Research Journal of Forestry

ISSN 1819-3439

Academic Journals Inc.

www.academicjournals.com

Research Journal of Forestry 7 (1): 1-15, 2013
ISSN 1819-3439 / DOI: 10.3923/rjf.2013.1.15

Seed Germination in Lowland Tropical Rainforest Trees: Interspecies, Canopy and Fruit Type Variations

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ABSTRACT

Tropical trees exhibit wide heterogeneity in their canopy status, fruit types, seed sizes and seed-size dependent seedling growth; information on the germination and growth with relation to these parameters is of enormous use to understand species distribution and management in any forest stand. This study reports seed germination performance of 48 tropical trees native to northeast India, a global hot spot, with relation to inter-species, seed size, canopy level and fruit type variations. Main fruit availability seasons were Sep.-Dec. and Jan.-Mar. and seed size varied significantly among the tropical trees (range 0.64 mg seed^{-1} to 25.47 g seed^{-1}). Of all, 16, 30 and 2 species comprised top, mid and lower-canopy status, respectively and most of them exhibited poor regeneration in the forest. Among all studied species, 81% exhibited rapid germination, 15% intermediate and 4% showed delayed germination. Overall seed germination was recorded >70% for 21 species, 40-68% for 19 and <35% for 8 species. *Vangueria spinosa* recorded maximum (95%), while *Linociera macrophyla* and *Heteropanax fragrans* minimum germination. Seed viability also varied significantly among species, 28% species had viable seeds for <60 days, 47% up to 61-180 days and remaining 25% for >181 days. Overall, the mid-canopy species were noted to have shown higher seed germination and prolonged viability. Considering that, tropical forests are under threat, it is expected studies regarding seed germination will enable successful nursery operations and planned seedling production. Also this will enhance the establishment of seedlings in the restoration activities of degraded sites through selection of native plants.

Key words: Tropical trees, germination days, canopy status, fruit types, seed viability, seed sizes, forest management, north east India

INTRODUCTION

The tropical forests occupy 7% of the earth's area with about half of the world's forest cover and 65% of global biodiversity (Whitmore, 1990). In Asia and the tropics, tropical forests have been foremost victims of anthropogenic pressure to the extent that most areas either replaced by secondary vegetation or denuded completely (Menon *et al.*, 2001). For sound management and continued economic gains from tropical forests, it is desired to assess reproductive seed biology of native tree species that contribute considerably to local biodiversity as well as also valued by the indigenous people (Hubbell and Foster, 1983; Deb and Sundriyal, 2008). Our understanding of tropical tree seeds has advanced considerably over past two decades, however only selected species are used in afforestation because of eases in their seed collection and management (viz., *Acacia, Casurina, Eucalyptus, Leucena*, etc.) (Smith *et al.*, 2002). This clearly reveals that our practices are limited to a few hundred of many thousand-tree species that occur in tropical forests (Turner, 2001; Vozzo, 2002). It is, therefore, desirable to screen and evaluate more and more native species for their germination and viability so that some of such species could also form a part in plantation schemes (Wang, 1991; Naithani *et al.*, 2004). The tropical trees show wide heterogeneity in terms of seed sizes (Vozzo, 2002; Khan, 2004; Shankar, 2006), canopy status and fruit types (Whitmore, 1990; Flores, 2002) and seed-size dependent seedling growth (Khan and Shankar, 2004; Sundriyal and Sundriyal, 2005). Information on the germination performance with relation to these parameters would be of immense use to understand species distribution and management of forest stands (Khan *et al.*, 2002).

In this investigation, selected tropical trees were examined for their fruit availability and seed characteristics, seed dormancy, germination and seed viability. Selected tropical tree were investigated for: (1) Interspecies seed germination, dormancy and viability capabilities of tropical trees and (2) Germination as influenced by species' canopy status and fruit types. It is expected that such information would be of immense use in the management of tropical forests and in fulfilling community needs of growing these species through afforestation.

MATERIALS AND METHODS

Study area and stand selection: The Namdapha National Park is located in the Changlang district of Arunachal Pradesh state in the northeast India (27°23'30"-27°39'40" N latitude to 96°15'2"-96°58'33" E longitude). The park has an area of 1985.25 km^2 having 177.43 km^2 in the buffer zone and 1807.82 km^2 in the core zone with an elevational range of 200-4570 m above sea level. The park exhibits tropical climate with an annual rainfall of 2500-3000 mm; the maximum temperature and relative humidity remain high throughout the year. The floristic richness of Namdapha National Park reveals 674 species of flowering plants of which 266 were reported as tree species (Chauhan *et al.*, 1996). Details of vegetation analysis of the park are also available (Deb *et al.*, 2009) though less information is available on seed availability and germination behaviors of most of tree species.

Species selection and seed germination test: A total of 48 tree species was selected for germination test, the criteria being their use value and local demand, the status of natural regeneration and availability of seed material. These species comprised 1/3 of lowland tropical rainforest tree species. For all species investigated for their germination, the mature and healthy fruits were collected from the tropical lowland forest of Namdapha National Park and nearby areas during 2005-2006 from different locations of robust individuals that are healthy and had a straight bole and widespread canopy cover. After collection, all the fruits/seeds were packed in polythene bags, brought to the laboratory and dried at room temperature. Field observations were recorded for an availability period of the mature fruits, no. of seeds per fruit, a type of fruit, canopy status of species and their regeneration status at forest stand (Deb and Sundriyal, 2008).

Experimental design and assessing interspecies, canopy and fruit type variations in germination: Average seed weight was measured for each species and the values presented as g/seed (or mg/seed). Seed germination tests were done separately for each species in three distinct batches (replicates) with 100 seeds per batch. The species with large and heavy seeds (viz., *Canarium strictum*, *Beilschmiedia assamica*, *Dipterocarpus macrocarpus* and *Aesculus assamicus*) were sown in polythene bags (height×diameter: 30×12 cm), while all other seeds were sown in root trainers (size 15×6 cm) having 20 holes; both filled with an even mixture of garden soil and farmyard manure (ratio 1:1). After seed sowing, all bags and root trainers were kept underneath the meshlon net at nursery to avoid direct sunlight and rains. All seeds were watered regularly as and when required to ensure proper germination. The germination was recorded as the clearly emerged cotyledons or plumule above the soil surface. For all species daily observations were taken to assess initiation of germination, number of seeds germinated and length of germination period (days) from start to completion. The individual species progression for germination was also noted. All species were divided into three categories according to germination rates: (i) Rapid: All seeds germinated within 12 weeks, (ii) Intermediate: Germination started before 12 weeks but was not completed by 12 weeks and (iii) Delayed: Germination started after 12 weeks (Ng, 1980).

To assess the viability, the seeds of different species were stored in a laboratory at room temperature. The seed viability was tested on monthly intervals by taking 15 seeds per batch (n = 3), the seeds were sown in root trainers and polythene bags according to the size of the seeds and germination was noted daily. The seeds were considered viable until there was no further germination. Mean germination time (days) calculated as:

$$\text{Mean germination time (MGT)} = \sum\left(\frac{nd}{N}\right)$$

where, n is number of seeds which germinated after each incubation period in days (d), N is the total number of seeds emerged at the end of the test (Hartmann and Kester, 1989).

To assess community level variation in germination amongst tropical trees, the species were also grouped as per their seed size, canopy status and fruit types. To assess effect of seed sizes on germination, all species were grouped as per their seed weights from light to heavy seeds. Similarly, the species were also categorized into top-, mid- and lower-canopy species (Deb and Sundriyal, 2008). The top-canopy species had a mean height over 25 m with straight bole that often reaches up to 40-50 m height with a girth of 2-4 m. The mid-canopy species reach up to 15-25 m in height though some individuals could attain even 30 m, such species show maximum dominance in tropical forest stands (Deb *et al.*, 2009). The lower-canopy species had a height of <15 m. The species also grouped as per their fruit types and germination assessed for varied fruit types. For all three categories (i.e., seed size, canopy level and fruit types) the data were gathered on the range of seed size (weight), germination, time taken from start to completion (cessation) of germination and length of seed viability (Smith *et al.*, 2002). The frequency of species distribution based on seed weight, days to germination and viability were also analyzed.

Data analysis: All experiments were laid on a complete randomized block design. The analysis of variance (ANOVA) was applied using SYSTAT for all the experiments (Wilkinson, 1986). The difference among mean was assessed at degree of confidence of 95%. The ANOVA was applied to germination, days for germination (initiation to completion), seed viability and seed size variations among species. Differences in germination with relation to canopy status and fruits types also tested for ANOVA. The LSD was estimated separately to compare the treatment means.

RESULTS

Fruit availability and seed weight characteristics: A total of 48 species belonging to 44 genera and 29 families were tested for the seed germination. Of these, 16 species represented the top-, 30 mid- and 2 lower-canopy status (Appendix 1). The mature fruit and seed availability period differed varied for different species (Fig. 1, Appendix 1). The maximum numbers of species bear seeds in September-December (28-33% species) and January-March (12-14% species). During April to August, 6 species had mature seeds (Fig. 1). The number of seeds per fruit varied amongst species; from 1 seed/fruit for *Dipterocarpus macrocarpus*, *Canarium strictum* and *Beilschmiedia assamica* to as high as 25-40 seeds/fruit for *Altingia excelsa*. Significant differences registered in seed size and number of seeds/kg ($p<0.001$) (Fig. 2). Most of the species had small seed sizes (<0.5 g seed^{-1}). Two species, viz. *Aesculus assamicus* and *Dipterocarpus macrocarpus* exhibited largest seed sizes comprising 39±5 and 70±10 seeds kg^{-1} for the respective species. *Duabanga grandiflora, Altingia excelsa, Cedrella toona, Morus indica, Terminalia chebula, Morus laevigata* and *Schima wallichii* produced small and lightest seeds. A total of 16 tree species recorded 100-1000 seeds kg^{-1}, 14 species 1001-10000, 7 species between 10001-100000 and 7 species with 100001 to 1500000 seeds kg^{-1} (Fig. 2). For all the studied species, a mean weight of 23±13 mg seed^{-1} was estimated. Of the total species taken in this investigation, 6 species were devoid of any regeneration in the forest stand, 30 species had poor regeneration while only 12 species showed fair regeneration. The mature seed availability varied for different species, maximum species had it during autumn (September-December), winter (January-March) and spring (April-May) seasons. Species with light seeds produced mature seeds during winter and spring seasons just before rains.

Inter-species seed germination, dormancy and viability: The sampled tree species showed variations in the seed dormancy, germination and seed viability (Table 1). The frequency of species from low-weight to high-weight recorded a declining trend (Fig. 3a). Of the total species investigated, the germination commenced within 10 days of seed sowing for 11 tree species (25%), between 10-20 days for 13 species (31%) and 21-30 days for 10 (24%) species, thus exhibited minimum dormancy (Fig. 3b). Thus altogether 81% exhibited rapid germination. Four and two species initiated their germination between 31-50 and 51-70 days, respectively, after seed sowing.

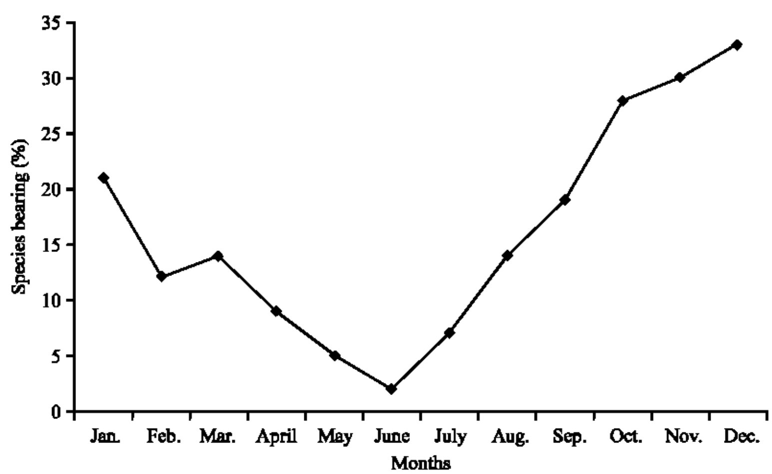

Fig. 1: Percent species bearing seeds in different months undertaken in the present study

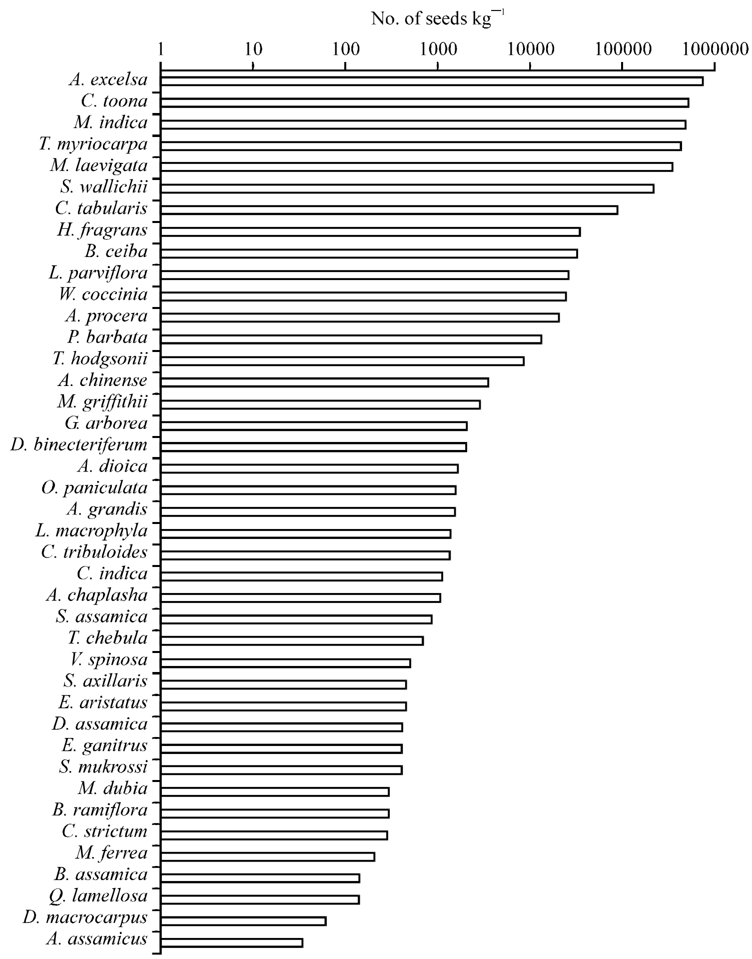

Fig. 2: No. of seeds kg^{-1} for different species undertaken for germination study (ANOVA: species seed mass $F_{47,1606} = 2088360$)

Only 2 species recorded their germination after 100 days of seed sowing, thus showed maximum dormancy. The germination completed within 20 days for 2 species, between 21-40 days for 10 species, 41-60 days for 16 species and 61-100 days for another 7 species. For 7 tree species, germination period extended beyond 100 days. The germination varied significantly among different species ($p<0.001$). The ANOVA for species x days was also highly significant ($p<0.001$). The frequency of seed-viability among tree species recorded inconsistent trend, exhibiting a bimodal distribution with maximum species borne viable seeds up to 4 months though for a few species it was as high as >7 months (Fig. 3c). Two species showed seed viability for <30 days, 9 species up to 31-60 days, 7 species 61-120 days, 12 species 121-180 days, 3 species 181-300 days, 3 species 301-360 days and 4 species >361 days (Table 1). The mean germination for different species varied (10-95%) between different tropical tree species (Table 1). For 21 species, over 70% seeds germinated of which 5 species recorded over 85% germination. Nineteen species registered 40-68% seed germination, while 8 species had <35% seed germination. The pooled data for all tree species revealed that 39 species showed rapid (germination completed within 12 weeks), 7 species intermediate (germination started within 12 weeks but completed after 12 weeks) and 2 species

Table 1: Mode of germination, days for germination and seed viability of studied species

Species	Mode of germination	Seed germination (%)	Germination period (days)	Seed viability (months)
Aesculus assamicus	-	85±8	20-60	10-13
Ailanthus grandis	Epigeal	80±7	22-100	6-7
Alangium chinense	-	73±10	6-20	10-14
Albizia procera	Epigeal	41±12	5-10	-
Altingia excelsa	Epigeal	44±8	15-55	3-5
Amoora wallichi	-	66±12	20-70	2-4
Aporosa dioica	Epigeal	80±13	45-131	-
Aquilaria agallocha	-	71±7	15-40	1-2
Artocarpus chaplasha	Hypogeal	66±15	10-32	1-1.5
Baccaurea ramiflora	Epigeal	35±16	20-110	3-5
Beilschmeidia assamica	Hypogeal	54±14	50-129	-
Bombax ceiba	-	83±6	8-35	7-10
Canarium strictum	Epigeal	85±3	30-130	15-17
Castanopsis indica	Hypogeal	53±9	30-60	4-5
Castanopsis tribuloides	Hypogeal	75±10	25-50	3-4
Cedrella toona	-	70±11	12-23	1-2
Chukrasia tabularis	Epigeal	40±11	7-35	6
Cinnamomum bejolghota	-	53±12	25-55	1-2
Dalbergia pinnata	Epigeal	88±6	10-42	10-13
Dipetrocarpus macrocarpus	Durian	75±7	10-50	1-2
Drypetes assamica	Hypogeal	73±12	152-200	5-7
Duabanga grandiflora	-	47±8	15-55	3-5
Dysoxylum binecteriferum	Hypogeal	66±7	10-28	2-4
Elaeocarpus aristatus	Epigeal	41±12	25-65	3-4
Elaeocarpus ganitrus	Epigeal	20±15	180-260	10-14
Gmelina arborea	-	68±12	10-35	10-12
Heteropanax fragrans	Epigeal	10±9	-	-
Lagerstromia parviflora	-	55±10	15-55	20-25
Linociera macrophyla	Epigeal	11±10	-	1
Magnolia griffithii	-	68±11	25-70	1-2
Melia dubia	Epigeal	20±12	-	8
Mesua ferrea	Hypogeal	80±14	10-50	3-4
Michelia champaca	-	77±11	15-50	1-2
Morus indica	-	45±17	50-80	4-6
Morus laevigata	-	50±15	30-60	4-6
Ostodes paniculata	Epigeal	68±14	10-62	1-2
Phoebe goalparensis	-	73±14	30-100	2-4
Premna barbata	-	65±15	20-50	4-5
Quercus lamellosa	Epigeal	72±6	35-60	4-6
Sapindus mukrossi	Epigeal	85±4	25-45	-
Schima wallichii	Epigeal	30±16	10-25	4
Shorea assamica	Epigeal	76±5	15-30	1-2
Spondias axillaris	Epigeal	84±5	26-132	5-6
Talauma hodgsonii	Epigeal	24±10	25-50	1
Terminalia chebula	Epigeal	25±11	-	-
Terminalia myriocarpa	Epigeal	60±5	15-40	3-4
Vangueria spinosa	Epigeal	95±4	-	-
Wrightia coccinia	Epigeal	71±6	-	-

-: Data not recorded

Table 2: Seed weight and germination behavior as influenced by canopy species in tropical trees species

Canopy	No. of species	Seeds weight (g)	Seed germination (%)	Germination period (days)	Seed viability (months)
Top	16	0.001-14.29	30-85	10-130	1-17
Middle	30	0.002-25.64	10-88	10-260	1-25
Lower	2	0.238-2.99	35-73	6-110	3-14

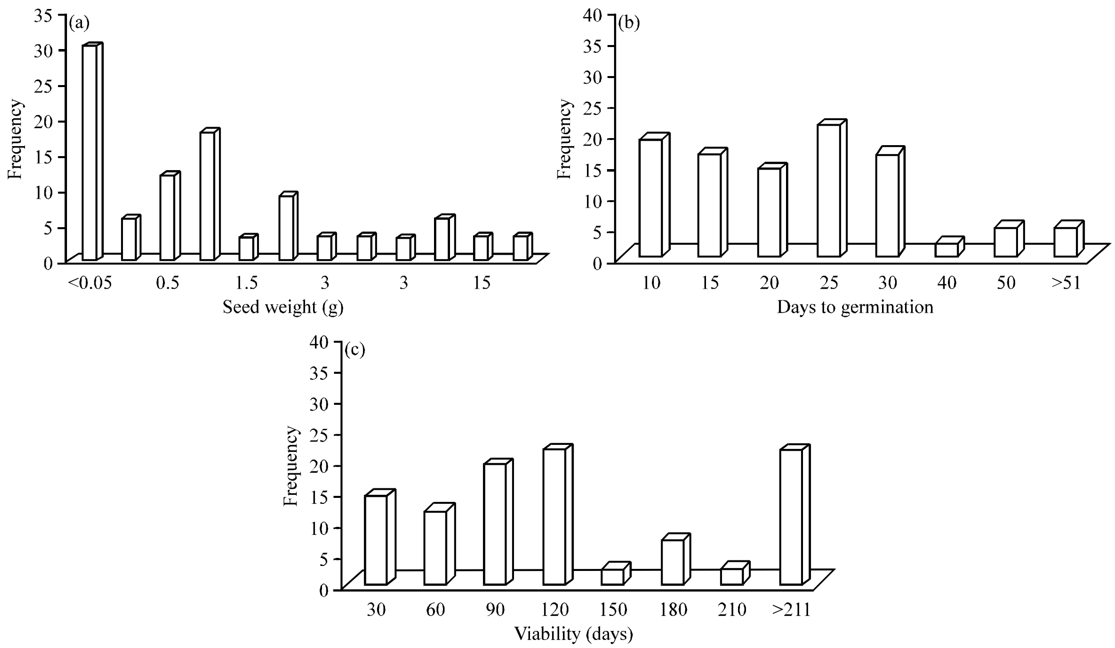

Fig. 3(a-c): Distribution pattern of (a) Seed size (g), (b) Days to germination and (c) Validity in relation to species frequency among the studies species

exhibited delayed germination (germination started after 12 weeks of seed sowing). Similarly, for most of the species the germination completed within 70 days. Among all studied species *Vangueria spinosa* recorded maximum (95%), while *Linociera macrophyla* and *Heteropanax fragrans* minimum germination (Table 2).

The germination initiation and cessation after seed sowing was accomplished within 5-10 days for *Albizia procera*, 8-35 days for *Bombax ceiba*, 12-25 days for *Dipterocarpus macrocarpus* and 10-50 days for *Mesua ferrea* (Fig. 4). The same period extended up to 30 days for *Morus indica*, 40 days for *Altingia excelsa* and *Ostodes paniculata*, 80 days for *Beilschmiedia assamica* and 120 days for *Canarium strictum*. *Elaeocarpus ganitrus* required 180-260 days to initiate and accomplish its germination (Table 1). Other species showed an intermediate range for completion of their germination.

The pooled data for all species showed a positive correlation between seed sizes and germination ($r = 0.22$, $p<0.05$) suggesting germination increases with increases in seed sizes (Fig. 5). The seed size also influenced the initiation and completion of germination. Generally small seeds showed early initiation ($r = 0.26$, $p<0.05$) as well completion of germination ($r = 0.40$, $p<0.05$). The seed viability showed weak positive correlation with seed size ($r = 0.06$, $p<0.05$). The day of germination had negative correlation with total seed germination showing that early germinating species had higher seed germination ($r = -0.22$, $p<0.05$). Similar was the case for completion of the germination ($r = -0.09$, $p<0.05$).

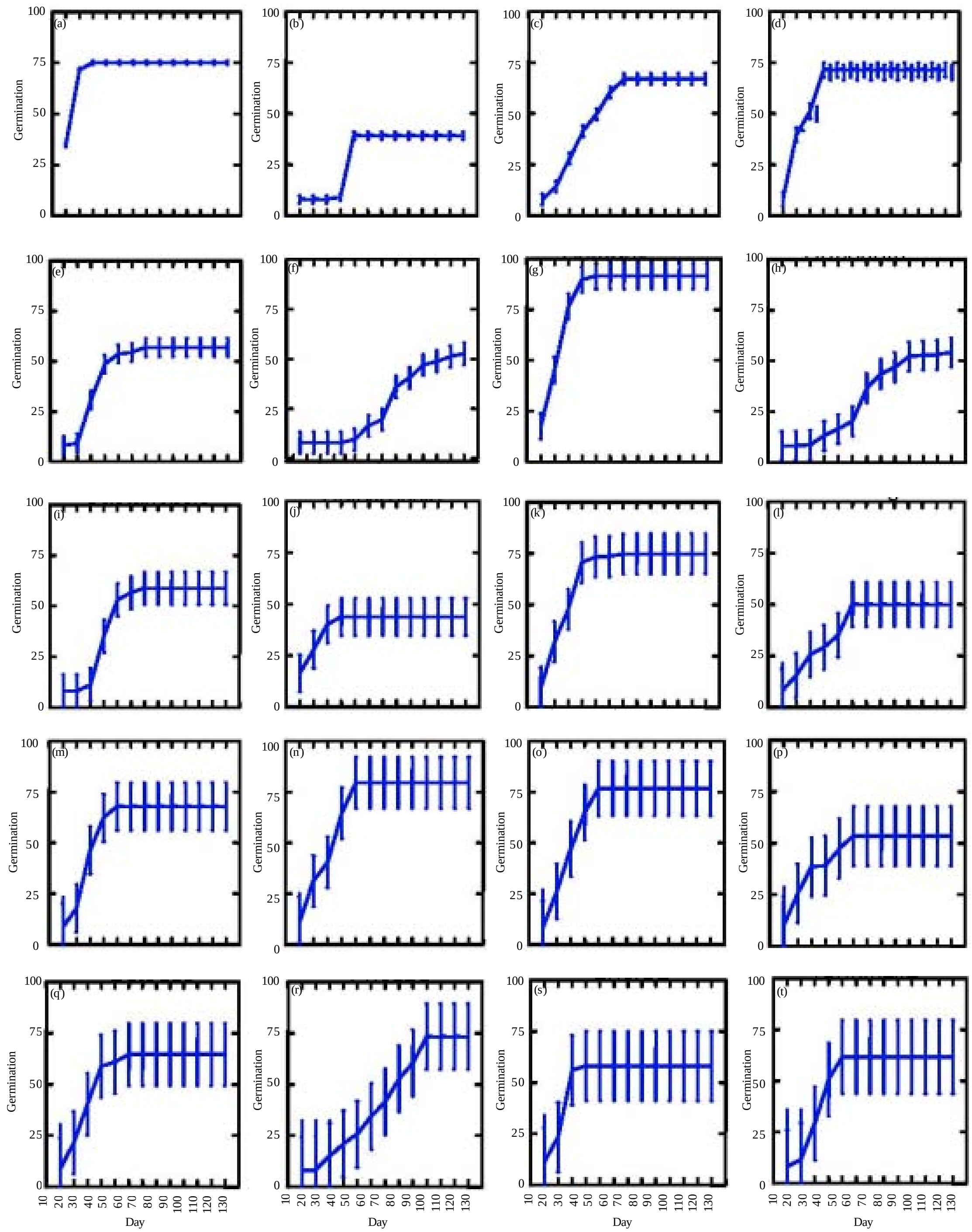

Fig. 4(a-t): Seed germination of selected tropical tree species: (a) *Albizia*, (b) *Altingia*, (c) *Amoora*, (d) *Aquilaria*, (e) *Baccaurea*, (f) *Beilschmeidia*, (g) *Bombax*, (h) *Canarium*, (i) *Castanopsis*, (j) *Chukrasia*, (k) *Dipterocapus*, (l) *Duabanga*, (m) *Gmelina*, (n) *Mesua*, (o) *Michelia*, (p) *Morus*, (q) *Ostodes*, (r) *Phoebe*, (s) *Shorea* and (t) *Terminalia*

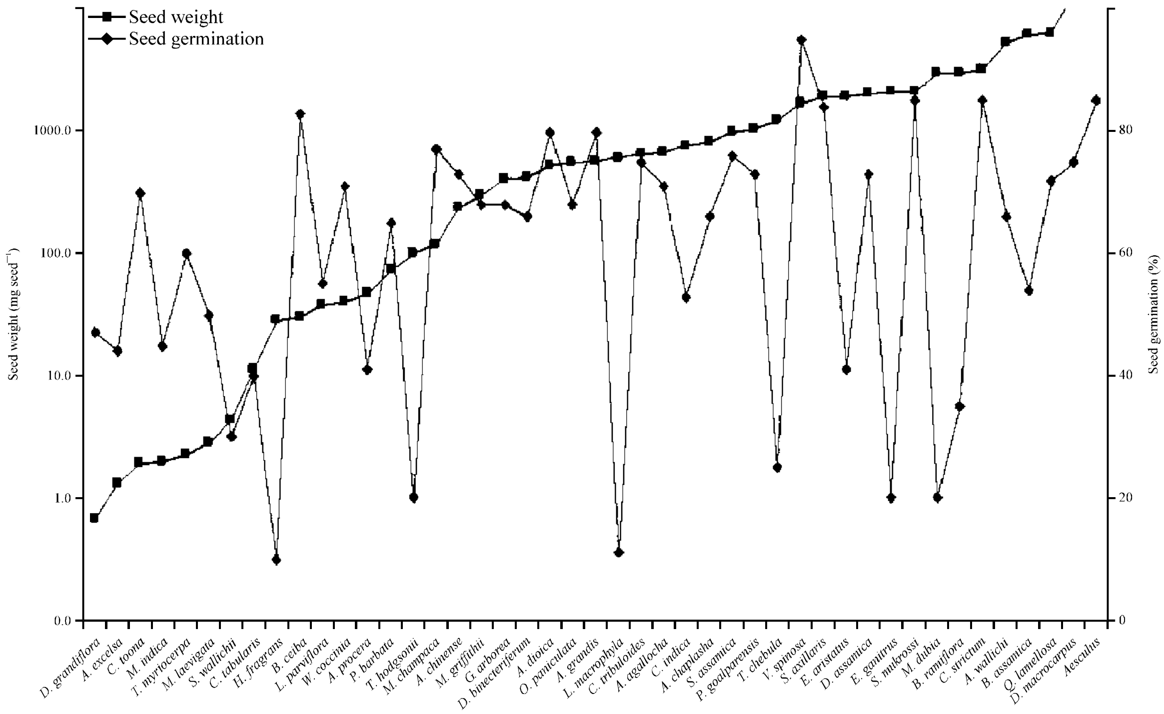

Fig. 5: Relationship between seed weight and germination of all investigated species of the lowland tropical forest

Germination capability of canopy species: The forest canopy stratification of the tropical trees revealed that 33, 63 and 4% comprised top-, mid- and lower-canopy status. The fruit availability for top and mid-canopy species recorded in different months round the year, while it was mainly during July-December for lower-canopy species. The seed size varied by over 14000, 13000 and 13 times within top-, mid- and lower-canopy species (Table 2). The germination initiated earlier in top-canopy species (Mean 13±8 days), followed by lower- (Mean 15±6 days) and mid-canopy species (34±6 days). Despite of the variations in the seed germination amongst canopy species, it was not significant (ANOVA-$F_{23,1}$ = 365, non-significant). The lower-canopy species completed their germination (Mean 36±20 days) earlier than the top-canopy (Mean 50±10 days) and mid-canopy species (Mean 75±8 days).

Fruit types and germination capability: An analysis of the fruit types revealed that 16 species comprised capsules, 11 drupes, 5 acorns, 4 samara, 3 pods and 2 species with follicles (Table 3). Among the dominant species of the forest, *Altingia excelsa* and *Ostodes paniculata* comprised capsules, *Beilschmiedia assamica* and *Canarium strictum* as drupes and *Dipterocarpus macrocarpus* had samara (winged fruit). The capsule fruits recorded abundantly during September-May, the acorns in September-April, while the nuts in October-December. The seed germination also varied with fruit types though it was not significant. The mean seed germination followed the trend as pod>samara>drupe>capsule>acorn>follicle>nuts. The days to start germination varied significantly among the fruit types ($p<0.01$), all showed early germination than the nuts. The cessation of germination also varied between fruit types ($p<0.001$) and species followed similar trends as for the start of the germination. The seed viability also varied among different fruit types and followed the order nut>pod>drupe>capsule>acorn>samara>follicles (Table 3).

Table 3: Major fruit types, seed characteristics and percentage germination for lowland tropical rainforest tree species

Fruit type	No. of species	Fruit availability	Mean seed weight (g)	Germination period (days)	Seed germination (%)	Seed viability (months)
Capsule	19	Sep.-May	0.001-28.57	8-110	11-100	1-25
Drupe	12	July-Dec.	0.074-3.57	10-150	25-85	1-17
Acorn	04	Sep.-April	0.002-7.41	25-80	45-75	3-6
Samara	04	Dec.-Jan.	0.002-14.3	10-100	60-80	1-7
Follicle	03	Aug.-Dec.	0.10-0.313	25-70	20-68	1-2
Pod	03	Oct.-Jan.	0.04-0.23	6-42	41-88	10-14
Nut	02	Oct.-Dec.	2.13-2.95	210-310	8-15	20-30

DISCUSSION

The mean germination varied remarkably between the investigated tree species. *Vangueria spinosa*, *Aesculus assamicus*, *Sapindus mukrossi*, *Canarium strictum*, *Dalbergia pinnata*, *Spondias axillaris*, *Bombax ceiba*, *Mesua ferrea* and *Ailanthus grandis* recorded high germination (>80%). Contrarily, *Melia dubia*, *Elaeocarpus ganitrus*, *Linociera macrophyla* and *Heteropanax fragrans* exhibited minimum germination. Higher germination was recorded for large seeds. Such seeds may contain more chemical defense and only small part of seeds may be eaten by pathogen at one time, thus providing more chances of embryo surviving (Turner, 2001). Of the total tree investigated, 48% species comprised small seeds (0.001-0.408 g seed^{-1}), 14% medium (0.5-<1.09 g seed^{-1}) and 36% species had large seeds (>13 g seed^{-1}) and sizes reflect the species status in the forest stands. The species with smaller seed sizes (such as *Duabanga grandiflora*, *Altingia excelsa*, *Cedrella toona*, *Morus indica*, *Terminalia chebula*, *Morus laevigata* and *Schima wallichii*) considered pioneers, while those with big seeds (such as *Dipterocarpus macrocarpus*, *Quercus lamellosa*, *Beilschmeidia assamica*, *Bombax ceiba* and *Aesculus assamicus*) were climax species in the forest stand. All investigated species showed remarkable seed size variation (1:40,000) between lightest and heaviest seeds. Such a wide seed-weight variation can be attributed to diverse micro-climatic conditions within a forest stand that can accommodate such contrasting range of species. The seed size is a significant ecological attribute of plants to increase seedling survival in forest stands under different micro-climatic conditions (Rose and Poorter, 2003). The higher variations in seed mass reveal that species may establish under the forest canopy or in small gaps (Foster and Janson, 1985). More seeds mean more attempts to produce viable descendants, though the reduced seed-size also increased risk of mortality (Turner, 2001). In tropical lowland forests of Namdapha National Park, more small size canopy-gaps have been reported that perhaps justifies the requirement of wide seed-size variations amongst tree species (Deb and Sundriyal, 2007). It is reported that the seed mass variations amongst the shade tolerant species were generally larger than shade intolerant species (Turner, 2001). Significant differences registered in seed sizes of species that greatly influence on mode of germination and days taken to initiate and complete the germination. The epigeal mode of germination (cotyledons raised above the soil surface) was more prevalent than the hypogeal mode (cotyledons remain in soil) and one species also exhibited durian type of germination. Most of the species completed their germination up to 70 days suggesting a dominance of recalcitrant seeds. A few completed their germination within 10 days of seed showing, while some required 180-260 days. Other species showed intermediate range for the completion of their germination. Similar results have been reported from other tropical forests (Vozzo, 2002). In tropical Malaysian forests, of the 330 forests species, 65% showed early germination (Ng, 1980).

Rapid germinators (recalcitrant) tend to have high seed water content and soft seed coat, such species are difficult to store. *Canarium strictum* and *Elaeocarpus ganitrus* had more orthodox seeds as they exhibited maximum time (days) for their seeds germination, which may be attributed to their hard seed coat. A large number of factors are responsible for delayed germination of seeds, viz. low water content, hard seed coat, small size and early stages of development of embryo and presence of chemical germination inhibitors (Vazquez-Yanes and Orozco-Segovia, 1996; Naithani *et al.*, 2004). Shade is also considered an important inducer of dormancy in the seeds of tropical trees (Turner 2001). The pooled data for all species showed positive correlation between seed sizes and germination. However the small seeds initiated early germination and completed it before the big seeds. Generally, species initiated early germination also had higher total seed germination. In the forest stand the seed sizes may help in natural selection process. The large seeded are considered adaptive shade-tolerant plants and because such seeds contain relatively large amounts of food reserves, it helps in seedling establishment even in dim light on the forest floor (Turner, 2001). The small sizes may provide more chances of survival despite of low germination as more can be produced per unit investment (Foster, 1986). Most tropical tree pioneers that are typical to early forest succession, have small orthodox dormant seeds that can be easily dispersed and may form a seed bank on forest floors; their germination is subject to environmental alteration or disturbances, such as natural or intentional clearing in the canopy (Flores, 2002; Sharma *et al.*, 2008). In contrast, a large number of climax species with big recalcitrant or intermediate seeds germinated quickly, thus show an advantage in terms of avoiding insect predation (Whitmore, 1990).

The seed germination also varied with fruit types though it was not significant. The mean seed germination followed the trend as pod>samara>drupe>capsule>acorn>follicle>nuts. Of the total species investigated, 33, 62.5 and 4% species exhibited top-, mid- and lower-canopy status. The seed size variations were more prominent in top- and mid-canopy species. The top-canopy species initiated early germination, than the lower- and mid-canopy species though the variations were not significant. However, the overall germination was higher for mid- than the top- and lower-canopy species. The seed viability duration was also longer for mid-canopy species. The overall higher average seed germination and larger period of seed viability for mid-canopy species could be attributed to their dominance in the forest stand (Deb and Sundriyal, 2008). The species had higher seed production, germination and viability capacities may be considered dominants in the forest stands. Seeds of climax species can germinate (seedlings become established) in dim light on the forest floor, whereas those of pioneer species require high light associated with a gap in the canopy for germination and seedling establishment (Swaine, 1996).

Field observation revealed that the frequency of seed production varied remarkably among the species. It was also noteworthy to mention that most of the species with lighter seed sizes produced mature seeds during winter and spring seasons, which is perhaps an adaptation of the species to initiate germination before rains. Many tropical species do not produce abundant crops of seeds annually. The mature seed availability during autumn, winter and spring seasons (viz., before rainy season) could be considered as an adaptation to ensure maximum germination of tropical forest species. Seed dormancy is a characteristic of few tropical species (Vazquez-Yanes and Orozco-Segovia, 1996). Most species showed low seed-viability; up to 4 months (37% species) and up to 7 months (32% species), though for a few it was >12 months (15% species). The germination of tropical tree seeds is generally immediate and their viability is very short (Ng, 1980; Sharma *et al.*, 2008). Seed longevity is generally higher for dry tropical than wet tropical species

(Khurana and Singh, 2001). The forest under investigation falls in later category. The seed sizes also influences viability though in this investigation such relationship was weak, generally small seeds showed larger viability then big one except for nuts. In Queensland, Australia, the small seeds have survived burial of up to 2 years than the largest seeds (Turner, 2001). Similar results also found for tropical trees of Malaysia (Kanzaki *et al.*, 1997). However, these reports are contrary to the reports of Ng (1980).

CONCLUSIONS

The tropical trees show wide heterogeneity in terms of seed sizes, canopy status, fruit types and seed-size dependent seedling growth and information on the ecology of germination and seedling growth with relation to these parameters is vital not only for understanding the community processes of plant recruitment and succession but also for developing strategies for the conservation of biodiversity and restoration of tropical forests. Until recently, the focus of multiplication of trees has been the commercial and economic species and lack of knowledge on germination and seedling growth of most of the native species was a major constraint faced by forest managers and nursery growers to include these species in plantation programs. Despite of wide global significance of the tropical rainforest, a broad range of native trees species are not yet screened and systematically analyzed for their germination. The present study provides seed availability period, seed-size variations, mode of germination, dormancy and viability and time taken for germination of 48 tree species native to tropical forests of northeast India, a global hotspot. The sampled tree species showed two major seasons for availability of seeds. It was interesting to note that the seeds size (weight) variations among lightest and heaviest seeds was as high as 40,000 times for various species. The study revealed that germination was species-type and seed-type dependent. The fruit type variations and canopy status of species also influence seed germination up to certain extent. Also, the seasonal (dry and wet seasons) availability of seeds also effect intensity of germination. The data has practical importance and implications for management and conservation of highly impacted tropical forests in the region. Since most of the trees are considered the best available species to meet the community needs and their densities are low in community forests, these could be adopted in afforestation and rehabilitation schemes. Most of the Unclassed State Forests (areas designated to meet community needs of fuel, timber and fodder) are in highly degraded state in the northeast, therefore species screened in this investigation could be adopted for restoration of such areas. In tropical forests, these species could also be used for forest gap area management. Information on these species could also help to avoid the use of alien tree species in plantations and use indigenous ones for community benefits. If community demands are met outside the park area by planting the demanded species, it can help to maintain tree diversity within Namdapha national park in near future. It is, therefore, suggested that more and more information be added on other tropical species so that rehabilitation and conservation of economically important as well as other species could be achieved using native tree species.

ACKNOWLEDGMENTS

The authors thank Director, G.B. Pant institute of Himalayan Environment and Development for providing facilities to conduct this study. Authorities of Department of Environment and Forests, govt. of Arunachal Pradesh are thanked for permitting to work in the Namdapha National Park and helping in various forms. This study was supported by a grant from Ministry of Environment and Forests, Govt. of India, New Delhi.

APPENDIX

Appendix 1: Studied species with taxonomic description, their availability, natural regeneration and usage

Species	Local name	Family	Fruit type	Fruit availability	Canopy	Regene- ration	Use value
Aesculus assamicus	Horse chestnut	Hippocastanaceae	Capsule	Sep.-Oct.	M	Nil	FW
Ailanthus grandis	Borpat	Simoroubiaceae	Samara	Dec.-Jan.	T	Nil	FW
Alangium chinense	Saw karoi	Alangiaceae	Pod	Oct.-Dec.	L	Nil	FW
Albizia procera	Koroi, siris	Leguminosae	Pod	Dec.-Jan.	T	poor	FW
Altingia excelsa	Jutuli	Hamaelidaceae	Capsule	Oct.-Jan.	T	Poor	FW, HC
Amoora wallichi	Amar	Meliaceae	Capsule	June-Julu	T	Poor	HC
Aporosa dioica	Lali	Euphorbiaceae	Capsule	Aug.-Sep.	M	Good	FW
Aquilaria agallocha	Agar	Thymelaeaceae	Capsule	June-July	M	Poor	WO
Artocarpus chaplasha	Sam	Moraceae	Capsule	June-Aug.	T	Fair	FW, HC
Baccaurea ramiflora	Leteku	Euphorbiaceae	Capsule	July-Aug.	L	Fair	FR
Beilschmeidia assamica	Amchoi	Lauraceae	Drupe	Nov.-Dec.	M	Good	FW, HC
Bombax ceiba	Semal	Bombaceae	Capsule	March-April	T	Poor	Cotton
Canarium strictum	Dhuna	Burseraceae	Drupe	Dec.-Jan.	T	Poor	RS, FR
Castanopsis indica	Hingori	Fagaceae	Acorn	Oct.-Nov.	M	Poor	FW
Castanopsis tribuloides	Kotus	Fagaceae	Acorn	Nov.-Dec.	M	Poor	FW
Cedrella toona	Jati poma	Meliaceae	Capsule	April-May	T	Poor	FW, HC
Chukrasia tabularis	Bogapoma	Meliaceae	Capsule	April	T	Poor	HC
Cinnamomum bejolghota	Tezpat	Lauraceae	Drupe	Sep.-Nov.	T	Good	FW
Dalbergia pinnata	Siris	Leguminosae	Pod	Nov.-Jan.	M	Poor	FW
Dipetrocarpus macrocarpus	Hollong	Dipterocarpaceae	Samara	Jan.-March	T	Fair	FW
Drypetes assamica	Siris	Leguminosae	Drupe	Sep.-Nov.	M	Poor	FW
Dysoxylum binecteriferum	Poma	Meliaceae	Capsule	Nov.-Jan.	M	Poor	FW
Duabanga grandiflora	Khokhan	Dnabangoideae	Capsule	March-May	T	Poor	HC
Elaeocarpus aristatus	Gahorisopa	Elaeocarpaceae	Drupe	Sept.-Oct.	M	Fair	FW
Elaeocarpus ganitrus	Rudraksh	Elaeocarpaceae	Nut	Dec.-Jan.	M	Poor	ORN
Gmelina arborea	Gamari	Verbenaceae	Drupe	May-June	M	Poor	HC
Heteropanax fragrans	Keseru	Araliaceae	Drupe	Dec.-Feb.	M	Poor	FFS
Lagerstromia parviflora	Sida	Lagerstromiaceae	Capsule	Oct.-Dec.	M	Nil	HC. FW
Linociera macrophyla	Pareug	Oleaceae	Capsule	Dec.-Feb.	M	Poor	FW
Magnolia griffithii	Sopa	Magnoliaceae	Follicle	Oct.-Dec.	M	Poor	FW
Melia dubia	Neem	Melia	Nut	Oct.-Nov.	M	poor	FW
Mesua ferrea	Nahar	Clusiaceae	Capsule	Sep.-Oct.	M	Poor	HC. FW
Michelia champaca	Titasora	Magnoliaceae	Follicle	Aug.-Sep.	T	Poor	HC, WC
Morus indica	Tutadi	Moraceae	Acorn	Feb.-April	M	Poor	HC. FW
Morus laevigata	Bola	Moraceae	Acorn	March-May	M	Nil	HC
Ostodes paniculata	-	Euphorbiaceae	Capsule	Nov.-Jan.	M	Good	HC, FW
Phoebe goalparensis	Bousum	Lauraceae	Drupe	Oct.-Nov.	M	Poor	FW
Premna barbata	Gohra	Verbenaceae	Drupe	Oct.-Dec.	M	Nil	HC
Quercus lamellosa	Bajrat	Fagaceae	Acorn	Sep.-Oct.	M	Poor	HC
Sapindus mukrossi	Ritha	Sapindaceae	Drupe	Nov.-Dec.	M	Poor	LS, FW
Schima wallichii	Makrishal	Theaceae	Capsule	Feb.-March	T	Poor	FW
Shorea assamica	Mekai	Dipterocarpaceae	Samara	Feb.-March	T	fair	HC, FW, RS
Spondias axillaris	Lapsi	Anacardiaceae	Drupe	Sep.-Nov.	M	Poor	FR
Talauma hodgsonii	Sopa	Magnoliaceae	Follicle	Aug.-Sep.	M	Fair	FW
Terminalia chebula	Hilika	Combretaceae	Drupe	Aug.-Oct.	M	Poor	FR, MED, FW
Terminalia myriocarpa	Hollock	Combretaceae	Samara	Dec.-Feb.	T	Nil	HC, FW, MU
Vangueria spinosa	Kotkora	Rubiaceae	Capsule	Nov.-Jan.	M	good	FW, FR
Wrightia coccinia	-	Apocynaceae	Capsule	Jan.-March	M	good	WC

FW: Firewood, FR: Fruit, RS: Resin, WC: Wood curving, MED: Medicine, LS: Local shampoo, HC: House construction, ORN: Ornamental, MU: Mushroom host, T: Tall canopy, M: Mid canopy and L: lower canopy

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