh (Latif and Islam 2014; Islam *et al.* 2014; Mahmood *et al.* 2016 and Islam *et al.* 2020). The one-variable (volume-diameter/girth) and two-variable volume tables of *S. apetala* were derived for the young stands located in Patuakhali and Bhola (Islam *et al.* 1992a) and the mature stands located in Chattogram and Patuakhali (Latif 1994). However, these volume equations and tables are not capable to produce accurate volume estimation for all the coastal plantations of *S. apetala* in Bangladesh. Therefore, a common volume equation and table is required for accurate volume estimation that will help in sustainable forest management, assessment of carbon stock and so on. The aim of this study was to generate a common volume equation and table for predicting the total and merchantable volume of planted and natural stands (other than Sundarban) of *S. apetala* in the coastal areas of Bangladesh. .

Materials and Methods

Study area

Bangladesh Forest Department has taken an initiative to expand and popularize afforestation programme in the new accreted char- land in the coastal belt of Bangladesh. *S. apetala* is the common tree species along newly accreted char and coast line of Bangladesh. This study has been conducted in the remnant the existence plantations and natural stands in several forest beat of these forest areas presented in Table 1.

Table 1. Study areas for estimation of volume for the keora grown in Bangladesh.

Forest Division	Range	Beat/area
Chattogram costal	Sador	Halishahar, Kattali and Fouzdarhat
	Sitakunda Mirsarai	Banshbaria and Bogachattar Dumkhali and Mogadia
Noakhali	Jahajmara	Char Osman, Char Kalam and Jahajmara
Patuakhali	Galachipa	Char Kashem, Kankanipara and Ashabaria
	Char Montaj	Sonar Char, Char Taposhi and Char Montaj
Bhola	Kukrimukri	Char Kukrimukri, Char Jamir, Char Dighal and Char Safi

Sampling of trees

The sample size were selected on the basis of girth at breast height (GBH) classes and height classes of *S. apetala*. All sample trees were selected to avoid specimens with broken top, hollow trunk, damage caused by natural calamities or animals and evidence of suppression or disease. A total of 430 sample trees belong to different GBH class (Table 2) were selected to derive the volume equations and tables. Sample trees were selected purposively and covered existence wide GBH range and height range. Another 30 sample trees at all girth classes were recollected for model validation.

Measurement of trees

Girth at breast height and total height of the sampled trees were measured with diameter tape and Haga-altimeter respectively. Sectional diameter of the stem and bigger branches (girth ≥30 cm) were taken at 1 m interval using ladder. At the same time bark thickness was measured from bark chip using a bark gauge. The collected fitting data set were categorized on the basis of GBH and height of the trees. The GBH-height class distribution of the sampled trees are given in Table 2.

Table 2. Stand table of collected volume data of *S. apetala* (keora).

Girth class (cm)	Number of sample trees under different Height Class (m)							
	≤9	9.1 -12	12.1 -15	15.1 -18	18.1 -21	21.1 -24	>24	Total
<35	2	2						4
35.1 -45	5	11	1					17
45.1 -55		8	2	1				11
55.1 -65		7	19	9	1			36
65.1 -75		9	25	24	7	3	2	70
75.1 -85		3	26	50	2	2	2	85
85.1 -95		2	22	36	12	5	5	82
95.1 -105			3	18	18	12	3	54
105.1 -115			2	9	4	11	5	31
115.1 -125			2	3	2	6	8	21
125.1 -135				2	2	1	4	9
>13 5						4	6	10
Total	**7**	**42**	**102**	**152**	**48**	**44**	**35**	**430**

Compilation of Data

Volume of log sections except top and bottom section were estimated by using the mean cross-sectional areas of the two ends of each section following Smalian's formula cubic volume = [(B+b)/2]×L, where B = the cross-sectional area at the large end of the log, b = the cross-sectional area at the small end of the log, and L = length of the log. In determining the volume of bottom sections, the formulae used for calculating the volume of a cylinder was considered. Assuming the top section as cone the volume was computed to one third of the cylindrical volume of the portion. We considered the top end diameter measurement for each tree as the base diameter of the cone. In computing the under bark volume of the tree the volume of top section i.e. cone was ignored. The total volume of the tree is the sum of the volume of all sections and branches volume found in a tree. The individual tree total volumes (V), GBH (G) and total height (H) were variable in regression techniques using various functions and transformations as required in the models.

Computation of volume function

Multiple regression analyses technique was adopted to select the best fit models. The following 21 models (Clutter *et al.* 1983; Bi Hamilton 1998; Latif and Islam 2014; Islam and Chowdhury 2017) were tested to select the equation of best fit with different variables are given in Table 3.

Following original and transformed variables were used to select the best suited regression models: Dependent variables: *V, Log (V).*

Table 3. Frequently used volume models.

Model No.	Models
1	$V = a + bG$
2	$V = a + bG + cG^2$
3	$V = a + bG^2$
4	$V = aG + bG^2$
5	$V = aG + bG^{-1}$
6	$V = aG + bG^{-2}$
7	$\log(V) = a + bG$
8	$V = a + b\log(G)$
9	$\log(V) = a + b\log(G)$
10	$V = a + bG^2H$
11	$V = a + bG + cH$
12	$V = a + bG + cG^2H$
13	$V = a + bG + cGH$
14	$V = a + bG + cH + dGH$
15	$V = a + bG + cH + dG^2H$
16	$V = a + bG^2 + cH + dGH$
17	$V = a + bG^2 + cH + dG^2H$
18	$V = a + bG^2 + cGH + dG^2H$
19	$V = a + b\log(G) + c\log(H)$
20	$\log(V) = a + b\log(G) + c\log(H)$
21	$V = a + bG^{-1} + cH^{-1}$

Where, V = volume in cubic meters, G = girth at breast height in centimeters, H = total height in meters, a is the regression constant and b, c and d are regression coefficients. The logarithmic functions are to the base e.

Independent variables: *G, G^2, G^{-1}, G^{-2}, H, H^{-1}, GH, G^2H, Log (G), Log(H).*

The dependent variables mentioned above were regressed with the independent variables. The equations of the best fit based on the highest multiple coefficients of determination; F-ratio and lowest residual mean square and AIC value statistic were chosen. Models for estimation of the total volume over bark and under bark selected.

Model validation

The best fit models were validated with another set of 30 trees of different girth class and compiled in the same procedure as earlier. The measured volumes of these 30 trees were compared with their predicted volume. The independent tests for validation were chi-square test of goodness of fit, paired t-test and percent absolute deviation (%AD). This was also compared with 45 degree line test by plotting the observed values and the predicated value in the graph (Latif 1994 and Islam *et al.* 1992a).

Model comparison

The best-fit volume model was compared with the previous developed local volume model of Keora by Latif (1994) and Islam *et al.* (1992a) (Table 4) in terms of Model Prediction Error (MPE), Model Efficiency (ME) and Root Mean Square Error (RMSE) (Mayer and Butler, 1993). This comparison was conducted with data set which recollected for validation and terms calculate with statistical tools represent by the following equations.

Table 4. Previous developed local volume models of *Sonneratia apetala* for comparison with best-fit model in this study.

No.	Model	Type	Source
1	$V = -0.0117 + 0.00000283756D^2 \times H$	Locally in Patuakhali, Bhola and Noakhali	Latif (1994)
2	$V = 0.0073 + 0.000003368D^2 \times H$	Locally in Chattogram	
3	$\ln(V) = -9.1937 + 1.7683 \times \ln(D) + 0.7385 \times \ln(H)$	Locally in Patuakhali	Islam *et al.* (1992a)
4	$\ln(V) = -9.2587 + 1.6463 \times \ln(D) + 0.9138 \times \ln(H)$	Locally in Bhola	

Where V = volume over bark in cubic meter, D = Diameter at breast height in cm, H = Total height in meter

The comparison tools are given in the equations

$$\text{MPE}(\%) = \frac{100}{n} \times \sum\left[\frac{(Y_p - Y_0)}{Y_0}\right] \qquad (1)$$

$$\text{ME} = 1 - \left[\frac{\sum(Y_0 - Y_p)^2}{\sum(Y_0 - \bar{Y})^2}\right] \qquad (2)$$

$$\text{MSE}(\%) = 100 \times \sqrt{\frac{1}{n}\sum(Y_p - Y_0)^2} \qquad (3)$$

Where n = Number of trees, Yp = Predicted volume from the model, Yo = Observed volume in field measurement, and $\bar{Y}$ = Mean of the observed volume. Regression between predicted volume (Yp) (in the X-axis) and observed volume (Yo) (in the Y-axis) were also derived for the best-fit volume model and developed model by Latif (1994) and Islam *et al.* (1992a) (Table 4). Significance of slope (b = 1) and intercept (a = 1) were tested (Pineiro *et al.* 2008) to understand the over estimation or under estimation of each predicted volume value from observed value by using 1:1 line (Sileshi 2014).

Data analysis

Collected data were organized and screened (removing the outliers) for analysis. Descriptive statistical analysis was further carried out in order to summarize the data. All analysis were carried out using MS Excel 2013, SPSS 17 Inc and EViews (Quantitative Micro Software, LLC) statistical package version 9.

Results

Dependent and independent variables

Total volume over bark have been calculated from total of 430 sample trees in this study. Descriptive statistics of dependent and independent variables represent in Table 5.

Table 5. Descriptive statistics for sample trees for model development.

Variables	No. of sample	Mean	Minimum	Maximum	Standard error	Standard deviation	Confidence level (95.0%)
Gbh (cm)	430	84.0	31.5	171.0	1.1	22.2	2.1
Height (m)	430	17.0	8.0	30.5	0.2	4.4	0.4
Volume (m^3)	430	0.5	0.0	2.6	0.0	0.3	0.0

Volume equations

The volume equations for estimation of total volume over-bark for *S. apetala* were selected. The model 9 and 20 were best fit for one way and two way volume equations respectively to estimate total volume over bark and volume under bark. The selected volume equations were given in Table 6.

Table 6. Selected best fit volume equation of *S. apetala.*

Selected Models	Fit statistics			
	R^2	RMSE	AIC	N
$\ln(V_{ob}) = -11.2916 + 2.354365 \times \ln(G)$	0.90	0.21	-0.38	430
$\ln(V_{ob}) = -11.1083 + 1.752458 \times \ln(G) + 0.878759 \times \ln(H)$	0.94	0.16	-0.97	430
$\ln(V_{ub}) = -11.3602 + 2.361471 \times \ln(G)$	0.90	0.22	-0.36	430
$\ln(V_{ub}) = -11.1771 + 1.76028 \times \ln(G) + 0.877715 \times \ln(H)$	0.94	0.17	-0.98	430

Where, G = girth at breast height in cm, H = total height in m, V_{ob} = total volume over bark in m^3; V_{ub} = total volume under bark in $m^3$and ln is natural logarithm (logarithm on base).

Model validation

The statistical requirement to best fitted models by considering those equations having the highest R^2 with lowest RMSE, Akaike Information Criterion (AIC) were tested. Results were presented in Table 6.

Independent test

The best suited volume equations for one way and two way were tested with a set of data recollected from 30 trees of different girth class and complied in the same procedure as earlier. The measured volume of these trees were collectively compared with the corresponding predicted volume using best fit models. The independent tests for validation were the chi-square test, paired t-test; absolute deviation percent (%AD) and 45 degree line test (Islam et *al.* 1992b; Latif and Islam 2001). The computed chi-square, t-values, absolute deviation percent and slope (45-dergee line test) of studied tree species for total volume over bark and under bark equations were given Table 7.

Table 7. Result of independent test for predicted volume equations of *S. apetala.*

Proportion	Model Types	*Chi*	*t*	*%AD*	*Slope °*
Over bark	One way	1.07	0.33	1.8	43.8
	Two way	0.60	1.00	4.2	44.1
Under bark	One way	1.03	0.35	1.9	44.2
	Two way	0.58	1.03	4.3	43.6

Total volumes over bark were calculated for ready use and presented in Table 9. The volume equations and tables were applicable for keora growing in the different coastal forest areas of Bangladesh.

Model comparison

The total volume best-fit model showed the lowest (-3.24%) MPE and RMSE (11.71%) and the highest ME (0.93), close to the reference value 1) compared to the local volume models of Latif (1994) and Islam *et al.* (1992a) (Table 8). The graphica l presentation from 1:1 line indicated that the best-fit volume model was capable to estimate the total volume more accurately. While locally used Latif (1994) and Islam *et al.* (1992a) model overestimated the total volume for *S. apetala* compared to the derived best-fit total volume model in this study (Fig. 1).

Table 8. Comparison of best-fit total volume over bark model with the Latif (1994) and Islam *et al.* (1992a) model.

Source	Type	MPE (%)	ME	MSE (%)
(A) Best fit model (V_{ob})	This study	-3.24	0.93	11.71
(B) Latif (1994)	Locally in Patuakhali	23.51	0.87	15.99
(C) Latif (1994)	Locally in Chattogram	20.09	0.89	13.64
(D) Islam *et al.* (1992a)	Locally in Patuakhali	32.51	0.53	29.99
(E) Islam *et al.* (1992a)	Locally in Bhola	31.06	0.56	28.83

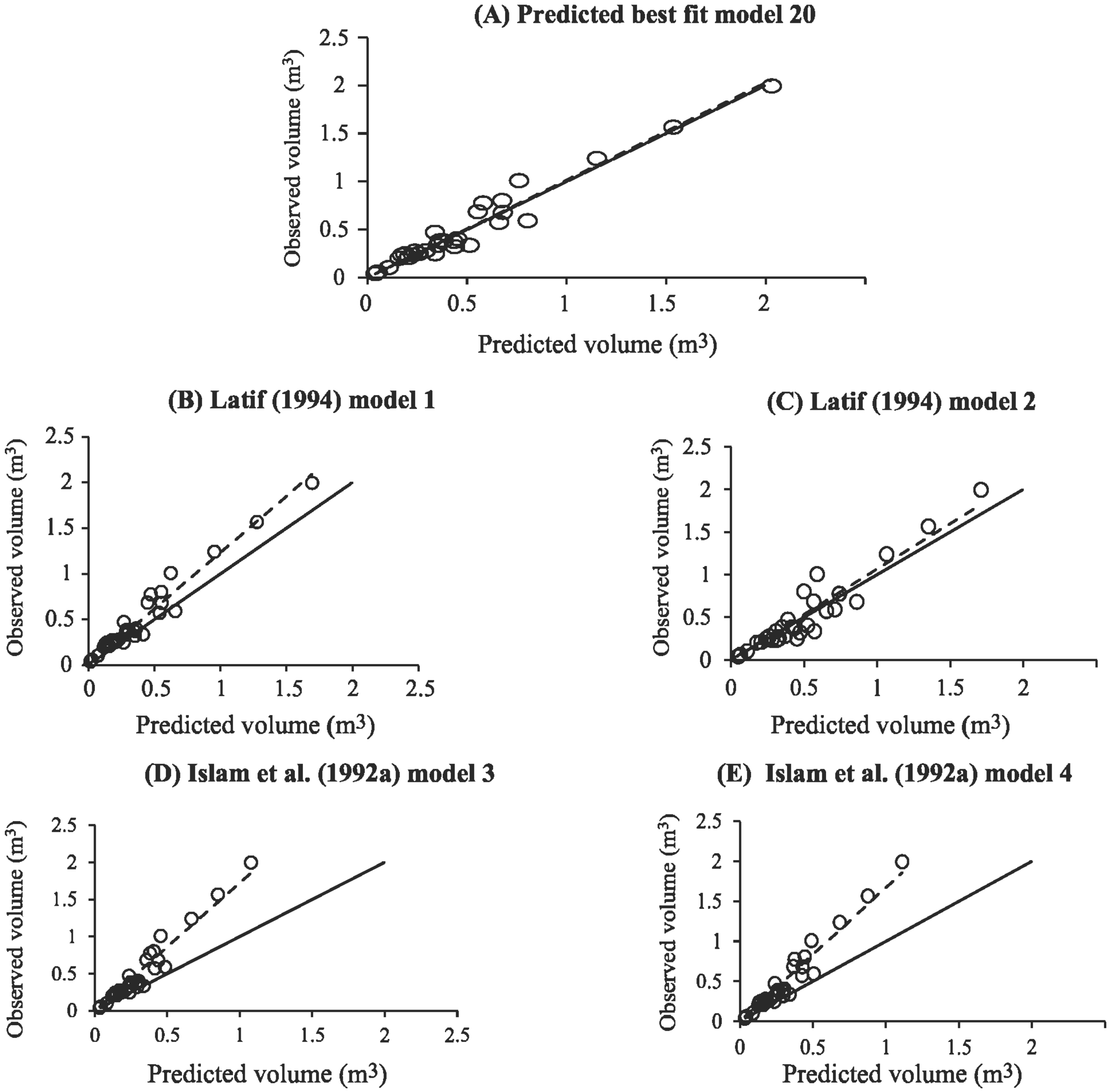

Figure 1. Comparison of best-fit total volume model with Latif (1994) and Islam *et al.* (1992a) volume model.

Table 9. One and Two way volume table for *S. apetala* grown in Bangladesh.

GBH (cm)	One-way (m^3)	Two-way volume (m^3) Height in meter (Head)											
		6	8	10	12	14	16	18	20	22	24	26	28
30	0.037	0.028	0.036	0.044	0.052	0.059	0.066	0.074	0.081	0.088	0.095	0.102	0.109
32	0.044	0.031	0.040	0.049	0.058	0.066	0.074	0.083	0.091	0.098	0.106	0.114	0.122
34	0.050	0.035	0.045	0.055	0.064	0.074	0.083	0.092	0.101	0.109	0.118	0.127	0.135
36	0.058	0.039	0.050	0.061	0.071	0.081	0.091	0.101	0.111	0.121	0.131	0.140	0.150
38	0.065	0.042	0.055	0.067	0.078	0.089	0.101	0.112	0.122	0.133	0.144	0.154	0.164
40	0.074	0.046	0.060	0.073	0.085	0.098	0.110	0.122	0.134	0.146	0.157	0.169	0.180
42	0.083	0.051	0.065	0.079	0.093	0.107	0.120	0.133	0.146	0.159	0.171	0.184	0.196
44	0.092	0.055	0.071	0.086	0.101	0.116	0.130	0.144	0.158	0.172	0.186	0.199	0.213
46	0.103	0.059	0.076	0.093	0.109	0.125	0.141	0.156	0.171	0.186	0.201	0.215	0.230
48	0.113	0.064	0.082	0.100	0.118	0.135	0.151	0.168	0.184	0.200	0.216	0.232	0.248
50	0.125	0.069	0.088	0.108	0.126	0.145	0.163	0.180	0.198	0.215	0.232	0.249	0.266
52	0.137	0.074	0.095	0.115	0.135	0.155	0.174	0.193	0.212	0.230	0.249	0.267	0.285
54	0.150	0.079	0.101	0.123	0.145	0.166	0.186	0.206	0.226	0.246	0.266	0.285	0.304
56	0.163	0.084	0.108	0.131	0.154	0.176	0.198	0.220	0.241	0.262	0.283	0.304	0.324
58	0.177	0.089	0.115	0.140	0.164	0.188	0.211	0.234	0.257	0.279	0.301	0.323	0.345
60	0.192	0.095	0.122	0.148	0.174	0.199	0.224	0.248	0.272	0.296	0.320	0.343	0.366

GBH (cm)	One-way (m^3)	Two-way volume (m^3) Height in meter (Head)											
		6	8	10	12	14	16	18	20	22	24	26	28
62	0.207	0.100	0.129	0.157	0.184	0.211	0.237	0.263	0.288	0.314	0.339	0.363	0.388
64	0.223	0.106	0.136	0.166	0.195	0.223	0.251	0.278	0.305	0.332	0.358	0.384	0.410
66	0.240	0.112	0.144	0.175	0.205	0.235	0.265	0.293	0.322	0.350	0.378	0.405	0.433
68	0.257	0.118	0.152	0.184	0.217	0.248	0.279	0.309	0.339	0.369	0.398	0.427	0.456
70	0.276	0.124	0.160	0.194	0.228	0.261	0.293	0.325	0.357	0.388	0.419	0.449	0.480
72	0.294	0.130	0.168	0.204	0.239	0.274	0.308	0.342	0.375	0.408	0.440	0.472	0.504
74	0.314	0.137	0.176	0.214	0.251	0.288	0.323	0.359	0.393	0.428	0.462	0.495	0.529
76	0.334	0.143	0.184	0.224	0.263	0.301	0.339	0.376	0.412	0.448	0.484	0.519	0.554
78	0.355	0.150	0.193	0.235	0.275	0.315	0.355	0.393	0.431	0.469	0.506	0.543	0.580
80	0.377	0.157	0.202	0.245	0.288	0.330	0.371	0.411	0.451	0.490	0.529	0.568	0.606
82	0.400	0.163	0.210	0.256	0.301	0.344	0.387	0.429	0.471	0.512	0.553	0.593	0.633
84	0.423	0.171	0.220	0.267	0.314	0.359	0.404	0.448	0.491	0.534	0.577	0.619	0.660
86	0.447	0.178	0.229	0.278	0.327	0.374	0.421	0.467	0.512	0.557	0.601	0.645	0.688
88	0.472	0.185	0.238	0.290	0.340	0.390	0.438	0.486	0.533	0.579	0.625	0.671	0.716
90	0.498	0.192	0.248	0.301	0.354	0.405	0.456	0.505	0.554	0.603	0.651	0.698	0.745
92	0.524	0.200	0.258	0.313	0.368	0.421	0.473	0.525	0.576	0.626	0.676	0.725	0.774
94	0.552	0.208	0.267	0.325	0.382	0.437	0.492	0.545	0.598	0.650	0.702	0.753	0.804
96	0.580	0.215	0.277	0.338	0.396	0.454	0.510	0.566	0.621	0.675	0.729	0.782	0.834
98	0.608	0.223	0.288	0.350	0.411	0.470	0.529	0.587	0.644	0.700	0.755	0.810	0.865

GBH (cm)	One-way (m^3)	Two-way volume (m^3) Height in meter (Head)											
		6	8	10	12	14	16	18	20	22	24	26	28
100	0.638	0.231	0.298	0.363	0.426	0.487	0.548	0.608	0.667	0.725	0.783	0.840	0.896
102	0.668	0.240	0.309	0.375	0.441	0.505	0.567	0.629	0.690	0.751	0.810	0.869	0.928
104	0.700	0.248	0.319	0.388	0.456	0.522	0.587	0.651	0.714	0.777	0.838	0.899	0.960
106	0.732	0.256	0.330	0.402	0.471	0.540	0.607	0.673	0.738	0.803	0.867	0.930	0.992
108	0.765	0.265	0.341	0.415	0.487	0.558	0.627	0.696	0.763	0.830	0.896	0.961	1.025
110	0.799	0.274	0.352	0.428	0.503	0.576	0.648	0.718	0.788	0.857	0.925	0.992	1.059
112	0.833	0.282	0.363	0.442	0.519	0.594	0.668	0.741	0.813	0.884	0.954	1.024	1.093
114	0.869	0.291	0.375	0.456	0.535	0.613	0.689	0.765	0.839	0.912	0.985	1.056	1.127
116	0.905	0.300	0.387	0.470	0.552	0.632	0.711	0.788	0.865	0.940	1.015	1.089	1.162
118	0.942	0.309	0.398	0.485	0.569	0.651	0.732	0.812	0.891	0.969	1.046	1.122	1.198
120	0.980	0.319	0.410	0.499	0.586	0.671	0.754	0.837	0.918	0.998	1.077	1.156	1.233
122	1.019	0.328	0.422	0.514	0.603	0.690	0.776	0.861	0.945	1.027	1.109	1.190	1.270
124	1.059	0.337	0.434	0.529	0.620	0.710	0.799	0.886	0.972	1.057	1.141	1.224	1.306
126	1.099	0.347	0.447	0.544	0.638	0.731	0.822	0.911	1.000	1.087	1.173	1.259	1.344
128	1.141	0.357	0.459	0.559	0.656	0.751	0.845	0.937	1.028	1.117	1.206	1.294	1.381
130	1.183	0.367	0.472	0.574	0.674	0.772	0.868	0.963	1.056	1.148	1.239	1.330	1.419
132	1.227	0.376	0.485	0.590	0.692	0.793	0.891	0.989	1.085	1.179	1.273	1.366	1.458
134	1.271	0.387	0.498	0.606	0.711	0.814	0.915	1.015	1.113	1.211	1.307	1.402	1.497
136	1.316	0.397	0.511	0.621	0.729	0.835	0.939	1.042	1.143	1.243	1.341	1.439	1.536

GBH (cm)	One-way (m^3)	Two-way volume (m^3) Height in meter (Head)											
		6	8	10	12	14	16	18	20	22	24	26	28
138	1.362	0.407	0.524	0.638	0.748	0.857	0.964	1.069	1.172	1.275	1.376	1.476	1.576
140	1.409	0.417	0.537	0.654	0.767	0.879	0.988	1.096	1.202	1.307	1.411	1.514	1.616
142	1.457	0.428	0.551	0.670	0.787	0.901	1.013	1.124	1.233	1.340	1.447	1.552	1.657
144	1.506	0.439	0.565	0.687	0.806	0.923	1.038	1.151	1.263	1.374	1.483	1.591	1.698
146	1.555	0.449	0.578	0.704	0.826	0.946	1.064	1.180	1.294	1.407	1.519	1.630	1.739
148	1.606	0.460	0.592	0.721	0.846	0.969	1.089	1.208	1.325	1.441	1.556	1.669	1.781
150	1.657	0.471	0.607	0.738	0.866	0.992	1.115	1.237	1.357	1.475	1.593	1.709	1.824
152	1.710	0.482	0.621	0.755	0.886	1.015	1.141	1.266	1.389	1.510	1.630	1.749	1.866
154	1.763	0.493	0.635	0.773	0.907	1.039	1.168	1.295	1.421	1.545	1.668	1.789	1.910
156	1.818	0.505	0.650	0.790	0.928	1.062	1.195	1.325	1.453	1.580	1.706	1.830	1.953
158	1.873	0.516	0.664	0.808	0.949	1.086	1.222	1.355	1.486	1.616	1.744	1.872	1.997
160	1.929	0.527	0.679	0.826	0.970	1.111	1.249	1.385	1.519	1.652	1.783	1.913	2.042
162	1.987	0.539	0.694	0.844	0.991	1.135	1.276	1.415	1.553	1.688	1.823	1.955	2.087
164	2.045	0.551	0.709	0.863	1.013	1.160	1.304	1.446	1.586	1.725	1.862	1.998	2.132
166	2.104	0.563	0.724	0.881	1.034	1.185	1.332	1.477	1.621	1.762	1.902	2.041	2.178
168	2.164	0.575	0.740	0.900	1.056	1.210	1.360	1.509	1.655	1.800	1.942	2.084	2.224
170	2.225	0.587	0.755	0.919	1.079	1.235	1.389	1.540	1.690	1.837	1.983	2.128	2.271

Discussion

Two volume equations (one and two way) were selected from 21 models for *S. apetala* grown in Bangladesh. The volume equations predict the total volume over bark and volume under bark. The data covers different climate regions around the country, represents different types of stands growing on different soil types and thus covers most of the site conditions suitable for forestry in Bangladesh. Regarding the sample trees within these were measured at different girth classes and used in this study. The descriptive statistics of dependent variable (volume) and independent variables (GBH and height) are represented in Table 5 which are performed to develop one way and two way volume equation of *S. apetala*.

The volume equations were transformed to a logarithmic form, a common procedure to obtain constant variance of the residuals. Volume model 9 for one way 20 for two way which had GBH and H as independent variables gave the best results based on fit and validation statistics and was most suitable according to residual analyses and model comparison for the studies tree species. Fit statistics of each of the equations for the species showed in Table 6. The R^2 values were generally high and acceptable for the equations while RMSE values were very low. In this table also shows that AIC values are low which are closed to zero. The coefficients of determination for selected one way both volume equations is 0.90 and two way both volume equations is 0.94. This means that the selected one way models describe over 90% and two way models describe 94% for keora of the total variations. The best fit models were selected for estimation of volume on GBH and total height. Islam *et al.* (2012, 2020) confirmed the suitability of these two models for estimating total volume of *Lagerstroemia speciosa* (L.) Pers and *Albizia richardiana* King and Prain. The combined variable equation (equation 20) showed more precision in the estimate as evinced by the values of absolute mean residual, R^2 values, root mean squared error, model prediction error, model efficiency and variance ratio (Table 6 and 8) and, hence, was considered the better option for volume prediction. Needless to mention that the combined variable equations, has been well recognised in volume predictions of many tree species with R^2 usually above 95% (Avery and Burkhart 2002). The models were fitted using the method of least squares. Logarithmic volume equations have the advantage of more nearly satisfying the homogeneity of variance assumption of ordinary regression but suffer from the disadvantage that a transformation bias is introduced (Avery and Burkhart 2002).

These volume tables should not be used to estimate volumes of individual trees in a stand. These tables may be used for the mean tree of a stand which may be multiplied by the number of stem to get the total volume of the stand. Estimation of volumes for the trees much outside the height and GBH ranges shown in the stand table should only be done with caution.

The predictive ability of the different equations were assessed using an independent data set (validating data set) for model validation. The volume equations obtained from the fitting data set were applied to the validating data set. The independent tests for validation were the chi-square test, paired t-test, absolute deviation percent (%AD) and 45 degree line test discussed as follows: The computed chi-square values of total volume over bark represented in (Table 7) were less than the tabular values. This implies that there is no significant difference between the actual values from the 30 test sample trees and the corresponding expected values as predicted by the selected models. The result of pared t-test for total volume over bark of studied tree species grown in Bangladesh are given in (Table 7) computed t-ratio for all the estimation were less than the tabular values. These imply that there were no significant differences between the observed and predicted values. Thus the prediction models might be accepted. Absolute deviation percent (%AD) between the observed and predicted values for total volume over bark and under bark with girth at breast height (GBH) and GBH & height for this study species was minimum, which also confirmed validity of the selected models. Graphs comparing the observed values and the predicted values were plotted in the graph paper. The observed values and the predicted values yielded slops very closed to 45 degrees, which have been presented in (Table 7). It was observed that the models tend to make an angle 45 degrees with the axes, meaning there were no significant difference between the actual and the predicted values.

The use of Latif (1994) and Islam *et al.* (1992a) model are estimated local total volume of *S. apetala* in Chattogram, Bhola and Patuakhali coastal forest which produce variation in volume estimation. The best-fit total volume model of *S. apetala* has shown a variation in estimating total volume compared to Latif (1994) and Islam *et al.* (1992a) model. However, the graphical presentation of 1:1 line indicated that the best-fit volume model is capable to estimate total volume was accurately than other previous developed model in comparison (Fig. 1). The variation in estimated volume may be due to the differences in tree species, climatic conditions, site conditions, forest types with its composition and management practices which ultimately influenced the architecture of tree and volume partitioning (Mahmood *et al.* 2016).

Conclusion

The present study was to develop total tree volume models for *S. apetala*. in Bangladesh based on nondestructive sampling. Although the data were collected from a specific region and plantation also natural, the volume models constructed can be expected to give a satisfactory estimate for the aggregate standing volume of natural and planted *S. apetala* stands in Bangladesh. The results showed combined variable equation (model 20) performed well in both the fitting and validation process. Therefore, the developed models in this study are capable to predict total volume for *S. apetala* in the study area at a higher accuracy. The contrasting results obtained between model fitting and validation emphasise the need for model validation as an important in the model construction process in order to get the best choices. But as with all volume equations, a test of applicability is always necessary if used outside the range of data And/or under other conditions.

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Determination of Physical and Mechanical Properties of Jhau (*Casuarina equisetifolia*) Grown in Chattogram

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Abstract

The physical and mechanical properties of Jhau (*Casuarina equisetifolia*) grown in Chattogram timber species were studied. The results indicate that jhau wood is fallen in very heavy and very strong categories. The specific gravity and the volumetric shrinkage of Jhau timber is higher than that of Chattogram teak which was recommended as standard for comparison of other timber species in Bangladesh. The species can be used for house posts, agricultural implements, tool handles and other household articles.

সারসংক্ষেপ

চট্টগ্রামে জন্মানো ঝাউ প্রজাতি কাঠের ভৌত ও শক্তি সম্বন্ধীয় গুণাগুণ পরীক্ষা করা হয়েছে। ফলাফল বিশ্লেষণ করে দেখা যায় যে, ঝাউ প্রজাতির কাঠ খুব ভারী ও শক্তি সম্পন্ন শ্রেণির অন্তর্ভূক্ত। এর আপেক্ষিক গুরুত্ব ও আয়তনিক সংকোচন আদর্শ কাঠ হিসেবে বিবেচিত সেগুন কাঠের চেয়ে বেশী। উক্ত প্রজাতির কাঠ ঘরের খুঁটি, কৃষি সরঞ্জাম, যন্ত্রপাতির হাতল ও অন্যান্য গৃহস্থালি আসবাব ইত্যাদি তৈরীর কাজে ব্যবহৃত হতে পারে।

Key words: *Casuarina equisetifolia*, Physical properties, Mechanical properties, Shrinkage, Specific gravity.

Introduction

Casuarina equisetifolia is indigenous to the tropics and sub tropics of southeast Asia and western pacific regions, including northern Australia (Ogata *et al*. 2008) and throughout northern Malaysia, Melanesia, Polynesia and Vanuatu (Pinyopusarerk and House 1993). It is a native of the seacoast of New South Wales of Australia. It is mostly planted as roadside avenue and shed trees throughout the country. There are many such old trees planted during the British Period. Sometimes occur naturally in the sea shore of Cox's Bazar, Teknaf (Das and Alam 2001). This species can grow under warm to hot subtropical and tropical climates and thrives where mean annual temperature range from 10º to over 30ºC, but it is adopted to a wide range of temperatures. In its natural habitat annual rainfall is from 700 to 2000 mm often with a dry season of 6-8 months. It has been successfully planted in areas with annual rainfall as little as 200-300 or as much as 5000 mm. It is also native to north Australia, Pacific islands, Philippines, Indonesia, India and Srilanka. It is widely planted as ornamental tree, roadside planting, and sand dune control. It is an excellent fuel, often referred to the best firewood in the world (Neptale 1990). The species has been introduced to many countries outsides its natural range and used for soil stabilization, reclamation work and coastal protection, as well as rehabilitation of degraded land (Midgley *et al.* 1983; EI-Lakany *et al.*1990). It is fast-growing species that has been introduced outside its natural range for sand dune stabilization and shelterbelts (Prasad and Dieters 1998). In Bangladesh, it is widely used for coastal protection and as a priority species in shortrotation plantations (Islam 2003), and is recommended for use in agroforestry systems (Jashimuddin *et al.* 2006). Because of the increasing areas of *Casuarina plantations* in Bangladesh it will rapidly become an important resource for forest industry. There is therefore a need to better understand the potential utilization of this species, as well as the patterns of variation in its wood properties when grown outside its natural range. Indigenous on sandy shores and dunes along the coast of Chittagong Tenasserim, and the Andamans.

In Bangladesh, this species has been planted for decades in coastal areas and near beaches for sand dune stabilization (Gafur *et al.* 1979). The wood is generally hard and dense, and tends to split when sawn (Burgess 1966). Jhau is popular for use as underground piles for construction work, as well as for fish-trap stakes and tool handles. Hardboard, particleboard and woodchips for pulping are also produced from this species (Guha *et al.* 1970). Therefore, a comprehensive assessment of the distribution pattern and driving factors of wood physical and mechanical properties are of great importance. The present study was undertaken for the determination of physical and mechanical properties of Jhau in order to ensure their proper end uses.

Materials and Methods

Collection of wood and preparation of samples

Three representative trees of *Casuarina equisetifolia* were collected from beach plantation in Chattogram Forest Division, Bangladesh. The ages of trees were 25-30 years with 10-15 m height and 85-100 cm girths. Three samples per bole were selected randomly from each of trees consecutive 2.50 m bolts above the stump height of each tree. All the bolts were fairly straight and free from natural defects. For determination of physical properties, namely moisture content (MC), specific gravity and shrinkage, each tree was divided into its but, middle and top portion. The sizes of the samples for MC and specific gravity were 2.54 cm× 2.54 cm × 5.08 cm and for shrinkage was 5.08 cm × 5.08 cm × 15.24 cm. For determination of physical and mechanical properties, samples were taken from bottom, middle and top portion.

For determination of mechanical properties the bolts were marked into 6.45 cm^2 according to the standard sawing diagram and were sawn to 6.45 cm × 6.45 cm × 2.50 m sticks. The sticks were prepared in pairs. One stick was taken from each pair for conducting tests in green condition and the other for air-dry condition. The sticks for air-dry test were stacked using suitable stickers inside a drying shed and allowed to attain the equilibrium moisture content of 12-14%.

Measurement of properties

Small clear specimens were tested, in both green and air-dry states, for the following physical and mechanical properties using the procedure given in ASTM (Anon 1971).

Physical properties

Moisture content was measured using the oven-dry method and volumetric shrinkage was dimensional change from the green to air/oven-dry condition expressed as a fraction. Oven-dry measurements were taken after the specimens were dried to constant weight in an oven at 103±2^{0}C. The Specific gravity was estimated from volume at test (green or air dry) and oven-dry weight using the standard immersion displacement method (Anon 1971).

Mechanical Properties

All the test sticks were dressed to 5.08 cm × 5.08 cm × 2.50 m strips and clear specimens to the sizes specified by the American Society for Testing of Materials (ASTM) standards D 143-52 (Anon 1971). The specimens of various parameters were tested in accordance with the specifications of ASTM except toughness. The tests for mechanical properties were carried out in a Riehle screw power type universal testing machine. The toughness tests were performed in a toughness-testing machine designed by the US Forest Products Laboratory, Madison, Wisconsin (Anon 1971).

Static bending

The size of specimens was 5.08 cm × 5.08 cm × 76 cm is tested on a 71.12 cm span with centre loading. It furnishes data on bending strength and stiffness for such uses as beams, joists etc. The parameters of static bending are as follows :

a) Stress at proportional limit (SPL)

Stress at proportional limit the mechanical value of δPL can be obtained by the equation 1.

$\delta PL = 3Pl/2bh^2$ ……………………(1)

b) Modulus of rupture (MOR)

The modulus of rupture R (eqn. 2) can be found by substituting the maximum load, P_1 for the load at the proportional limit

$R=3P_1l/2bh^2$ ……………………….... (2)

c) Modulus of elasticity(MOE)

The modulus of elasticity (eqn. 3) can be determined and substitution

$E=Pl^3/4ybh^2$ ……………………….(3)

Where,

P = Load at the limit of proportionality,

l = Span of the test specimen,

b = Breadth of the test specimen,

h = Depth of the test specimen,

P_1 = Total load and,

Y= Deflection at the limit of proportionality

Compression parallel to grain

The size of specimens was 5.08 cm × 5.08 cm × 20 cm It furnishes data on strength and resistance to deformation when loaded in Compression parallel to grain in a short post.

Compression perpendicular to grain

The size of specimens was 5.08 cm ×5.08 cm ×15 cm. It furnishes data necessary in computing the bearing area required at the ends of beams, joists or loads applied over limited area.

Hardness

The size of specimens was 5.08 cm × 5.08 cm × 15 cm. It furnishes measure of resistance to indentation and wear which is useful in selecting species for flooring, trim, etc.

Toughness

The size of specimens was 2cm x 2cm x 28 cm is tested over a 24 cm span. Data on impact resistance in bending can be approximated from properties obtained by several test methods.

Statistical analysis

The co-efficient of variation (CV) is the ratio of the standard deviation to the mean. The co-efficient of variation puts the expression of viability on a relative basis.

Results

General properties and description of wood

The tree has light red to dark reddish-brown heartwood, sometimes darker in older trees, and usually-distinct, thick, buff-colored sapwood with a fine to moderately-fine texture. The grain is typically straight or shallowly interlocked. The wide medullary rays result in an attractive prominent figure on radial surfaces when logs are quarter sawn.

The average values of physical properties such as moisture content, specific gravity and volumetric shrinkage of *Casuarina equisetifolia* wood were determined in green and air-dry conditions are presented in Table 1. The values of physical properties of Chattogram teak (*Tectona grandis*) having 40 years age group are also included in the Table 1 to compare the suitability of jhau relative to teak. Teak of 40 years old has been considered as the standard for comparing the properties as it is well known and widely used timber in Bangladesh for all sorts of work. (Yakub *et al.* 1978). From initial moisture content of 40% to 15% final moisture content (MC). Minor defects were observed in air-dry samples during drying.

Table 1. Physical properties of *Casuarina equisetifolia* compared to teak.

Species	Locality of timber with age	No. of trees	Seasoning condition	Moisture content (%)	Specific gravity *		Shrinkage % **	
					Volume at test	Volume at oven dry	Volumetric	
							12%	OD
Chattogram teak (*Tectona grandis*)	Kaptai, Chattogram Hill tracts Age 40 years	03	Green	155.0	0.58	0.61	4.50	5.00
			Air-dry	12.0	0.59			
Jhau (*Casuarina equisetifolia*)	Sea-beach Chattogram Age 25-30 years	03	Green	40.0	0.87	1.04	9.6	12.0
			Air-dry	15.0	0.92			

* based on oven dry weight

** from green to oven dry condition based on green

The average values of mechanical properties the individual strength value was computed from the data collected for nine different tests like static bending, compression parallel to grain, compression perpendicular to grain, hardness, shear parallel to grain; nail holding capacity, cleavage and toughness were presented in Table 2.

The co-efficient of variation (CV) is the ratio of the standard deviation to the mean. The co-efficient of variation puts the expression of viability on a relative basis

The average values of various strength properties including co-efficient of variation (CV%) in the both green and air-dry conditions and compare the suitability of jhau relative to teak. (Yakub *et al.* 1978).

Table 2. Comparison of mechanical properties of jhau (*Casuarina equisetifolia*) with teak (*Tectona grandis*).

Properties	Species/ Seasoning conditions/Values			
	Jhau (*Casuarina equisetifolia)*		Chittagong teak (*Tectona grandis)*	
	Green (C. V.%)	Air dry (C.V.%)	Green	Air dry
Static bending				
Stress at proportional limit (Kg/cm²)	527 (11.0)	642 (20.0)	514	628
Modulus of rupture (Kg/cm²)	990 (6 .0)	1306 (24.0)	867	1008
Modulus of elasticity (1000 Kg/cm²)	150 (16.8)	178 (13.7)	120	131
Compression parallel to grain				
Stress at proportional limit (Kg/cm²)	312 (17.3)	410 (22.0)	288	374
Maximum crushing strength (Kg/cm²)	410 (16.0)	640 (22.0)	383	513
Compression perpendicular to grain				
Stress at proportional limit (Kg/cm²)	149 (18.0)	201 (13.7)	67	119
Hardness (Kg)				
Side (kg)	995 (17.2)	1080 (6.5)	506	495
End (kg)	940 (13.6)	1191 (3.0)	541	532
Nail holding capacity				
Side (Kg)	199 (15.5)	145 (17.5)	138	95
End (kg)	195 (12.2)	91(28)	79	68
Shear parallel to grain (kg/cm²)				
Shearing stress (Radial)	165 (16.0)	163 (24)	86	197
Shearing stress (Tangential)	172 (14.3)	195 (14.0)	103	115
Cleavage load to cause splitting				
Radial kg/cm of width	96 (24.7)	86 (33.3)	68	66
Tangential kg/cm of width	96 (16.0)	84 (29.3)	77	79
Tension perpendicular to grain (kg/cm²)				
Tensile strength (Radial)	60 (25.0)	70 (20.0)	44	41
Tensile strength (Tangential)	63 (20.3)	72 (28.2)	49	47
Toughness (cm-kg/specimen)				
Radial	587 (4.2)	549 (12.0)	387	381
Tangential	610 (9.1)	564 (10.0)	419	326

The values of physical and mechanical properties were also compared in Table 3 with the physical and mechanical properties of teak to find out the suitability of *Casuarina equisetifolia* expressed as percentage.

Table 3. Physical and mechanical properties of *Casuarina equisetifolia* relative to teak expressed as percentage.

Properties	Species/seasoning conditions/values *Casuarina equisetifolia*	
	Green	Air-dry
Specific gravity based on oven dry weight and volume		
At test	150	156
At oven dry	170	-
Volumetric Shrinkage (%) from green to oven dry condition based on green dimension	213	240
Static bending		
Stress at proportional limit	102	102
Modulus of rupture	114	129
Modulus of elasticity	125	136
Compression parallel to grain		
Stress at proportional limit	108	105
Maximum crushing strength	107	105
Compression perpendicular to grain: Stress at proportion limit	222	169
Hardness		
Side	197	218
End	174	224
Shear parallel to grain		
Shearing stress, Radial	192	83
Shearing stress, Tangential	167	169
Cleavage, load to cause splitting		
Radial	141	130
Tangential	125	106
Tension perpendicular to grain		
Tensile strength, Radial	136	171
Tensile strength, Tangential	129	153
Nail withdrawal		
Side	144	153
End	247	134
Toughness		
Radial	152	144
Tangential	146	173

Discussion

The Results showed that the *Casuarina equisetifolia* is a very heavy timber. It is evident from data that the specific gravity of 0.92 ; volumetric shrinkage is 9.6 % from green to air dry condition. On the other hand, the specific gravity and volumetric shrinkage for *T. grandis* was 0.59 and 5.00 % in air dry condition respectively. Chowdhury *et al.*

(2007) reported University of Chattogram-grown wood basic density for Jhau wood as 800 kg/ m3. Jhau is a high-density wood is supported by findings of other authors (e.g. Burgess 1966; Sosa-Suarez *et al.*1990). Sosa-Suarez *et al.* (1915) reported that basic density of the species in Cuba as 840 kg/m3, while Jain and Lala (1966) reported Indian-grown wood as 740 kg/m3. On the other hand, Sea-beach in Chattogram–grown basic density for Jhau was 920 kg/m3. Chattogram–grown density of Jhau is higher than other countries grown in Jhau. The specific gravity of sundri (*Heritiera fomes*) is 0.94 in air dry condition (Satter *et al.* 1999). On the other hand, the specific gravity and as strength is directly related to wood density (Shrivastava 1997).

The results showed that all the parameters have higher values in both green and air-dry conditions for jhau as compared to teak (Table 2). Jhau is a very strong timber with Modulus of Rupture (MOR) is 1306 kg/cm²; Modulus of Elasticity (MOE) is 178 kg/cm². Modulus of Rupture (MOR) and Modulus of Elasticity (MOE) of sundri (*Heritiera fomes*) was 1352 kg/cm² and 142 kg/cm² (Satter *et al.* 1999). Modulus of Rupture (MOR) is higher than that of Jhau and Modulus of Elasticity (MOE) is less than that of Jhau. Maximum crushing strength of parallel to the grain is 640 kg/cm², compressive strength of perpendicular to the grain is 201 kg/cm² and surface values of hardness was found side 1080 (kg), end 1191 (kg) in air-dry condition. On the other hand, The strength values of Jhau wood for shearing strength and tensile strength in air-dry condition are higher than that of green values except nail holding capacity (Table 2). Data indicated that all the strength properties of the species were higher than those of teak.

Conclusion

Investigations of physical and mechanical properties of beach plantation-grown in Chattogram Jhau (*Casuarina equisetifolia*) is a very heavy and strong wood but moderate stable. The heartwood is light red to dark reddish brown. The timber is generally dark colored, fissile, strong, heavy and very tough. It can be used in making agricultural implements and construction works. The species can be used for boat building, poles, piles, planking, fences, tool handles and other uses.

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Floristic Composition and Regeneration Status of Kaptai National Park

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Abstract

Kaptai National Park (KNP) is a protected area and represents a tropical semi-evergreen hill forest and home of widest variety of biodiversity in the country. Floristic composition and regeneration status of Kaptai National Park was assessed through stratified random sampling method. A total of 200 sample plots were taken of 20 m × 20 m in size for trees and 2 m × 2 m in size for regeneration data collection. Result of the study showed that there were 114 tree species belonging to 42 families and 77 regenerating species belonging to 35 families were recorded from the sample plots. The highest tree stem and regenerating seedlings density was found 373 stem ha^{-1} and 11788 stem ha^{-1} for *Aporosa dioica*. The study indicated that *A. dioica* is the most dominant tree species and its natural regeneration was also abundant in Kaptai National Park. On the other hand, Shannon-Wiener's diversity index, Margalef's diversity index, Simpson's and Pielou's diversity index were recorded for all the tree species. The percentage distribution of seedlings was maximum (56.56%) in 0-50 cm height range for all species. The number of seedlings reduced proportionately with height growth indicating a reduction of recruitment to next growth stage. Among the regenerating species, *Grewia nervosa* showed maximum (9.15%) seedling recruitment. The study is made baseline information on the natural regeneration of tree species diversity in the protected area which is helpful to future research work on plant population change, conservation and sustainable management planning for Kaptai National Park.

সারসংক্ষেপ

কাপ্তাই জাতীয় উদ্যান একটি সুরক্ষিত বনাঞ্চল এবং একটি ক্রান্তীয় অর্ধ-চিরহরিৎ পাহাড়ি বন ও দেশের বিস্তৃত জীব-বৈচিত্র্যের আবাসস্থল। কাপ্তাই জাতীয় উদ্যানে দৈবচয়ন পদ্ধতিতে উদ্ভিদের তথ্য সংগ্রহের জন্য ২০ মি. X ২০ মি.আয়তনের এবং পুনর্জন্মের তথ্য সংগ্রহের জন্য ২ মি. X ২ মি. আয়তনের সর্বমোট ২০০টি প্লট তৈরি করা হয়েছে। প্রাপ্ত ফলাফল হতে দেখা যাচ্ছে সর্বমোট ৪২টি পরিবারের অধীনে ১১৪ টি উদ্ভিদ প্রজাতির তথ্য এবং ৩৫ টি পরিবারের অধীনে ৭৭ টি উদ্ভিদ প্রজাতি হতে উদ্ভিদের পুনর্জন্মের (Regeneration) তথ্য প্লটগুলো হতে রেকর্ড করা হয়েছে। *Aporosa dioica* প্রজাতির গাছ সবচেয়ে বেশি হেক্টর প্রতি ৩৭৩টি এবং পুনর্জন্মানো চারার সংখ্যা (Regenerating seedlings) হেক্টর প্রতি ১১,৭৮৮টি। কাপ্তাই ন্যাশনাল পার্কের জরিপ হতে দেখা যাচ্ছে যে, *A. dioica* প্রজাতির উদ্ভিদ এবং ইহার পুনর্জন্মের হার সবচেয়ে বেশি। এছাড়াও শ্যানন-উইনার্স, মারগালেফ, সিম্পসন এবং পিলোর বৈচিত্র্য সূচকেরসূত্র দ্বারা গাছের প্রজাতি রেকর্ড করা হয়েছে। ০-৫ সে. মি. উচ্চতার সকল প্রজাতির চারার সর্বাধিক বিস্তার ছিল ৫৬.৫৬%। উচ্চতা বৃদ্ধির সাথে চারার সংখ্যা হ্রাস পাওয়ায় এটাই ইঙ্গিত প্রদান করে যে পরবর্তী সময়ে চারার সংখ্যা কমে যেতে পারে। *Grewia nervosa* এর সর্বাধিক ৯.১৫% চারার উপস্থিতি পরিলক্ষিত হয়েছে। কাপ্তাই ন্যাশনাল পার্কে পরিচালিত স্টাডিটির মাধ্যমে সংরক্ষিত উদ্ভিদ বনাঞ্চলের প্রাকৃতিক পুনর্জন্মের একটি বেসলাই তথ্য সংগ্রহ করা হয়েছে। যা ভবিষ্যতে উদ্ভিদের সংখ্যার পরিবর্তন ও সংরক্ষণ বিষয়ে গবেষণা এবং টেকসই বন ব্যবস্থাপনা, পরিকল্পনা প্রণয়নে সহায়তা করবে।

Key words: Biodiversity, Protected area, Important value index, Diversity indices.

Introduction

The plant diversity in the forests plays a significant role in maintaining and balancing natural eco-system (Sajib *et al.* 2016; Rahman *et al.* 2017). KNP represents tropical rainforest, mainly of semi-evergreen to evergreen type of vegetation (Uddin and Hassan 2012). Natural regeneration of the forest plant species is essential for conservation and maintenance of biodiversity (Hossain *et al.* 2004). Plants regeneration is important to maintain and expand their populations. The pattern of population structure of woody plants can show the regeneration profile and it is often used to indicate their regeneration status (Bekele 1994; Teketay 1996). Regeneration is a complex ecosystem process involving vegetative and sexual reproduction, dispersal and establishment in relation to environmental factors (Barnes *et al.* 1998). Biotic and abiotic factors along with disturbance regimes strongly influence the regeneration process, recruitment, species abundance and status of plant species in an ecosystem. Presence of sufficient number of seedlings, saplings, and young trees in a given population indicate a successful regeneration (Saxena and Singh 1984). Knowledge about the pattern of natural regeneration status is important to forest management (Zegeye *et al.* 2011; Hossain *et al.* 1999).

Muhammed *et al.* (2008a) mentioned that natural forests of the country have been deteriorating at an alarming rate due to various threats and biotic pressures like population, land use changes, inappropriate and poor management practices (Khan *et al.* 2008). Many researchers (Hossain *et al.* 2013; Haider *et al.* 2013; Chowdhury *et al.* 2018 etc.) have carried out various studies on floristic composition and regeneration status. But till today the forest resources of the country are declining in an alarming rate. In the circumstances, it is necessary to enhance the natural regeneration of forest tree species by suitable artificial and natural process for protecting forest flora and maintaining sustainability of yield, goods and services (Haque and Alam 1988). So, this research study was taken to update and assess the present natural regeneration composition, status and diversity of tree species in KNP to undertake conservation and management activity of the hill forest in future.

Materials and Methods

Study area

The study was carried out at Kaptai National Park (KNP) which was situated in the Rangamati Hill District and fell between the Karnaphuly and Kaptai Mountain Ranges (Fig.1). The park was located near Kaptai Bazar in the north-eastern corner of the Kaptai Upazila. It was about 57 kilometer from Chittagong town. KNP was being managed under Chittagong Hill Tracts South Forest Division. It was declared as National Park in 1999 with an area of 5,464.78 hectares (13,498.0 Acres). Before the declaration of the national park, it was the part of Sitapahar Reserve. It consisted of two Ranges called Kaptai Range and Karnaphuly Range. The park lies at 22° 27' 0" to 22° 32' 0" N latitudes and 92° 30' 0" to 92° 16' 0" E longitudes. The maximum rainfall is about 90% from May to September and the average annual rainfall is about 2,513 mm. The highest and lowest average temperatures are 25.30°C and 24.10°C respectively (Rangamati Weather Station 2014). Maximum humidity is 84% in June and the minimum humidity is 76% in January.

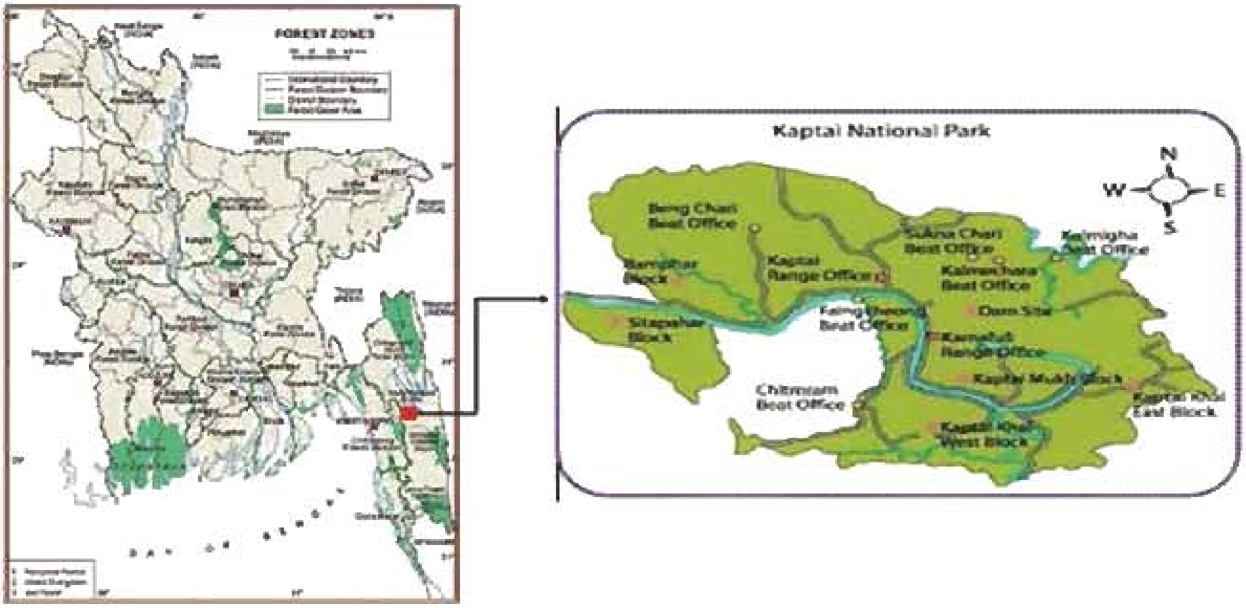

Figure 1. The location map of the study area- Kaptai National Park (KNP), Bangladesh.

Methodology

The quantitative assessments of natural regeneration conditions and tree species diversity was completed based on field survey and stratified random sampling methods. A total of 200 sample plots were studied; the optimum quadrat size (20 m x 20 m) was laid out applying the species area curve following Williams (1991). For the regeneration study, 2 m × 2 m subplots were taken in the middle point of each sample plots and thus a total of 200 regeneration subplots from the study area were studied. The area of each plot was determined by measuring tape and rope. Seedlings having ≤ 2 cm diameter at breast height (DBH) was considered as regeneration. The name and number of seedlings of each species were recorded in the regeneration plots. In each quadrat the diameter at breast height of each tree (≥5 cm dbh) was measured. The total height and diameter of all trees at breast height (dbh) inside the demarcated plots were measured using Suunto Clinometer and diameter tape respectively.

The plant samples were collected from the sampling plots and the common plant species were identified directly in the field. Habitat and habit form were also recorded. Herbarium specimen of unidentified plant samples with fertile material (flower, fruit and seed) were collected and prepared for identification after necessary processing. Herbarium specimens were identified by consulting with plant taxonomist and comparing them with authentic herbarium samples of Bangladesh Forest Research Institute Herbarium (BFRIH), Chattogram and Bangladesh National Herbarium (BNH), Dhaka as well as recognized references, e.g. Prain (1903); Heinig (1925); Siddiqui *et al.* (2007) and Ahmed *et al.* (2008). Finally the voucher specimens were preserved in the BFRI herbarium.

Data analysis

The field data were compiled and analyzed to determine density, relative density (RD %), frequency, relative frequency (RF %), abundance, relative abundance (RA %) and Importance Value Index (IVI) for study area according to the methods of Shukla and Chandel (2007), Magurran (1988) and Dallmeier *et al.* (1992). The equations (Eq. No. 1-7) used for calculating phytosociological characters were listed in Table 1. Also, biodiversity indices such as Shannon-Wiener's diversity index, Simpson's diversity index, species (Pielou's) evenness index, Margalef's species richness index etc., for the KNP were selected from published articles and compared it with the findings of other government managed forests of the country. The equations (Eq. No. 1-4) used for calculating biodiversity indices were listed in Table 2.

Table 1. The list of equations used for calculating phytosociological characters of the vegetation.

Equation no.	Phyto-sociological attributes	Equation	References
1	Density (D)	$D = \frac{a}{b}$	Shukla and Chandel (2000)
2	Relative Density (RD)	$R\ D = \frac{n}{N} \times 100$	Dallmeier *et al.* (1992), Misra (1968)
3	Frequency (F)	$F = \frac{c}{b}$	Shukla and Chandel (2000)
4	Relative Frequency (RF)	$R\ F = \frac{F_i}{\sum_{i=1}^{s}(F_i)}$	Dallmeier *et al.* (1992), Misra (1968)
5	Abundance (A)	$A = \frac{n}{c}$	Shukla and Chandel (2000)
6	Relative Abundance (RA)	$R\ A = \frac{A_i}{\sum_{i=1}^{s}(A_i)}$	Shukla and Chandel (2000)
7	Important Value Index (IVI)	IVI = RD + RF + RA	Shukla and Chandel (2000), Dallmeier *et al.* (1992)

Note: a= Total no. of individuals of a species in all the quadrats, b= Total no. of quadrats studied, n= Total No. of individuals of the species, N= Total No. of individuals of all the species, c= Total no. of quadrats in which the species occurs, F_i = Frequency ofone species, A_i= Abundance of one species

Table 2. The list of equations used for calculating biodiversity indices of the vegetation.

Equation no.	Biodiversity indices	Formula	References
1	Shannon-Wiener's diversity index (H)	$H=-\sum_{i=1}^{n} p_i ln p_i$	Shannon and Wiener (1963)
2	Margalef's species richness index (R)	$R = \frac{(s-1)}{\ln (N)}$	Margalef (1958)
3	Simpson's diversity index (D)	$D = \sum_{i=1}^{n} p_i^2$	Simpson (1949)
4	Species (Pielou's) evenness index (E)	$E = \frac{H}{\ln (s)}$	Pielou (1966)

Note: H = Shannon-Wiener's diversity index, N = Total no. of individuals of all the species, P_i = Number of individuals of i^{th} species/Total number of individuals, S = Total number of species

Results

Diversity of tree species

Tree is an important component of any forest. The study was recorded from all samples plots a total of 114 species belongs to 42 families from the KNP (Table 3). Among the recorded species, Euphorbiaceae was the dominated family with 13 species followed by Moraceae (12 species), Meliaceae (6 species), Verbenaceae (5 species) and Rubiaceae, Lauraceae, Anacardiaceae, Dipterocarpaceae and Sterculiaceae families have four species in each family.

Diversity indices of tree species

Among the 114 plant species the highest number of plant species per hectare were found (373 stem ha^{-1}) for *Aporosa dioica* followed by *Grewia nervosa* (367 stem ha^{-1}), *Aporosa wallichii* (301 stem ha^{-1}) and *Tectona grandis* (294 stem ha^{-1}). The lowest number plants per hectare were found (9 stem ha^{-1}) for *Anisoptera scaphula* followed by *Azadirachta indica* (10 stem ha^{-1}) and *Artocarpus lacucha* (11 stem ha^{-1}) in the national park. A rich ecosystem with high species diversity has a high value of Shannon–Wiener diversity index, while a lower value indicated an ecosystem with little diversity. Different diversity indices values were calculated to represent tree species diversity of the study area. Among these Shannon-Wiener's index (3.53), Species evenness index (0.74), Margalef's diversity index (13.05) and the Simpson's diversity index (0.94). In the present study, the Shannon–Wiener diversity index (3.53) for tree species was comparatively higher than that the (2.98) reported by Nath *et al.* (2000) in the Sitapahar natural forest of Chittagong and 3.25 in Tankawati natural forest of Chittagong (South) Forest Division (Motaleb and Hossain 2011). Whereas Simpson's diversity index (0.94) showed less species diversity which represented that the area was not dominated by only a single species; it was dominated by mixure of tree species. The values of Shannon-Wiener's index (3.53) and Margalef's species richness index (13.05) indicated higher species diversity in KNP in comparison to other natural forest in the country.

Phytosociological characters of the tree species

Tree stem ha^{-1}, relative density, relative frequency, relative abundance and Importance Value Index (IVI) of the recorded tree species are shown in Table 3. Thirty dominant tree species accounted for 84.56% of the individuals (5241 out of 6198). The highest tree density was found for *Aporosa dioica* 373 stem ha^{-1}. While maximum relative density was recorded in *A. dioica* (12.03%) followed by *Grewia nervosa* (11.84%), *A. wallichii* (9.71%), *Tectona grandis* (9.46%) and *Protium serratum* (5.39%), maximum relative frequency was recorded in *T. grandis* (7.06%) followed by *G. nervosa* (6.67%), *A. dioica* (5.70%), *A. wallichii* (4.68%), *P. serratum* (3.85%), *Artocarpus chama* (2.78%). The species with highest relative abundance was *Michelia champaca* (3.72 %) followed by *A. dioica* (2.63%), *A. wallichii* (2.59%), *G. nervosa* (2.21%) and *Shorea robusta* (1.93 %). *G. nervosa* with importance value index (IVI) of (20.72) was the most dominant tree followed by *A. dioica* (20.36), *T. grandis* (18.20), *A. wallichii* (16.97) and *P. serratum* (10.98).

Table 3. Stem per hectare, relative density (RD), relative frequency (RF), relative abundance (RA) and Importance Value Index (IVI) of tree species in KNP.

SL. No.	Local name	Scientific name	Family	Stem ha^{-1}	RD (%)	RA (%)	R F (%)	IVI
1	Kechua	*Aporosa dioica* (Roxb.) Mull. Arg.	Euphorbiaceae	373	12.03	2.63	5.70	20.36
2	Assar	*Grewia nervosa* (Lour.) Panigr.	Tiliaceae	367	11.84	2.21	6.67	20.72
3	Kechua	*Aporosa wallichii* Hook. f.	Euphorbiaceae	301	9.71	2.59	4.68	16.97
4	Segun	*Tectona grandis* L.f.	Verbenaceae	294	9.46	1.67	7.06	18.20
5	Gutgutya	*Protium serratum* (Wall.*ex* Coelbr.) Engl.	Burseraceae	167	5.39	1.75	3.85	10.98
6	Bura	*Macaranga denticulata* (Bl.) Mull. Arg.	Euphorbiaceae	95	3.05	1.53	2.48	7.06
7	Sheora	*Streblus asper* Lour.	Moraceae	77	2.48	1.30	2.39	6.17
8	Leea	*Leea acuminata* Wall.	Leeaceae	71	2.29	0.90	3.17	6.36
9	Jarul	*Lagerstroemia speciosa* (L.) Pers.	Lythraceae	70	2.24	1.37	2.05	5.65
10	Puti jam	*Syzygium fruticosum* DC.	Myrtaceae	57	1.84	0.84	2.73	5.41

SL. No.	Local name	Scientific name	Family	Stem ha^{-1}	RD (%)	RA (%)	R F (%)	IVI
11	Lotkon	*Baccaurea ramiflora* Lour.	Euphorbiaceae	56	1.79	1.43	1.56	4.78
12	Madanmasta	*Actinodaphne angustifolia* Nees	Lauraceae	50	1.60	0.91	2.19	4.70
13	Chapalish	*Artocarpus chama* Buch.-Ham.	Moraceae	50	1.60	0.72	2.78	5.09
14	Dakrom	*Mitragyna parvifolia* (Roxb.) Korth.	Rubiaceae	49	1.58	0.83	2.39	4.79
15	Pitraj	*Aphanamixis polystachya* (Wall.) Parker	Meliaceae	48	1.55	0.71	2.73	4.98
16	Sinduri	*Mallotus philippensis* (Lamk.) Muell.-Arg.	Euphorbiaceae	46	1.48	0.83	2.24	4.55
17	Jat koroi	*Albizia procera* (Roxb.) Benth.	Mimosaceae	43	1.37	0.95	1.80	4.12
18	Garjan	*Dipterocarpus turbinatus* Gaertn.	Dipterocarpaceae	42	1.34	1.22	1.36	3.93
19	Lana assar	*Pterospermum semisagittatum* Buch.-Ham. *ex* Roxb.	Sterculiaceae	37	1.18	1.51	0.97	3.66
20	Bon kunch	*Micromelum minutum* (G. Froster) Wight & Arn.	Rutaceae	36	1.15	1.72	0.83	3.70
21	Menda	*Litsea monopetala* (Roxb.) Pers.	Lauraceae	34	1.10	0.78	1.75	3.63
22	Mahogani	*Swietenia mahagoni* (L.) Jacq.	Meliaceae	33	1.06	1.60	0.83	3.50
23	Dumur	*Ficus hispida* L.f.	Moraceae	33	1.06	0.78	1.70	3.55
24	Moss	*Pterospermum acerifolium* (L.) Willd.	Sterculiaceae	31	0.99	0.79	1.56	3.33
25	Goda	*Vitex peduncularis* Wall. *ex* Schauer	Verbenaceae	31	1.00	0.75	1.66	3.41
26	Kao gola	*Garcinia cowa* Roxb. *ex* DC	Clusiaceae	28	0.89	0.78	1.41	3.08
27	Kannyari	*Gardenia coronaria* Buch.- Ham.	Rubiaceae	28	0.90	0.89	1.27	3.06
28	Ichri	*Anogeissus acuminata* (Roxb. *ex* DC) Guill *ex* Perr.	Combretaceae	28	0.88	0.81	1.36	3.06

SL. No.	Local name	Scientific name	Family	Stem ha^{-1}	RD (%)	RA (%)	R F (%)	IVI
29	Champa	*Michelia champaca* L.	Magnoliaceae	27	0.87	3.72	0.29	4.88
30	Dhaki jam	*Syzygium firmum*Thwaites	Myrtaceae	25	0.81	0.61	1.66	3.07
31	Bar pata	*Fernandoa adenophylla* (Wall. *ex* G. Don)	Bignoniaceae	22	0.71	0.70	1.27	2.67
32	Sal	*Shorea robusta* Roxb. *ex* Gaertn.f.	Dipterocarpaceae	21	0.68	1.93	0.44	3.04
33	Bon -lichu	*Walsura robusta* Roxb.	Meliaceae	19	0.61	1.43	0.54	2.58
34	Barela	*Holigarna caustica* (Dennst) Oken	Anacardiaceae	18	0.58	0.65	1.12	2.35
35	Dholi batna	*Lithocarpus acuminata* (Roxb.) Rehder	Fagaceae	16	0.52	0.83	0.78	2.12
36	Bohera	*Terminalia bellirica* (Gaertn.) Roxb.	Combretaceae	15	0.47	0.60	0.97	2.04
37	Minjiri	*Senna siamea* (Lamk.) Irwin & Barneby	Caesalpiniaceae	14	0.44	1.39	0.39	2.22
38	Maricha	*Maesa ramentacea* (Roxb.) A. DC.	Myrsinaceae	14	0.45	0.83	0.68	1.96
39	Am barela	*Myristica linifolia* Roxb.	Myristicaceae	14	0.44	0.80	0.68	1.91
40	Pitali	*Trewia nudiflora* L.	Euphorbiaceae	13	0.42	1.07	0.49	1.98
41	Nala-amsi	*Persea bombycina* (King *ex* Hook.f.) Kosterm.	Lauraceae	13	0.40	0.94	0.54	1.88
42	Dharmara	*Stereospermum colais* (Buch.-Ham. *ex* Dillw.) Mabb.	Bigoniaceae	13	0.40	0.94	0.54	1.88
43	Chagaler bori	*Lepisanthes rubiginosa* (Roxb.) Leenhouts	Sapindaceae	12	0.37	0.56	0.83	1.76
44	Telsur	*Hopea odorata* Roxb.	Dipterocarpaceae	11	0.34	1.45	0.29	2.08
45	Parul	*Stereospermum suaveolens* (Roxb.). DC.	Bignoniaceae	11	0.34	0.67	0.63	1.64
46	Khanda dumur	*Ficus hirta* Vahl.	Moraceae	11	0.35	0.61	0.73	1.69

SL. No.	Local name	Scientific name	Family	Stem ha^{-1}	RD (%)	RA (%)	R F (%)	IVI
47	Bandarhola	*Duabunga grandiflora* (Roxb. *ex* DC.) Walp.	Sonneratiaceae	5	0.16	0.59	0.34	1.09
48	Suregada	*Suregada multiflora* (A. Juss.) Bail.	Euphorbiaceae	5	0.15	0.53	0.34	1.01
49	Mandar	*Erythrina variegata* L.	Fabaceae	4	0.13	0.47	0.34	0.94
50	Udal	*Sterculia villosa* Roxb. *ex* Smith.	Sterculiaceae	4	0.11	0.58	0.24	0.93
51	Kalo jam	*Syzygium cumini* (L.) Skeels	Myrtaceae	4	0.13	0.55	0.29	0.97
52	Gamari	*Gmelina arborea* (Roxb.) DC.	Verbenaceae	4	0.13	0.66	0.24	1.03
53	Haldu	*Haldina cordifolia* (Roxb.) Ridsdale.	Rubiaceae	4	0.11	0.58	0.24	0.93
54	Agar	*Aquilaria malaccensis* Lamk.	Thymelaeaceae	4	0.13	1.65	0.10	1.88
55	Kanjail Bhadi	*Bischofia javanica* Bl.	Euphorbiaceae	3	0.08	1.03	0.10	1.21
56	Kurchi	*Holarrhena antidysenterica* (L.) Wall.	Aopcynaceae	3	0.10	0.62	0.19	0.91
57	Sonalu	*Cassia fistula* L.	Caesalpiniaceae	3	0.10	0.62	0.19	0.91
58	Raskao	*Carallia brachiata* (Lour.) Merr.	Rhizophoraceae	3	0.10	0.41	0.29	0.80
59	Civit	*Swintonia floribunda* Griff.	Anacardiaceae	3	0.08	0.52	0.19	0.79
60	Joggya dumur	*Ficus racemosa* L.	Moraceae	3	0.10	0.50	0.24	0.84
61	Panidumur	*Ficus nervosa* Heyne *ex* Roth	Moraceae	3	0.08	0.52	0.19	0.79
62	Chundul	*Tetrameles nudiflora* R.Br.	Datiscaceae	3	0.08	0.52	0.19	0.79
63	Barun	*Crataeva magna* (Lour.) DC.	Capparaceae	3	0.08	1.03	0.10	1.21
64	Dhup	*Canarium resiniferum* Brace *ex* King	Burseraceae	2	0.05	0.41	0.15	0.61
65	Jhumka bhadi	*Engelhardtia spicata* Leschen *ex* Bl.	Juglandaceae	2	0.05	0.62	0.10	0.77

SL. No.	Local name	Scientific name	Family	Stem ha^{-1}	RD (%)	RA (%)	R F (%)	IVI
66	Kadam	*Neolamarckia cadamba* (Roxb.) Bosser	Rubiaceae	2	0.05	0.41	0.15	0.61
67	Ormosia	*Ormosia robusta* (Roxb.) Baker	Fabaceae	2	0.05	0.41	0.15	0.61
68	Khona	*Oroxylum indicum* (L.) Benth. *ex* Kurz	Bignoniaceae	2	0.05	0.41	0.15	0.61
69	Chalmoogra	*Hydnocarpus kurzii* (King) Warb.	Flacourtiaceae	2	0.05	1.24	0.09	1.34
70	Arsol	*Vitex glabrata* R. Br.	Verbenaceae	2	0.05	0.41	0.14	0.61
71	Bot	*Ficus benghalensis* L.	Moraceae	2	0.06	0.41	0.19	0.67
72	Bara dumur	*Ficus auriculata* Lour.	Moraceae	2	0.06	0.83	0.10	0.99
73	Paduk	*Pterocarpus indicus* Willd.	Fabaceae	2	0.05	1.24	0.05	1.34
74	Amloki	*Phyllanthus emblica* Linn.	Euphorbiaceae	2	0.06	0.41	0.19	0.67
75	Bolos	*Sapium baccatum* Roxb.	Euphorbiace	2	0.05	1.24	0.05	1.33
76	Amra	*Spondias pinnata* (L.f.) Kurz	Anacardiaceae	2	0.05	0.62	0.10	0.77
77	Miringa	*Derris robusta* (Roxb.*ex* DC)	Fabaceae	2	0.06	0.83	0.10	0.99
78	Raktan	*Lophopetalum wightiamum* Arn.	Cleastraceae	1	0.03	0.41	0.05	0.48
79	Pine	*Pinus caribaea* Morelet	Pineaceae	1	0.02	0.41	0.05	0.48
80	Chalta	*Dillenia indica* L.	Dilleniaceae	1	0.03	0.41	0.10	0.54
81	Belpoi	*Elaeocarpus varunna* Buch.-Ham. *ex* Master	Elaeocarpaceae	1	0.02	0.41	0.05	0.48
82	Hargaza	*Dillenia pentagyana* Roxb.	Dilleniaceae	1	0.03	0.41	0.10	0.54
83	Dud kurch	*Wrightia arborea* (Dennst.) Mabberley	Aopcynaceae	1	0.02	0.41	0.05	0.48
84	Kusum	*Schleichera oleosa* (Lour.) Oken.	Sapindaceae	1	0.03	1.41	0.10	1.54
85	Dhamon	*Grewia serrulata* DC.	Tiliaceae	1	0.02	0.41	0.05	0.48
86	Aam	*Mangifera indica* L.	Anacardiaceae	1	0.03	0.41	0.10	0.54

SL. No.	Local name	Scientific name	Family	Stem ha^{-1}	RD (%)	RA (%)	R F (%)	IVI
87	Bon simul	*Bombax insigne* Wall.	Bombacaceae	1	0.02	0.41	0.05	0.48
88	Tamal	*Diospyros Montana* Roxb.	Ebenaceae	1	0.02	0.41	0.05	0.48
89	Haritaki	*Terminalia chebula* Retz.	Combretaceae	1	0.02	0.41	0.05	0.48
90	Buddha narikel	*Pterygotaalata* (Roxb.) R. Br.	Sterculiaceae	1	0.02	0.41	0.05	0.48
91	Paikor	*Ficus rumphii* Bl.	Moraceae	1	0.03	0.41	0.10	0.54
92	Bajna	*Zanthoxylum rhetsa* (Roxb.) DC.	Rutaceae	1	0.03	0.82	0.10	0.95
93	Sil batna	*Quercus gomeziana* A. Camus	Fagaceae	1	0.04	0.83	0.08	0.95
94	Borojiri bot	*Ficus benjamina* L.	Moraceae	1	0.02	0.41	0.05	0.48

Figure 2. Sample plots laying out and regeneration data collection from Kaptai National Park.

Natural regeneration status

A total of 77 regenerating tree species belonging to 35 families were recorded from the 200 sample plots of KNP. Among the families Euphorbiaceae was the highest number of 10 regenerating tree species, Moraceae 7 species and Meliaceae 5 species.

Diversity indices of regenerating tree species

The highest stem density (11,788 stem ha^{-1}) was found in the national park. The Shannon-Wiener's index (3.42), species evenness index (0.40) Margalef's diversity index (8.84) and the Simpson's diversity index (0.99) was calculated for the study area (Table 4).

Diversity of regenerating tree species

The importance value index of the seedlings of KNP is shown in Table 4. The average highest seedling density of regenerating tree species was found *Aporosa dioica* 11,788 stem ha^{-1} followed by *A. wallichii* (9,675), *Protium serratum* (9,525), *Grewia nervosa* (4,013), *Lagerstroemia speciosa* (3,963) and *Syzygium fruticosum* (3,150). The highest relative density of the species was found *A. dioica* (10.21%) followed by *A. wallichii* (8.38%), *P. serratum* (8.25%), *G. nervosa* (3.47%), *L. speciosa* (3.43%), *Macaranga denticulata* (3.11%) and *S. fruticosum* (2.73%). Although the highest relative frequency was found *G. nervosa* (7.15%) followed by *A. dioica* (6.11%), *A. wallichii* (5.01%), *P. serratum* (4.54%), *Leea acuminata* (3.45%), *Aphanamixis polystachya* (3.08%) and *Artocarpus chama* (2.98%) and the highest relative abundance was recorded *Shorea robusta* (2.71%) followed by *P. serratum* (2.46%), *Swietenia mahagoni* (2.40%), *Persea bombycina* (2.33%) and *Callicarpa macrophylla* (2.28%). The highest IVI of regenerating seedling species was recorded *A. dioica* (18.58) followed by *A. wallichii* (15.66), *P. serratum* (15.25), *G. nervosa* (11.29), *L. speciosa* (7.78) and *M. denticulata* (7.35). According to results *A. dioica* is the dominant regenerating species of KNP.

Table 4. Seedling density, Relative density (RD), Relative frequency (RF), Relative abundance (RA) and Importance Value Index (IVI) of 77 dominant regenerating plants in KNP.

SL. No.	Local name	Scientific name	Seedlings ha^{-1}	RD (%)	RA (%)	RF (%)	IVI
1	Kechua	*Aporosa dioica* (Roxb.) Mull. Arg.	11788	10.21	2.27	6.11	18.58
2	Kechua	*Aporosa wallichii* Hook. f.	9675	8.38	2.27	5.01	15.66
3	Gutgutya	*Protium serratum* (Wall. *ex* Coelbr.) Engl.	9525	8.25	2.46	4.54	15.25
4	Assar	*Grewia nervosa* (Lour.) Panigr.	4013	3.47	0.66	7.15	11.29
5	Jarul	*Lagerstroemia speciosa* (L.) Pers	3963	3.43	1.90	2.45	7.78
6	Madanmasta	*Macaranga denticulata* (Bl.) Mull. Arg.	3588	3.11	1.58	2.66	7.35
7	Puti jam	*Syzygium fruticosum* DC.	3150	2.73	1.26	2.92	6.92
8	Shorea	*Streblus asper* Lour.	2675	2.32	1.23	2.56	6.10

SL. No.	Local name	Scientific name	Seedlings ha^{-1}	RD (%)	RA (%)	RF (%)	IVI
9	Garjan	*Dipterocarpus turbinatus* Gaertn.	2563	2.22	2.06	1.46	5.74
10	Chapalish	*Artocarpus chama* Buch.-Ham.	2538	2.20	1.00	2.98	6.17
11	Madanmasta	*Actinodaphne angustifolia* Nees.	2513	2.18	1.26	2.35	5.78
12	Dakroom	*Mitragyna parvifolia* (Roxb.) Korth.	2475	2.14	1.14	2.56	5.84
13	Leea	*Leea acuminata* Wall.	2463	2.13	0.84	3.45	6.42
14	Mahogani	*Swietenia mahagoni* (L.) Jacq.	2350	2.03	2.40	1.15	5.59
15	Sinduri	*Mallotus philippensis* (Lamk.) Muell-Arg.	2150	1.86	1.05	2.40	5.31
16	Maricha	*Maesa ramentacea* (Roxb.) A. DC.	2075	1.80	2.12	1.15	5.07
17	Moss	*Pterospermum acerifolium* (L.) Wild.	2013	1.74	1.41	1.67	4.83
18	Sil koroi	*Albizia procera* (Roxb.) Benth.	1988	1.72	1.21	1.93	4.86
19	Dumur	*Ficus hispida* L.f.	1663	1.44	1.07	1.83	4.34
20	Lana assar	*Pterospermum semisagittatum* Buch.-Ham. *ex* Roxb.	1638	1.42	1.02	1.88	4.32
21	Dhaki jam	*Syzygium firmum* Thwaites	1600	1.39	1.09	1.72	4.20
22	Kannyari	*Gardenia coronaria* Buch.- Ham.	1588	1.37	1.37	1.36	4.11
23	Pitraj	*Aphanamixis polystachya* (Wall.) Parker	1575	1.36	0.60	3.08	5.05
24	Ichri	*Anogeissus acuminata* (Roxb. *ex* DC.) Guill. & perr.	1513	1.31	1.62	1.10	4.03
25	Menda	*Litsea monopetala* (Roxb.) Pers.	1450	1.26	1.02	1.67	3.95
26	Bon kunch	*Micromelum minutum* (G. Froster) Wight & Arn.	1338	1.16	1.16	1.36	3.67
27	Telsur	*Hopea odorata* Roxb.	1325	1.15	2.13	0.73	4.01
28	Sal	*Shorea robusta* Roxb. *ex* Gaertner.f.	1325	1.15	2.71	0.57	4.43

SL. No.	Local name	Scientific name	Seedlings ha^{-1}	RD (%)	RA (%)	RF (%)	IVI
29	Tetuya-koroi	*Albizia odoratissima* (L.f.) Benth.	1238	1.07	1.64	0.89	3.60
30	Kala koroi	*Albizia lebbeck* (L.) Benth.	1150	0.99	1.36	0.99	3.35
31	Nala-amsi	*Persea bombycina* (King *ex* Hook.f.) Kosterm.	1138	0.98	2.33	0.57	3.88
32	Khalta	*Diospyros pilosula* (A.DC.) Hiern.	1088	0.94	1.75	0.73	3.42
33	Barpata	*Fernandoa adenophylla* (Wall. *ex* G. Don) van Steenis	1088	0.94	0.94	1.36	3.24
34	Dharmara	*Stereospermum colais* (Buch.-Ham. *ex* Dillw.) Mabb.	1088	0.94	1.16	1.10	3.20
35	Pitali	*Trewia nudiflora* L.	1038	0.90	1.37	0.89	3.16
36	Goda	*Vitex peduncularis* Wall. *ex* Schauer	1025	0.89	0.82	1.46	3.17
37	Barta	*Artocarpus lacucha* Buch.-Ham	975	0.84	1.22	0.94	3.00
38	Boilam	*Anisoptera scaphula* (Roxb.) Pierre	950	0.82	1.78	0.63	3.23
39	Kumkoi	*Bridelia retusa* (L.) A. Juss.	900	0.78	1.56	0.68	3.01
40	Kanak	*Schima wallichii* (DC.) Korth.	875	0.76	1.51	0.68	2.95
41	Barmala	*Callicarpa macrophylla* Vahl	813	0.70	2.28	0.42	3.41
42	Bohera	*Terminalia bellirica* (Gaertn.) Roxb.	788	0.68	1.04	0.89	2.61
43	Khanda dumur	*Ficus hirta* Vahl.	775	0.67	1.16	0.78	2.62
44	Kaow	*Garcinia cowa* Roxb. *ex* DC	775	0.67	0.67	1.36	2.70
45	Dholi batna	*Lithocarpus acuminata* (Roxb.) Rehder	763	0.66	1.07	0.84	2.57
46	Sonalu	*Cassia fistula* L.	688	0.60	1.29	0.63	2.51
47	Bonboroi	*Ziziphus rugosa* Lamk.	688	0.60	1.41	0.57	2.58
48	Chagaler bori	*Lepisanthes rubiginosa* (Roxb.) Leenhouts	650	0.56	0.86	0.89	2.31

SL. No.	Local name	Scientific name	Seedlings ha^{-1}	RD (%)	RA (%)	RF (%)	IVI
49	Am berala	*Myristica linifolia* Roxb.	650	0.56	1.04	0.73	2.34
50	Udal	*Sterculia villosa* Roxb. *ex* Smith.	650	0.56	0.97	0.78	2.32
51	Toon	*Toona ciliata* M. Roem.	600	0.52	1.12	0.63	2.27
52	Barela	*Holigarna caustia* (Dennst) Oken	563	0.49	0.67	0.99	2.14
53	Deshi gab	*Diospyros malabarica* (Desr.) Kostel.	525	0.45	1.07	0.57	2.10
54	Parul	*Stereospermum suaveolens* (Roxb.) DC.	525	0.45	0.91	0.68	2.04
55	Chikrassi	*Chukrasia tabularis* A. Juss.	513	0.44	1.92	0.31	2.68
56	Sil bhadi	*Garuga pinnata* Roxb.	488	0.42	0.91	0.63	1.96
57	Tezbohol	*Cinnamomum iners* Reinw. *ex* Bl.	475	0.41	0.97	0.57	1.96
58	Kalo jam	*Syzygium cumini* (L.) Skeels	450	0.39	1.69	0.31	2.39
59	Chatim	*Alstonia scholaris* (L.) R. Br.	425	0.37	1.19	0.42	1.98
60	Lotkon	*Baccaurea ramiflora* Lour.	400	0.35	0.45	1.04	1.84
61	Kharulla	*Aporosa oblonga* Muell.-Arg.	338	0.29	0.84	0.47	1.61
62	Uriam	*Mangifera sylvatica* Roxb.	338	0.29	0.76	0.52	1.57
63	Bon lichu	*Walsura robusta* Roxb.	338	0.29	0.69	0.57	1.56
64	Bandarhola	*Duabunga grandiflora* (Roxb. *ex* DC.) Walp.	300	0.26	0.96	0.37	1.59
65	Chundul	*Tetrameles nudiflora* R.Br.	288	0.25	1.62	0.21	2.07
66	Bon jolpai	*Elaeocarpus floribundus* Bl.	275	0.24	0.62	0.52	1.38
67	Maricha	*Suregada multiflara* (A. Juss.) Baill.	275	0.24	0.88	0.37	1.49
68	Joggyadumur	*Ficus racemosa* L.	263	0.23	1.18	0.26	1.67
69	Kurchi	*Holarrhena antidysenterica* (L.) Wall.	250	0.22	1.12	0.26	1.60
70	Khona	*Oroxylum indicum* (L.) Kurz	250	0.22	1.87	0.16	2.25
71	Roskao	*Carallia brachiata* (Lour.) Merr.	225	0.19	0.84	0.31	1.35

SL. No.	Local name	Scientific name	Seedlings ha^{-1}	RD (%)	RA (%)	RF (%)	IVI
72	Kanjail Bhadi	*Bischofia javanica* Bl.	200	0.17	1.12	0.21	1.51
73	Pain dumur	*Ficus nervosa* Heyne *ex* Roth.	200	0.17	1.12	0.21	1.51
74	Arsol	*Vitex glabrata* R. Br.	200	0.17	1.50	0.16	1.83
75	Haldu	*Haldina cordifolia* (Roxb.) Ridsdale.	188	0.16	0.84	0.26	1.27
76	Barun	*Crataeva magna* (Lour.) DC.	150	0.13	1.12	0.16	1.41
77	Amloki	*Phyllanthus emblica* L.	150	0.13	0.84	0.21	1.18

Distributions of seedlings in different height classes

The vertical profile of a forest provides a clear concept of forest stratification. Regenerates height up to 250 cm were considered as seedlings. The percentage distribution of all seedlings of all species into different height (cm) classes was provided in Fig. 3.

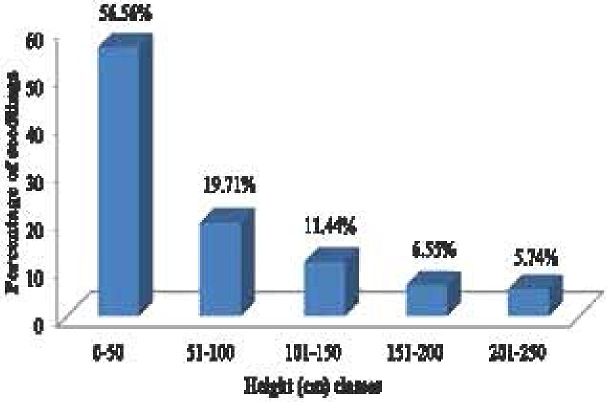

Figure 3. Percentage distribution of all the seedlings into different height (cm) classes.

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

Recruitment of the seedlings

The recruitment of seedlings is an important factor 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-1 were shown in Table 5. *Grewia nervosa* had maximum 9.15% seedlings recruitment percentage followed by *A. dioica* (3.16%), *A. wallichii* (3.11%) and *Aphanamixis polystachya* (3.05%). The conservation measures of biological diversity should be based on regeneration potentials of plant species.

Table5. Percentage recruitment of 15 major regenerating tree species in relation to trees ha^{-1} and seedlings ha^{-1} at KNP.

SL. No.	Scientific Name	Family	Stem ha^{-1}	Seedlings ha^{-1}	Recruitment (%)
1	*Grewia nervosa* (Lour.) Panigr.	Tiliaceae	367	4013	9.15
2	*Aporosa dioica* (Roxb.) Mull. Arg.	Euphorbiaceae	373	11788	3.16
3	*Aporosa wallichii* Hook. f.	Euphorbiaceae	301	9675	3.11
4	*Aphanamixis polystachya* (Wall.) Parker	Meliaceae	48	1575	3.05
5	*Streblus asper* Lour.	Moraceae	77	2675	2.88
6	*Swietenia mahagoni* (L.) Jacq.	Meliaceae	33	2350	1.40
7	*Macaranga denticulata* (Bl.) Mull. Arg.	Euphorbiaceae	95	3588	2.65
8	*Albizia procera* (Roxb.) Benth.	Mimosaceae	43	1988	2.16
9	*Mallotus philippensis* (Lamk.) Mull. Arg.	Euphorbiaceae	46	2150	2.14
10	*Actinodaphne angustifolia* Nees	Lauraceae	50	2513	1.99
11	*Mitragyna parvifolia* (Roxb.) Korth.	Rubiaceae	49	2475	1.98
12	*Artocarpus chama* Buch.-Ham.	Moraceae	50	2538	1.97
13	*Syzygium fruticosum* DC.	Myrtaceae	57	3150	1.81
14	*Lagerstroemia speciosa* (L.) Pers.	Lythraceae	70	3963	1.77
15	*Protium serratum* (Wall. *ex* Coelbr.) Engl.	Burseraceae	167	9525	1.75

Discussion

The present study gave an idea about tree composition and regeneration status in natural forest of KNP. The conservation processes of natural diversity should be based on regeneration potentials of plant species (Verma *et al.* 1999). It was a significant indicator for assessing the overall condition of a forest ecosystem (Rahman *et al.* 2011).

The study reveals that 77 regenerating tree species belonging to 35 families were recorded from KNP. The number of species was comparatively lower than Hossain *et al.* (2013). Which reported 120 regenerating species under 36 families from Dudhpukuria-Dhopachari Wildlife Sanctuary (DDWS) in Chittagong South Forest Division.

However, the required species are much than others e.g. Hossain *et al.* (2004) reported 64 regenerating tree species in the natural forest of Chittagong South Forest Division; Motaleb and Hossain (2007) reported 29 regenerating tree species from the semi-evergreen forest of Chittagong South Forest Division; Rahman *et al.* (2011) stated 55 regenerating plant species in Khadimnagar National Park and Tilagarh Eco-Park; Haider *et al.* (2017) reported 70 regenerating tree species from Lawachara, Adampur (Kalengi) and Sree-Gobinapur natural forests under Moulvibazar district of Sylhet Forest Division; Nur *et al.* (2016) reported 17 regenerating tree species from Chittagong North Forest Division; Chowdhury *et al.* (2018) reported 15 regenerating tree species from Rampahar Forest Reserve, Rangamati South Forest Division.

Comparatively higher regenerating status in KNP from other protected natural forest area might be due to one of the protected areas was kept under the study which was having minimum human interference. This might be the main cause of higher number of seedlings in the initial stage of seedling development. But the height class distribution indicated occurrences of illegal removal of trees from the forest and regenerated seedlings could not survive due to fuel wood collectors. In order to maintain the species diversity of the study area, an ecologically sound management system was desirable with minimum disturbance. The families Euphorbiaceae, Moraceae, Meliaceae and Dipterocarpaceae showed the higher regeneration potentials due to maximum seed dispersal capability and favorable climatic conditions for natural regeneration. *Aporosa dioica*, *Grewia nervosa*, *Syzygium fruticosum*, *Macaranga denticulata*, *Aporosa wallichii*, *Dipterocarpus turbinatus* and *Protium serratum* showed the dominant regeneration species. The present study revealed that higher regeneration potentials for some of the economically and ecologically important tree species. However, still there are many causes which may be critical for the occurrence and establishment of natural regeneration. The species that have low IVI should be given priority in conservation programme. Protection and assisted natural regeneration (ANR) may be another alternative option for effective natural regeneration and conservation of renovating these species rich natural forests to artificial plantations.

Conclusion

The present study provides findings of the tree species composition and natural regeneration status of KNP. The diversity indices of the study showed the potential promise of natural regeneration in KNP compared to other natural forest diversity indices. The forest was heavily exploited and affected in the past, but now there is a lot of regeneration after the declaration of protected area. New recruits were found and indicating that they were not headed to extinction. But the cutting of seedlings and saplings particularly by fuel wood collectors poses threats on new recruitments. These types of activities must be stopped immediately; otherwise this will reduce natural forest restoration capacity. The data of natural regeneration information of the tree species will be helpful to the policy makers, conservationists and management planners in formulating and implementing future forest resource conservation and preparing a sustainable management plan of KNP.

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Preliminary Performance of Sal (*Shorea robusta*) with its Associates and Site Suitable Species at Degraded Sal Forest Areas of Northern Region of Bangladesh

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Abstract

A study was investigated to assess the preliminary growth performance of sal (*Shorea robusta*) in mixture with its four associates e.g. chakua koroi (*Albizia chinensis*), motor koroi (*Albizia lucidor*), shimul (*Bombax ceiba*), udal (*Sterculia villosa*) and other three site suitable species e.g. neem (*Azadirachta indica*), teligarjan (*Dipterocarpus turbinatus*), dhakijam (*Syzygium firmum*) in degraded sal forest in the northern region of Bangladesh. Two experiments were established in June 2017 and June 2018 at Charkai Silviculture Research Station, Birampur, Dinajpur. Sal and motor koroi, chakua koroi, neem and teli garjan were planted in four treatments with four replications in 2017. In 2018 sal and shimul, udal, dhakijam were planted in three treatments with four replications. Randomized complete block design was followed. Plantation was established in June-July. Each replication plot was 14 m × 14 m in size with 49 seedlings for mono-plantation and 49 seedlings for mixed plantation in 4ঃ3 ratio at 2 m × 2 m spacing. Single line alternate was applied in mixed plot for raising plantation. In the experiment, preliminary data on the survival rate, height (cm) and diameter (mm) of two-years-old and one-year-old seedlings of sal and associate species from single and mixed plantation data were collected in July, 2019. Analysis of data showed significant differences among sal and selected treatment species at 5% significant level other than neem. These findings revealed that, as site suitable species, garjan and dhakijam showed the significant growth performance in mixture with sal as well as in mono-plantation. Moreover, chakua koroi, motor koroi and udal can also be considered as good associates of this suggested sal mixed plantation.

সারসংক্ষেপ

বাংলাদেশের উত্তরাঞ্চলের অবক্ষয়িত শাল বাগানে, শালের সহযোগী হিসেবে মটর কড়ই, চাকুয়া কড়ই, শিমুল, উদাল এবং স্থান উপযুক্ত প্রজাতি হিসেবে নিম, তেলিগর্জন, ঢাকিজামের সঙ্গে শাল মিশ্রণের প্রাথমিক বর্ধন ক্ষমতা মূল্যায়নের জন্য পরীক্ষাটি করা হয়। এ উদ্দেশ্যে চরকাই সিলভিকালচার গবেষণা কেন্দ্রে ২০১৭ এবং ২০১৮ সালে দুটি পরীক্ষা করা হয়। শাল এবং মটর কড়ই, চাকুয়াকড়ই, তেলিগর্জন, নিম ২০১৭ সালে চারটি র‌্যাপলিকেশন সহ চারটি ট্রিটমেন্টে রোপণ করা হয়। ২০১৮ সালে শাল এবং শিমুল, উদাল, ঢাকিজাম চারটি র‌্যাপলিকেশন সহ তিনটি ট্রিটমেন্টে রোপণ করা হয়। প্রতিটি ক্ষেত্রে র‌্যান্ডমাইজড কমপ্লিট ব্লক ডিজাইন (RCBD) অনুসরণ করা হয়। জুন-জুলাই মাসে চারা রোপন করা হয়। প্রতিটি প্লটের আকার ছিল ১৪ মি.×১৪ মি., যেখানে একক বাগানের জন্য ৪৯ টি চারা এবং মিশ্র বাগানে ও ৪৯ টি চারা ৪ঃ৩ অনুপাতে ২ মি.×২ মি. দূরত্বে রোপণ করা হয়। মিশ্র বাগান সৃজনের লক্ষ্যে প্রতিটি প্লটে এক লাইন অন্তর চারা রোপণ করা হয়। পরীক্ষায়, জুলাই, ২০১৯ সালে একক এবং মিশ্র বাগানের উপাত্ত থেকে শাল এবং সহযোগী প্রজাতির দুই বছর বয়সী এবং এক বছর বয়সী চারার বেঁচে থাকার হার, উচ্চতা (সে.মি.) এবং ব্যাস (মি.মি.) সম্পর্কিত প্রাথমিক তথ্য সংগ্রহ করা হয়। তথ্য বিশ্লেষণে ৫% লেভেলে নিম প্রজাতি ছাড়া অন্য প্রজাতির সঙ্গে শালের তাৎপর্যপূর্ণ পার্থক্য দেখা যায়। এই পরীক্ষণে প্রতীয়মান হয় যে, স্থান উপযোগী প্রজাতি হিসেবে তেলিগর্জন এবং ঢাকিজাম উভয়ই শালের সাথে মিশ্র ও একক বাগানে তাৎপর্যপূর্ণ বর্ধনশীলতা প্রদর্শন করে। এছাড়াও চাকুয়া কড়ই, মটর কড়ই এবং উদাল শালের মিশ্রবাগানে ভাল সহযোগী হিসেবে বিবেচনা করা যেতে পারে।

Key words: Degraded sal forest, Mixed plantation, Restoration, Sal associates, Site suitable species.

Introduction

Sal (*Shorea robusta* Roxb. *ex* Gaertn.f.) forests in Bangladesh are the only plain land natural forest resource which is valuable from both economic and environmental aspects. Sal is the most important timber yielding plants of the tropical moist deciduous forests. It is very strong, durable and fire protecting species. The timber is also used for general construction purpose, especially for house building, electrical poles, telephone poles, boat construction, furniture and other carpentry works (Rahman 2021). Though sal is the dominant tree species in these forests, grows well mix with other valuable associate tree species (Bashak and Alam 2016). Wood of these species is used for construction, furniture, bullock-cart wheels, axles etc. (FRA 2020). The increased population with few alternative employment opportunities poses a serious threat to the sal forest which has been identified as the main cause of sal forest destruction (Alam *et al*. 2008).

The importance of sal forests in the central and northern parts of Bangladesh because of the demand of large populations (Motiur 2006). Most of the sal forests originally belonged to feudal landlords and were not put under scientific management for a long period (Salam and Noguchi 2005). Sal forests in Bangladesh are now substantially degraded and poorly stocked (Gautam and Devoe 2006). Introduction of fast-growing exotic species changes the forest composition and ecological functions of the forests that will render these forests less sustainable and destroy the habitat of the wildlife (Gain 2005). Land management in sal forest includes agroforestry, woodlot and sal coppice management, recreation and conservation area management through establishment of ecoparks and national parks in different locations which ultimately bringing barren, degraded and encroached lands under forest cover by engaging local people in management (Alam *et al*. 2008).

Plantation forests are increasing rapidly in the world in order to alleviate deforestation and degradation of natural forests, along with providing various goods and services (Liu *et al*. 2018). Mono-plantation have been dominated in practice and well documented in forest research, but in the face of increasing climate change and resource scarcity, there is a growing interest in mixed-species plantation systems (Bolte *et al*. 2004; Spiecker *et al*. 2004; Hein and Dhote 2006; Cavard *et al*. 2011; Hulvey *et al*. 2013, Pretzsch *et al*. 2014; Forester 2014; Lof *et al*. 2014; Pretzsch 2014; Neuner *et al*. 2015; Metz *et al*. 2016; Pretzsch and Schütze 2016; Zeller *et al*. 2017; Coll *et al*. 2018). Mixed plantation stands of valuable indigenous species provide diverse products along with species improve carbon storage in litter, soil and ecosystems than do monoculture plantation stands (He *et al*. 2013). Mixed-tree plantations can be a good silvicultural alternative to large-scale monoculture plantations for climate change mitigation, facilitated by the sequestration of atmospheric carbon dioxide (Kanowski and Catterall 2010). To protect and conserve the natural sal forest of Bangladesh, silvicultural systems must be improved to promote effective regeneration

(Rahman *et al.* 2010) and also for sustainable management. To restore the natural sal forests, it is very much imperative to enrich the sal forest through mixed plantation of sal with its associates and other site suitable species. So the study has been undertaken to develop a mixed plantation combination of sal tree along with the site suitable species e.g. neem, teligarjan, dhakijam for the enrichment of degraded sal forest with other valuable associates e.g. chakua koroi, motor koroi, simul and udal.

Materials and Methods

Experimental site

The experiment was carried out during June-July in 2017 and 2018 at Charkai Silviculture Research Station, Birampur, Dinajpur, Bangladesh (Fig.1). The experimental site enjoys a tropical monsoon climate characterized by hot, humid summer and cool, dry winter (Mahmood *et al.* 2005). The experimental site (nursery) lies approximately at the intersection of 88⁰ 41′ east longitude and 25⁰ 39′ north latitude with 37 m altitude. Geographically the area was formed by flat to very gently sloping. Soil condition is deep soil with good drainage, clay loam, slightly acidic to almost neutral soil ranges from p^H 5.5-6.0 (top soil) and 5.0-5.5. (Below soil) (Sterringa 1989). Soil color was brown, derived from plio-pleistocene sediments (Rashid 2001).

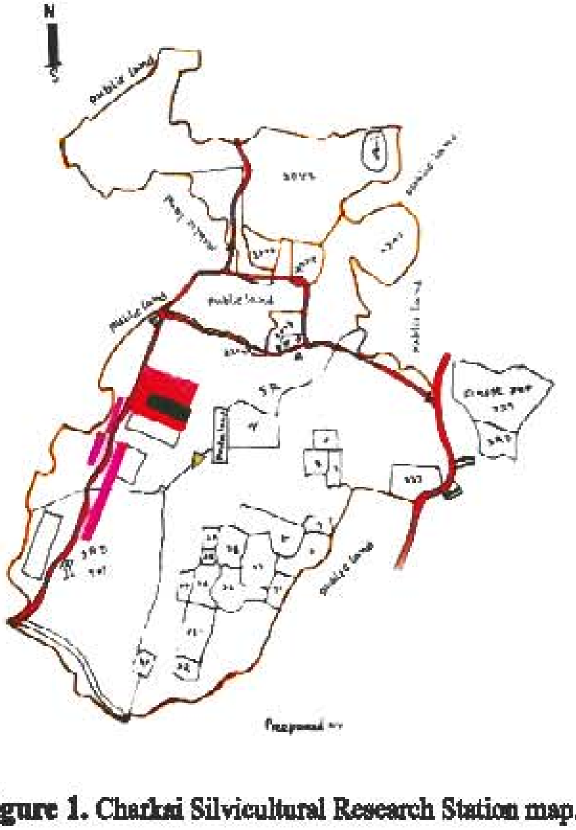

Figure 1. Charkai Silvicultural Research Station map.

Seed collection and seedling raising

Seeds were collected from the selected mother trees. Sal and its associate's seedlings were raised in the nursery at Charkai Silviculture Research Station. Seedlings of sal and its different associates as well as site suitable species were raised in 15 x 17 cm size polybags filled up with a 3:1 ratio mixer of soil and cowdung. In the nursery, seedlings were maintained through weeding, watering, sorting, rearrangement, etc. Seedlings grading was done before one month of the plantation. One-year-old seedlings of the selected species were used to raise the plantation.

Experimental design

To develop a mixed plantation combinationn of sal with different site suitable species have been selected in 2017 and 2018. In 2017, total 36 sampling plots were randomly set up for four treatments and in 2018; a total of 28 sampling plots were randomly set up for three treatments.

Treatments of 2017 plantation

Treatments for control (Individual) plantation	Treatments for mixed plantation
T_{00} =Sal (*Shorea robusta*)	
T_{01}= Chakua koroi (*Albizia chinensis*)	T_1 = (Sal + Chakua koroi)
T_{02}= Neem (*Azadirachta indica*)	T_2= (Sal + Neem)
T_{03}= Motor koroi (*Albizia lucidor*)	T_3 = (Sal + Motor koroi)
T_{04} = Garjan (*Dipterocarpus turbinatus*)	T_4= (Sal + Garjan)

Treatments of 2018 plantation

Treatments for control (Individual) plantation	Treatments for mixed plantation
T_{00} = Sal (*Shorea robusta*)	
T_{01}= Shimul (*Bombax ceiba*)	T_1= (Sal +Shimul)
T_{02}= Udal (*Sterculia villosa*)	T_2= (Sal +Udal)
T_{03}= Dhakijam (*Syzygium firmum*)	T_3= (Sal +Dhakijam)

The experimental area was completely cleared off by slashing on April-May. The plantation was established in June-July. Randomized Complete Block Design was followed with four replications. Each replication was 14 m × 14 m in size with 49 seedlings for mono-plantation and 49 seedlings also for mixed plantations in 4:3 ratio. Four lines were used for sal and three lines for selected species. Single line alternate was applied in mixed plantation. Preliminary data of the seedlings were collected considering survival, height, and diameter in July 2019.

Statistical analysis

Average survival percentages (%), height (m), diameter (cm) were compared among pure and mixed plots of the species. Analysis of variance and tests for means ($p<0.05$) were run using the means of each variable from each of the three replications. All the data were collected and analyzed statistically by using the computer software package SPSS and were subjected to analysis by Duncan's Multiple Range Test (DMRT).

Results

The recorded data of survival percentage and preliminary growth performance of sal mixed with site suitable and associates species in 2017 (garjan, motor koroi, chakua koroi, neem) and in 2018 (dhakijam, udal, shimul) were analyzed in Table 1 and Table 2.

Observation from 2017 plantation

Survivability, Height and Collar diameter

From the experimental plot in 2017, at the age of two years plantation, there was a significant difference observed in survivability of sal in mixture with garjan, motor koroi but no significant difference was found in mixture with chakua koroi and neem. The highest value of survivability was found in the sal+garjan combination (95%) and the lowest survivability was found in *S. robusta* mono-plantation (88%). The decreased order of survivability percentage for sal was sal + garjan > sal + motor koroi > sal + chakua koroi > sal + neem > sal individual (Table 1).

Table 1. Growth performance of sal and its associates in mixed plantation at Charkai Research Station, Dinajpur in 2017(two years old).

Treatments	Plantation	Parameters		
		Survival %	Height(cm)	Collar diameter (mm)
T_{00}	Sal	88.0 ± 2.55^{bc}	62.5 ± 3.18^{b}	7.1 ± 0.26^{b}
T_1	Sal + Chakua koroi	90.0 ± 3.82^{bc}	69.0 ± 2.7^{a}	7.8 ± 0.19^{a}
T_2	Sal + Neem	90.0 ± 2.74^{bc}	53.0 ± 2.89^{c}	5.5 ± 0.25^{c}
T_3	Sal + Motor koroi	93.0 ± 3.54^{ab}	70.0 ± 2.68^{a}	8.0 ± 0.36^{a}
T_4	Sal + Garjan	95.0 ± 2.55^{a}	65.0 ± 2.92^{b}	7.3 ± 0.37^{b}
Sig. difference		0.014*	0.000*	0.000*

Note: In a column values are significantly different at p≤0.05, according to Duncan's Multiple Range test (DMRT) test. (±) indicates the standard deviation of mean. (*) Indicates 5% level of significance.

The study also revealed that there was a significant difference between associate species and sal. It was found that except motor koroi all associate species showed better survivability with sal than its individual plantation. The increased order of survivability for the selected associates were garjan + sal > chakuakoroi + sal > neem + sal > motor koroi + sal (Table 2, 3, 4 and 5).

There was a significant difference in height increment for sal in mixture with garjan, motor koroi, chakua koroi, neem where the highest value of height of sal was found in sal+motor koroi combination 70.0 cm and the lowest height was found in sal + neem mixed plantation 53.0 cm (Table 1). The order of maximum height for Sal was observed according to the following combination sal + motor koroi > sal + chakua koroi > sal + garjan > sal individual > sal + neem (Table 1).

The present study revealed that there was also a significant difference between the selected treatment species and sal. The investigation found that except garjan, all other selected species didn't show better height with sal than its mono-plantation. The decreased order of maximum height for the selected combinations was garjan + sal > chakua koroi + sal > neem + sal > motor koroi + sal (Table 2, 3, 4 and 5).

Table 2. Growth performance of chakua koroi in mixture with sal in 2017 plantation.

Treatments	Plantation	Parameters		
		Survival %	Height (cm)	Collar diameter (mm)
T_{01}	Chakua koroi	85.0 ± 2.24^b	120 ± 5.24^a	13.0 ± 0.29^a
T_1	Chakua koroi + Sal	88.0 ± 3.81^a	113 ± 2.92^b	11.0 ± 0.43^b
Sig. difference		0.167	0.031*	0.000*

Note: In a column values are significantly different at $p \leq 0.05$, according to Duncan's Multiple Range test (DMRT) test. (±) indicates the standard deviation of mean. (*) Indicates 5% level of significance.

Table 3. Growth performance of neem in mixture with sal in 2017 plantation.

Treatments	Plantation	Parameters		
		Survival %	Height (cm)	Collar diameter (mm)
T_{02}	Neem	72.0 ± 2.74^b	45.5 ± 3.04^a	4.18 ± 0.19^b
T_2	Neem +Sal	79.0 ± 5.7^a	35 ± 2.74^b	5.0 ± 0.29^a
Sig. difference		0.038*	0.000*	0.001*

Note: In a column values are significantly different at $p \leq 0.05$, according to Duncan's Multiple Range test (DMRT) test. (±) indicates the standard deviation of mean. (*) Indicates 5% level of significance.

Table 4. Growth performance of motor koroi in mixture with sal in 2017 plantation.

Treatments	Plantation	Parameters		
		Survival %	Height (cm)	Collar diameter (mm)
T_{03}	Motor koroi	91.0 ± 2.12^a	110.0 ± 4.06^a	13 ± 0.28^a
T_3	Motor koroi + Sal	87.0 ± 2.24^b	103.0 ± 2.9^b	12 ± 0.19^b
Sig. difference		0.020*	0.014*	0.000*

Note: In a column values are significantly different at $p \leq 0.05$, according to Duncan's Multiple Range test (DMRT) test. (±) indicates the standard deviation of mean. (*) Indicates 5% level of significance.

Table 5. Growth performance of garjan in mixture with sal in 2017 plantation.

Treatments	Plantation	Parameters		
		Survival %	Height(cm)	Collar diameter (mm)
T_{04}	Garjan	89.0 ± 3.16^b	70.8 ± 1.6^b	8.0 ± 0.27^b
T_4	Garjan +Sal	93.0 ± 1.58^a	77 ± 4.47^a	9.2 ± 0.41^a
Sig. difference		0.035*	0.019*	0.001*

Note: In a column values are significantly different at $p \leq 0.05$, according to Duncan's Multiple Range test (DMRT) test. (±) indicates the standard deviation of mean. (*) Indicates 5% level of significance.

The collar diameter of sal in mono-plantation and mixed plantation showed that there was a significant difference in diameter increment for of sal in mixture with garjan, motor koroi, chakua koroi, neem where the highest value of diameter was found in sal + motor koroi combination 8.0 cm and the lowest diameter was found in sal + neem mixed plantation 5.5 mm (Table 1). The decreased order of the collar diameter value for sal was sal+ motor koroi > sal + chakua koroi > sal + garjan > sal individual > sal + neem. From Duncan's Multiple Range Test (DMRT) it's observed that the height and collar diameter of sal with motor koroi and chakua koroi was better in comparison to others due to fast-growing characteristics (Table 1).

There was also a significant difference in collar diameter between selected species and sal. The investigation found that garjan showed the maximum collar diameter with sal than its individual plantation. The decreased order of the collar diameter for the selected combinations was garjan + sal > neem + sal> motor koroi + sal > (chakua koroi + sal).

Observation from 2018 plantation

Survivability, Height and Collar diameter

Results from the 2018 experimental plot showed there was no significant difference in survivability of sal in mixture with dhakijam, shimul, udal at one year old age plantation. The highest value of survivability of sal was found in sal + dhakijam combination (97%) and the lowest survivability was found in sal mono-plantation (96%). The decreased order of survivability percentage for sal was sal + dhakijam > sal + shimul > sal + udal > sal individual plantation (Table 6).

Table 6. Growth performance of sal in mixture with the selected treatments species at Charkai Research Station, Dinajpur in 2018 (One year old).

Treatments	Plantation	Parameters		
		Survival %	Height(cm)	Collar diameter (mm)
T_{00}	Sal	96.0 ± 2.12^{a}	61.5 ± 2.69^{c}	5.1 ± 0.32^{c}
T_1	Sal + Shimul	96.0 ± 1.58^{a}	70.0 ± 1.6^{a}	6.0 ± 0.26^{b}
T_2	Sal + Udal	97.0 ± 2.55^{a}	74.0 ± 2.55^{a}	7.0 ± 0.38^{a}
T_3	Sal + Dhakijam	97.0 ± 1.60^{a}	65.0 ± 3.16^{b}	6.0 ± 0.25^{b}
Sig. difference		0.743	0.000*	0.000*

Note: In a column values are significantly different at $p \leq 0.05$, according to Duncan's Multiple Range test (DMRT) test. (±) indicates the standard deviation of mean. (*) Indicates 5% level of significance.

The study also revealed that there was no significant difference between selected mixed species and sal. The investigation found that all selected mixed species showed better survivability with sal individually as well as in mixed plantation. The increased order of survivability for the selected combination species are dhakijam +sal > shimul+sal> udal+sal (Table 7, 8 and 9).

Table 7. Growth performance of shimul in mixture with sal in 2018 plantation.

Treatments	Plantation	Parameters		
		Survival %	Height(cm)	Collar diameter (mm)
T_{01}	Shimul	95.0 ± 2.55^a	89.2 ± 1.61^a	9.0 ± 0.22^b
T_1	Shimul + Sal	97.0 ± 1.58^a	84 ± 1.54^b	12.0 ± 0.36^a
Sig. difference		0.678	0.000*	0.000*

Note: In a column values are significantly different at $p \leq 0.05$, according to Duncan's Multiple Range test (DMRT) test. (±) indicates the standard deviation of mean. (*) Indicates 5% level of significance.

Table 8. Growth performance of udal in mixture with sal in 2018 plantation.

Treatments	Plantation	Parameters		
		Survival %	Height(cm)	Collar diameter (mm)
T_{02}	Udal	94.0 ± 2.5^a	110.0 ± 1.77^a	12.1 ± 0.27^a
T_2	Udal + Sal	95.0 ± 2.24^a	101 ± 1.58^b	12.0 ± 0.12^a
Sig. difference		0.743	0.000*	0.687

Note: In a column values are significantly different at $p \leq 0.05$, according to Duncan's Multiple Range test (DMRT) test. (±) indicates the standard deviation of mean. (*) Indicates 5% level of significance.

Table 9. Growth performance of dhakijam in mixture with sal in 2018 plantation.

Treatments	Plantation	Parameters		
		Survival %	Height(cm)	Collar diameter (mm)
T_{03}	Dhakijam	98.0 ± 1.6^a	50.0 ± 1.76^b	4.7 ± 0.31^a
T_3	Dhakijam + Sal	98.0 ± 1.5^a	53.0 ± 0.79^a	5.0 ± 0.19^b
Sig. difference		0.893	0.000*	0.000*

Note: In a column values are significantly different at $p \leq 0.05$, according to Duncan's Multiple Range test (DMRT) test. (±) indicates the standard deviation of mean. (*) Indicates 5% level of significance.

The result from the experimental plot 2018 showed a significant difference in height of sal and the mixed species dhakijam, shimul, udal. The highest value of height was found in sal + udal combination 72.0 cm and the lowest height was found in Sal mono-plantation 61.5 cm (Table 6). The decreased order of maximum height for sal was recorded according to the following combination sal + udal > sal + shimul > sal+dhakijam > sal individual plantation.

The study also revealed that there was also a significant difference between selected mixed species and sal. From the investigation, it was found that only dhakijam + sal combination showed better height with sal than other combination plantations. The decreased order of the height value for the selected combination species were dhkijam + sal > shimul +sal > udal + sal (Table 7, 8, 9).

The results from the one-year-old age experimental plot (2018) showed a significant difference in collar diameter of sal in mixture with dhakijam, shimul, udal. The highest value of diameter was found in sal + udal combination (7.0 mm) and the lowest diameter (5.1 mm) was found in sal mono-plantation in Table 2. The order of diameter decrement for sal was sal + udal > sal + shimul > sal + dhakijam>sal individual (Table 6).

The study also revealed that there was also a significant difference between selected mixed species and Sal. From the investigation, it was found that only shimul + sal combination showed the collar diameter with sal than the others combinations. The decreased order of the highest collar diameter for the selected combination species were shimul +sal > udal +sal > dhakijam +sal. From duncan's Multiple Range Test (DMRT) it was observed that the height and collar diametes of sal with dhakijam were better in comparison to others which showed a significant difference at 5% level (Table 7, 8 and 9).

Discussion

In this study, chakua koroi, motor koroi, shimul, udal, neem, garjan, dhakijam were considered as treatments. The survival percentage, height, and diameter of sal with its associates (chakua koroi, motor koroi, shimul, udal) and site suitable species (neem, garjan, dhakijam) seedlings were measured and analyzed. In this respect, the given values have been determined according to variance analysis, found that there were statistically significant differences in height increment between sal individual and its associates as well as site suitable species ($p<0.05$). According to the results of the Duncan Multiple Range Tests it has been found that the survival percentage, height, and diameter of seedlings in mono plots were lower than the seedlings in mixed plots. According to Dutta and Hossain (2017), the reasons for better initial growth performance in mixed plantations than in pure plots may be due to greater intra-specific competition among the seedlings for various resources in pure than in mixed plots.

From the experiment it was also revealed that the initial growth performance of sal with its associates and site suitable species showed better performance in combinations than in pure plantations. neem and motor koroi showed a different result. The growth rate of sal in mixure with neem showed less performance than its mono-plantation. On the other hand, the growth rate of sal in sal and motor koroi combination is higher than the mono plantation of sal where the growth rate of motor koroi decreased. It might be due to mixing of fast-growing with slow-growing and nitrogen-fixing with non-nitrogen-fixing species which covered the statement a successful mixed-species plantation might combine fast-growing with slow-growing species, short-lived with long-lived species, light-demanding with shade-tolerant species, shallow with deep rooting species, nitrogen-fixing with non-nitrogen-fixing species or slim-crowned and height oriented with wide-crowned and more laterally expanding species. But sal mixed with neem, both species showed poor growth performance. These species are slow-growing and light demander but tolerate fairly heavy shade at the early stage of development (Hossain 2015) which silvicultural characters are the same and ultimately not favors as a mixed combination according to Forrester *et al*. (2005, 2006); Yadav and Mishra (2013); Pretzsch (2014) and Nguyen *et al*. (2015) statement. But neem individual survival percentage (72%), height and diameter (45.5cm & 4.18 mm) which was support the statement "mixed-species plantations can have negative or positive effects on tree growth" (Piotto 2008).

The second experiment was carried out by sal in mixed with shimul, udal, dhakijam. From the result, it was found that there was no significant difference in sal with shimul, udal but there is a significant difference in dhakijam. The growth performance of sal was better mixed with shimul and udal as a dominant species and good associates of degraded sal forest. On the other hand, dhakijam as a site suitable species mixed with sal showed better survival, height and collar diameter in both dhakijam and sal (Table 6).

From the above discussion, it was explored that mixed plantation stands or valuable indigenous plantation stands substantially will improve degraded land through litter fall, enhance nitrogen fixation in soil and ecosystems than do monoculture plantation stands. This research results also imply that planting sal in mixed combination will be a good silvicultural practice for enhancing soil fertility and restore degraded Sal forest land.

Conclusion

The present study suggested that garjan and dhakijam as site suitable species showed highest growth performance in mixture with sal. However, chakua koroi, motor koroi and udal were also showed significant difference with sal and can also be considered as good associates of this suggested mixed combination. This type of mixed plantation might be the best combination to restore degraded Sal forest areas of northern region of Bangladesh and make the demand of indigenous species by meeting the SDG-Goal-15 (Life on Land). However, further research should be carried out with other site suitable tree species at the field level before going for large scale plantation programs.

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Comparative Growth Performance of *Uvaria cordata* seedlings: A Woody Climber Species of Hill Forests of Bangladesh

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Abstract

Mature seeds of *Uvaria cordata* (Dunal) Alston were sown in polybag, nursery bed, propagator house, and root trainer and investigated to find out the suitable media for raising seedlings for conservation programs of species in Chittagong University Campus. The germination percentage, germination index, germination value, shoot length, collar diameter, leaf number were assessed for 12 months old seedlings in the nursery. The germination percentage (92.31%), germination energy (35.89%), and germination value (2.6493) were found the highest in T_2 treatment (seed sown in nursery bed) and significantly ($p<0.05$) different from other treatments except for T_0 (polybag). Maximum germination index (0.2713), germination uniformity (0.0039), and minimum germination start time (30 days) observed in T_0 (polybag), significantly ($p< 0.05$) different from other treatments. After 12 months of germination, maximum shoot height (25.57 cm), collar diameter (6.32 mm) and leaf number (16.40) revealed highest in T_3 treatment. Seeds sown in polybags were revealed comparatively better germination behavior than other treatments. Seeds sown in root trainer were found suitable for vigorous seedlings production for *Uvaria cordata*.

সারসংক্ষেপ

এই গবেষণায়, পলিব্যাগ, নার্সারি বেড, প্রপাগেটর হাউজ এবং রুট ট্রেইনারে *Uvaria cordata* বীজ বপন করা হয় এবং বৃহৎ পরিসরে বৃক্ষরোপণ কর্মসূচির জন্য উন্নতমানের চারা উৎপাদনের লক্ষ্যে উপযুক্ত মিডিয়া বের করার চেষ্টা করা হয়। নার্সারিতে ১২ মাস বয়সী চারার অঙ্কুরোদগমের হার, অঙ্কুরোদগমের সূচক, অঙ্কুরোদগমের মান, চারার দৈর্ঘ্য, কান্ডের ব্যাস, পাতার সংখ্যা নির্ধারণ করা হয়। অঙ্কুরোদগম হার (৯২.৩১%), অঙ্কুরোদগম শক্তি (৩৫.৮৯%) এবং অঙ্কুরোদগম মান (২.৬৪৯৩) $T_২$ (নার্সারি বেড) সবচেয়ে বেশি পাওয়া যায় এবং $T_০$ (পলিব্যাগ) ব্যতীত অন্যান্য ট্রিটমেন্টের তাৎপর্যপূর্ণ ($p <$ ০.০৫) পার্থক্য পরিলক্ষিত হয়। $T_৩$ ট্রিটমেন্টের ক্ষেত্রে অঙ্কুরোদগমের ১২ মাস পরে, চারার সর্বাধিক উচ্চতা (২৫.৫৭ সে.মি.), কান্ডের ব্যাস (৬.৩২ মি.মি.) এবং পাতার সংখ্যা (১৬.৪০) রেকর্ড করা হয়। পলিব্যাগে বপন করা বীজ অন্যান্য ট্রিটমেন্টের তুলনায় ভাল অঙ্কুরোদগম হার প্রদর্শন করে। রুট ট্রেইনারে বপন করা বীজগুলি *Uvaria cordata* এর প্রাণবন্ত চারা উৎপাদনের জন্য উপযুক্ত বলে প্রতীয়মান হয়।

Keywords: Germination, Germination value, Growing media, Propagator house, Root trainer, Seedling growth.

Introduction

World biodiversity is exhausting at an alarming rate because of human intrusions and environmental degradation, creating a high risk of disappearance of species (Rashid *et al.* 2014). Pitmen and Jorgenson (2002) mentioned that under the World Conservation Union (IUCN) Classification Scheme, half of the world's plant species may qualify as threatened with extinction. According to IUCN's Threatened Plants Unit, about 60,000 plant species (25%) would turn into either extinct or rare within 2050 (Uberoi 2010). Plant genetic diversity is being disturbed in Bangladesh in a dreadful way (Hossain *et al.* 2013). The major causes of forest degradation in Bangladesh are agricultural expansion, over-extraction of wood and non-wood resources, infrastructure development, population growth, deforestation, encroachment and inappropriate management (Hossain 1998; Hossain *et al.* 2008; Hossain *et al.* 2017). The encroachment problem in the forest areas of Chattogram, CHT and Cox's Bazar is political and involves both the Rohingya and climate refugees (Ahmed *et al.* 2011). The number of angiosperm flora described in Encyclopedia of Flora and Fauna is 3,611 (Ahmed *et al.* 2008), of which at least 13% of these species are becoming threatened.

The genus *Uvaria* of the Annonaceae family is a woody climber species. *Uvaria cordata* (locally known as Bagh-runga, Gagh-ranga) is woody sarmentose shrubs, leaves petiolate, oblong, acute, base rounded, or cordate (Khanam and Rahman 2008). Flowers red, terminal or lateral, sepals orbicular, petals oblong. Flowering and fruiting occur in April-July (Rahman 2013). The genus is widespread in wet tropical forests in Africa, Madagascar, continental Asia, Malaysia, Northern Australia, and Melanesia (Meade 2005). The species naturally found in Bangladesh, Malaysia, and Singapore (Rahman 2013). In Bangladesh, it occurs in the forests of Tangail (Madhupur Sal forest) and Chattogram. The conservation status of the species is considered as Not Evaluated (NE) by Khanam and Rahman (2008), but vulnerable by Rahman (2013). Interest in producing quality seedlings by application of improved and modern nursery techniques has increased in India (Gera and Ginwal 2002). Integrated knowledge of the seed collection, storage, germination requirements, and seedling growth performance of native tree species is vital for biodiversity conservation and restoration plans (Khurana and Singh 2001; Smith *et al.* 2008), but most of the studies are concentrated on fast-growing and commercially well-known tree species. Very scarce information are available for this species. The aim of the present study was to investigate how different growing media effects on germination and seedling growth performance of *Uvaria cordata* in the nursery.

Figure 1. Fruits, seeds and seedlings of *Uvaria cordata.*

Materials and Methods

Study site

The study was carried out in the nursery of the Institute of Forestry and Environmental Sciences, University of Chittagong, Chattogram during March 2018 to May 2019 (lies between 91°50′E longitude and 22°30′N latitude) (Hossain *et al.* 2005). The climate is tropical monsoon with an average monthly highest temperature of 29.75°C and a monthly lowest of 21.24 °C. The maximum temperature usually occurs in May at 32.60°C and the minimum in January at 14.10°C (Peel *et al.* 2007).

Uvaria cordata fruits were collected from Bangabandhu Safari Park at Dulhazara, Chakaria, Cox's Bazar during March 2018. Phenotypic characteristics of fruits and seeds were measured. Seeds were extracted from fruits, dried in the open sun for three days. (Fig. 1).

Experimental design

The soil used for filling polybags were collected from the forest floor, dried and sieved well (<3mm) and mixed with decomposed cow dung in a ratio of 3:1. 15×10 cm size polybags were used for the experiment. The media used in the propagator house were fine Sylhet sand. Forest topsoil was used in the open nursery bed. Growing media used in root trainer are made by using soil and cow dung in a ratio of 2:1. Collected seeds were sown in prepared polybag, seedbed, propagator house, and root trainer respectively. The study was made up of 4 treatments, 3 replications in each treatment (15 seeds per replication) in a Randomized Complete Block Design. Forty-five (45) healthy seeds were chosen randomly for each treatment. Total 180 seeds were used in this experiment. Daily germination progress was recorded as soon as the seeds start germination. The seedlings, raised in nursery bed, propagator house and root trainer were transferred to polybag after 2 months of germination of seeds. The pricked out seedlings were kept in shade for 2 weeks and then transferred to sunlight. Proper care and maintenance were continued regularly. Shoot height measurement was started at 5 months old seedlings and continued up to 12 months. Collar diameter, leaf number, branch number of the seedlings was recorded at the end of the experiment. The treatments were as:

T_0- Seeds sown in polybag (15 x 10 cm) with growing media of soil and cow dung (3:1)

T_1- Seeds sown in propagator house

T_2- Seeds sown in an open conventional nursery bed

T_3- Seeds sown in root-trainer with growing media of soil and cowdung (2:1)

Data collection and analysis

Germination percentage (GP): The number of seeds out of 100 seeds from the starting of germination to the termination of germination (Kumar 1999).

$$\text{Germination \% (GP)} = \frac{\text{No of seed germinated}}{\text{No of seed sown}} \times 100$$

Cumulative germination % (CGP):
It assessed at the end of seeds germination by summed up daily germination (Hasnat *et al.* 2019).

$$\text{CGP} = \frac{\text{Cumulative number of seeds germinated}}{\text{Number of seeds sown}} \times 100$$

Germination energy (GE): It is measured by computing the daily germination percentage of its peak time (Dwivedi 1993).

Germination index (GI): According to AOSA (1983) GI was calculated using this formula:

Germination index (GI) =

$$\frac{\text{No, of germinated seeds}}{\text{Days of first count}} + \cdots + \frac{\text{No, of germinated seeds}}{\text{Days of first count}}$$

Mean germination time (MGT): It calculates the rate and the time-spread of germination (Bewley *et al.* 2013; Soltani *et al.* 2015) and it should determine the time to half of the germination. The formula: MGT= $\Sigma\, Dn/\Sigma n$

Where, D = the number of days counted from the starting of germination, n = the number of seeds that were germinated on day D (Ellis and Roberts 1981; Afzal *et al.* 2005).

Germination Uniformity (GU): It was calculated by using the formula:

$$GU = \frac{\Sigma n}{(\Sigma(Fn-t)^{\wedge}2 \times n)}$$

Where, t is the time in days, beginning from day 0, the day of germination, and n is the number of seeds germinated at t and F are alike to MGT (Abdolahi *et al.* 2012).

Germination value (GV): It was calculated by multiplication of the peak value of germination and mean daily germination (Hasnat *et al.* 2019).

GV = Peak value of germination × mean daily germination

Germination capacity: It is the percentage of seeds germinated in an experiment from the starting to end. It was classified as follows: a) 90-100%- very good, b) 70-90%-good, c) 50-70%- average, d) 30-50%- poor e) 20-30%- very poor, and f) (<) less than 10% extremely poor (Kumar 1999).

Statistical analysis

All the recorded data were analyzed statistically by using computer package software SPSS ver. 23. Duncan's Multiple Range Test (DMRT) was employed to define the statistical significance and it was shown by different letters in different tables.

Results

The average length and width of fruits were 3.86±0.08 cm and 1.74±0.08 cm respectively. Seeds length and width were 0.84 ± 0.06 cm and 0.34±0.02 cm respectively. Fruits and seeds average weight was found 6.112±0.24 gm, 0.1816±0.006 gm respectively. About 164 fruits and 5,500 seeds were recorded in one kg.

Germination performance

The germination performance of *U. cordata* seeds was affected by different treatments (Table 1). Seed germination started first in T_0 (30th day after the seeds were sown) and T_2 required maximum time (at 43th day) to initiate germination. Maximum germination percentage (92.31%) was recorded in T_2 followed by 89.74% in T_0 (seeds sown in polybag), 79.49% in T_3 (seeds sown in root-trainer), and lowest 61.54% in T_1 treatment. In case of germination percentage, T_0 and T_2 was significantly ($p<0.05$) different from T_1. The maximum germination energy period (49.33 days) was found in T_2, significantly ($p<0.05$) different from other treatments (Table 1).

Table1. Effect on germination behavior of *U. cordata* seeds by different treatments.

Treatments	Germination start after (days)	Germination end after (days)	Germination energy period (days)	Germination (%)	Germination capacity
T_0	30	59	40.67±2.56^{b}*	89.74±11.18^{a}	Good
T_1	35	54	42.00±1.54^{b}	61.54±4.44^{b}	Average
T_2	43	53	49.33±2.03^{a}	92.31±4.44^{a}	Very good
T_3	36	59	42.67±1.67^{b}	79.49±5.12^{ab}	Good

* Means followed by the same letter (s) in the same column do not vary significantly at $p<0.05$, according to Duncan's Multiple Range Test (DMRT).

The maximum germination index (0.2713) was recorded in T_0 and minimum germination index (0.1837) was recorded in T_1 (Table 2). Mean germination time was maximum (50.94) in T_2 which is significantly ($p<0.05$) different from other treatments. The highest germination uniformity (0.0039) was found in T_0 and maximum germination value (2.6493) was recorded in T_2 treatment. Germination energy was maximum in T_2 (35.89) and slightly vary from T_0 (Table 2).

Table 2. Effect on germination behavior of *U. cordata* seeds in different treatments.

Treatments	Germination energy %	Germination index (GI)	Mean germination time (MGT)	Germination uniformity (GU)	Germination value
T_0	28.21±2.56^{ab}*	0.2713±0.029^{a}	43.71±1.25^{c}	0.0039±0.0011^{a}	2.3873±0.47^{a}
T_1	20.51±2.06^{b}	0.1837±0.013^{b}	43.94±0.19^{c}	0.0013±0.0002^{b}	1.2107±0.17^{b}
T_2	35.89±2.69^{a}	0.2360±0.085^{ab}	50.94±0.79^{a}	0.0006±0.0003^{b}	2.6493±0.27^{a}
T_3	25.64±2.19^{b}	0.2257±0.015^{ab}	46.47±0.14^{b}	0.0016±0.0003^{b}	1.8047±0.18^{ab}

* Means followed by the same letter (s) in the same column do not vary significantly at $p<0.05$, according to Duncan's Multiple Range Test (DMRT).

Mean cumulative germination percentage

The cumulative germination percentage is the daily germination percentage for each treatment. Cumulative germination of T_0 starts after 30 days of seed sown and rose rapidly and continued up to 89.74% within 59 days. On 53th day, The highest cumulative germination recorded in T_2 (92.31%), it showed rapid rising with time. T_1 showed the lowest germination percentage (61.54%), and it rose slowly (Fig. 2).

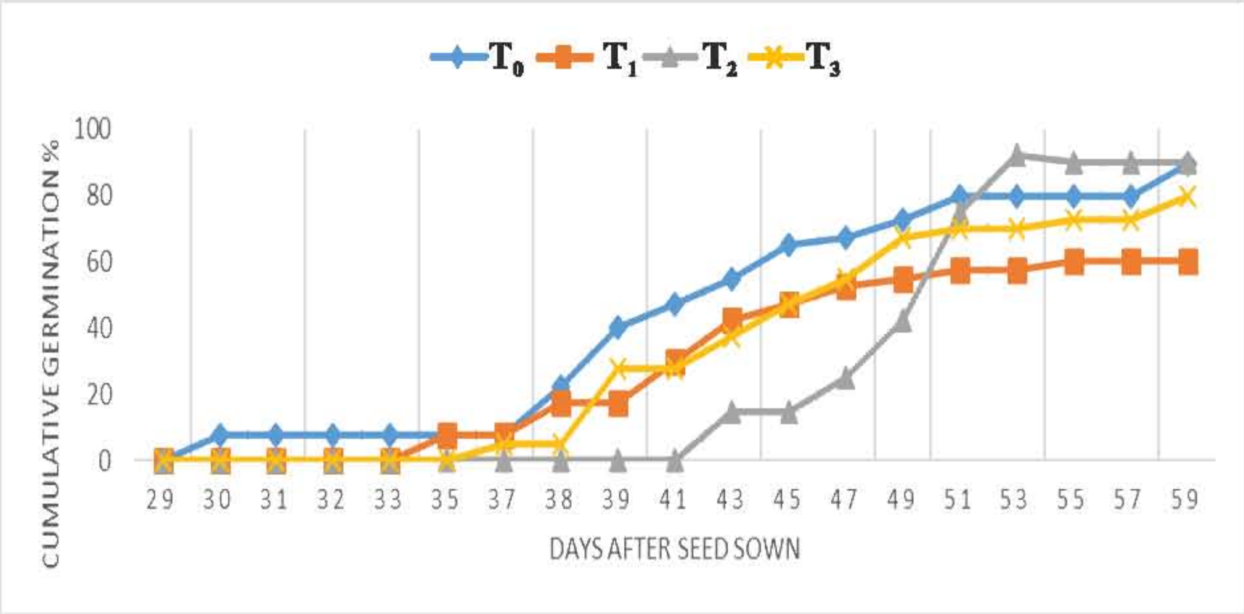

Figure 2. Cumulative germination percentage of *U. cordata* seedlings with different treatments.

Maximum collar diameter (6.32 mm) was found in T_3 but there was no significant difference among other treatments (Table 3). Maximum and minimum leaf number was recorded in T_3 (16.40) and T_1 (11.40) respectively. T_0 and T_2 showed same branch number after 12 months of growth (Table 3).

Table 3. Comparative morphological study of 12 months old *U. cordata* seedlings in different treatments.

Treatments	Collar diameter (mm)	Leaf number	Branch number
T_0	5.38±0.24[a]	12.60±1.50[a]	1.80±0.73[a]
T_1	5.44±0.45[a]	11.40±3.42[a]	0.80±0.58[a]
T_2	5.84±0.50[a]	11.80±2.36[a]	1.80±0.58[a]
T_3	6.32±0.16[a]	16.40±1.07[a]	1.60±0.24[a]

* Means followed by the same letter (s) in the same column do not vary significantly at $p<0.05$, according to Duncan's Multiple Range Test (DMRT).

Growth performance

Different treatments affect the morphological growth of *U. cordata* seedlings. After 12 months of seed germination, the highest mean shoot height (25.57 cm) was recorded in T_3 (seeds sown in root trainer) and the lowest mean shoot height (15.6 cm) was observed in T_2 (seeds sown in nursery bed). T_0 treatment attained mean shoot height of 19.87cm after 12 months of seed germination (Fig. 3).

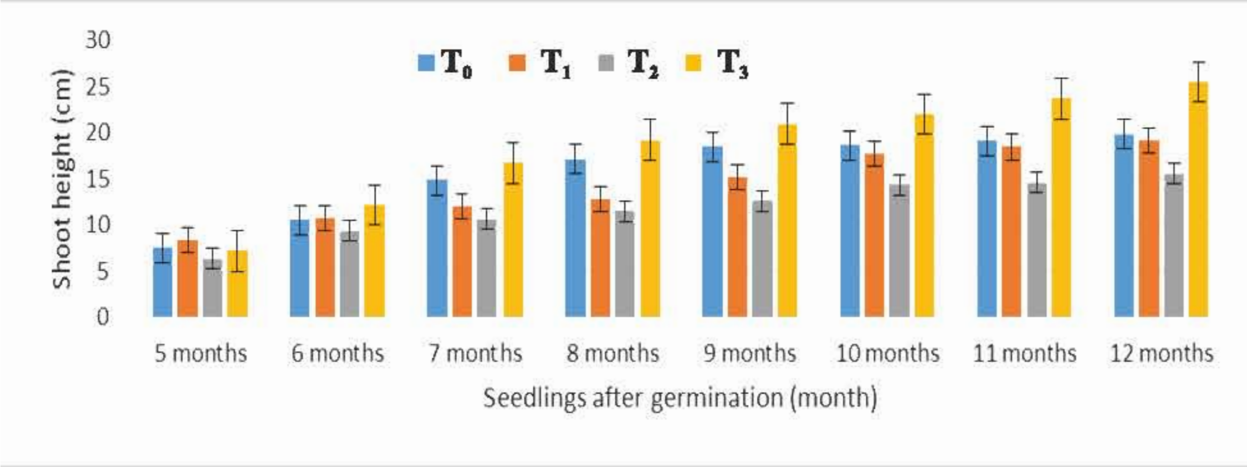

Figure 3. Growth of *Uvaria cordata* seedlings in response to different treatments.

Discussion

Germination and seedling establishment are critical stages that affect both the quality and quantity of crop yields (Subedi and Ma 2005). Germination and seedlings growth performance of *U. cordata* was significantly varied among different treatments. Germination percentage was observed maximum in open nursery bed (92.31%) and minimum in propagator house (61.54%). Seeds sown in polybag (T_0) required minimum time (30 days) to initiate the germination and seeds sown in nursery bed (T_3) took the maximum germination time (43 days). Germination value, Germination energy, MGT was found the highest in nursery bed (T_2). Germination uniformity and index showed maximum in seeds sown in polybag (T_0). After 12 months of seed germination, the highest mean shoot height (25.57 cm), collar diameter (6.32 mm), leaf number (16.40) recorded in T_3.

In Bangladesh, seed biology studies mostly concentrated on seed pre-sowing treatments (Alamgir and Hossain 2005; Azad *et al.* 2006, 2010, 2011; Haider *et al.* 2014; Hasnat *et al.* 2019; Dey *et al.* 2020) but few information on growing media and container effects on seed germination is available (Dey and Hossain 2019).

Water, air, and mineral nutrient availability of the growth medium are the most important physical factors affecting seedlings growth (Currie 1984). Seedlings raised in root trainer produces fibrous and well-developed root system which enables to absorb water and nutrients from the soil more efficiently, ultimately leading to better growth and survival (Benson and Shepherd 1977). Singh *et al.* (2018) revealed that root trainer raised seedlings showed maximum plant percent, plant height, collar diameter, and other parameters than container raised seedlings. Open nursery bed was made by using forest topsoil which provided sufficient nutrients for achieving maximum germination percentage but not influenced to attain vigorous seedlings production. On the contrary, seeds were sown in root trainer with soil and cow dung mixture (2:1) failed to show better germination behavior but developed strong root system which helped further in vigorous seedlings production.

Conclusion

Growing media characteristics induce significant effects on germination and growth performance of *U. cordata* seedlings in the nursery. It is evident from the study that seeds sown in the polybag showed maximum germination of seeds within short period of time. On the other hand seeds sown in the root trainer produced vigorous seedlings. To find out the unique growing media and container, further study is recommended.

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Suitability of Medium Density Fiberboard Made from Hybrid *Acacia* Wood

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Abstract

This experiment was conducted to evaluate the suitability of medium density fiberboard (MDF) made from hybrid *Acacia* wood fiber as raw material and urea formaldehyde (UF) as resin binder. Single layer fiberboards were fabricated by five different densities e.g. 700, 725, 750, 775 and 800 kg/m³ using hybrid *Acacia* wood fiber. Mechanical and physical properties including modulus of rupture (MOR), internal bond strength (IB), thickness swelling (TS) and water absorption (WA) of the fiberboards were tested according to the Indian Standard (IS 2380:1977). The results of the physical and mechanical properties of the fiber boards were compared with Indian Standard (IS 12406: 2003), Euro Standard (D-6300, 1990) and American National Standards Institute (ANSI) MDF standard (A208.2, 1994). The results showed that the 800 kg/m³ density fiberboards made from hybrid *Acacia* wood had the best MOR value and maximum IB strength characteristics among the others. For 800 kg/m³ density fiberboards the MOR value was above the Indian & ANSI Standard but lower than the Euro Standard; and the IB strength value was above the Indian, Euro & ANSI Standard specifications. Water absorption and thickness swelling properties were used to determine the water resistance of the fiberboards.

সারসংক্ষেপ

হাইব্রিড একাশিয়া কাঠের তন্তু এবং ইউরিয়া ফরম্যালডিহাইড রেজিন দ্বারা তৈরিকৃত মধ্যম ঘনত্বের ফাইবার বোর্ডের (MDF) উপযুক্ততা যাচাইয়ের পরীক্ষা চালানো হয়। হাইব্রিড একাশিয়া কাঠের ফাইবার দ্বারা এক স্তরবিশিষ্ট বিভিন্ন ঘনত্বের ফাইবার বোর্ড তৈরি করা হয় যেমন ৭০০, ৭২৫, ৭৫০, ৭৭৫ এবং ৮০০ কেজি/ঘন মি.। ফাইবার বোর্ডগুলোর ভৌত এবং যান্ত্রিক বৈশিষ্ট্যাবলী ইন্ডিয়ান স্ট্যান্ডার্ড (IS ২৩৮০:১৯৭৭) অনুসারে পরীক্ষিত। ফাইবার বোর্ডগুলোর ভৌত এবং যান্ত্রিক বৈশিষ্ট্যাবলীর পরীক্ষণীয় ফলাফল ইন্ডিয়ান স্ট্যান্ডার্ড (IS ১২৪০৬: ২০০৩), ইউরোপীয় স্ট্যান্ডার্ড (D-৬৩০০, ১৯৯০) এবং ANSI স্ট্যান্ডার্ড (A২০৮.২,১৯৯৪)-এর সাথে তুলনা করা হয়। ফলাফল বিশ্লেষণে দেখা যায় যে, ৮০০ কেজি/ঘন মি. ঘনত্বের ফাইবার বোর্ডগুলোর Modulus of rupture (MOR) এবং Internal bond (IB) শক্তির মান অন্যান্য ঘনত্বের বোর্ডের মানের চেয়ে সর্বোত্তম। ৮০০ কেজি/ঘন মি. ঘনত্বের ফাইবার বোর্ডের MOR শক্তির মান ইন্ডিয়ান এবং ANSI স্ট্যান্ডার্ড মানের উপরে কিন্তু ইউরোপীয় স্ট্যান্ডার্ড মানের নিচে। অন্যদিকে IB শক্তির মান ইন্ডিয়ান, ইউরোপীয় এবং ANSI স্ট্যান্ডার্ড মানের উপরে। ফাইবার বোর্ডের পানি সহ্য করার ক্ষমতা পরিমাপ করার জন্য বোর্ডগুলোর পানি শোষণ ক্ষমতা এবং তাদের পুরুত্বের স্ফীতি পরীক্ষা করা হয়।

Key words: Hybrid *Acacia* wood, Internal bond strength (IB), Medium density fiberboard (MDF), Modulus of rupture (MOR), Urea formaldehyde (UF).

Introduction

Wood composite panels are one of the building materials that are widely used as a raw material in furniture, shelving, cabinet making and other non-load-bearing construction applications. Particleboards and fiberboards, two types of composite panels though often classified together, are usually made with different techniques, materials and are utilized in different conditions.

The utilization of medium density fiberboard (MDF) as an alternative to solid wood is rising day by day. MDF is one of the fastest growing composite products in the global wood-based panel market (Akgul *et al.* 2013). It is an engineered wood product made by breaking down hardwood or softwood residuals into wood fibers, combining it with a resin binder and forming panels by applying high temperature and pressure. MDF is generally denser than plywood and particleboard. It can be used as a building material similar to plywood. MDF is also useable for furniture such as cabinets and household materials like doors, because of its strong surface.

For solid wood warping, cracking and bug infestations are the most common disadvantages. MDF does not get twisted or cracked like wood. It is durable, easier to customize and available in larger sizes than solid wood. MDF is cheaper than solid wood and lasts longer with proper maintenance.

The production of MDF has extensively increased recently and has a major market share in the wood composite industry (Akgul and Camlibel 2008; Evans 1997). The demand for composite wood products, such as plywood, oriented strand board (OSB), hardboard, particleboard, MDF and veneer board products has been recently increased significantly throughout the world (Sellers 2000; Youngquist 1999).

The first MDF was made in 1965 at a particleboard plant in New York. The MDF capacity has increased rapidly around the world. Since the first production in 1965, the world capacity of MDF is now estimated at 36 x 10^6 m^3 yr^{-1} (Wadsworth 2002). In Iran, the first MDF factory was established in 2004 with an annual capacity of 4 x 10^4 m^3. MDF production in 2012 has enhanced almost 16 times compared to 2004 (Firouzabadi and Ghorbannezhad 2014).

Hybrid *Acacia* was discovered in road side stands in Malaysia as reported by Pinso and Nasi (1991). It is a fast growing tree species and its basic density is 472 kg/m^3 (Jusoh *et al.* 2014). *Acacia mangium* and *Acacia auriculiformis* can cross-pollinate naturally resulting in hybrid *Acacia* that grows much faster than the parent trees (Tham 1976). About 40 years ago, *A. mangium* and *A. auriculiformis* were introduced in Bangladesh as shade trees in the tea gardens (Banik and Islam 1996). Although this species is used by furniture and plywood industries, information regarding its gluing properties is not adequately known. Adequate knowledge of the gluing characteristics is essential for optimum utilization of this wood resource for the relevant industries. The study was undertaken to find out the suitability of fiberboard made from hybrid *Acacia* wood and its maximum utilization.

Materials and Methods

Materials preparation

Hybrid *Acacia* woods were collected from Kalurghat, Chattogram. The wood was cut into pieces of shorter length. The pieces were hammer milled to chips using screen of 0.60 cm diameter. The chips were then sieved through 20-mesh screen to remove dust and dried in the batch oven at 70°C temperature to reduce the moisture content to 10%. The chips were cooked by direct steaming at 120°C temperature in a stainless steel rotary digester of 0.02 m^3 capacity under 10 kg/cm^2 digester pressures for one hour. They were then refined in a single-rotating disk attrition mill to get fiber from each cooking. The fibers were oven-dried at 3-4% moisture content before the panel formation.

$$(\%)\ \text{Moisture content} = \frac{\textit{Original weight} - \textit{Oven dry weight}}{\textit{Oven dry weight}} \times 100 \qquad (1)$$

Manufacture of fiberboard

Since the MDF panels usually have a density of 600-900 kg/m^3 (IS: 12406, 2003), it was randomly selected five densities within this range. Five single layer MDF boards were prepared under five treatments (e.g. T_1 = 700, T_2 = 725, T_3 = 750, T_4 = 775 and T_5 = 800 kg/m^3) in the laboratory hot press machine using hybrid *Acacia* wood fiber. The dimensions of the fiberboards were 50 cm × 50 cm × 1.25 cm having the target density. The temperature of the platens of the hot press was maintained at 160-170°C. Twenty percent (20%) liquid UF glue based on oven dry fiber was used in the fiberboard preparation. The liquid UF glue was catalyzed with 2% NH_4Cl (ammonium chloride). A fiber mat board was formed and pre-pressed manually in wooden fabricated bordered frame. After that the mat was pressed initially for 6 minutes in the hot press machine. This pressure was then lowered in two steps firstly for 4 minutes and then an additional of 2 minutes. Finally the fiberboards were conditioned at 65 ± 5% relative humidity and 20 ± 2°C temperature before they were put to tests. The overall conditions for making fiberboards are given in Table 1.

Table 1. Experimental conditions for manufacturing of fiberboards.

Board thickness (mm)	Solid content of UF (%)	Mat moisture (%)	Press temperature (° C)	Specific pressure (psi)	Pressure time (min)	Density (kg/m^3)
12	50	11-12	160-170	500	6	700-800
				150	4	
				50	2	

Test samples preparation

The fiberboards were cut into various test samples to determine the MOR, IB, WA and TS properties according to IS: 2380 (Anon. 1977) specification. The performance of fiberboards was evaluated by its mechanical and physical properties which were later compared with the standard results shown in Table 2.

Modulus of rupture (MOR)

The bending strength MOR was carried out in a Riehle screw power type universal testing machine (UTM) according to the IS: 2380 (Anon. 1977) specification. Specimen sizes of 35 cm × 7.50 cm × 1.25 cm are tested on a 30 cm span with center loading. The test parameters of modulus of rupture are as follows.

The modulus of rupture, *MOR* (eqn.2) can be found by substituting the maximum load, P for the load at the proportional limit.

$$MOR = \frac{3Pl}{2bh^2} \qquad (2)$$

Where, MOR = modulus of rupture in kg/cm^2
P = maximum load in kg
l = length of span in cm
b = width of the test specimen in cm
h = depth of the test specimen in cm

Internal bond strength (IB)

The IB strength test was also performed using the UTM with the specification of IS: 2380 (Anon. 1977). In this case, wooden blocks of 75 mm × 50 mm × 25 mm were glued through cold press with the test specimens. Hence the urea formaldehyde glue catalyzed with 4% hardener (NH_4Cl) was used.

The internal bond (IB) strength in kg/cm^2:

$$IB = \frac{P}{A} \qquad (3)$$

Where, P = maximum load in kg
A= area of the test specimen in cm^2

Water absorption (WA)

Water absorption due to general absorption of water was done using the specimens of 100 mm × 100 mm soaked in 25 mm depth of cold water (25±2^{o}C) for 24 hours. For this experiment, three specimens were taken from each board.

$$\text{WA (\%)} = \frac{increase\ of\ weight\ with\ water}{Ovendry\ weight} \times 100 \quad \text{.......... (4)}$$

Thickness swelling (TS)

The samples, tested for WA measurement, were used to determine TS with the platform type thickness gauze with an accuracy of 0.01 mm.

$$\text{TS (\%)} = \frac{increase\ in\ dimension\ or\ volume}{original\ dimension\ or\ volume} \times 100 \quad \text{.......... (5)}$$

At the end of 24 hours, the test specimens were withdrawn from water, wiped with a damp cloth, reweighed and re-measured the thickness as before. The percentage of WA and TS were then calculated. The test results were then compared with the standards given in Table 2.

Statistical design of experiment and analysis

The experiments were carried out in a completely randomized design (CRD) with 5 replications. SPSS statistical software was used for the data analysis. Analysis of variance (ANOVA) and least significant difference (LSD) test were carried out to evaluate the significance of differences among the different densities of boards.

Table 2. Some standards specifications for physical and mechanical property of MDF Boards.

Specification of some standards	Board thickness (mm)	Board density (kg/m^3)	MOR (kg/cm^2)	IB (kg/cm^2)	TS (%)	WA (%)
					24 hrs	24 hrs
Indian Standard (IS 12406, 2003)	6-20	600 - 900	250.00	8.00	7	30
Euro Standard (D-6300, 1990)	12		350.00	6.50	15	NA
ANSI Standard (A208.2, 1994)	6-19		240.00	6.00	NA	NA

NA= not specified in test requirements.

Results

Analysis of variance was used to assess any correlation between boards of different densities. The results of ANOVA showed that the effects of different densities have significant effects at $p \leq 0.01$ towards the MOR, TS and WA properties. The IB strength value is not significant compare to other parameters at $p \geq 0.01$. The mean value according to least significant difference of MOR, IB, TS and WA were given in Table 3.

Table 3. Mechanical and physical properties of MDF boards made from Hybrid *Acacia* wood.

Type of fiberboard	Board density (kg/m^3)	MOR (kg/cm^2)	IB (kg/cm^2)	TS (%)	WA (%)
				24 hrs	24 hrs
Single layer	700	200 ± 19.24	5.60 ± 0.06	18.08 ± 0.03	38.45 ± 0.02
	725	220 ± 9.35	5.72 ± 0.08	17.21 ± 0.04	35.68 ± 0.04
	750	225 ± 7.91	5.85 ± 0.04	16.65 ± 0.04	33.62 ± 0.07
	775	248 ±6.28	6.40 ± 0.08	16.35 ± 0.04	33.25 ± 0.04
	800	252 ± 5.87	8.10 ± 0.34	12.67 ± 0.03	28.72 ± 0.07
F-value		25.20	1.05	8.23	1092.50
Significant value		1.89E-04	0.11250	0.003018	2.39E-10

Mean ± SD (Standard deviation)

From the Table 3, it was found that the MOR values of the fiberboards were different for five different densities. Fiberboards containing 800 kg/m³ density was the highest MOR value compared to the other densities (Fig. 1). The MOR value of 800 kg/m³ fiberboard was 252.00 kg/cm² which satisfied the Indian Standard (250.00 kg/cm²) and ANSI Standard (240.00 kg/cm²) but did not meet the Euro Standard (350.00 kg/cm²) specification.

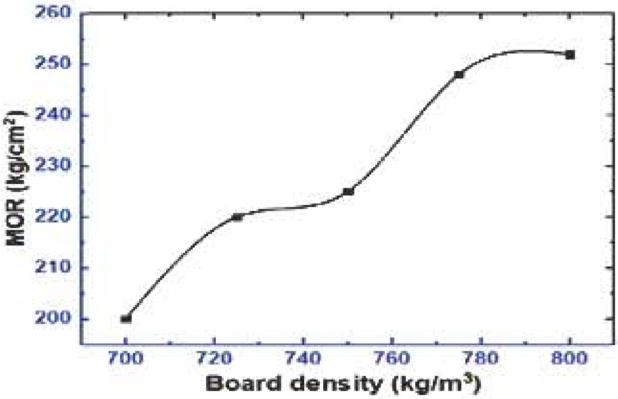

Figure 1. Modulus of rupture (MOR) of the fiberboards.

The internal bond (IB) strength value of 800 kg/m³ density fiberboard was higher than that of other densities (Fig. 2). Fiberboards made from 775 kg/m³ density met the requirements of ANSI Standard (6.00 kg/cm²) and nearest to the Euro Standard (6.50kg/cm²). Whereas IB strength value of 800 kg/m³ density fiberboard (8.10 kg/cm²) met the requirements of Indian (8.00 kg/cm²), Euro (6.50 kg/cm²) and ANSI Standard (6.00 kg/cm²) specification.

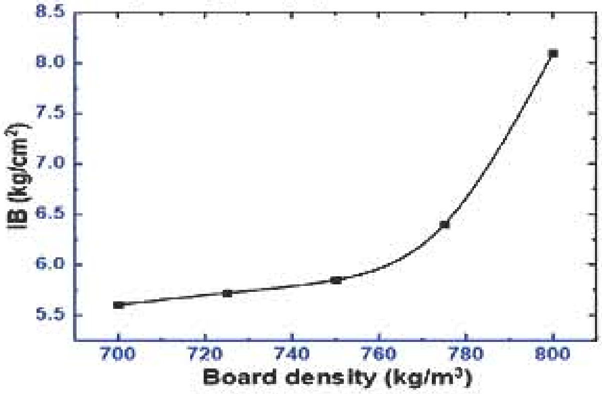

Figure 2. Internal bond strength (IB) of the fiberboards.

The WA and TS properties had been determined for different densities of fiberboards made from hybrid *Acacia* wood fiber. The test samples were soaked under water for 24 hours, weight and thickness differences

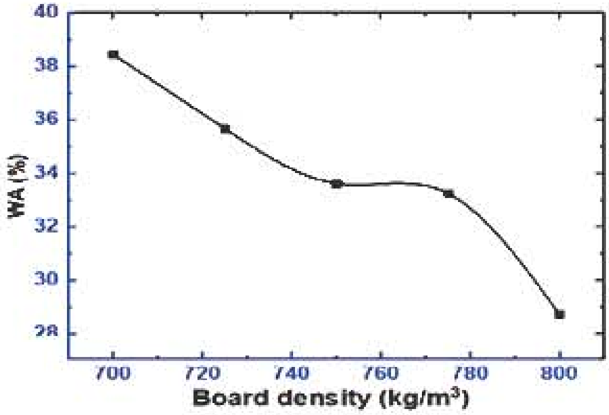

Figure 3. Water absorption (WA) of the fiberboards.

were measured for the determination of WA and TS (Fig. 3 and 4). The observed TS values of the different types of fiberboards were 18.08 to 12.67% after 24 hours of water soaking.

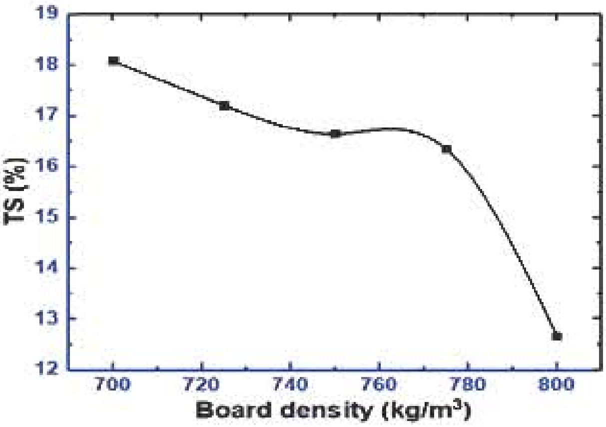

Figure 4. Thickness swelling (TS) of the fiberboards.

Discussion

After data analysis, it was observed that the MOR value was increased with increasing the panel density. However, the extent of this growth was not proportional. Fiberboards containing a density of 800 kg/m³ was the highest

MOR values than the others. There was a significant difference between boards of different densities at 1% level (Table 3). The higher density MDF made it stronger and more resistant to break when under heavy loads. Kollmann *et al.* (1975) pointed out that MOR was the most important mechanical property of particleboards with respect to their particle application as structural elements.

The numerical values of IB strength properties were found different for different densities of fiberboards. These values were found to affect in a similar fashion with a variation of board density. The result demonstrated that an increase in board density leads to an increase in IB strength. This was not significant at 1% level (Table 3). The IB strength property gave information about the structure of MDF, which ensured a fine adhesive property and a good dimensional stability on the fiberboard structure.

The TS is one of the basic properties that determine whether the panel will be used in dry or humid situation. When MDF is exposed to water contact, wood fibers swell and residual stress that is created during the MDF pressing process is released, which leads to an increase in the thickness of the panel (Ayrilmis *et al.* 2009). The strength characteristics of MDF panels are also reduced by both WA and TS properties (Ayrilmis *et al.* 2011). From the Table 3, it has been observed that, the TS and WA of the fiberboards decreased with increasing the panel density. These growth values were not proportional. The average value of TS of all densities fiberboard was close to the Euro Standard but did not meet the Indian Standard requirements. The TS and WA values are significant at 1% level (Table 3).

The TS of the boards is related to the amount of water absorption, so higher water absorption contributes to higher swelling in thickness. According to IS 12406 (Anon. 2003) specification, the absorption of water by standard fiberboard is 30% for 24 hours of soaking and the percentage of TS of the standard board is 7% after the same time interval. From the results, it is observed that the mean WA of 800 kg/m³ fiberboard after 24 hours of soaking was lower (28.72%) than that of other densities. For WA analysis, considering all only 800 kg/m³ fiberboards satisfied the IS 12406 (Anon. 2003) specification requirement (30%).

After 24 hours of water soaking, a value of TS below 12% guarantees the dimensional stability of MDF when it is used as a material for interior application and furniture production (Popovska *et al.* 2012). MDF boards commonly used in the interior for household purposes. Household furniture kept at a safe distance from water, although accidental water exposure will not reduce the durability of the panel and its properties. Kollmann *et al.* (1975) reported that the highest TS after two hours of immersion in water should not exceed 6-10% of the original thickness. However, the addition of suitable additives may improve the properties of the fiberboards.

Conclusion

The test results revealed that the higher MOR values were obtained from the denser panels of MDF made from hybrid *Acacia* wood. In this experiment, almost 80% of fibers yield was found from hybrid *Acacia* wood on the oven-dry weight basis. The fiberboards prepared with a density of 800 kg/m³ hybrid *Acacia* wood fiber had the most suitable values for the MOR, TS & WA parameters compared to other densities. However, the fiberboards e.g. 700, 725, 750 and 775 kg/m^3 made from hybrid *Acacia* wood can also be used conventionally for household purposes. It can be concluded that hybrid *Acacia* wood was much suitable for the production of MDF at density of 800 kg/m^3.

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