Seed traits and their correlates in Indian tropical trees

Thesis submitted towards the partial fulfilment of

BS-MS Dual degree programme

By

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Certificate

This is to certify that this dissertation entitled "**Seed traits and their correlates in Indian tropical trees"** towards the partial fulfilment of the BS-MS dual degree programme at the Indian Institute of Science Education and Research (IISER), Pune represents original research carried out by Brihaspati Kumar Gaurav, Reg No. 20091013 at IISER Pune under the supervision of Dr. Deepak Barua and Dr. Ankur Patwardhan, Garware College, Pune during the academic year 2013-2014.

Date:

Signature of the Supervisor

Dr. Deepak Barua
Assistant Professor
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Declaration

I hereby declare that the matter embodied in the thesis entitled **“Seed traits and their correlates in Indian tropical trees”,** is the result of the investigations carried out by me at the Biology Department, IISER Pune under the supervision of Dr. Deepak Barua and the same has not been submitted elsewhere for any other degree.

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Abstract

There exists a huge diversity in seed traits among the plant species. Ecological consequences of such variations are manifold and often vary between floras, habitats and taxonomic groups. Very few ecological studies concerned with seed traits have been done in Indian flora. Functional relationships of seed traits with plant traits like germination percentage, germination rate, dispersal, seedling establishment / survival, viability, etc. in Indian plants and especially in tropical trees have not been sufficiently investigated and evidence for any association remains equivocal in most cases. To find possible correlates of seed traits in Indian tropical tree species, we collected seeds/fruits of 80 tropical tree species from Bhimashankar in Western Ghats, Pune and Pakke Wildlife sanctuary (Arunachal Pradesh). Fruit and seed traits, which include fruit mass, fruit dimensions, number of seeds per fruit, seed mass and seed dimensions were measured. Germination assays and seedling establishment experiments were carried out in the laboratory. Data for dispersal mode, fruit type, month of dispersal, fruit maturation time, plant height, plant habit, habitat type and leaf habit were obtained from secondary sources. Interactions of these traits with seed / fruit / diaspore traits and among themselves were investigated. Diaspore mass was found to be associated with dispersal mode, fruit type and season of dispersal. Dispersal mode was associated with both fruit type and season of dispersal. Seed mass was associated with plant height, plant habit and habitat type. Leaf habit had no significant effect on seed size. Seed mass was positively correlated with seedling growth rate. However, no significant correlation was observed between fruit mass and fruiting duration, seed mass and germination percentage, and seed mass and seedling survival.

Introduction

Seeds consist of an embryo, an endosperm or seed reserve and a seed-coat or testa. Seeds also possess dispersal appendages like plumes, hairs, hooks, barbs, elaiosomes, arils or flesh. Seeds along with their dispersal appendages are called diaspores. So, seed traits include any feature of seed as a whole or its constituents (seed-coat, endosperm, etc). A large part of the studies on seed traits is observed to be focused on seed size and its relation with plant functions, which include seed dormancy, germination, seed viability, seedling establishment and survival, dispersal mode, growth form, plant height, genome size, as well as with environmental factors like shade, moisture-availability, nutrient content, fungal infection, etc.

Seed size generally increases form grasses through shrubs to trees (Leishman and Westoby, 1994). Since growth form and plant height are positively correlated, seed size and plant height are also expected to be positively correlated. Indeed, it has been reported many times for different habitats (Rees, 1996). A possible explanation is that plant height can increase dispersal distance of heavier/larger seeds. The relationship in case of wind or gravity dispersal is, therefore, expected to be stronger than that in case of animal-dispersal. In reality, however, the relationship holds equally strongly for the animal-dispersed species (Leishman et al., 1995).

There is a pattern of larger seeds in tropical flora in comparison to the seeds in temperate flora, independent of differences in growth form or plant height and dispersal mode (Lord et al., 1997). It may be a result of higher temperatures in tropics, which lead to higher metabolic costs of growth and, which in turn leads to larger seeds.

Evolutionary divergences in seed size are correlated with those in dormancy (Hodkinson et al., 1998; Rees, 1996). Due to the finding that small seeds dominate the seed bank (Eriksson and Eriksson, 1997), it was proposed that small seeds were more likely to be dormant. The idea behind this proposition is that the higher level of bet-hedging against zero survival via one mechanism, which in this case is large-seededness, weakens the selection for other mechanisms like seed dormancy (Venable and Brown, 1988; Philippi and Seger, 1989). However, among a wide range of Australian species, small seeds were not significantly more dominant than big seeds (Leishman and Westoby, 1998), and in 47 native species of New Zealand, seeds of dormant species were not found to be consistently smaller (Moles et al., 2000).

Theoretical models predict that large seeds are more likely to show early germination than small seeds (Venable and Brown, 1988; Rees, 1994). Large-seeds are expected to be predated more than small seeds and should, therefore, select for early germination. On the other hand, small-seeded species, being more persistent in soil are expected to exhibit delayed germination. This has been found in grasslands (Grime et al.,1981). However, recently, Norden et al. (2008) used a meta-analysis of published data sources containing information for seed size and time to germination for 1037 tree species from five tropical areas worldwide (Brazil, India, Ivory Coast, Malaysia and Panama) and found significant positive relationship between these two traits. Murali (1997) had also found strong positive correlation between these traits in his study including 99 tropical species. This indicates that predation may not be a major selective force on time to germination in large seeds as they may also exhibit defenses (chemical or physical); and that several other factors like water absorption rate, physical defenses, physical dormancy, etc. might be playing important roles here. Also, selective forces may shape this pattern between seed size and time to germination. Small-seeded species might be germinating early to acquire suitable sites before competitive larger-seeded species, while latter might be spreading germination in time to avoid risks associated with environmental hazards.

Regarding any association between seed size and germination percentage, evidence remains equivocal. For example, Aiken and Springer (1995), in their study of six switchgrass cultivars, and Hojjat (2011), in his study of 24 Lentil genotypes, report an increase in germination as seed size increased, while Shipley and Parent (1991), in their study of 64 wetland species, and Eriksson and Eriksson (1998), in their study of 11 species, did not find any such correlation. However, none of these studies provide accurate reasons for respective observations. It is possible that the correlation observed between seed size and germination percentage may arise from secondary correlation via seedling establishment / survival. Large scale studies are definitely needed to come to any definite conclusion in this case.

Large seeds have been shown to cause better seedling survival than small seeds in different establishment sites among different species (Marshall, 1986; Chambers, 1995; Greene and Johnson, 1998). Many studies have shown that large-seeded species are more successful than small-seeded species in competitive environments (Black, 1958; Gross and Werner, 1982; Reader, 1993; Burke and Grime, 1996). Large-seeded species also show less seedling mortality in shade than the small-seeded species (Leishman and Westoby, 1994; Saverimuttu and Westoby, 1996; Walters and Reich, 2000). Also, in non-lethal shade, growth of small-seeded species is relatively poorer than that of large-seeded ones (Osunkoya et al., 1993; Osunkoya et al., 1994; Saverimuttu and Westoby, 1996). Limited studies done to explore the significance of seed size in other hazards like low moisture level and nutrient deprivation show equivocal evidence about benefit of large size for seedling establishment and survival. Seedlings from large seeds survived better in the condition of stimulated herbivory (Armstrong and Westoby, 1993; Bonfil, 1998). The greater success of large-seeded species in comparison to that of small-seeded species in different hazards can be attributed to the former's larger seedling size, which provides better access to light and deeper water levels, or to their greater cotyledon reserve storage relative to active parts of the seedling, which enables them to sustain in the situation of carbon-deficiency, or to lower relative growth rate of their seedlings that enables them to sustain in the situation of carbon-deficiency (Westoby et al., 1996).

Larger seeds (> 100 mg) are generally adapted for vertebrate-dispersal; seeds < 0.1 mg are generally dispersed unassisted, while seeds between 0.1-100 mg tend to be adapted for many dispersal modes (Hughes et al., 1994). A possible explanation for unassisted seeds generally being less than 0.1 mg is that the unassisted dispersal becomes less effective above this size and the relative cost of having a specialized structure is high below this size. Large seeds are generally harder to disperse than small ones – they need larger animals, stronger winds or more powerful propulsion (Kelly, 1995). Thus, selection for large seed size may bring with it selection for altered dispersal devices or may constrain the array of efficacious dispersal agents. Very large seeds cannot go far ballistically or by adhering to animal exteriors, they cannot be carried by small animals (such as ants) and they need very large wings to be successfully wind-dispersed. One option may be dispersal by vertebrates (Willson et al., 1990a), and larger seeds generally require larger vertebrates to carry them (Foster and Janson, 1985; Wheelwright, 1985; Hammond and Brown, 1995). There can also be an indirect relationship between seed size and dispersal mode via plant height and growth form.

Seed shape is shown to be related to seed persistence (Thompson et al., 1993). Compact and round seeds get easily incorporated in soil. However, there are some exceptions (Peco et al., 2003; Thompson et al., 2001; Moles et al., 2000). A relation between depth distribution and seed shape has also been found in certain habitats like Southern Kalahari (Kos, 2007). A negative correlation between time to germination and seed shape (i.e., variation in seed roundness) has been shown. It has been found that species with seeds with appendages such as hairs or that were conically shaped had faster than average germination. Species with a spherical seed shape, on the other hand, had slower germination than expected (Kos and Poschlod, 2010; Grime et al., 1981). Germination percentage has been shown to be positively related to seed shape in certain habitats like Horqin Steppe, the arid temperate desertified grassland in northeastern China (Liua et al., 2007). Seed shape is also important in endozoochory. Seed survival after ingestion by Fallow deer is negatively related to variance in seed 'roundness' (Bakker et al., 2008).

Seed coat has been shown to be cause of dormancy in many species; for example, in seeders, where fire breaks the dormancy (Pugnaire and Lozano, 1997). It also helps to form persistent seed banks as in legumes, where seed coats are very impermeable (Baskin and Baskin, 1989). Studies on the ecological importance of seed coat mucilage have provided valuable information about its roles in critical stages of the plant life cycle. It provides moist environment promotes seed development. It affects dispersal and in arid environments, prevents seeds from drying. By reducing oxygen diffusion to the seed, it also regulates dormancy (Yang et al., 2012). Antibacterial and antifungal activity in seed coats has also been demonstrated (Osborn and Harper, 1951; Warr et al., 1992). In natural conditions, resistance to microbial attack, acting together with seed dormancy mechanisms, may ensure longevity of persistent seeds in the soil.

A small number of studies deal with ecological consequences of variation in seed chemical composition. It has been shown that a seed's chemical composition is influenced by habit and habitat (Levin, 1974). Studies indicate that a seed's chemical composition is influenced by the dispersal mode of the species (Lokesha et al., 1992). When the dispersal efficiency increases with a decrease in seed size (as in wind- and animal-dispersed species), seed resources are more often constituted of a greater proportion of fat than protein or carbohydrate. However, increased fat content is shown to reduce the seed viability owing to lipid peroxidation (Spencer, 1931; Conger and Raudolph, 1968). Several other factors, such as predation, ploidy level and dormancy are also known to influence a seed's chemical composition.

Very few ecological studies concerned with seed traits and their correlates have been done in Indian flora. Most of them deal with intraspecific variation in seed traits. Also, the number of species dealt with in interspecific studies is very small. This study, we examine seed and fruit size of 75 woody tree, shrub and liana species found in Indian tropical forests and their relationship with plant attributes like germination percentage, time to germination, seedling establishment, seedling growth rate, plant height, plant habit (tree, shrub, liana), plant type (evergreen, deciduous), dispersal mode, time of dispersal, fruit maturation time, fruit type (berry, drupe, capsule, pod, achenes, samara, etc.) and habitat type (open, edge open, edge, edge closed, closed).

The reasons for expecting relationship between seed/fruit size and germination percentage, time to germination, seedling establishment, seedling growth rate, plant height, plant habit, dispersal mode have been explained above. We expect a relationship between habitat type and seed size because of the differential performance of seedlings of large-seeded and small-seeded species in similar light conditions or shade, which has been described in detail previously.

Specific fruit types are known to aid different mechanisms of seed dispersal (Lorts et al., 2008). For example, both capsules and achenes are frequently dispersed by wind in the open, arid habitat, whereas fleshy fruits (berries, drupes and pomes) are generally dispersed by animals. Also, seed size has been shown to be associated with mode of dispersal in previous studies. Therefore, we expect a relationship between fruit type and seed size. The relationship between fruit/seed size with fruit maturation time is based on the assumption that greater the fruit/seed size, greater will be the time required for its development.

Evergreen and deciduous trees use very different strategies for reproduction. While evergreen trees tend to be K selected, deciduous species tend to be r-selected. This implies that deciduous trees are expected to produce large number of small seeds, while evergreen species are expected to produce large seeds.

In Indian tropical forest scenario, annual climate can be roughly divided into dry and monsoon periods. Suitable time for germination is likely to be rains or post monsoon period. So we expect that seeds which do not persist longer in seed bank, i.e. large seeds, to disperse during these favourable periods. Also, dispersal time may be influenced by availability of dispersal mode, which has been shown to interact with seed size. Thus, we expect time of dispersal to be related with seed size.

Materials and methods

Collection sites: Seeds from 36 tropical species (Appendix-1A) were collected from near Bhimashankar Wildlife Sanctuary, which is situated in the northern part of Western Ghats of Maharashtra and spread across over an area of 130.78 km^2 ($19^o21`$N- $19^o11`$N, $73^o31`$E-$73^o37`$E approximately). It includes portions of Ambegaon and Rajgurunagar (Khed) Talukas in Pune District, Karjat taluka in Raigad District and Murbad taluka in Thane District. This region is situated at the crest of the main Sahyandri range (approx altitude 1000m) and includes portions running gradually into the eastern plains as well as steep terraced western slopes leading to the Konkan. (Borges and Rane, 1992). The average annual rainfall is approximately 3000mm and is delivered by the south-west monsoon winds only from the months of June to September-October; remaining completely fog bound and also creating distinct seasonal periods; wet and dry season. The average maximum and minimum daily temperatures are 36^oC in May and 7^oC in December. High velocity winds are experienced in this region from December to March. The major forest types found in here are moist semi-evergreen seasonal cloud forest and moist deciduous forests.

Seeds of 14 tropical species (Appendix-1C) found in the Pakke Wildlife Sanctuary, Arunachal Pradesh, were obtained from Amruta Rane of Nature Conservation Foundation. The Pakke Wildlife Sanctuary (862 km^2, 92°36′ – 93°09′E and 26°54′ – 27°16′N, 150 to 2040 m ASL) lies in the foothills of the Eastern Himalaya in the East Kameng district of Arunachal Pradesh. Both the South-West and North-East monsoon are prevalent here. The average annual rainfall is 2500 mm. The mean (± SD) maximum temperature was 29.3°C (± 4.2) and the mean minimum temperature was 18.3°C (± 4.7), based on data from 1983 to 1995 recorded by the Tipi Orchid Research Centre. Most of the rainfall occurs between June and September (South-West monsoon), with some winter rain from December to February. March to May is hot, and some thunderstorms and showers occur in April-May (www.pakketigerreserve.org).

Seeds of 25 tropical species (Appendix-1B) were obtained from three areas in Pune – Panchawati Hill (Vetal Tekdi), National Chemical Laboratory campus and near

Mulshi. Pune has a hot semi-arid climate bordering with tropical wet and dry with average temperatures ranging between 20 to 28 °C. Pune experiences three seasons: summer, monsoon and a winter. Typical summer months are from March to May. The warmest month in Pune is April; although summer doesn't end until May, the city often receives heavy thunder showers in May (and humidity remains high). The monsoon lasts from June to October with moderate rainfall. Most of the 722 mm (28.43 in) of annual rainfall in the city fall between June and September, and July is the wettest month of the year. Hailstorms are also common in this region. Winter begins in November (Wikipedia).

Ripe fruits or fully matured diaspores were collected from trees whenever possible, and from floor otherwise, in the months of April, May, June, August, September and October.

<u>Processing</u>: Seeds of some species like *Bauhinia purpurea*, *Delonix regia*, etc were collected in after they were dry and ready for dispersal and were stored directly in ziplock bags. Fruits of fleshy fruited species like *Carissa carandas*, *Jasminum malabaricum*, etc, were depulped manually; the seeds were rinsed and air dried. Fruits of some fleshy fruited species like *Actinodaphne gullavara*, *Ziziphus rugosa*, etc, were soaked in water for a couple of hours and then depulped manually to extract the seeds, which were then air-dried. Hard fruits and pods of some species like *Terminalia chebula*, *Terminalia catappa*, *Cassia grandis*, etc, were first air dried and stored. Seeds were later on extracted from them by mechanically breaking the dry fruits/pods. Predated seeds were carefully removed. Seeds from Pakke were obtained in processed stage.

<u>Storage</u>: Extracted and air-dried seeds were kept in ziplock-bags. Unextracted fruits and pods were first air-dried and kept in paper envelops to be processed later.

<u>Measurement of traits</u>: Weights and dimensions of fleshy fruits were taken before depulping or soaking. Weights of processed and air-dried seeds and dry fruits (such as pods of *Albizia lebbeck*) were taken within two months of collection. Weights were measured by using a digital weighing balance, while length, breadth and height of fruits and seeds were measured by using a digital vernier calliper. Around 6-10 seeds of each individual were measured. In addition, total weight of a large number

of seeds of an individual, whenever possible, was also measured. Around 3-10 fruits of each individual were measured for fruit traits.

Germination assays: Seeds of species collected from Bhimashankar and Pune were chosen for germination assays (Appendix-2). Three treatments – a control, warm stratification (for morphologically dormant seeds) and cold stratification (for physiologically dormant seeds), were done, except for some species for whom we did only control due to unavailability of required number of seeds. For control, seeds were placed on four layers of soaked germination paper in square petri-plates of size 80 mm by 80 mm by 15 mm. The plates were sealed by parafilm and kept in Perceival germination chambers at 25ºC and 12:12 light dark cycle. Cold and warm treatments were done in the same manner, except that initially seeds were placed between 2-2 layers of soaked germination papers in dark at 5ºC and 15ºC respectively for 1 month and then they were shifted to germination chambers under conditions similar to control.

Germination census was done weekly for 7 weeks and emergence of the radicle was recorded as seed germination. Germination papers were moistened with water whenever they showed signs of drying up during census.

Seedling establishment: After 14 days, germinated seeds (Appendix-3) were transferred from germination chambers to the green house in soil-filled pots of size 10cm by 5cm by 5cm at 27ºC. The seedlings were observed weekly for 4 weeks and their height and number of leaves were recorded.

Secondary data collection: Data for dispersal mode, fruit type, month of dispersal, fruit maturation time, plant height, plant habit and leaf habit (Appendix-4,5) were obtained from various data sources including online databases, research papers, personal communication with experts and personal observation.

Statistical analysis: All data were analysed by using STATISTICA. Seed/fruit traits and germination/seedling-establishment data were checked for normality using Shapiro-Wilk W test. They were then log transformed and the normality test was performed again (Appendix-6). As the seed and fruit mass data did not follow normal distribution after log transformation, we did non-parametric tests in addition to the parametric tests with log-transformed seed/fruit trait data for all our hypotheses. Based on our knowledge of dispersal unit (Appendix-4), I selected between seed and fruit mass for each species to determine diaspore mass, which was then log transformed to be used for the tests involving hypotheses based on dispersal.

One way ANNOVA and Kruskal Wallis test were done to examine variation of diaspore mass (log) with dispersal mode, month of dispersal, season of dispersal, fruit type, plant height, plant habit, and that of seed size with plant height, plant habit, leaf habit and habitat type.

Pearson correlation and Spearman rank order correlation tests were done to check for possible correlation between diaspore mass and fruit maturation time, seed mass and germination percentage, seed mass and seedling growth rate, and seed mass and seedling survival.

Chi square test was done to find out relationships between dispersal mode and fruit type, and dispersal mode and month/season of dispersal.

Results

Seed mass ranged from 0.000038g (*Woodfordia fruticosa*) to 17.5483g (*Entada rheedii*), and also of fruit mass, from 0.000262g (*Ficus tsjahela*) to 310.80g (*Entada rheedii*).

Diaspore mass varied significantly with dispersal mode (ANNOVA: F(3,73)=6.8348, p=0.00040. Kruskal-Wallis: H(3,N=77) =16.89014, p =0.0007). Autochorus and wind-dispersed species had significantly lower diaspore mass than zoochorus and water-dispersed species.

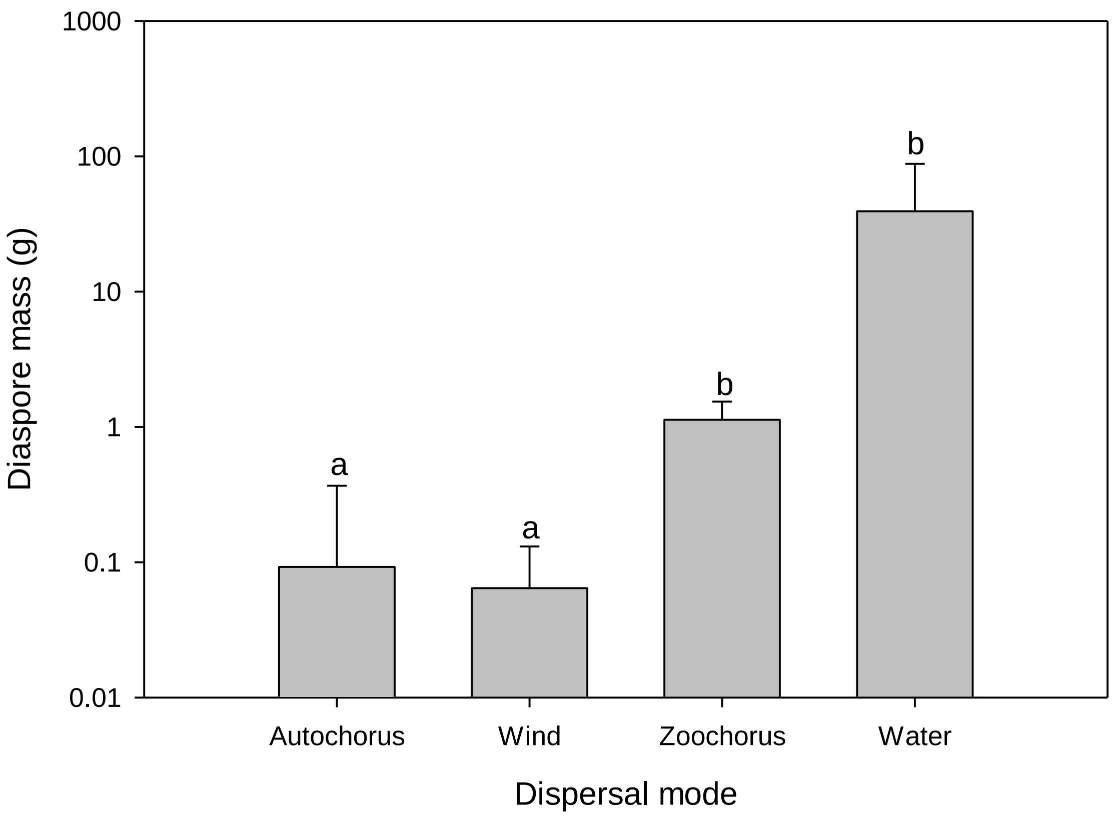

Figure 1: Average diaspore mass for different dispersal modes. Error bars represent + standard error. Different letters correspond to diaspore mass that were significantly different from each other (p<0.05). Sample size for the dispersal modes: Autochorous - 10; Wind - 10; Zoochorous - 55; Water - 2.

Average diaspore mass differed significantly for different fruit types in parametric test (ANNOVA: F(9,67)=2.9776, p=0.00485), but the difference was marginally significant in non parametric test (Kruskal-Wallis test: H(9,N=77) =14.75306 p =0.0980). Nutlet had the smallest average diaspore mass, while drupe had the highest. Dispersal mode and fruit type are associated with each other (Pearson Chi-square Coefficient = 43.00048, df=27, p=0.02618).

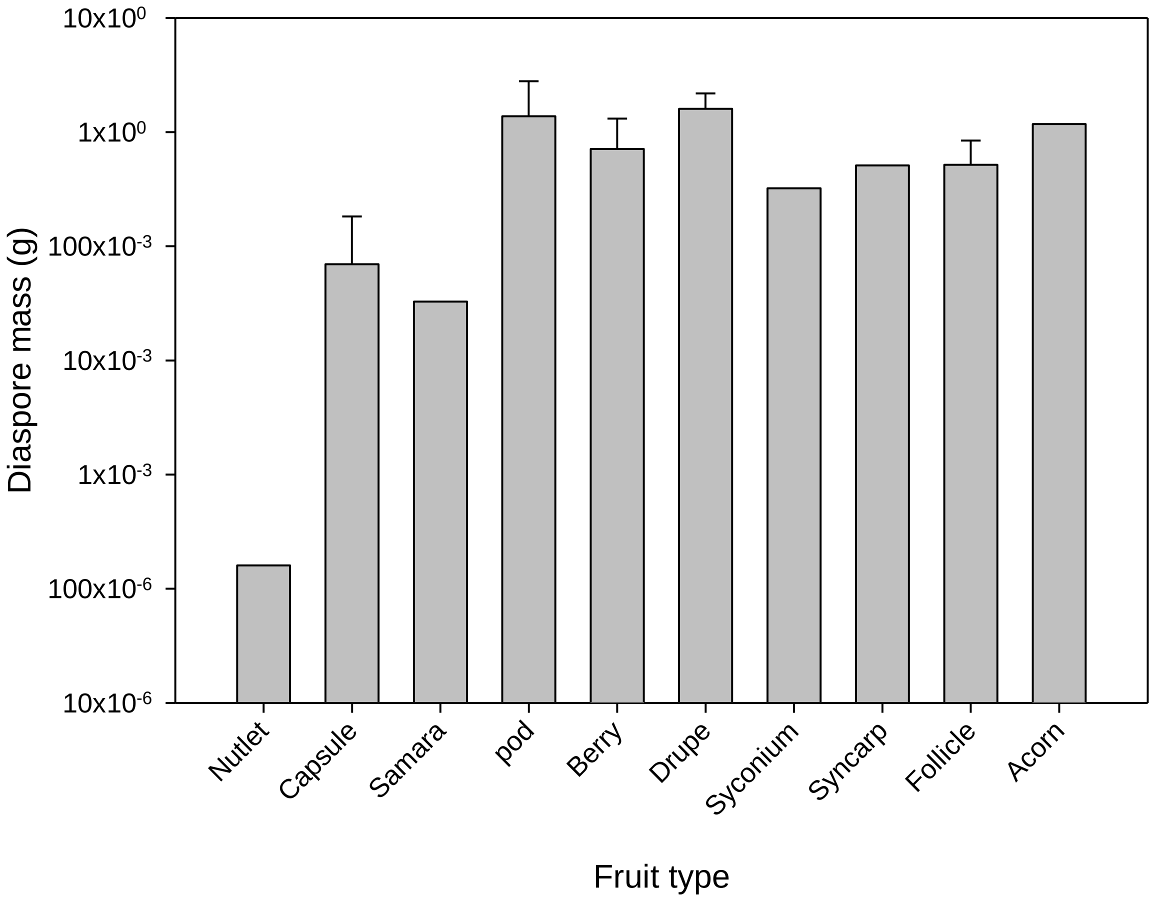

Figure 2: Average diaspore mass for different fruit types. Error bars represent + standard error. Sample size for the fruit types: Nutlet – 1, Capsule – 14, Samara – 1, Pod – 18, Berry – 14, Drupe – 24, Syconium – 1, Syncarp – 1, Follicle – 2, Acorn – 1.

Average diaspore masses for different months of dispersal were not significantly different (ANNOVA: F(7,58)=1.1170, p=0.36504; Kruskal-Wallis test: H(7,N=66) =9.945583 p =0.1917), but when the months were grouped into seasons of ‘dry’ and ‘rains’, average diaspore mass of seeds dispersed in dry season was found to be significantly lower than that of seeds dispersed in rains (ANNOVA: F(1, 64)=6.1070, p=0.01614; Kruskal-Wallis test: H(1,N=66) = 5.965727, p =0.0146). Chi-square test revealed that dispersal modes of species and the season in which they disperse are significantly related (Pearson Chi-square Coefficient = 18.37782, df=9, p=0.03105).

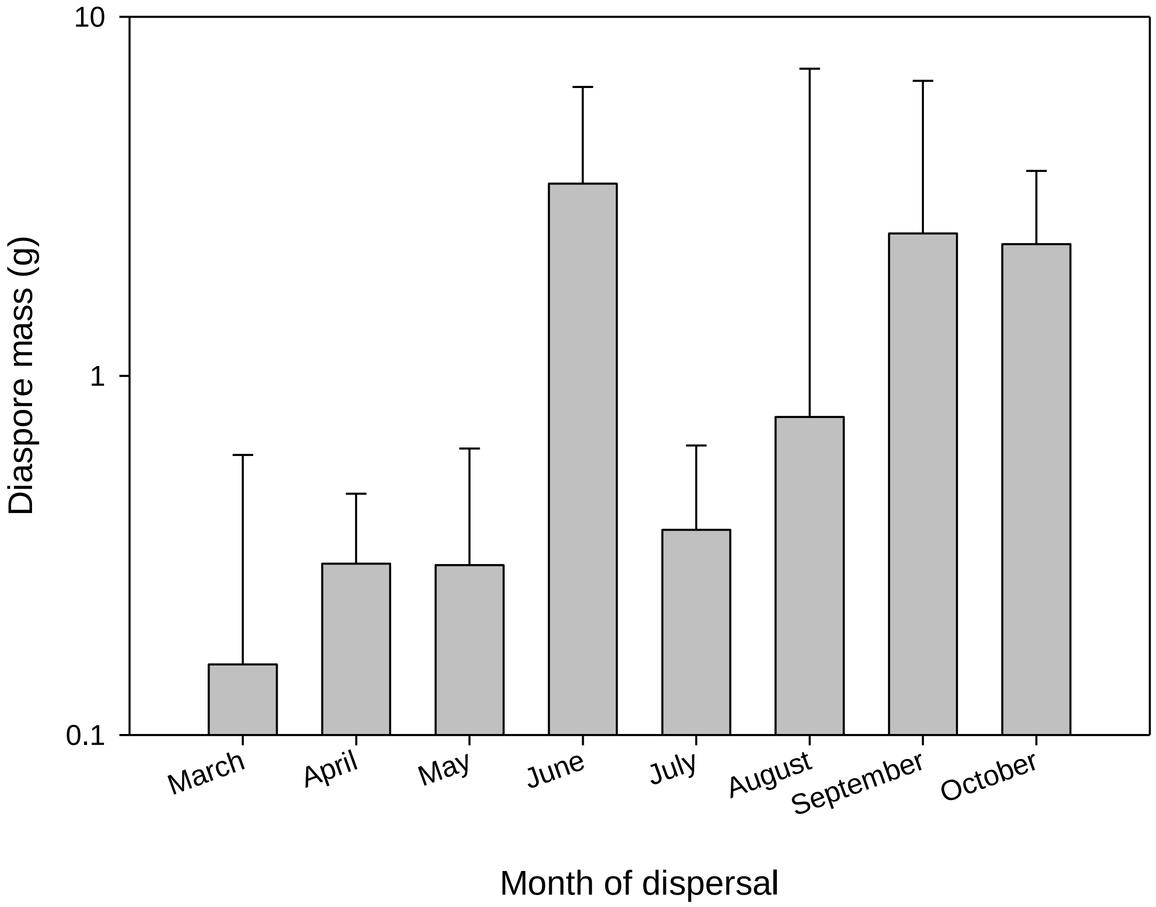

Figure 3: Average diaspore mass for different months of dispersal. Error bars represent + standard error. Sample size for different months: March – 7, April – 10, May – 26, June – 10, July – 4, August – 3, September – 3, October – 3.

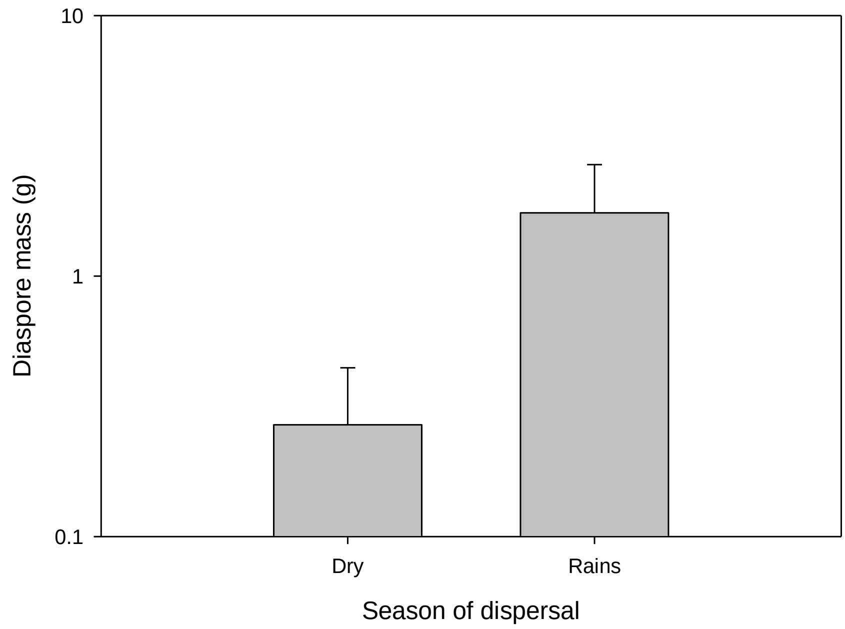

Figure 4: Average diaspore mass for different seasons of dispersal. Error bars represent + standard error. Sample size for the seasons: Dry – 43, Rains – 23.

There was no significant correlation between fruit mass and fruit maturation time (Pearson r = 0.181, n=35, p=0.299; Spearman r = 0.108, p=0.535).

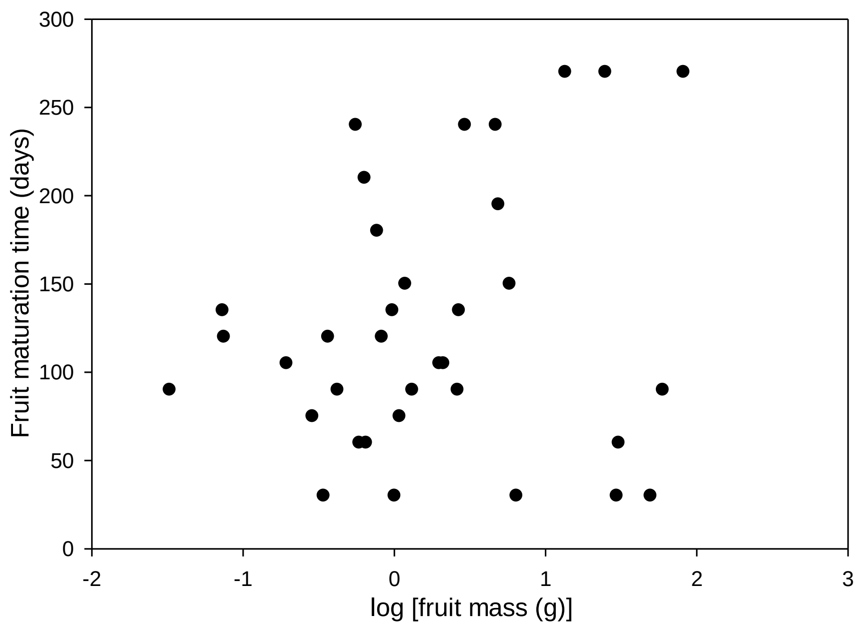

Figure 5: The variation of fruit mass (log transformed) with fruit maturation time. Sample size = 35.

Average diaspore mass was not significantly different for three different plant height catagories (ANNOVA: F(2,64)=1.653664, p=0.199418), however average seed mass of small (5 to 10m) plants, was significantly smaller than that of medium (10-20m) and large (20-30) plants (ANNOVA: F(2,62)=7.4740, p=0.00124; Kruskal-Wallis test: H(2,N=65)=15.60772 p=0.0004).

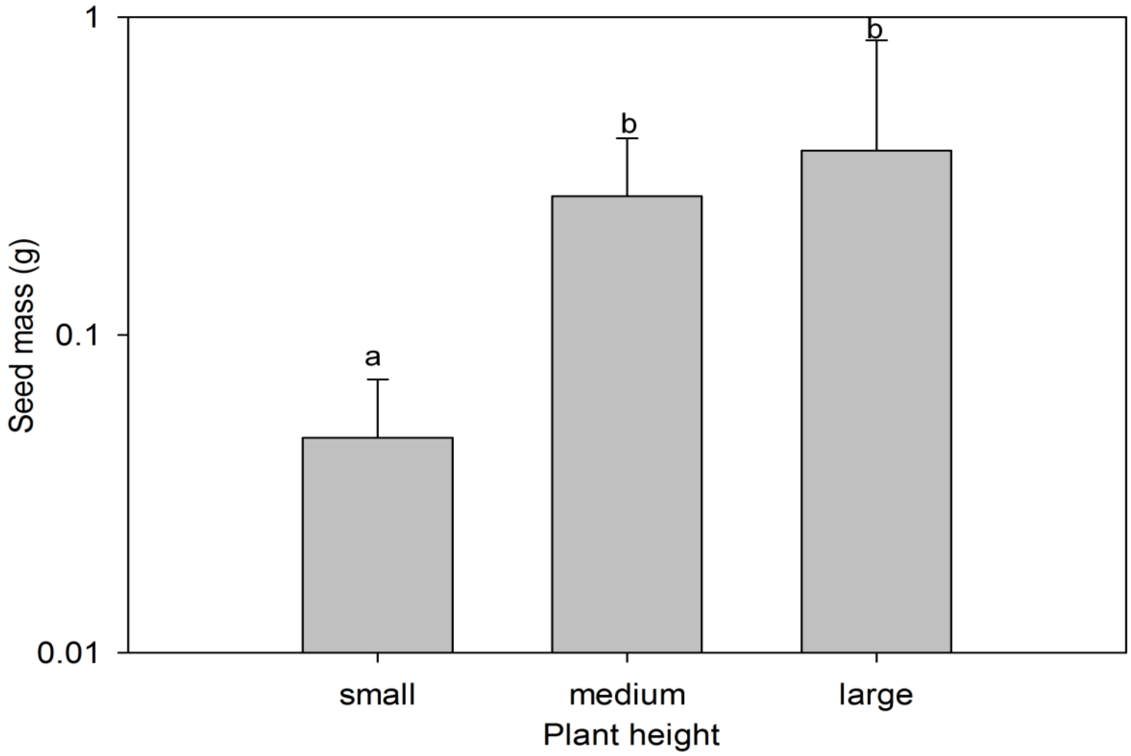

Figure 6: Average seed mass for different categories of plant height. Different letters correspond to seed mass that were significantly different from each other (p<0.05).Error bars represent + standard error. Sample size for different plant height catagories: Small – 35, Medium – 21, Large – 11.

Average seed size (ANNOVA: F(3,66)=6.7725, p=0.00047; Kruskal-Wallis test: H(3,N=70)=17.34719, p=0.0006) and average diaspore size varied significantly with plant habit (ANNOVA: F(3,67)=3.6597, p=0.01662; Kruskal-Wallis test: H(3,N=71)=5.52719, p=0.1370). Shrubs and shrub/tree had significantly lower average seed mass than trees.

Figure 7: Average seed mass for different plant habits. Different letters correspond to seed mass that were significantly different from each other (p<0.05).Error bars represent + standard error. Sample size for different plant habits: Shrub – 7, Shrub/tree – 4, Liana – 7, Tree – 52.

Average seed mass varied significantly with habitat type (ANNOVA: F(4,37)=3.8008, p=0.01096; Kruskal-Wallis test: H(4,N=42)=11.88892, p=0.0182). Average seed mass for open habitat was significantly lower than that for closed habitat.

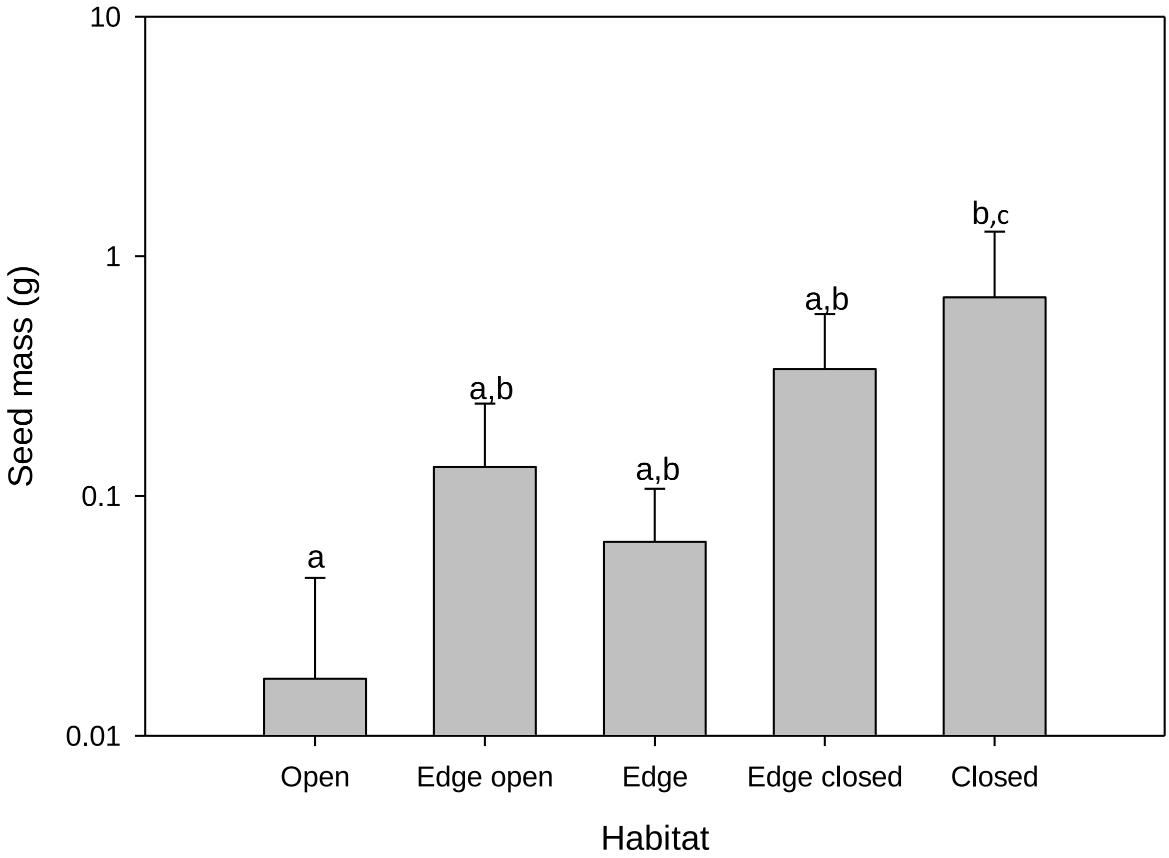

Figure 8: Average seed mass for different habitat types. Different letters correspond to seed mass that were significantly different from each other ($p<0.05$).Error bars represent + standard error. Sample size for different habitat types: Open – 10, Edge open – 9, Edge – 11, Edge closed – 5, Closed - 7.

The average seed mass of deciduous species was lower than that of evergreen species, but overall effect of leaf habit on seed size was not significant (ANNOVA: $F(1,74)=2.0112$, $p=0.16034$; Mann-Whitney U Test: $p=0.22946$).

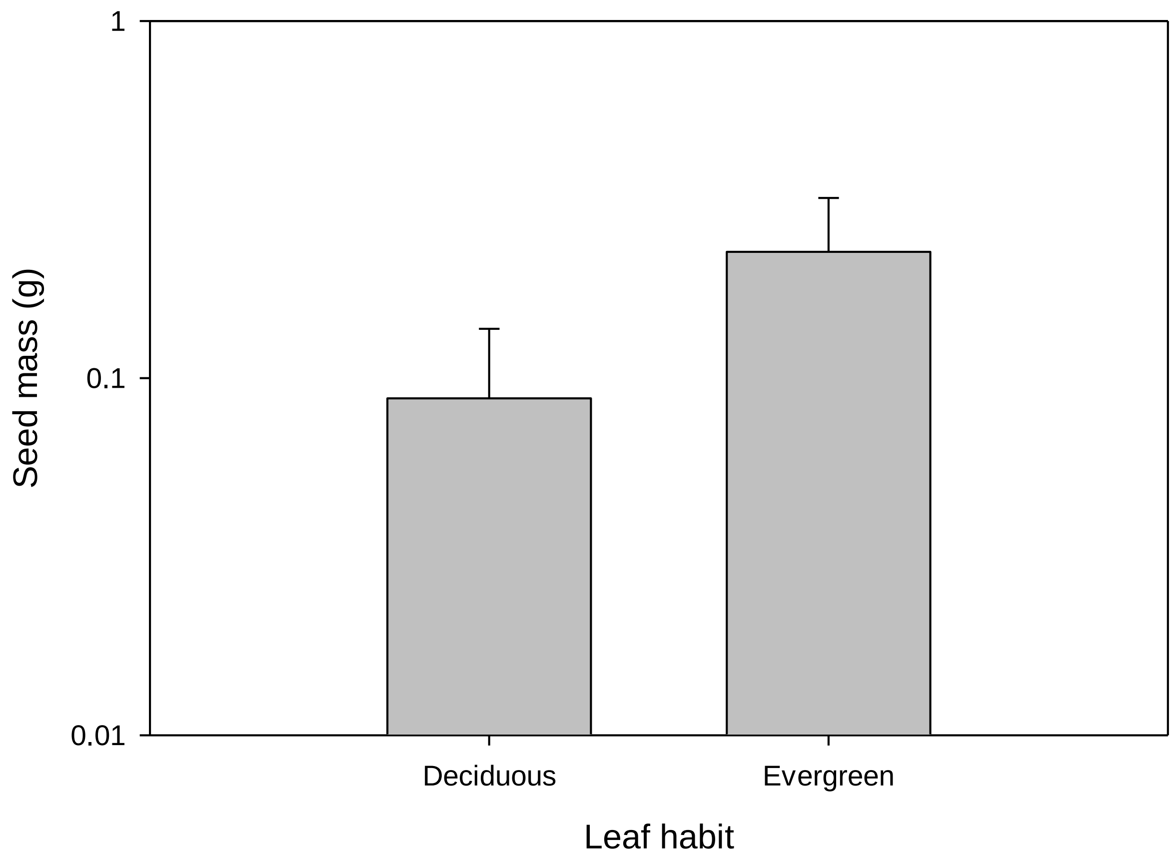

Figure 9: Average seed mass for different leaf habits. Error bars represent + standard error. Sample size for different leaf habits: Deciduous – 38, Evergreen – 39.

There was no significant correlation between seed mass and final germination percentage (Pearson r = 0.030124, n=43, p=0.848; Spearman r = 0.096047, p=0.540084), and seed mass and percent of seedlings surviving on day 28 (Pearson r = 0.241826, n=29, p=0.206; Spearman r = 0.262283, p=0.169283). However, there was a strong positive correlation between seed mass and seedling growth rate (Pearson r = 0.700850, n=27, p=0.000. Spearman r = 0.769348, p = 0.000003).

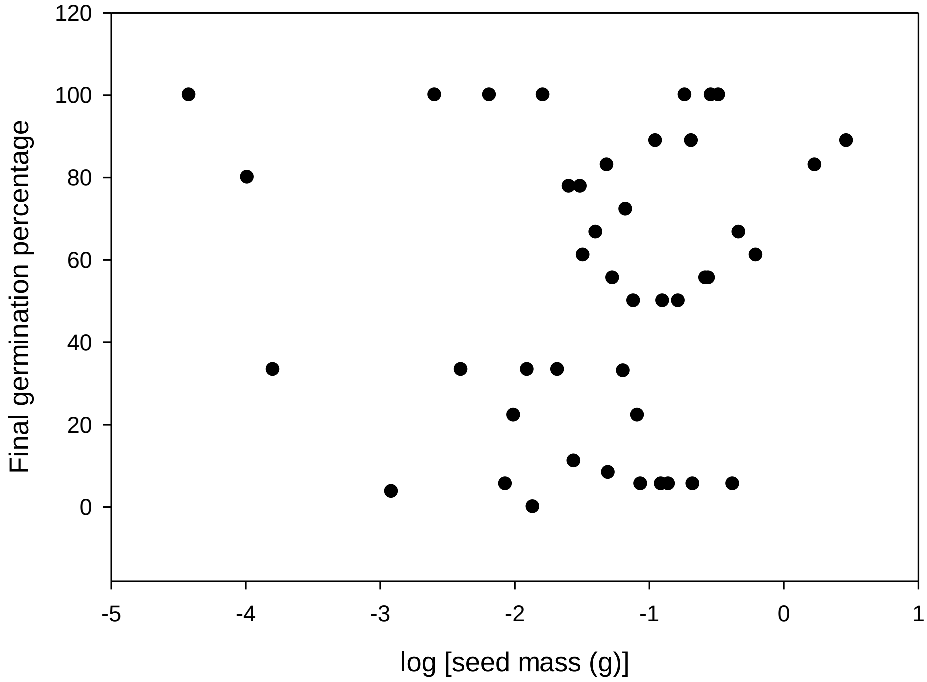

Figure 10: The variation of seed mass (log transformed) with final germination percentage. Sample size = 43.

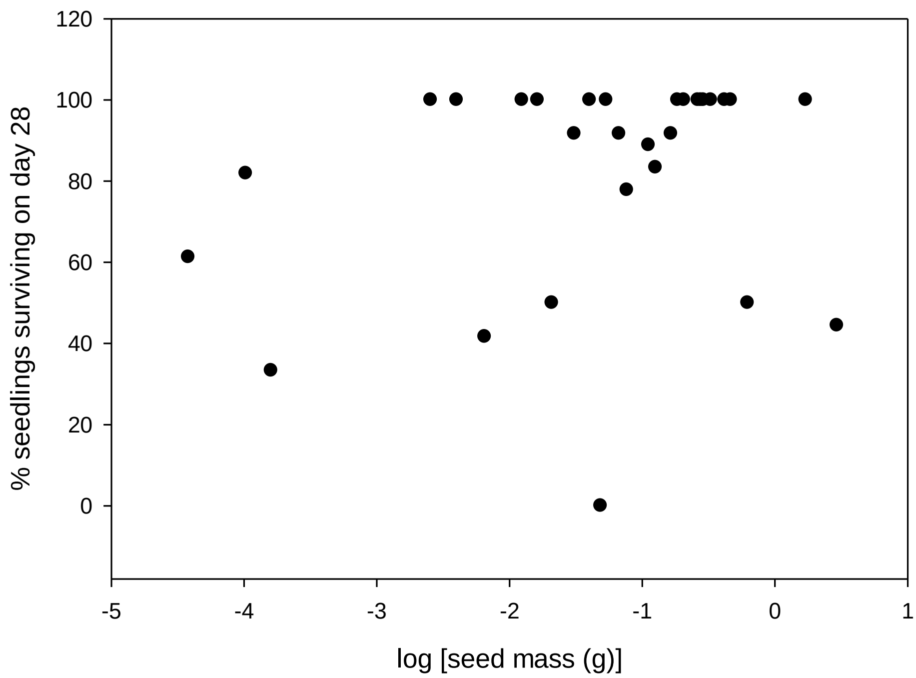

Figure 11: The variation of seed mass with percentage of seedlings surviving at day 28. Sample size = 29

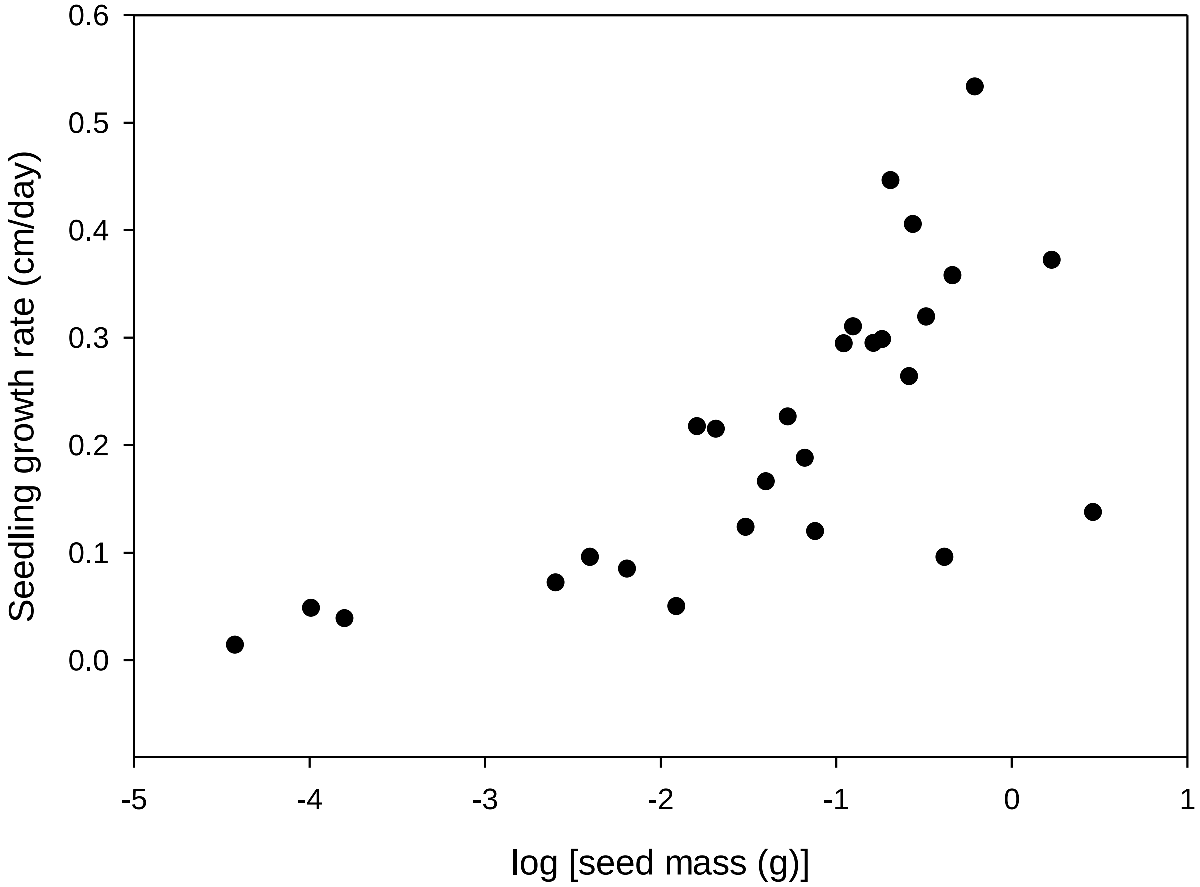

Figure 12: The variation of seed mass with seedling growth rate. Sample size = 27

Discussion

As expected, diaspore size and dispersal mode were found to be dependent on each other. Wind-dispersed and unassisted seeds are not expected to travel a long distance if they are heavy. On the other hand, zoochorus species, because of migratory nature of birds and mammals, and water dispersed species, taking advantage of water currents, can travel large distances even if they have are relatively heavier.

Dispersal by a particular type of disperser also requires its availability at the time of dispersal and modifications in dispersal unit to suit that mode. In line with these predictions, we found that dispersal mode and season of dispersal, and dispersal mode and fruit type are associated with each other. Thus, association of diaspore size with fruit type and season of dispersal might just be secondary and born out of strong association of diaspore size and dispersal mode.

One way to increase dispersal distance is by increasing height. Large plants can disperse unassisted seeds to a larger distance than small plants. So, large plants are expected to make heavier seeds, while small plants are not. Thus, seed size increases with plant height and plant habit (which is related to plant height).

The finding that seed size increases from open to closed habitats can be a result of large seeded species performing better in low light condition or shade than small seeded species. It can also be a result of different reproductive strategies adopted by plants in different stages of succession, occupying different habitats accordingly. While pioneers produce large number of small seeds and focus primarily on achieving large dispersal distance, climax species produce large seeds to have better seedling survival / establishment in the presence of competition and shade. The strong positive correlation found between seed size and seedling growth rate confirms that large seeded species are well suited in climax forests or in conditions of shade.

A relationship between leaf habit and seed size was expected considering the different strategies adopted by deciduous and evergreen species for survival, r and K strategies respectively. Though the average seed mass for deciduous species was found to be lower than that for evergreen species, overall effect of leaf habit on seed size was not significant. If the tests are repeated with increased sample size, a significant relationship between leaf habit and seed size might be observed.

Surprisingly, no correlations were found between seed size and germination percentage, and seed size and seedling survival. Possible reasons for this outcome may be late start of germination assays (approx. 6-7 months after collection), small sample size and opportunistically conducted seedling establishment/survival assay.

I did not check for effects of phylogeny on the relationships observed as each of 32 out of 39 families of species were observed to contribute only one species in our dataset. Also, I did not do any multivariate analysis, which might have uncovered interesting results. I have also not taken into account seed predation and dormancy (I tried to take care of it through various treatments in the germination assays, but they did not yield any new information).

The seed/fruit samples were collected opportunistically and were from three different regions (Bhimashankar, Pune and Pakke). Also, number of species in our dataset is much smaller compared to the number of species found in tropical forests of India. This indicates that our dataset may not be representative of the tropical forests of India. Similar studies with greater number of species belonging to these forests will be useful in this regard.

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Appendix-1: List of species whose seeds/fruits of were collected in 2013. Seeds/fruits were either collected from tree or from floor. Processing was done mainly in three ways – Soaking in water for a few hours, depulping and air-drying (SD); Depulping and air-drying (DA), dry physical extraction (PE). Since seeds of species from Pakke were obtained in processed state months after their collection, accurate information about when and how they were collected and processed is not available.

A. Bhimashankar

Family	Species	Month	No. of individuals	Tree/floor	Processing	Unit collected
Anacardiaceae	*Mangifera indica* L.	Jun	3	Floor	SD	Fruit
Apocynaceae	*Carissa carandas* L.	Jun	4	Tree	DA	Fruit
Bignoniaceae	*Heterophragma quadriloculare* (Roxb.) K.Schum.	Jun	3	Tree	PE	Fruit
Celastraceae	*Maytenus rothiana* Lobr.-Callen	Mar	3	Tree	SD	Fruit
Clusiaceae	*Garcinia talbotii* Raizada ex Santapau	Jun	1	Tree	SD	Fruit
Combretaceae	*Terminalia chebula* Retz.	Oct	6	Tree	PE	Fruit
Combretaceae	*Terminalia tomentosa* Wight & Arn.	Apr	3	Tree	none	Fruit
Ebenaceae	*Diospyros sylvatica* Roxb.	Jun	1	Floor	SD	Fruit
Elaeagnaceae	*Elaeagnus conferta* Roxb.	Mar	3	Tree	SD	Fruit
Euphorbiaceae	*Macaranga peltata* (Roxb.) Müll.Arg.	Apr	3	Tree	none	Fruit
Euphorbiaceae	*Mallotus philippensis* (Lam.) Müll.Arg.	Mar	3	Tree	none	Fruit
Euphorbiaceae	*Ricinus communis* L.	Jun	3	Tree	SD	Fruit
Gnetaceae	*Gnetum ula* Brongn.	Jun	3	Floor	SD	Fruit
Lamiaceae	*Callicarpa tomentosa* (L.) L.	Apr	3	Tree	DA	Fruit
Lamiaceae	*Colebrookea oppositifolia* Sm.	May	3	Tree	none	Fruit
Lauraceae	*Actinodaphne angustifolia* Nees	Apr	3	Tree	SD	Fruit
Lecythidaceae	*Careya arborea* Roxb.	Jun	1	Tree	SD	Fruit
Lythraceae	*Woodfordia fruticosa* (L.) Kurz	Apr	3	Tree	PE	Fruit
Melastomataceae	*Memecylon umbellatum* Burm. f.	Jun	1	Floor	PE	Fruit
Meliaceae	*Dysoxylum gotadhora* (Buch.-Ham.) Mabb.	Jun	1	Floor	SD	Fruit
Moraceae	*Ficus tsjahela* Burm. f.	Jun	1	Floor	none	Fruit
Myristicaceae	*Myristica dactyloides* Gaertn.	Jun	2	Tree	PE	Fruit
Myrtaceae	*Syzygium cumini* (L.) Skeels	Apr	1	Tree	SD	Fruit
Oleaceae	*Jasminum malabaricum* Wight	Jun	6	Tree	SD	Fruit
Oleaceae	*Olea dioica* Roxb.	Apr	3	Floor	SD	Fruit
Phyllanthaceae	*Bridelia retusa* (L.) A.Juss.	Oct	3	Tree	DA	Fruit
Phyllanthaceae	*Glochidion hohenackeri* (Müll.Arg.) Bedd.	Mar	3	Tree	none	Fruit

Rhamnaceae	*Ziziphus rugosa* Lam.	Apr	3	Tree	SD	Fruit
Rubiaceae	*Catunaregam spinosa* (Thunb.) Tirveng.		3	Tree	Unknown	Fruit
Rubiaceae	*Meyna spinosa* Roxb. ex Link	Jun	3	Tree	SD	Fruit
Rubiaceae	*Psydrax dicoccos* Gaertn.	Mar	3	Tree	SD	Fruit
Salicaceae	*Casearia tomentosa* Roxb.	Jun	Bulk	Tree	SD	Fruit
Salicaceae	*Flacourtia indica* (Burm.f.) Merr.	Jun	2	Tree	DA	Fruit
Sapindaceae	*Lepisanthes tetraphylla* Radlk.	Jun	Bulk	Floor	SD	Fruit
Smilacaceae	*Smilax ovalifolia* Roxb. ex D.Don	Jun	3	Tree	SD	Fruit
Sterculiaceae	*Sterculia guttata*	Apr	1	Tree	none	Fruit
Thymelaeaceae	*Gnidia glauca* (Fresen.) Gilg	Apr	3	Tree	none	Fruit
Vitaceae	*Leea indica* (Burm. f.) Merr.	Jun	6	Tree	SD	Fruit
	Morivel	Mar	2	Tree	none	Seed

B. Pune

Family	Species	Month	No. of individuals	Tree/floor	Processing	Unit collected
Bignoniaceae	*Spathodea campanulata* P.Beauv.	May	Bulk	Floor	none	Seed
Bignoniaceae	*Tecoma stans* (L.) Juss. ex Kunth	May	3	Tree	PE	Fruit
Combretaceae	*Terminalia catappa* L.	May	Bulk	Floor	none	Seed
Leguminosae	*Pongamia pinnata* (L.) Pierre	May	1	Floor	none	Seed
Leguminosae	*Acacia catechu* (L.f.) Willd.	Apr	3	Tree	PE	Fruit
Leguminosae	*Acacia nilotica* (L.) Delile	Apr	3	Tree	PE	Fruit
Leguminosae	*Albizia lebbeck* (L.) Benth.	Apr	3	Tree	PE	Fruit
Leguminosae	*Albizia saman* (Jacq.) Merr.	May	1	Floor	PE	Fruit
Leguminosae	*Bauhinia purpurea* L.	May	4	Floor	none	Seed
Leguminosae	*Cassia fistula* L.	May	2	Tree	PE	Fruit
Leguminosae	*Cassia grandis* L.f.	May	3	Floor	PE	Fruit
Leguminosae	*Dalbergia sissoo* DC.	Apr	3	Tree	PE	Fruit
Leguminosae	*Delonix regia* (Hook.) Raf.	May	3	Floor	PE	Fruit
Leguminosae	*Entada rheedii* Spreng.	Oct	Bulk	Floor	none	Seed
Leguminosae	*Gliricidia sepium* (Jacq.) Walp.	May	3	Floor	none	Seed
Leguminosae	*Parkia biglandulosa* Wight & Arn.	May	2	Tree	PE	Fruit
Leguminosae	*Peltophorum pterocarpum* (DC.) K.Heyne	May	2	Floor	PE	Fruit
Leguminosae	*Prosopis juliflora* (Sw.) DC.	May	3	Tree	PE	Fruit

Leguminosae	*Sesbania grandiflora* (L.) Pers.	May	1	Tree	none	Seed
Leguminosae	*Tamarindus indica* L.	Jun	3	Tree	SD	Fruit
Malvaceae	*Ceiba pentandra* (L.) Gaertn.	May	3	Tree	none	Seed
Meliaceae	*Azadirachta indica* A.Juss.	Jun	6	Tree	SD	Fruit
Myrtaceae	*Callistemon citrinus* (Curtis) Skeels	May	3	Tree	PE	Fruit
Santalaceae	*Santalum album* L.	May	3	Tree	PE	Fruit
Ulmaceae	*Holoptelea integrifolia* Planch.	May	3	Tree	PE	Fruit
	Unidentified 1	Apr	2	Floor	none	Seed
	Unidentified 2	Apr	1	Floor	none	Seed
	Unidentified 3	Oct	Bulk	Floor	none	Seed

C. Pakke

Family	Species	No. of individuals
Achariaceae	*Gynocardia odorata* R.Br.	Bulk
Anacardiaceae	*Choerospondias axillaris* (Roxb.) B.L.Burtt & A.W.Hill	Bulk
Anacardiaceae	*Spondias pinnata* (L. f.) Kurz	Bulk
Burseraceae	*Canarium resiniferum* Bruce ex King	Bulk
Elaeocarpaceae	*Elaeocarpus rugosus* Roxb. ex G.Don	Bulk
Elaeocarpaceae	*Elaeocarpus serratus* L.	Bulk
Fagaceae	*Castanopsis indica* (Roxb. ex Lindl.) A.DC.	Bulk
Lamiaceae	*Gmelina arborea* Roxb.	Bulk
Lauraceae	*Beilschmiedia assamica* Meisn.	Bulk
Lauraceae	*Beilschmiedia gammieana* King ex Hook.f.	Bulk
Magnoliaceae	*Magnolia hodgsonii* (Hook.f. & Thomson) H.Keng	Bulk
Meliaceae	*Aphanamixis polystachya* (Wall.) R.Parker	Bulk
Moraceae	*Artocarpus chama* Buch.-Ham.	Bulk
Rosaceae	*Prunus ceylanica* (Wight) Miq.	Bulk

Appendix-2: List of species whose seeds were used in germination essays. All the treatments were started in 2013.

Species	Start date (control)	Start date (warm)	Start date (cold)	Container used	No. of Replicates	Seeds per rep.
Acacia catechu (L.f.) Willd.	10-Dec	5-Dec	2-Dec	Petri-plate	3	6
Acacia nilotica (L.) Delile	10-Dec	6-Dec	2-Dec	Petri-plate	3	3
Actinodaphne angustifolia Nees	9-Dec	5-Dec	4-Dec	Petri-plate	3	6
Albizia lebbeck (L.) Benth.	9-Dec	5-Dec	3-Dec	Petri-plate	3	6
Albizia saman (Jacq.) Merr.	10-Dec	6-Dec	2-Dec	Petri-plate	1	6
Azadirachta indica A.Juss.	9-Dec	5-Dec	3-Dec	Petri-plate	6	6
Bauhinia purpurea L.	9-Dec	5-Dec	3-Dec	Petri-plate	3	6
Bridelia retusa (L.) A.Juss.	9-Dec	6-Dec	3-Dec	Petri-plate	3	6
Callicarpa tomentosa (L.) L.	10-Dec	5-Dec	3-Dec	Petri-plate	3	9
Callistemon citrinus (Curtis) Skeels	11-Dec	7-Dec	2-Dec	Petri-plate	3	9
Careya arborea Roxb.	10-Dec			Petri-plate	1	3
Carissa carandas L.	9-Dec	5-Dec	4-Dec	Petri-plate	3	6
Casearia tomentosa Roxb.	9-Dec	5-Dec	2-Dec	Petri-plate	3	3
Cassia fistula L.	11-Dec	5-Dec	2-Dec	Petri-plate	3	6
Cassia grandis L.f.	10-Dec	5-Dec	2-Dec	Petri-plate	3	6
Ceiba pentandra (L.) Gaertn.	11-Dec	6-Dec	2-Dec	Petri-plate	3	6
Colebrookea oppositifolia Sm.	11-Dec	7-Dec	4-Dec	Petri-plate	3	9
Dalbergia sissoo DC.	10-Dec	6-Dec	2-Dec	Petri-plate	3	3
Delonix regia (Hook.) Raf.	9-Dec	5-Dec	3-Dec	Petri-plate	3	6
Diospyros sylvatica Roxb.	10-Dec			Petri-plate	1	3
Dysoxylum gotadhora (Buch.-Ham.) Mabb.	10-Dec	5-Dec	2-Dec	Petri-plate	1	3
Elaeagnus conferta Roxb.	10-Dec	5-Dec	2-Dec	Petri-plate	3	3
Entada rheedii Spreng.	11-Dec	7-Dec	4-Dec	Box	Bulk	3
Ficus tsjahela Burm. f.	10-Dec	7-Dec	2-Dec	Petri-plate	1	9
Flacourtia indica (Burm.f.) Merr.	9-Dec	5-Dec	3-Dec	Petri-plate	3	6
Garcinia talbotii Raizada ex Santapau	10-Dec	7-Dec	2-Dec	Petri-plate	Bulk	3
Gliricidia sepium (Jacq.) Walp.	9-Dec	6-Dec	3-Dec	Petri-plate	3	6
Glochidion hohenackeri (Müll.Arg.) Bedd.	10-Dec			Petri-plate	3	3,3,6
Gnetum ula Brongn.	10-Dec	5-Dec	3-Dec	Petri-plate	1	3
Gnidia glauca (Fresen.) Gilg	11-Dec	6-Dec	4-Dec	Petri-plate	3	6
Heterophragma quadriloculare (Roxb.) K.Schum.	11-Dec	6-Dec	2-Dec	Petri-plate	3	4
Holoptelea integrifolia Planch.	11-Dec			Petri-plate	3	3

Jasminum malabaricum Wight	9-Dec	5-Dec	3-Dec	Petri-plate	3	6
Leea indica (Burm. f.) Merr.	9-Dec	5-Dec	3-Dec	Petri-plate	6	9
Lepisanthes tetraphylla Radlk.	10-Dec	6-Dec	3-Dec	Petri-plate	3	3
Macaranga peltata (Roxb.) Müll.Arg.	9-Dec	5-Dec	3-Dec	Petri-plate	3	6
Mallotus philippensis (Lam.) Müll.Arg.	9-Dec	5-Dec	2-Dec	Petri-plate	3	3
Mangifera indica L.	11-Dec	7-Dec	4-Dec	Box	3	3
Maytenus rothiana Lobr.-Callen	9-Dec	5-Dec	3-Dec	Petri-plate	3	6
Meyna spinosa Roxb. ex Link	9-Dec	5-Dec	3-Dec	Petri-plate	3	3
Myristica dactyloides Gaertn.	11-Dec	7-Dec	4-Dec	Box	Bulk	6
Olea dioica Roxb.	9-Dec	5-Dec	3-Dec	Petri-plate	3	6
Parkia biglandulosa Wight & Arn.	10-Dec	5-Dec	2-Dec	Petri-plate	3	6
Peltophorum pterocarpum (DC.) K.Heyne	10-Dec	6-Dec	2-Dec	Petri-plate	3	6
Pongamia pinnata (L.) Pierre	11-Dec	7-Dec	4-Dec	Box	1	6
Prosopis juliflora (Sw.) DC.	10-Dec	6-Dec	2-Dec	Petri-plate	3	6
Psydrax dicoccos Gaertn.	11-Dec	5-Dec	3-Dec	Petri-plate	3	3
Ricinus communis L.	10-Dec	5-Dec	3-Dec	Petri-plate	3	6
Santalum album L.	10-Dec	6-Dec	2-Dec	Petri-plate	3	3
Sesbania grandiflora (L.) Pers.	10-Dec	6-Dec	2-Dec	Petri-plate	1	6
Smilax ovalifolia Roxb. ex D.Don	10-Dec	5-Dec	2-Dec	Petri-plate	3	4,4,6
Spathodea campanulata P.Beauv.	11-Dec	6-Dec	3-Dec	Petri-plate	3	3
Syzygium cumini (L.) Skeels	10-Dec	6-Dec	4-Dec	Petri-plate	1	3
Tamarindus indica L.	9-Dec	5-Dec	3-Dec	Petri-plate	3	3,6,6
Tecoma stans (L.) Juss. ex Kunth	11-Dec	6-Dec	2-Dec	Petri-plate	3	6
Terminalia catappa L.	10-Dec			Petri-plate	1	3
Terminalia chebula Retz.	10-Dec	6-Dec	2-Dec	Petri-plate	6	6
Terminalia tomentosa Wight & Arn.	11-Dec	6-Dec	4-Dec	Petri-plate	3	3
Woodfordia fruticosa (L.) Kurz	10-Dec	7-Dec	2-Dec	Petri-plate	3	10
Ziziphus rugosa Lam.	9-Dec	5-Dec	4-Dec	Petri-plate	3	3
Morivel	11-Dec	7-Dec	4-Dec	Petri-plate	3	6
Unidentified 1	10-Dec	5-Dec	3-Dec	Petri-plate	3	6
Unidentified 2	10-Dec	5-Dec	3-Dec	Petri-plate	1	6
Unidentified 3	11-Dec	7-Dec	4-Dec	Box	Bulk	6

Appendix-3: List of species used in seedling establishment and survival experiments. Number of seeds per replicate differ for every replicate for most of the species as number of germinated seeds varied in each of them and/or success in transferring the seeds from plates/boxes to pots varied randomly.

Species	Treatment	Date of planting	No. of replicates	No. of seeds per replicate
Acacia catechu (L.f.) Willd.	Control	31-Dec-13	2	5,6
Albizia lebbeck (L.) Benth.	Control	31-Dec-13	3	2,2,3
Albizia saman (Jacq.) Merr.	Control	31-Dec-13	1	2
Azadirachta indica A.Juss.	Control	31-Dec-13	6	3,2,2,3,3,5
Bauhinia purpurea L.	Control	31-Dec-13	3	4,6,3
Callistemon citrinus (Curtis) Skeels	Control	31-Dec-13	3	5,7,5
Carissa carandas L.	Control	31-Dec-13	2	6,6
Cassia grandis L.f.	Control	31-Dec-13	1	2
Colebrookea oppositifolia Sm.	Control	31-Dec-13	2	3,3
Dalbergia sissoo DC.	Control	31-Dec-13	3	3,3,2
Delonix regia (Hook.) Raf.	Control	31-Dec-13	1	1
Diospyros sylvatica Roxb.	Control	31-Dec-13	1	3
Flacourtia indica (Burm.f.) Merr.	Control	31-Dec-13	2	1,1
Gliricidia sepium (Jacq.) Walp.	Control	31-Dec-13	3	6,3,4
Heterophragma quadriloculare (Roxb.) K.Schum.	Control	31-Dec-13	2	2,3
Holoptelea integrifolia Planch.	Control	31-Dec-13	1	3
Maytenus rothiana Lobr.-Callen	Control	31-Dec-13	3	4,5,3
Meyna spinosa Roxb. ex Link	Control	31-Dec-13	3	1,1,2
Morivel	Control	31-Dec-13	2	1,2
Parkia biglandulosa Wight & Arn.	Control	31-Dec-13	1	1
Peltophorum pterocarpum (DC.) K.Heyne	Control	31-Dec-13	3	3,2,3
Pongamia pinnata (L.) Pierre	Control	31-Dec-13	1	5
Sesbania grandiflora (L.) Pers.	Control	31-Dec-13	1	2
Spathodea campanulata P.Beauv.	Control	31-Dec-13	1	1
Tamarindus indica L.	Control	31-Dec-13	2	2,6
Tecoma stans (L.) Juss. ex Kunth	Control	31-Dec-13	2	6,6
Terminalia tomentosa Wight & Arn.	Control	31-Dec-13	3	3,1,2
Unidentified 1	Control	31-Dec-13	3	4,4,5
Woodfordia fruticosa (L.) Kurz	Control	31-Dec-13	3	10,11,13
Albizia lebbeck (L.) Benth.	Cold	3-Feb-13	3	1,2,1
Albizia saman (Jacq.) Merr.	Cold	3-Feb-13	1	1
Bauhinia purpurea L.	Cold	3-Feb-13	1	1
Callistemon citrinus (Curtis) Skeels	Cold	3-Feb-13	3	7,7,3
Carissa carandas L.	Cold	3-Feb-13	1	2
Cassia fistula L.	Cold	3-Feb-13	1	1
Colebrookea oppositifolia Sm.	Cold	3-Feb-13	3	7,4,1
Dalbergia sissoo DC.	Cold	3-Feb-13	1	1
Ficus tsjahela Burm. f.	Cold	3-Feb-13	1	4
Mallotus philippensis (Lam.) Müll.Arg.	Cold	3-Feb-13	1	1
Maytenus rothiana Lobr.-Callen	Cold	3-Feb-13	3	3,5,1
Meyna spinosa Roxb. ex Link	Cold	3-Feb-13	1	1

Morivel	Cold	3-Feb-13	3	4,3,3
Parkia biglandulosa Wight & Arn.	Cold	3-Feb-13	2	1,1
Peltophorum pterocarpum (DC.) K.Heyne	Cold	3-Feb-13	1	1
Prosopis juliflora (Sw.) DC.	Cold	3-Feb-13	3	1,1,3
Spathodea campanulata P.Beauv.	Cold	3-Feb-13	1	1
Tamarindus indica L.	Cold	3-Feb-13	1	4
Tecoma stans (L.) Juss. ex Kunth	Cold	3-Feb-13	3	5,4,6
Woodfordia fruticosa (L.) Kurz	Cold	3-Feb-13	1	9
Acacia catechu (L.f.) Willd.	Warm	19-Jan-14	1	2
Albizia lebbeck (L.) Benth.	Warm	19-Jan-14	3	2,2,4
Albizia saman (Jacq.) Merr.	Warm	19-Jan-14	1	1
Azadirachta indica A.Juss.	Warm	19-Jan-14	2	1,1
Bauhinia purpurea L.	Warm	19-Jan-14	2	5,4
Callistemon citrinus (Curtis) Skeels	Warm	19-Jan-14	3	9,6,3
Carissa carandas L.	Warm	19-Jan-14	2	6,5
Cassia grandis L.f.	Warm	19-Jan-14	1	1
Colebrookea oppositifolia Sm.	Warm	19-Jan-14	2	2,2
Dalbergia sissoo DC.	Warm	19-Jan-14	2	2,1
Gliricidia sepium (Jacq.) Walp.	Warm	19-Jan-14	2	3,3
Heterophragma quadriloculare (Roxb.) K.Schum.	Warm	19-Jan-14	1	3
Leea indica (Burm. f.) Merr.	Warm	19-Jan-14	1	1
Maytenus rothiana Lobr.-Callen	Warm	19-Jan-14	2	2,3
Meyna spinosa Roxb. ex Link	Warm	19-Jan-14	2	1,2
Morivel	Warm	19-Jan-14	1	5
Parkia biglandulosa Wight & Arn.	Warm	19-Jan-14	2	1,3
Peltophorum pterocarpum (DC.) K.Heyne	Warm	19-Jan-14	3	3,4,4
Pongamia pinnata (L.) Pierre	Warm	19-Jan-14	1	2
Prosopis juliflora (Sw.) DC.	Warm	19-Jan-14	2	1,1
Spathodea campanulata P.Beauv.	Warm	19-Jan-14	2	1,1
Tamarindus indica L.	Warm	19-Jan-14	2	3,2
Tecoma stans (L.) Juss. ex Kunth	Warm	19-Jan-14	3	3,4,6
Terminalia tomentosa Wight & Arn.	Warm	19-Jan-14	3	1,2,1
Woodfordia fruticosa (L.) Kurz	Warm	19-Jan-14	3	7,9,8

Appendix-4: Data on fruit type, dispersal unit, dispersal mode, time of dispersal, fruit maturation time and number of seeds per fruit collected from various secondary sources and seed/fruit mass measured in laboratory. A: Autochorus, Z: Zoochorus, WD: Wind, WR: Water. Numbers in parentheses represent respective sources of information, which are provided at the end of Appendix-5.

Species	Fruit type	Dispersal Unit	Dispersal mode	Time of dispersal (16)	Fruit maturation time (days) (16)	Seed mass (g)	Fruit mass (g)	No. of seeds per fruit
Acacia catechu (L.f.) Willd.	Pod (4)	Fruit	A (22)	Apr	240	0.05352	0.5572	2-8
Acacia nilotica (L.) Delile	Pod (3)	Fruit	Z (11)	Apr	240	0.10240	4.6948	9-15
Actinodaphne angustifolia Nees	Berry (4)	Fruit	Z (22)	Jun	120	0.23176	0.3664	1
Albizia lebbeck (L.) Benth.	Pod (3)	Fruit	WD (22)	May	150	0.20632		5-10
Albizia saman (Jacq.) Merr.	Pod (13)	Fruit	Z (13)	May		0.18478	18.2633	13-17
Aphanamixis polystachya (Wall.) R.Parker	Capsule (1)		Z (1)			0.82044		2-3
Artocarpus chama Buch.-Ham.	Syncarp (1)	Seed	Z (1)	Jul	60	0.51000		1
Azadirachta indica A.Juss.	Drupe (4)	Fruit	Z (17)	Jun	90	0.16477	1.3176	1
Bauhinia purpurea L.	Pod (4)	Seed	A	Apr	120	0.32926		3-10
Beilschmiedia assamica Meisn.	Drupe (1)		Z (1)			3.58250		
Beilschmiedia gammieana King ex Hook.f.	Drupe (1)		Z (1)			1.46833		
Bridelia retusa (L.) A.Juss.	Drupe (10)	Fruit	Z (22)	Sep	120	0.08593	0.8293	2
Callicarpa tomentosa (L.) L.	Drupe (22)	Fruit	Z (22)	Jul	120	0.00122	0.0748	3-4
Callistemon citrinus (Curtis) Skeels	Capsule (4)	Seed	Z (6)	May		0.00010		
Canarium resiniferum Bruce ex King	Drupe (1)		Z (1)			4.49833		
Careya arborea Roxb.	Berry (10)	Fruit	Z (22)	Jun	90	0.46000	59.8161	2
Carissa carandas L.	Berry (15)	Fruit	Z (15)	May	105	0.04021	2.1150	2-4
Casearia tomentosa Roxb.	Capsule (10)	Seed	Z (22)	Aug	135	0.01368	2.6852	12-18
Cassia fistula L.	Pod (22)	Fruit	Z (22)	May	270	0.21183	81.9333	28-73
Cassia grandis L.f.	Pod (4)	Fruit	Z (20)	May		0.46444	103.1922	23-38
Castanopsis indica (Roxb. ex Lindl.) A.DC.	Acorn (1)		A (1)			1.17667		3-4
Catunaregam spinosa (Thunb.) Tirveng.	Berry (16)	Fruit	Z (16)	Apr	300	0.02128		70-150
Ceiba pentandra (L.) Gaertn.	Capsule (3)	Seed	WD (22)	Apr	150	0.09472		
Choerospondias axillaris (Roxb.) B.L.Burtt & A.W.Hill	Drupe (1)		Z (1)			1.75800		5
Colebrookea oppositifolia Sm.	Nutlet (5)	Seed	A (22)	Mar	60	0.00016		

Dalbergia sissoo DC.	Pod (4)	Fruit	WD (22)	May	240	0.01629		1
Delonix regia (Hook.) Raf.	Pod (4)	Fruit	A+WR	May		0.41878	87.8556	28-48
Diospyros sylvatica Roxb.	Berry (9)	Fruit	Z (22)	Jun		0.28878		2-8
Dysoxylum gotadhora (Buch.-Ham.) Mabb.	Capsule (9)	Fruit	Z (21)	Jun		2.54500		4
Elaeagnus conferta Roxb.	Drupe (6)	Fruit	Z (22)	Mar	30	0.13021	1.0048	1
Elaeocarpus rugosus Roxb. ex G.Don	Drupe (1)	Fruit	Z (1)	Sep	60	1.06167		
Elaeocarpus serratus L.	Drupe (4)	Fruit	Z (1)	Oct	60	2.63400		
Entada rheedii Spreng.	Pod (4)	Seed	WR			17.54833	310.8000	10
Ficus tsjahela Burm. f.	Syconium (9)	Sycon.	Z (22)	Apr			0.0003	
Flacourtia indica (Burm.f.) Merr.	berry (1)	Fruit	Z (1)	Aug	75	0.02088	1.0859	4-6
Garcinia talbotii Raizada ex Santapau	Berry (9)	Fruit	Z (22)	Jun		1.60000	26.5648	2
Gliricidia sepium (Jacq.) Walp.	Pod (4)	Seed	A	May		0.11172	4.2222	4-10
Glochidion hohenackeri (Müll.Arg.) Bedd.	Capsule (4)	Seed	A	Mar	135	0.00985	0.0734	
Gmelina arborea Roxb.	Drupe (3)		Z (1)		90	0.64167		2-4
Gnetum ula Brongn.	Drupe (15)	Fruit	Z (15)	Jun		0.25146	3.4786	1
Gnidia glauca (Fresen.) Gilg	Berry (7)	Seed	WD	May	90	0.00856		1
Gynocardia odorata R.Br.	Berry (1)	Fruit	Z (1)			1.39167		
Heterophragma quadriloculare (Roxb.) K.Schum.	Capsule (3)	Seed	WD (22)	Apr	30	0.12617	29.5944	60-120
Holoptelea integrifolia Planch.	Samara (7)	Fruit	WD (7)	May	90	0.01243	0.0328	1
Jasminum malabaricum Wight	Berry (15)	Fruit	Z (15)	Jul	60	0.30768	0.6519	1
Leea indica (Burm. f.) Merr.	Berry (4)	Fruit	Z (22)	Oct	135	0.02538	0.9742	4-8
Lepisanthes tetraphylla Radlk.	drupe (9)	Fruit	Z (22)	May	30	0.28667	6.4368	2-3
Macaranga peltata (Roxb.) Müll.Arg.	capsule (9)	Fruit	Z (22)	May	105	0.08672	0.1943	1
Magnolia hodgsonii (Hook.f. & Thomson) H.Keng	Aggregate follicle (1)		Z (1)			0.31667		
Mallotus philippensis (Lam.) Müll.Arg.	capsule (4)	Fruit	Z+ A (1)	Mar	90	0.02761	0.4217	3
Mangifera indica L.	Drupe (4)	Fruit	Z (22)	Jun	30	8.13389	49.5790	1
Maytenus rothiana Lobr.-Callen	Capsule (22)	Seed	Z (22)	Mar	150	0.06701	1.1852	4-6
Memecylon umbellatum Burm. f.	Berry (3)	Fruit	Z (22)	May	60	0.14717	0.5876	1
Meyna spinosa Roxb. ex Link	Drupe (26)	Fruit	Z	Aug	60	0.26284	30.5019	4-6
Myristica dactyloides Gaertn.	capsule (9)	Seed	Z (22)	Jun		3.69250	43.1076	1
Olea dioica Roxb.	Drupe (4)	Fruit	Z (22)	May	90	0.13953		1

Parkia biglandulosa Wight & Arn.	Pod (4)	Fruit	Z (12)	May		0.27638	6.8200	4-13
Peltophorum pterocarpum (DC.) K.Heyne	Pod (4)	Fruit	WD (6)	May		0.07667	1.3933	1-2
Pongamia pinnata (L.) Pierre	Pod (22)	Fruit	Z (22)	May	90	1.70667	2.6260	1
Prosopis juliflora (Sw.) DC.	Pod (4)	Seed	Z (25)	May	150	0.03231	5.7956	10-30
Prunus ceylanica (Wight) Miq.	Drupe (1)		Z (22)			0.38833		2
Psydrax dicoccos Gaertn.	Drupe (7)	Fruit	Z (22)	Apr	75	0.07815	0.2877	
Ricinus communis L.	capsule (4)	Fruit	Z	May	105	0.12311	1.9903	3
Santalum album L.	Drupe (3)	Fruit	Z (7)	May	210	0.18834	0.6376	1
Sesbania grandiflora (L.) Pers.	Pod (4)	Fruit		May		0.04862	2.0375	13-28
Smilax ovalifolia Roxb. ex D.Don	Berry (4)	Fruit	Z (15)	Jul	180	0.04976	0.7720	3
Spathodea campanulata P.Beauv.	Pod (4)	Seed	WD (24)	May		0.00400		500
Spondias pinnata (L. f.) Kurz	Drupe (3)	Fruit	Z (1)			7.21200		1-3
Sterculia guttata	Follicle (4)	Seed	A (16)	Apr	270	0.84360	24.9009	11-15
Syzygium cumini (L.) Skeels	Berry (22)	Fruit	Z (22)	May	60	0.29667		1
Tamarindus indica L.	Pod (4)	Seed	Z (23)	Jun	270	0.62323	13.5424	4-9
Tecoma stans (L.) Juss. ex Kunth	Capsule (4)	Seed	WD (7)	May		0.00651		
Terminalia catappa L.	Drupe (6)	Fruit	Z (6)	Mar	60	1.02111		1
Terminalia chebula Retz.	Drupe (4)	Fruit	Z (22)	Oct	195	0.42000	4.8960	1
Terminalia tomentosa Wight & Arn.	Drupe (4)	Fruit	WD (7)	Mar	240		2.9400	1
Woodfordia fruticosa (L.) Kurz	capsule (3)	Fruit	A (22)	May	45	0.00004		
Ziziphus rugosa Lam.	drupe (4)	Fruit	Z (15)	Apr	30	0.08211	0.3419	1

Appendix-5: Data on plant height, plant habit, leaf habit and habitat type collected from various secondary sources. Numbers in parentheses represent respective sources of information, which are provided at the end of the table.

Species	Height (m)	Habit	Leaf habit	Habitat type (16)
Acacia catechu (L.f.) Willd.	5 to 10 (4)	Tree	Deciduous (4)	
Acacia nilotica (L.) Delile	3 to 5 (3)	Tree	Evergreen (6)	
Actinodaphne angustifolia Nees	3 to 5 (4)	Tree	Evergreen (4)	Edge
Albizia lebbeck (L.) Benth.	5 to 10 (3)	Tree	Deciduous (3)	
Albizia saman (Jacq.) Merr.	25	Tree	Deciduous (13)	
Aphanamixis polystachya (Wall.) R.Parker	20	Tree	Evergreen (2)	

Artocarpus chama Buch.-Ham.			Deciduous (18)	
Azadirachta indica A.Juss.	10 to 15 (4)		Deciduous (4)	
Bauhinia purpurea L.	10 to 16 (4)		Deciduous (4)	
Beilschmiedia assamica Meisn.			Evergreen (6)	
Beilschmiedia gammieana King ex Hook.f.			Evergreen (6)	
Bridelia retusa (L.) A.Juss.	5 to 8 (4)	Tree	Deciduous (22)	Edge
Callicarpa tomentosa (L.) L.	3 to 5 (3)	Tree	Evergreen (22)	Edge
Callistemon citrinus (Curtis) Skeels	5 to 10 (4)	Tree	Evergreen (4)	
Canarium resiniferum Bruce ex King			Evergreen (19)	
Careya arborea Roxb.	10 to 15 (3)	Tree	Deciduous (4)	Edge open
Carissa carandas L.		Shrub	Evergreen (16)	Open
Casearia tomentosa Roxb.		Shrub	Deciduous (16)	Edge
Cassia fistula L.	5 to 8 (3)	Tree	Deciduous (22)	
Cassia grandis L.f.	10 to 15 (4)	Tree	Deciduous (4)	
Castanopsis indica (Roxb. ex Lindl.) A.DC.	20	Tree	Evergreen (14)	
Catunaregam spinosa (Thunb.) Tirveng.	3 to 5 (3)	Tree	Deciduous (16)	Edge open
Ceiba pentandra (L.) Gaertn.	10 to 25 (3)	Tree	Deciduous (22)	
Choerospondias axillaris (Roxb.) B.L.Burtt & A.W.Hill	30	Tree	Deciduous (14)	
Colebrookea oppositifolia Sm.	1 to 3 (3)	Shrub	Deciduous (4)	Open
Dalbergia sissoo DC.	10 to 20 (4)	Tree	Deciduous (4)	
Delonix regia (Hook.) Raf.	15 to 20 (4)	Tree	Deciduous (4)	
Diospyros sylvatica Roxb.	35	Tree	Evergreen (22)	Closed
Dysoxylum gotadhora (Buch.-Ham.) Mabb.	30	Tree	Evergreen (22)	Edge closed
Elaeagnus conferta Roxb.	2 to 5 (4)	Liana	Evergreen (22)	Edge open
Elaeocarpus rugosus Roxb. ex G.Don		Tree	Evergreen (8)	
Elaeocarpus serratus L.	5 to 8 (4)	Tree	Evergreen (4)	
Entada rheedii Spreng.		Liana		
Ficus tsjahela Burm. f.	25	Tree	Deciduous (22)	Edge open
Flacourtia indica (Burm.f.) Merr.	3 to 5	Shrub/Tree	Deciduous (16)	Edge open
Garcinia talbotii Raizada ex Santapau	5 to 8 (4)	Tree	Evergreen (4)	Closed
Gliricidia sepium (Jacq.) Walp.	15 to 20 (4)	Tree	Deciduous (4)	

Glochidion hohenackeri (Müll.Arg.) Bedd.	3 to 5 (4)	Shrub/Tree	Evergreen (4)	Edge open
Gmelina arborea Roxb.	10 to 20 (3)	Tree	Deciduous (3)	
Gnetum ula Brongn.		Liana	Evergreen (1)	Closed
Gnidia glauca (Fresen.) Gilg	2 to 3 (3)	Shrub/Tree	Deciduous (16)	Open
Gynocardia odorata R.Br.	30	Tree	Evergreen (14)	
Heterophragma quadriloculare (Roxb.) K.Schum.	5 to 15 (3)	Tree	Deciduous (3)	Edge
Holoptelea integrifolia Planch.	10 to 20 (4)	Tree	Deciduous (4)	
Jasminum malabaricum Wight	3 to 5 (3)	Liana	Evergreen (16)	Open
Leea indica (Burm. f.) Merr.	1 to 3 (4)	Shrub	Evergreen (22)	Open
Lepisanthes tetraphylla Radlk.	5 to 8 (4)	Tree	Evergreen (4)	Edge closed
Macaranga peltata (Roxb.) Müll.Arg.	12	Tree	Evergreen (22)	Edge
Magnolia hodgsonii (Hook.f. & Thomson) H.Keng	15	Tree	Evergreen (6)	
Mallotus philippensis (Lam.) Müll.Arg.	3 to 5 (4)	Tree	Evergreen (4)	Edge
Mangifera indica L.	10 to 20 (4)	Tree	Evergreen (4)	Closed
Maytenus rothiana Lobr.-Callen	2 to 3 (4)	Shrub	Evergreen (22)	Open
Memecylon umbellatum Burm. f.	3 to 5 (3)	Tree	Evergreen (3)	Everywhere
Meyna spinosa Roxb. ex Link	2 to 3 (4)	Tree	Deciduous (16)	Edge open
Myristica dactyloides Gaertn.	10 to 20 (4)	Tree	Evergreen (4)	Closed
Olea dioica Roxb.	3 to 5 (4)	Tree	Evergreen (4)	Edge closed
Parkia biglandulosa Wight & Arn.	15 to 20 (4)	Tree	Deciduous (4)	
Peltophorum pterocarpum (DC.) K.Heyne	15 to 20 (4)	Tree	Evergreen (4)	
Pongamia pinnata (L.) Pierre	10 to 20 (3)	Tree	Deciduous (22)	
Prosopis juliflora (Sw.) DC.	5 to 10 (4)	Tree	Evergreen (4)	
Prunus ceylanica (Wight) Miq.		Tree	Evergreen (22)	
Psydrax dicoccos Gaertn.	3 to 5 (3)	Tree	Evergreen (22)	Edge
Ricinus communis L.	3 to 5 (4)	Shrub	Evergreen (16)	Closed
Santalum album L.	3 to 5 (3)	Tree	Evergreen (3)	
Sesbania grandiflora (L.) Pers.	5 to 10 (4)	Tree	Evergreen (4)	
Smilax ovalifolia Roxb. ex D.Don	2 to 5 (3)	Liana	Deciduous (16)	Open
Spathodea campanulata P.Beauv.	10 to 15 (4)	Tree	Deciduous (4)	
Spondias pinnata (L. f.) Kurz	10 to 12 (3)	Tree	Deciduous (3)	

Sterculia guttata	5 to 10 (4)	Tree	Deciduous (16)	Edge
Syzygium cumini (L.) Skeels	10 to 20 (4)	Tree	Evergreen (4)	Edge closed+open
Tamarindus indica L.	10 to 15 (4)	Tree	Deciduous (4)	
Tecoma stans (L.) Juss. ex Kunth	2 to 3 (4)	Shrub/tree	Deciduous (4)	
Terminalia catappa L.	25	Tree	Deciduous (6)	
Terminalia chebula Retz.	5 to 10 (4)	Tree	Deciduous (16)	Edge open
Terminalia tomentosa Wight & Arn.	10 to 25 (4)	Tree	Deciduous (4)	Edge open
Woodfordia fruticosa (L.) Kurz	2 to 3 (3)	Shrub	Deciduous (22)	Open
Ziziphus rugosa Lam.	6 to 9 (4)	Liana	Deciduous (22)	Edge

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Appendix-6: Result of Shapiro-Wilk test of normality performed on seed/fruit traits before and after log transformation, and germination data and seedling survival/growth data. A data set with a p-value < 0.05 rejects the null hypothesis that the data are from a normally distributed population.

Traits	Shapiro-Wilk W	P-value	Normality
Seed mass	0.93583	0.00090	not normal
log seed mass	0.93583	0.00090	not normal
Seed width	0.88127	0	not normal
log seed width	0.96806	0.05785	normal
Seed breadth	0.82924	0	not normal
log seed breadth	0.98187	0.36791	normal
Seed length	0.82115	0	not normal
log seed length	0.99004	0.83362	normal
Fruit mass	0.43176	0	not normal
log fruit mass	0.94681	0.03251	not normal
Fruit length	0.70187	0	not normal
log fruit length	0.93211	0.02604	not normal
Fruit breadth	0.48715	0	not normal
log fruit breadth	0.95184	0.11063	normal
Fruit width	0.39030	0	not normal
log fruit width	0.93737	0.05149	normal
Germination percent	0.90575	0.00188	not normal
Seedling growth rate	0.95616	0.30119	normal
Percentage of seedlings surviving	0.71925	0	not normal