CHAPTER 4

Results

4.1 Seed Biology

4.1.1 Seed Germination and Median Length of Dormancy

Percent germination in the nursery was calculated from three replicates of 50 seeds of 17 native tree species. The mean (± SE) percentage across all species was 44.7 ± 3.6 %, ranging from 6 to 92 %. *Gmelina arborea* (6.0 ± 1.2 %) germinated the least, whereas *Artocarpus lacucha* (92.0 ± 2.0 %) germinated the most (Table 4.1). Species could be divided into 3 groups, according their germination: 1) low germination (<30 %): *Dimocarpus longan*, *Diospyros glandulosa*, *Gmelina arborea* and *Spondias pinnata*, 2) intermediate germination (30-60%): *Acrocarpus fraxinifolius*, *Alangium kurzii*, *Choerospondias axillaris*, *Hovenia dulcis*, *Manglietia garrettii*, *Melia azedarach*, *Phyllanthus emblica* and *Syzygium albiflorum* and 3) high germination (>60 %): *Adenanthera microsperma*, *Artocarpus lacucha*, *Bauhinia variegata*, *Horsfieldia glabra* and *Prunus cerasoides*.

The selected native tree species showed various lengths of dormancy. The average dormancy across species was 69.4 ± 8.2 days, ranging from 8 to 244 days (depending on species). *C. axillaris* exhibited the longest dormancy (244.5 ± 14.1 days), whilst *B. variegata* had the shortest (8.0 ± 0.1 days). The species tested could be divided into 3 groups, based on median length of dormancy (MLD): 1) a short-dormancy group (MLD <30 days): *A. microsperma*, *A. lacucha, Bauhinia variegata*, *D. longan, G. arborea* and *S. pinnata*; 2) an intermediate-dormancy group (MLD 30-100 days): *A. kurzii*, *C. tribuloides, H. glabra*, *H. dulcis, M. azedarach, P. cerasoides* and *S. albiflorum* and 3) a prolonged-dormancy group (MLD >100 days): *A. fraxinifolius*, *C. axillaris*, *D. glandulosa* and *P. emblica*.

Table 4.1 Percent seed germination, median length of dormancy (MLD), initial seed moisture content (MC) and seed mass of 17 native tree species in a nursery in northern Thailand. Germination and MLD calculated from nursery experiments with 3 replicates of 50 seeds each. Seed MC calculated from three replicates of 15 dried seeds. Dry seed mass averaged from 20 dried seeds.

Species	Sowing date	Germination (%)		MLD (days)		Seed MC (%)		Dry seed mass (g)	
		Mean	SE	Mean	SE	Mean	SE	Mean	SE
Acrocarpus fraxinifolius	11/04/15	43.3	8.7	118.3	6.7	10.3	0.1	0.034	0.001
Adenanthera microsperma	26/02/15	68.7	4.4	23.3	2.0	7.1	0.2	0.102	0.003
Alangium kurzii	14/07/15	52.0	6.1	53.0	0.0	16.1	0.2	0.148	0.016
Artocarpus lacucha	04/06/15	92.0	2.0	24.8	5.3	46.4	1.2	0.353	0.017
Bauhinia variegata	22/05/15	85.3	3.7	7.8	0.1	10.7	0.1	0.275	0.012
Choerospondias axillaris	14/07/15	46.7	6.8	244.3	8.1	20.6	1.0	1.700	0.080
Dimocarpus longan	02/10/14	8.7	0.7	17.0	2.3	43.4	1.3	0.378	0.026
Diospyros glandulosa	18/11/14	8.7	3.5	128.3	1.8	44.2	0.3	0.149	0.005
Gmelina arborea	26/05/15	6.0	1.2	23.3	2.0	13.3	0.1	0.432	0.032
Horsfieldia glabra	20/05/15	63.3	3.7	35.0	0.4	18.0	1.0	3.800	0.124
Hovenia dulcis	26/02/15	34.7	7.9	73.0	2.9	7.9	0.2	0.023	0.001
Manglietia garrettii	23/10/14	49.3	5.3	106.7	6.3	15.2	0.6	0.052	0.001
Melia azedarach	05/01/15	31.3	3.5	79.2	2.3	10.6	0.2	0.048	0.001
Phyllanthus emblica	05/01/15	38.7	5.9	107.0	5.5	10.8	0.1	0.024	0.001
Prunus cerasoides	11/04/15	64.0	1.2	46.3	21.4	19.5	0.3	0.229	0.007
Spondias pinnata	30/03/15	18.0	5.0	26.4	3.0	8.4	0.1	6.370	0.362
Syzygium albiflorum	04/06/15	49.3	2.7	66.3	2.4	35.7	0.8	1.636	0.060

A. fraxinifolius and *A. microsperma* seeds were subjected to an additional experiment to trial the effects of seed scarification; a treatment known to shorten MLD. Seed scarification had no significant effect on percent seed germination in *A. microsperma* (control seeds 68.7 ± 4.4 %, scarified seeds 59.3 ± 1.8 %, *t*-test, p=0.12), but it did significantly reduce MLD by 14 days on average, from 23.3 ± 2.0 days (control) to 9.0 ± 1.0 days (*t*-test, p< 0.01). For *A. fraxinifolius* seeds, the treatment both significantly increased germination and shortened dormancy. Percent germination increased by 45 % from 43.3 ± 8.7 % for control seeds to 88.9 ± 2.9 % for scarified seeds *t*-test, p<0.01). MLD was shortened by 99 days, on average, from 118.3 ± 6.7 days for the control seeds to only 9.0 ± 0.0 days for scarified seeds (*t*-test, p< 0.01).

It appeared that species that germinated rapidly also tended to have higher germination percentages, but regression analysis showed that the correlation was neither strong nor significant (r=0.43, p=0.08, N=17, Figure 4.1).

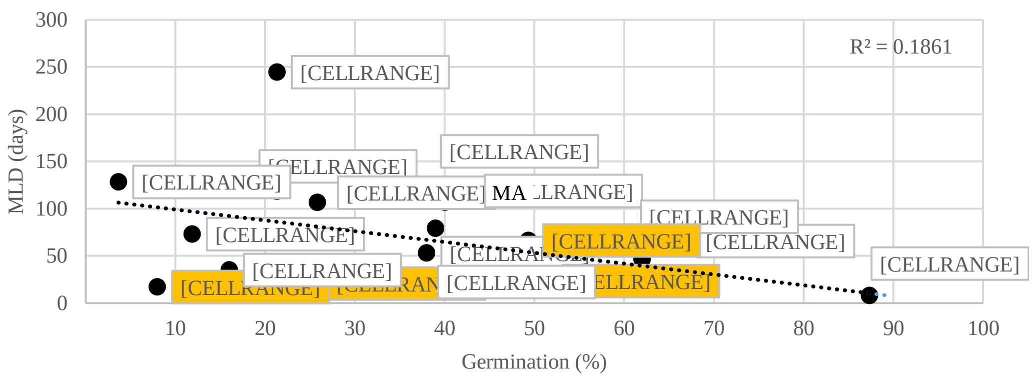


Figure 4.1 Relation of mean percent germination and median length of dormancy (MLD) of 17 tree species in the nursery condition. Plotted by species (N=17). Dotted line is a trend of relation. Orange boxes indicate recalcitrant species and white boxes are orthodox; AF=*A. fraxinifolius*, AM=*A. microsperma*, AK=*A. kurzii*, AL=*A. lacucha*, BV=*B. variegata*, CA=*C. axillaris*, DL=*D. longan*, DG=*D. glandulosa*, GA=*G. arborea*, HG=*H. glabra*, HD=*H. dulcis*, MG=*M. garrettii*, MA= *M. azedarach*, PE=*P. emblica*, PC=*P. cerasoides*, SP=*S. pinnata*, SA=*S. albiflorum.*

Species were grouped according to germination performance and length of dormancy (Table 4.2). *D. longan*, *G. arborea* and *S. pinnata* formed a low-germination/short-dormancy group, whereas *A. microsperma, A. lacucha* and *B. variegata* formed a high-germination/short-dormancy group. Four species, *A. kurzii, H. dulcis, M. azedarach* and *S. albiflorum* formed an intermediate-germination/intermediate-dormancy group, whilst *H. glabra* and *P. cerasoides* formed a high-germination/intermediate-dormancy group. *A. fraxinifolius, C. axillaris, M. garrettii* and *P. emblica* formed an intermediate-germination/prolonged-dormancy group. Only a single species, *D. glandulosa*, had both low-germination and prolonged dormancy.

Table 4.2 Categories of percent germination and median length of dormancy (MLD) of 17 tree species in the nursery condition.

MLD [a] (days)	Germination percent [b]		
	Low	Intermediate	High
Short	*D. longan* *G. arborea* *S. pinnata*		*A. microsperma,* *A. lacucha* *B. variegata*
Intermediate		*A. kurzii* *H. dulcis* *M. azedarach* *S. albiflorum*	*H. glabra* *P. cerasoides*
Prolonged	*D. glandulosa*	*A. fraxinifolius* *C. axillaris* *M. garrettii* *P. emblica*	

[a] Short-dormancy (MLD < 30 days); intermediate (MLD 30-100 days); prolonged (MLD > 100 days)

[b] Low-germination (< 30 %); intermediate (30-60 %); high (> 60%)

4.1.2 Seed Mass and Seed Moisture Content

Propagules, dispersed by forest trees (or "dispersal units"), are not always just seeds. Sometimes, they include the inner fruit wall (endocarp) surrounding one or several seeds. These structures are termed "pyrenes". In this study, I include pyrenes along with seeds (as they are both units of dispersal). Four of the study species were dispersed as pyrenes. *P. cerasoides* produces single seeded pyrenes ("cherry stones"), *G. arborea* produces 1-4 seeded pyrenes, whilst, *C. axillaris* and *S. pinnata* produce pyrenes, containing up to a maximum of 5 seeds.

S. pinnata produced the heaviest seeds (mean dry mass 6.370 ± 0.362 g), whilst *H. dulcis* produced the lightest (0.023 ± 0.001 g, Table 4.1). The seeds of 5 species were categorized as small (0.01-0.099 g) (following the protocol of Doust, *et al*. (2006)): *A. fraxinifolius*, *H. dulcis*, *M. garrettii*, *M. azedarach* and *P. emblica.* The majority of the studied species (12 of 17) had seeds of intermediate size (0.1-4.99 g): *A. microsperma, A. kurzii*, *A. lacucha*, *B. variegata*, *C. tribuloides*, *C. axillaris*, *D. longan*, *D. glandulosa*, *G. arborea*, *H. glabra*, *H. dulcis*, *P. cerasoides and S. albiflorum* and only one species, *S. pinnata,* had large seeds (>5.0 g).

Seed moisture content (MC) varied from 7 % to 46.6 % MC (Table 4.1). The seeds of 3 of the studied species had very low MC: *A. microsperma* (7.1 ± 0.2 %,), *H. dulcis* (7.9 ± 0.2 %) and *S. pinnata* (8.4 ± 0.1 %). In contrast, *A. lacucha* (46.4 ± 1.2 %) contained the highest moisture content.

4.2 Seed Storage

Tests of seed storage properties were carried out on 17 native tree species. Species were then classified by storage behaviour, following Hong and Ellis (1996). Seeds of the studied species were sown at the initial moisture content, immediately after collection, then dried to 10 % and 5% MC and stored at 5% MC at -20 °C. The percent germination and dormancy were compared among moisture content levels. *S. pinnata* was excluded from the storage behaviour classification due to the difficulty of reducing the moisture content of its pyrenes - the largest of the diaspores in this study, as previously mentioned, but was included in tests of storage conditions without seed moisture content reduction. *Castanopsis tribuloides* was an additional species tested from the direct seeding study.

4.2.1 Seed Storage Behaviour

The viability of seeds of 10 species: *A. microsperma*, *A. kurzii*, *B. variegata*, *C. axillaris*, *G. arborea*, *H. dulcis*, *M. garrettii*, *M. azedarach*, *P. emblica* and *P. cerasoides* was not significantly reduced after storage at 5% MC at -20 °C for a month. This group was classified as orthodox i.e. no loss of viability after storage at sub-zero temperatures for a long duration. *A. fraxinifolius* significantly lost viability, when the seeds were dried to 5% MC and stored at -20 °C (ANOVA, p=0.02, Table 4.3). *D. glandulosa* could be dried to 10% MC, but they totally lost viability when dried to 5% MC and stored at -20 °C. These two species were, therefore, classified as intermediate. Seeds of five species; *A. lacucha*, *C. tribuloides*, *D. longan*, *H. glabra* and *S. albiflorum* were very sensitive to desiccation and freezing, completely losing viability when dried to 10% and 5% MC. These species were classified as recalcitrant (Table 4.3).

Table 4.3 Effects of drying and freezing on initial germination of 17 tree species, Seed were reduced to different moisture contents (MC). Germination percentages are means of 3 replicates (30 seeds per replicate), under nursery conditions.

Species	Initial MC (%)		Initial germination (%)			Germination of seeds with10% MC (%)			Germination of seeds with 5% MC (%)			Germination of seeds with 5% MC and stored at -20 °C for 1 month (%)		*p*
	Mean	SE	Sowing date	Mean	SE	Sowing date	Mean	SE	Sowing date	Mean	SE	Mean	SE	
Orthodox														
Adenanthera microsperma	7.1	0.2	26/02/15	59.3^{b}	1.8		-	-	19/03/15	47.8^{ab}	8.0	76.7^{a}	1.9	0.01
Alangium kurzii	16.1	0.2	14/07/15	52.0^{a}	6.1	31/07/15	50.0^{a}	3.3	07/08/15	15.6^{b}	1.1	37.8^{a}	2.9	<0.01
Bauhinia variegata	10.7	0.1	22/05/15	85.3^{a}	3.7		-	-	02/06/15	62.2^{b}	4.8	76.7^{ab}	1.9	0.01
Choerospondias axillaris	20.6	1.0	14/07/15	46.7	6.8				30/07/15	-	-	33.3	5.1	0.19
Gmelina arborea	13.3	0.1	26/05/15	6.0	1.2		-	-	02/06/15	7.8	1.1	3.3	1.9	0.21
Hovenia dulcis	7.9	0.2	26/02/15	34.7^{ab}	7.9		-	-	30/03/15	50.0^{a}	3.3	21.1^{b}	2.2	0.02
Manglietia garrettii	15.2	0.6	23/10/14	49.3^{ab}	5.3	24/01/14	68.9^{a}	6.8	19/03/15	43.3^{ab}	3.8	32.2^{b}	7.8	0.02
Melia azedarach	10.6	0.2	05/01/15	31.3	3.5		-	-	10/03/15	28.9	3.9	11.1	5.9	0.08
Phyllanthus emblica	10.8	0.1	05/01/15	38.7^{a}	5.9		-	-	16/03/15	13.3^{b}	1.9	25.6^{ab}	6.8	0.04
Prunus cerasoides	19.5	0.3	11/04/15	64.0^{ab}	1.2	14/04/15	54.4^{b}	9.7	30/04/15	82.2^{a}	2.2	81.1^{a}	2.2	0.01
Intermediate														
Acrocarpus fraxinifolius	10.3	0.1	11/04/15	88.9^{a}	2.9		-	-	20/04/15	56.7^{b}	6.9	60^{b}	8.8	0.02
Diospyros glandulosa	44.2	0.3	18/11/14	8.7	0.3	28/11/14	16.7	1.9	03/02/15	0	0	0	0	0.15
Recalcitrant														
Artocarpus lacucha	46.4	1.2	04/06/15	92.0	1.2	14/06/15	0	0	18/06/15	0	0	0	0	
Castanopsis tribuloides	33.6	0.6	16/10/15	62.7	0.6	18/11/15	0	0	25/11/15	0	0	0	0	
Dimocarpus longan	43.4	1.3	02/10/14	8.7	1.3	7/10/14	0	0	14/10/14	0	0	0	0	
Horsfieldia glabra	18.0	1.0	20/05/15	63.3	1.0	01/07/16	0	0	17/10/15	0	0	0	0	
Syzygium albiflorum	35.7	0.8	04/06/15	49.3	0.8	19/07/15	0	0	21/07/15	0	0	0	0	

-Superscript letters indicate statistically different within species (mean differentiation using Turkey's HSD, α= 0.05).

Mean dormancy of *D. glandulosa*, *G. arborea* and *P. cerasoides* was not significantly affected by the storage treatments (ANOVA, p=0.18, 0.08 and 0.24 respectively, Table 4.4). In contrast, mean dormancy length of *B. variegata*, *C. axillaris*, *H. dulcis*, *M. garrettii*, *M. azedarach* and *P. emblica* significantly declined with reduced seed moisture content (Table 4.4). *A. fraxinifolius* was the only species with significantly longer dormancy when seeds were stored at 5% MC and -20 °C (ANOVA, p<0.01, Table 4.4)

Table 4.4 Effects of drying and freezing on initial median length of dormancy (MLD) of 17 tree species, Seed were reduced into different moisture contents (MC). MLD were shown in the table, calculated from three replicates of 30 seeds in the nursery condition.

Species	Initial MLD (days)		MLD of seeds with 10% MC (days)		MLD of seeds with 5% MC (days)		MLD of 5% MC and stored at -20 °C for 1 month (days)		*p*
	Mean	SE	Mean	SE	Mean	SE	Mean	SE	
Orthodox									
Adenanthera microsperma	9.0^{ab}	1.0	-	-	12.1^{a}	0.4	8.0^{b}	0.6	0.02
Alangium kurzii	53.0^{ab}	0.0	33.9^{b}	4.0	61.0^{ab}	13.7	73.8^{a}	3.9	0.03
Bauhinia variegata	7.8^{a}	0.1	-	-	5.0^{b}	0.2	4.6^{b}	0.1	<0.01
Choerospondias axillaris	244.3*	8.2	-	-	-	-	46.0	23.0	<0.01
Gmelina arborea	23.3	2.0	-	-	6.0	1.5	14.7	7.3	0.08
Hovenia dulcis	73.0^{a}	1.9	-	-	15.7^{b}	0.6	16.5^{b}	2.5	<0.01
Manglietia garrettii	106.7^{a}	6.3	66.1^{b}	10.2	30.4^{c}	0.7	30.5^{c}	0.5	<0.01
Melia azedarach	79.2^{a}	2.3	-	-	38.3^{ab}	4.9	31.9^{b}	16.0	0.03
Phyllanthus emblica	107.0^{a}	5.5	-	-	62.2^{b}	2.8	57.9^{b}	0.3	<0.01
Prunus cerasoides	46.3	21.4	35.6	14.7	13.3	0.3	11.4	0.6	0.24
Intermediate									
Acrocarpus fraxinifolius	9.0^{b}	0.0	-	-	5.0^{c}	0.0	16.7^{a}	0.3	<0.01
Diospyros glandulosa	128.3	1.8	122.1	5.8	-	-	-	-	0.18
Recalcitrant									
Artocarpus lacucha	24.8	9.2	-	-	-	-	-	-	-
Castanopsis tribuloides	51.2	8.3	-	-	-	-	-	-	-
Dimocarpus longan	17.0	2.3	-	-	-	-	-	-	-
Horsfieldia glabra	35.5	0.4	-	-	-	-	-	-	-
Syzygium albiflorum	66.3	2.4	-	-	-	-	-	-	-

-An asterisk (*) in row indicates statistical difference between seed moisture contents within species (*t*-test, p < 0.05).
-Superscript letters indicate statistically different within species (mean differentiation using Turkey's HSD, α= 0.05).

4.2.2 Storage Duration

In this section, I examine in more detail the storage behaviour of each species over 12 months' storage.

4.2.2.1 *Acrocarpus fraxinifolius*

Storage over 12 months had no effect on germination percent of *A. fraxinifolius* seeds, but it did significantly accelerate germination. Mean germination percent of seeds with normal moisture content (control) was 88.9 ± 1.9 % (significantly different compared with all other storage conditions; ANOVA, p=0.53, Figure 4.2 a). MLD was significantly reduced under all storage conditions over 12 months (ANOVA, p<0.01, Figure 4.2 b).

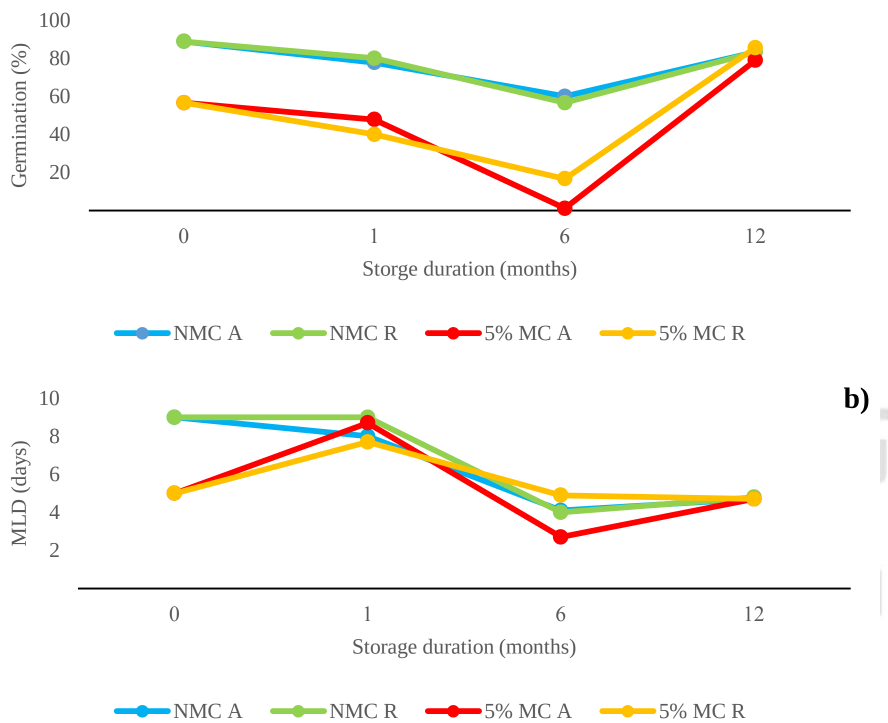


Figure 4.2 Mean percent seed germination and median of dormancy (MLD) of *A. fraxinifolius* in different moisture contents (normal (NMC) and 5% (5% MC)), storage temperatures (ambient (A) and refrigerator, 5 °C (R)) and storage durations (0, 1, 6 and 12 months), testing in nursery with 3 replicates of 30 seeds, a) Germination and b) MLD.

a)

4.2.2.2 *Adenanthera microsperma*

Storage increased germination and accelerated it. Refrigeration without drying was the best treatment. Mean percent germination of control seeds was 59.3 ± 1.8 %. Seeds with 5% MC stored at refrigerator total lost viability after 12 months' storage. Mean germination of normal MC seed, stored at refrigerator had the highest percent germination (82.2±2.9%) compared to control and 5% MC stored at ambient temperature (ANOVA, p=0.01, Figure 4.3 a). Mean MLD was significantly reduced after 12 months' storage (ANOVA, p<0.01, Figure 4.3 b).

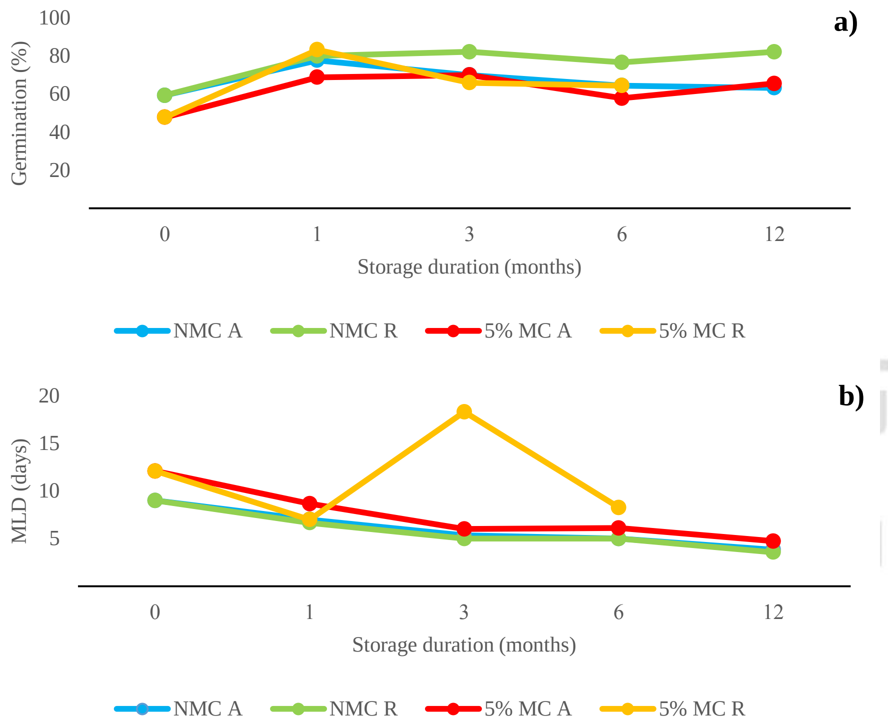
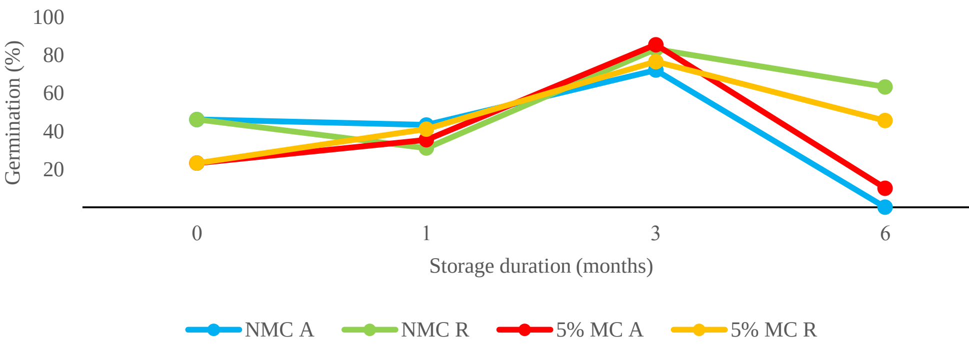


Figure 4.3 Mean percent seed germination and median of dormancy (MLD) of *Adenanthera microsperma* in different moisture contents (Normal (NMC) and 5% (5% MC)), storage temperatures (ambient (A) and refrigerator, 5 °C (R)) and storage durations (0, 1, 3, 6 and 12 months), testing in nursery with 3 replicates of 30 seeds, a) Germination and b) MLD.

4.2.2.3 *Alangium kurzii*

Storage under ambient temperatures killed all or most *A. kurzii* seeds, within 6 months, whereas refrigeration allowed both dried and NMC seeds to survive with no significant decline in germination percent. The control seeds had 46.2 ± 2.2 % germination. Mean germination of seeds with NMC and 5% MC stored at refrigerator showed no significant differences with control (ANOVA, p=0.02, Figure 4.4 a). Mean dormancy of 5% MC at refrigerator was the longest, while 5% MC seeds was the shortest (ANOVA, p=0.02, Figure 4.4 b).



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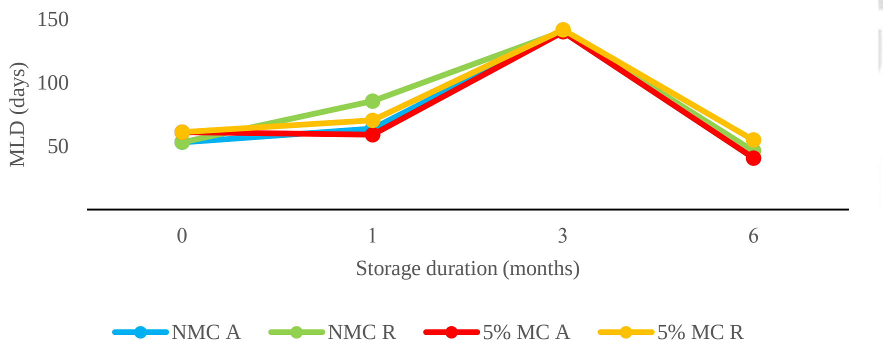


b)

Figure 4.4 Mean (±) percent seed germination and median of dormancy (MLD) of *Alangium kurzii* in different moisture contents (normal (NMC) and 5% (5% MC)), storage temperatures (ambient (A) and refrigerator, 5 °C (R)) and storage durations (0, 1, 3 and 6 months), testing in nursery with 3 replicates of 30 seeds, a) Germination and b) MLD.

4.2.2.4 *Bauhinia variegata*

Refrigeration and drying maintained seed viability similar to that of the control, but ambient conditions killed all seeds within 6 months. Mean percent germination of the control was 85.3 ± 3.7%. Germination of refrigerated seeds was not significantly different compared with the control, whereas, 5% MC seeds, stored at ambient temperature germinated significantly less than the control at 12 months' storage (68.0±6.9%, ANOVA, *p*<0.01, Figure 4.5 a). Mean MLD shortened significantly with increasing storage duration (ANOVA, *p*<0.01, Figure 4.5 b).

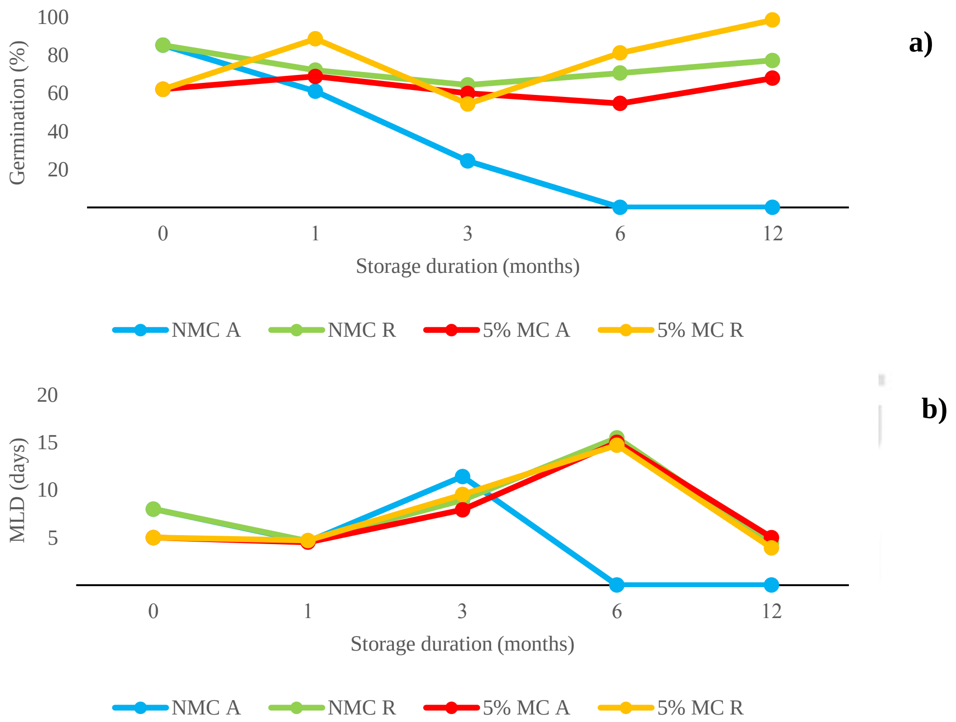


Figure 4.5 Mean percent seed germination and median of dormancy (MLD) of *Bauhinia variegata* in different moisture contents (normal (NMC) and 5% (5% MC)), storage temperatures (ambient (A) and refrigerator, 5 °C (R)) and storage durations (0, 1, 3, 6 and 12 months), testing in nursery with 3 replicates of 30 seeds, a) Germination and b) MLD.

4.2.2.5 *Choerospondias axillaris*

Storage, under all conditions tested, significantly and substantially reduced seed viability (ANOVA, p<0.01, Figure 4.6 a). Mean MLD was also significantly shortened after 12 months' storage (ANOVA, *p*<0.01, Figure 4.6 b).

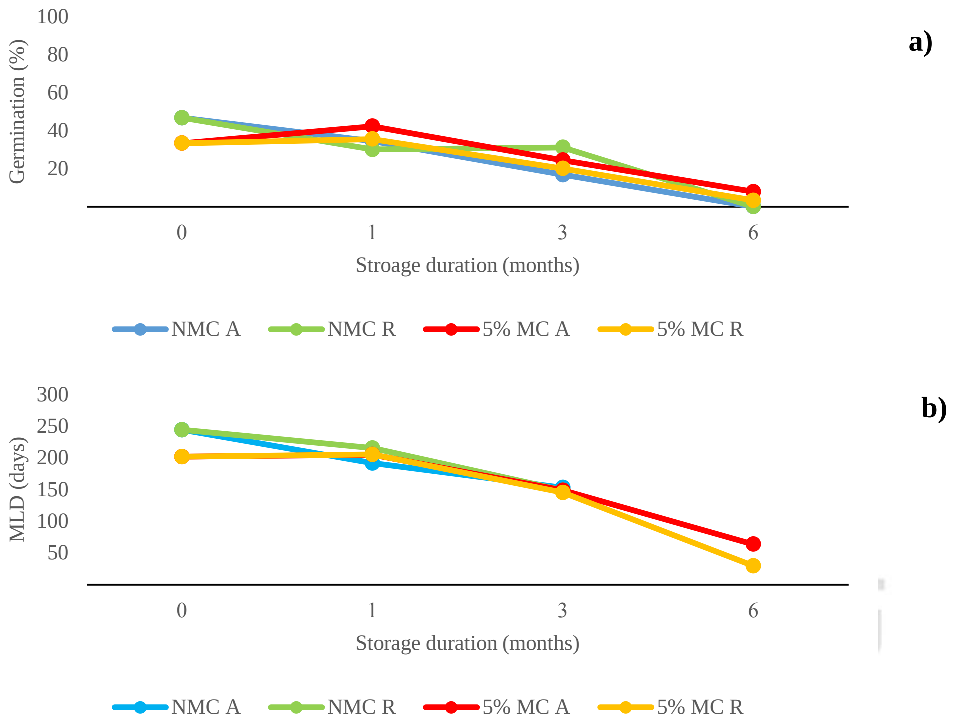
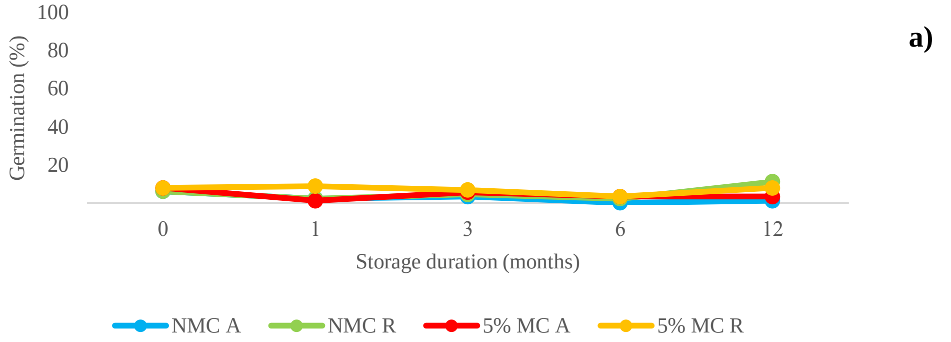


Figure 4.6 Mean percent seed germination and median of dormancy (MLD) of *Choerospondias axillaris,* in different moisture contents (normal (NMC) and 5% (5% MC)), storage temperatures (ambient (A) and refrigerator, 5 °C (R)) and storage durations (0, 1, 3 and 6 months), testing in nursery with 3 replicates of 30 seeds, a) Germination and b) MLD.

4.2.2.6 *Gmelina arborea*

Germination of *G. arborea* seeds was low under all conditions (mostly <10%). Mean percent germination of control was 6.0 ± 1.2 %. Refrigerated seeds at normal MC and dried seeds at both temperatures did not significantly differ in their percent germination compared with the control, although seeds stored under ambient conditions did have the lowest percent germination (ANOVA, p<0.01, Figure 4.7 a). Mean MLD of the seeds, subjected to all treatments, did not differ significantly from that of the control after 12 months' storage (ANOVA, p=0.23, Figure 4.7 b).



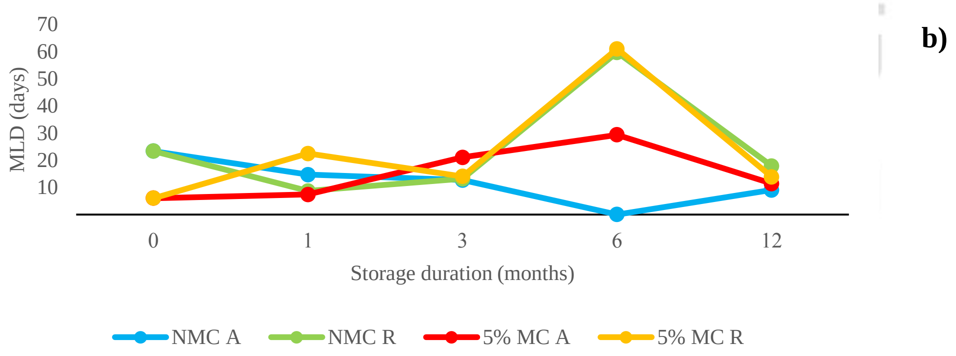


Figure 4.7 Mean percent seed germination and median of dormancy (MLD) of *Gmelina arborea* in different moisture contents (normal (NMC) and 5% (5% MC)), storage temperatures (ambient (A) and refrigerator, 5 °C (R)) and storage durations (0, 1, 3, 6 and 12 months), testing in nursery with 3 replicates of 30 seeds, a) Germination and b) MLD.

4.2.2.7 *Hovenia dulcis*

Storage treatments had no effect on percent germination (ANOVA, p=0.26, Figure 4.8a). Mean percent germination of control was 34.7±5.0%. Mean MLD shortened significantly with storage duration, except for seeds stored under ambient conditions (ANOVA, p<0.01, Figure 4.8 b).

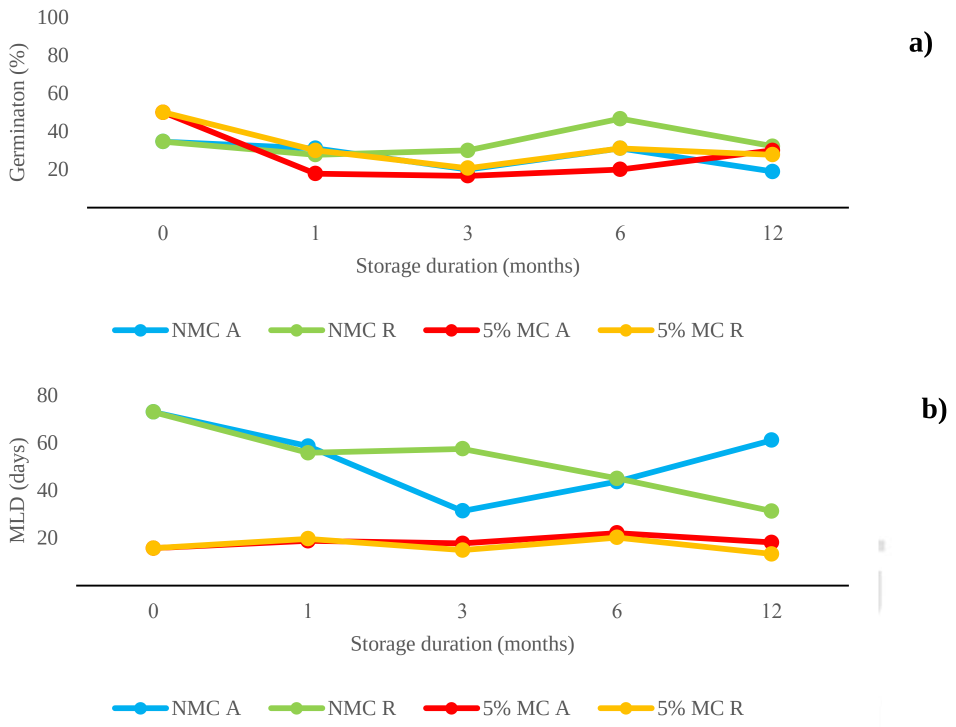


Figure 4.8 Mean percent seed germination and median of dormancy (MLD) of *Hovenia dulcis* in different moisture contents (normal (NMC) and 5% (5% MC)), storage temperatures (ambient (A) and refrigerator, 5 °C (R)) and storage durations (0, 1, 6 and 12 months), testing in nursery with 3 replicates of 30 seeds, a) Germination and b) MLD.

4.2.2.8 *Manglietia garrettii*

Only refrigerated non-dried seeds survived for 12 months. Their viability remained similar to that of the control seeds (*t*-test, *p*=0.59, Figure 4.9 a), but their mean MLD was significantly shortened by 55.5 days (*t*-test, p<0.01, Figure 4.9 b).

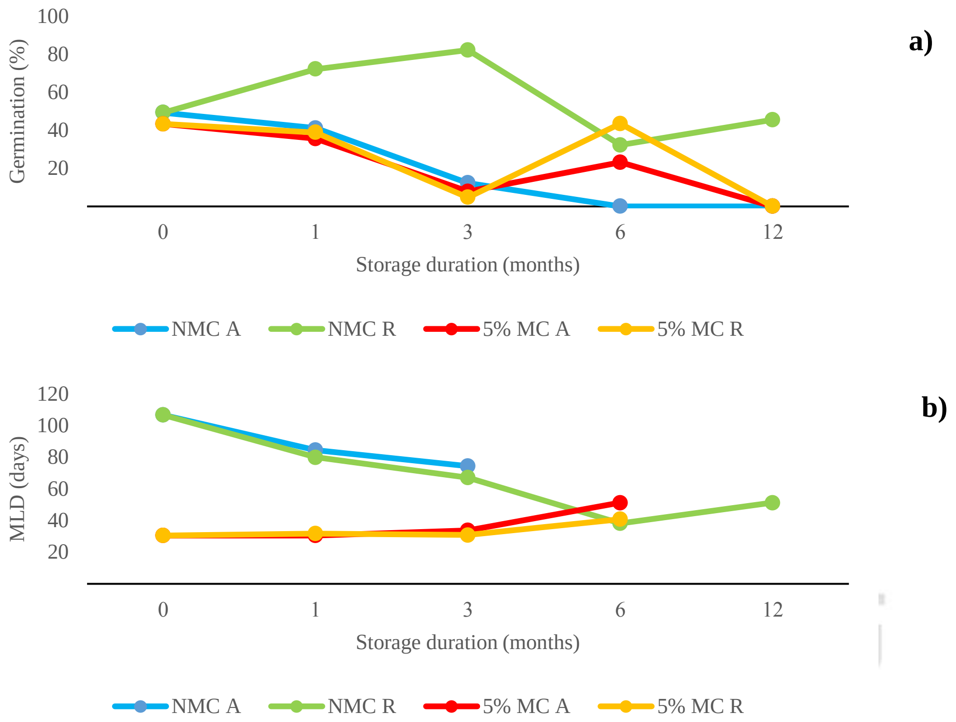


Figure 4.9 Mean (±) percent seed germination and median of dormancy (MLD) of *Manglietia garrettii* in different moisture content (normal (NMC) and 5% (5% MC)), storage temperature (ambient (A) and refrigerator, 5 °C (R)) and storage duration (0, 1, 6 and 12 months), testing in nursery with 3 replicates of 30 seeds, a) Germination and b) MLD.

4.2.2.9 *Melia azedarach*

Whilst germination was fairly low for this species, the treatments produced various results. Mean percent germination of refrigerated normal MC seeds and non-refrigerated dried seeds did not differ with that of the control. However, viability of seeds stored under ambient conditions and refrigerated, dried seeds 5% MC was significantly reduced (ANOVA, *p*<0.01, Figure 4.10 a). Drying significantly reduced mean MLD (ANOVA, *p*=0.01, Figure 4.10 b).

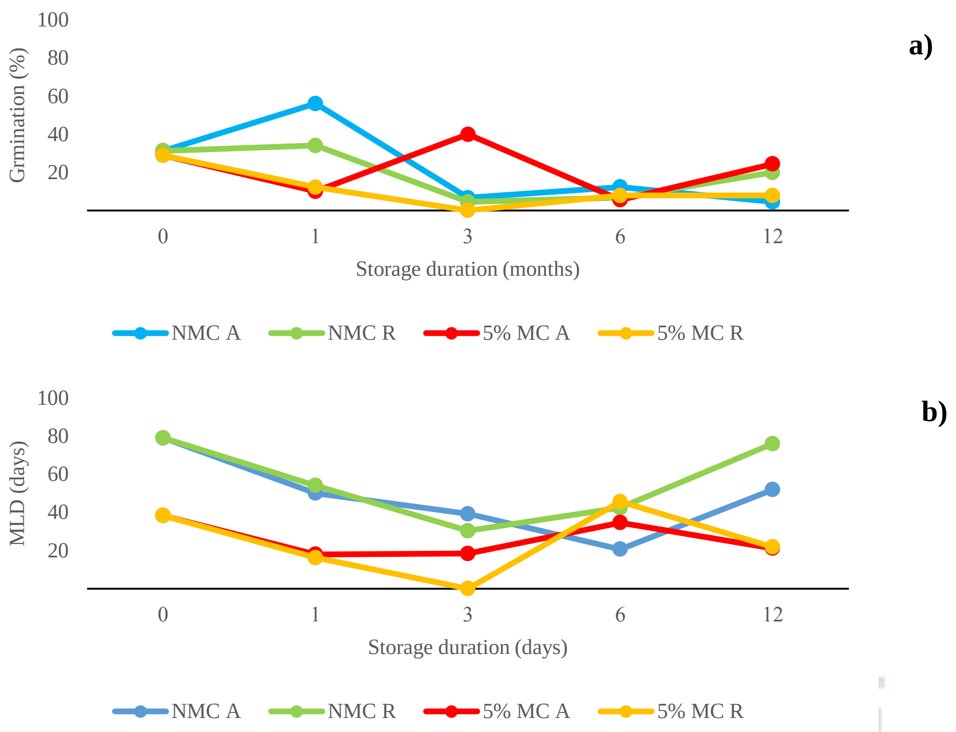


Figure 4.10 Mean (±) percent seed germination and median of dormancy (MLD) of *Melia azedarach* in different moisture content (normal (NMC) and 5% (5% MC)), storage temperature (ambient (A) and refrigerator, 5 °C (R)) and storage duration (0, 1, 6 and 12 months), testing in nursery with 3 replicates of 30 seeds, a) Germination and b) MLD.

4.2.2.10 *Phyllanthus emblica*

P. emblica seeds also had fairly low germination. Refrigeration killed them, whereas the viability of seeds stored under ambient conditions remained similar to that of the control seeds, although viability declined slightly (but significantly) for dried seeds outside the refrigerator (ANOVA, p=0.05, Figure 4.11 a). In general, mean MLD declined with storage by 93.3 days (for dried seeds at ambient temperature), except for non-dried non-refrigerated seeds whose MLD did not differ significantly from that of the control seeds (ANOVA, p<0.01, Figure 4.11 b).

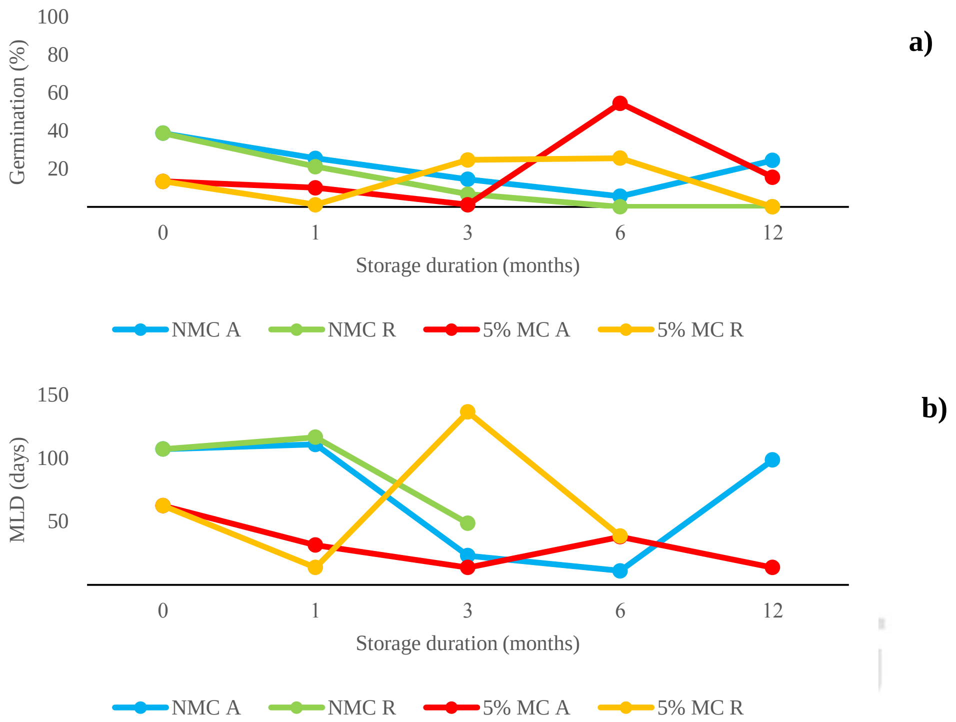
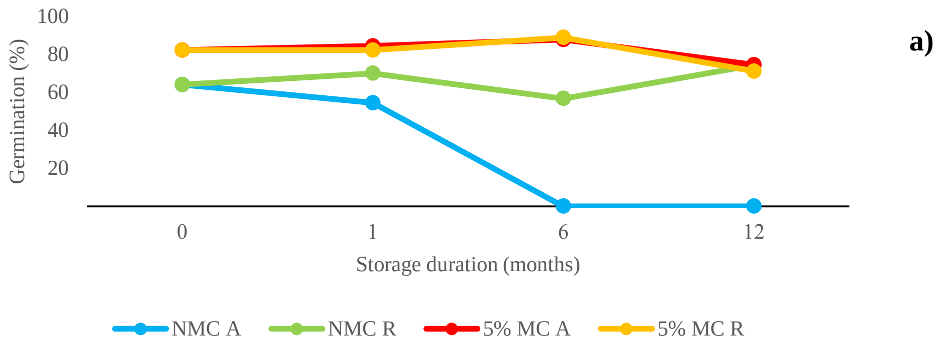


Figure 4.11 Mean (±) percent seed germination and median of dormancy (MLD) of *Phyllanthus emblica* in different moisture content (normal (NMC) and 5% (5% MC)), storage temperature (ambient (A) and refrigerator, 5 °C (R)) and storage duration (0, 1, 6 and 12 months), testing in nursery with 3 replicates of 30 seeds, a) Germination and b) MLD.

4.2.2.11 *Prunus cerasoides*

Under ambient conditions, all seeds were killed within 6 months, but none of the other treatments had any effect on seed viability (ANOVA, *p*=0.13, Figure 4.12 a). All treatments significantly reduced the mean MLD from about 50 to about 10 days. Although mean dormancy also showed no significantly differences between treatments (ANOVA, p=0.11, Figure 4.12 b).



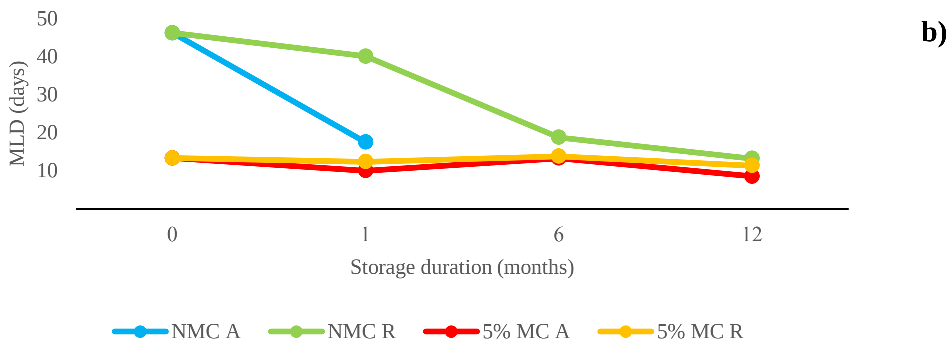
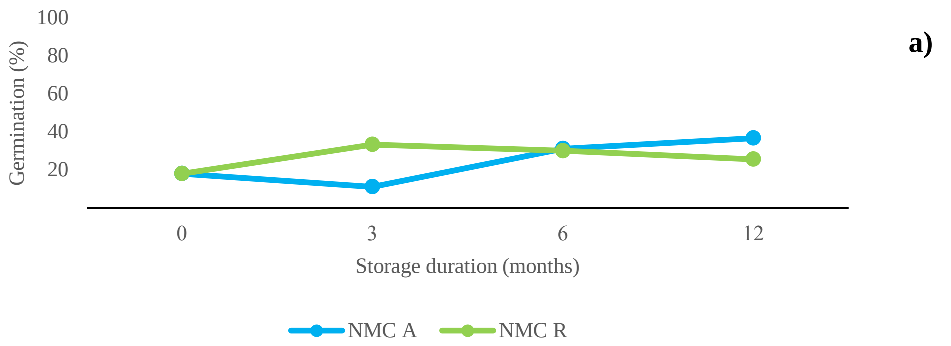


Figure 4.12 Mean (±) percent seed germination and median of dormancy (MLD) of *Prunus cerasoides* in different moisture content (normal (NMC) and 5% (5% MC)), storage temperature (ambient (A) and refrigerator, 5 °C (R)) and storage duration (0, 1, 6 and 12 months), testing in nursery with 3 replicates of 30 seeds, a) Germination and b) MLD.

4.2.2.12 *Spondias pinnata*

Germination was low and refrigeration had no effect on both seed viability (test at different times, ANOVA, *p*=0.23, Figure 4.13 a) and mean MLD (ANOVA, *p*=0.32, Figure 4.13 b).



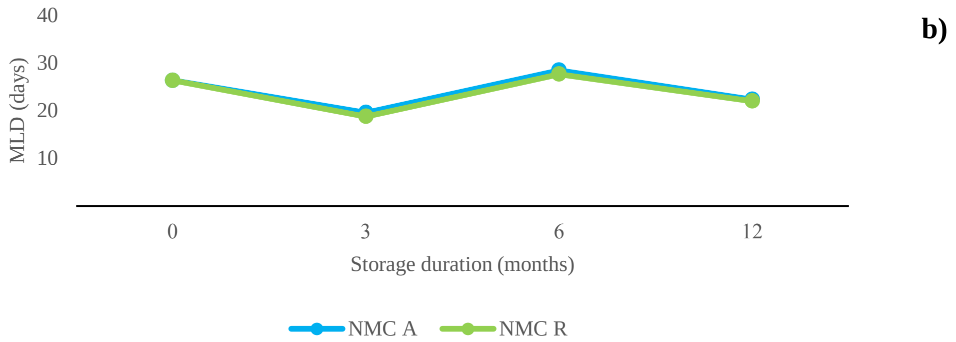


Figure 4.13 Mean (±) percent seed germination and median of dormancy (MLD) of *Spondias pinnata* in different storage temperature (ambient (A) and refrigerator, 5 °C (R)) and storage duration (0, 1, 6 and 12 months), testing in nursery with 3 replicates of 30 seeds, a) Germination and b) MLD.

4.3 Field Trials

4.3.1 Seed Germination

D. longan was the first species sown in the field (October 2014) and *A. kurzii* and *C. axillaris* were the last (July 2015). Two analyses were carried out: i) to compare seed germination at collection time in the nursery (optimal conditions) and field (natural conditions) and ii) to compare between two sowing times: immediately after collection and at the beginning of the rainy season after storage since collection.

Comparing immediate sowing at collection time, between nursery experiments (Immediately sown in Nursery, IN) and field trials (Immediately sown in Field, IF), percent germination did not differ significantly between the nursery and field for all species except three: *A. fraxinifolius*, *A. lacucha* and *C. axillaris* germinated significantly better in the nursery (IN>IF by 42%, 32% and 25%, respectively, *t*-test, $p < 0.05$, Figure 4.14).

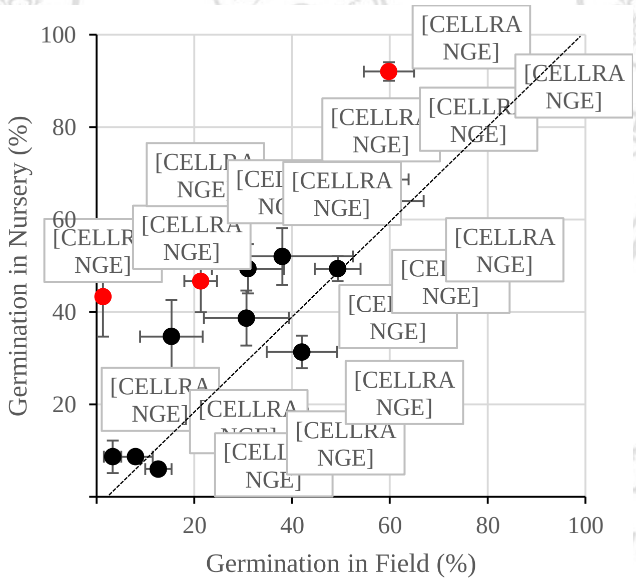


Figure 4.14 Comparison of mean (± SE) percent seed germination of 17 tree species, seeds sown at collection time, in the field (IF) and in the nursery (IN), 3 replicates of 50 seeds. Red circles indicate significant difference between the two bars within each species (t-test, p < 0.05). Dashed line indicates axis X equals axis Y. AF=*A. fraxinifolius*, AM=*A. microsperma*, AK=*A. kurzii*, AL=*A. lacucha*, BV=*B. variegata*, CA=*C. axillaris*, DL=*D. longan*, DG=*D. glandulosa*, GA=*G. arborea*, HG=*H. glabra*, HD=*H. dulcis*, MA= *M. azedarach*, MG=*M. garrettii*, PE=*P. emblica*, PC=*P. cerasoides*, SP=*S. pinnata*, SA=*S. albiflorum.*

Similarly, after storage, mean percent germination at the beginning of rainy season did not differ significantly between nursery experiments (Stored seeds sown in the Nursery, SN) and field trials (Stored seeds sown in the Field, SF) for all species except three: *M. azedarach, M. garrettii* and *P. emblica* germinated significantly better in the field than in the nursery (SF>SN by 36%, 16% and 25%, respectively, *t*-test, p<0.05, Figure 4.15).

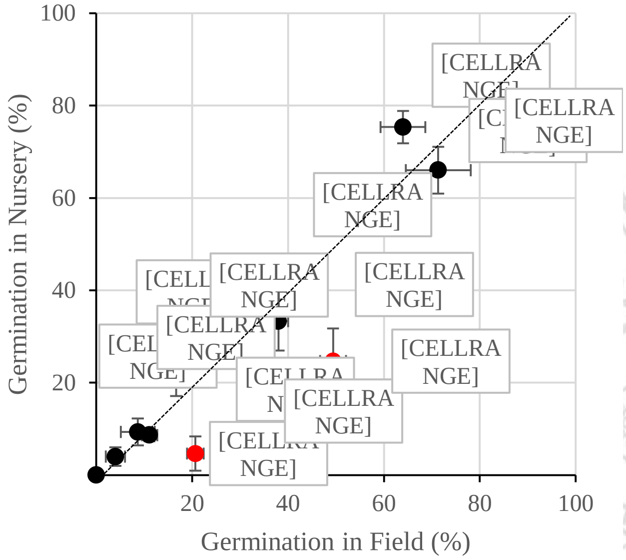


Figure 4.15 Comparison of mean (± SE) percent seed germination of 13 tree species between two sowing conditions after seed storage, in the field (SF) and in the nursery (SN), 3 replicates of 50 seeds. Red circles indicate significant difference between the two bars within each species (t-test, p < 0.05). Dashed line indicates axis X equals axis Y. AF=*A. fraxinifolius*, AM=*A. microsperma*, AK=*A. kurzii*, AL=*A. lacucha*, BV=*B. variegata*, CA=*C. axillaris*, DL=*D. longan*, DG=*D. glandulosa*, GA=*G. arborea*, HG=*H. glabra*, HD=*H. dulcis*, MA= *M. azedarach*, MG=*M. garrettii*, PE=*P. emblica*, PC=*P. cerasoides*, SP=*S. pinnata*, SA=*S. albiflorum.*

Comparing between the two sowing times (immediate and after storage) in field trials, one species, *H. glabra*, germinated only when sown immediately at collecting time (51.4 ± 4.4 %, Figure 4.16). Similarly, immediately sown *A. lacucha* seeds germinated far more (51 % significantly higher) than stored seeds, even though the seeds were stored for only 11 days (*t*-test, p<0.01, Figure 4.16). In contrast, *A. fraxinifolius* was the only species with percent germination of seeds sown after storage significantly higher (by 40 %) than for those sown at collection time (*t*-test, p<0.01, Figure 4.16).

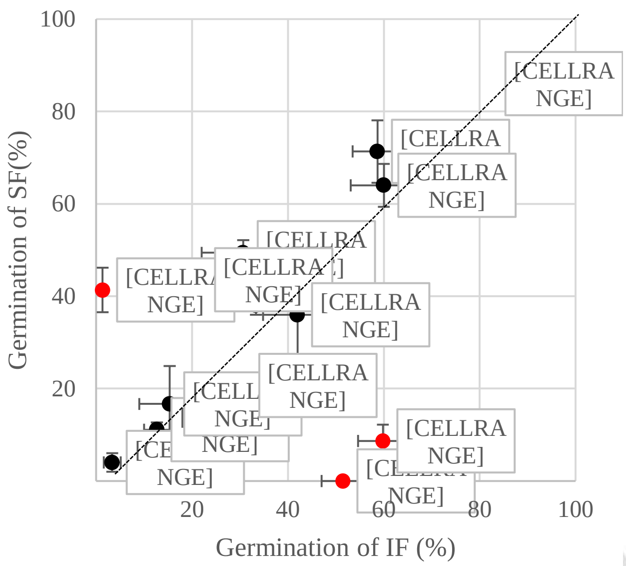


Figure 4.16 Comparison of mean (± SE) percent seed germination of 13 tree species between two sowing times in the field condition, at collection time (IF) and at the beginning of rainy season after storage (SF), 3 replicates of 50 seeds. *A. microsperma* and *A. fraxinifolius* seeds were scarified in SF treatment. Red circles indicate significant difference between the two bars within each species (t-test, $p < 0.05$). Dashed line indicates axis X equals axis Y. AF=*A. fraxinifolius*, AM=*A. microsperma*, AK=*A. kurzii*, AL=*A. lacucha*, BV=*B. variegata*, CA=*C. axillaris*, DL=*D. longan*, DG=*D. glandulosa*, GA=*G. arborea*, HG=*H. glabra*, HD=*H. dulcis*, MA= *M. azedarach*, MG=*M. garrettii*, PE=*P. emblica*, PC=*P. cerasoides*, SP=*S. pinnata*, SA=*S. albiflorum.*

Seeds of *D. longan* and *S. albiflorum* became desiccated and lost viability rapidly after seed collection and the seeds of *A. kurzii* and *C. axillaris* were collected during the rainy season, so germination tests on these species were performed only on seeds sown at collecting time.

Considering the most effective treatment for each species, the mean (± SE) percent seed germination was compared across species to rank them according to germination, as a major component of suitability for direct or aerial seeding. *B. variegata* exhibited the highest percent germination (88.7 ± 1.3 %), from immediate sowing at collection time (IF), followed by stored seeds of *A. microsperma* and *P. cerasoides* sown at the start of the rainy season (71.3.0 ± 6.8 % and 64.0 ± 4.7 %, respectively). In contrast, *D. glandulosa* (SF) germinated the least (only 4.0 ± 2.0 %,). A similar result was obtained with *D. longan* (IF) (only 8.1 ± 3.5 %, Figure 4.17).

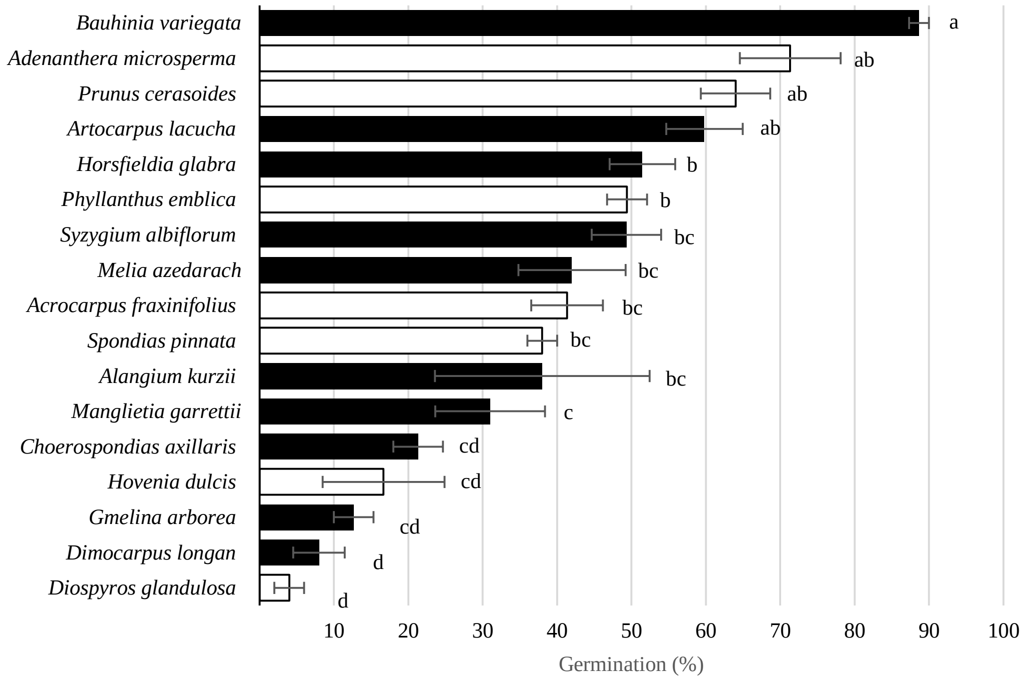


Figure 4.17 Mean (± SE) percent seed germination of the best performance treatment of each tree species in the field. Black bars are treatment of seed sown at collection times and white bars are treatment of seed sown at beginning of rainy season after storage (N=3). Bars not sharing the same superscript letters are statistically different among species (mean differentiation using Turkey’s HSD, α= 0.05).

4.3.2 Median Length of Dormancy (MLD)

Mean dormancy was compared between seeds sown in the nursery and field at seed collection time (IN & IF). Six species took significantly longer to germinate in the field than in the nursery; *A. lacucha* (IF>IN 22 days, *t*-test, *p*=0.01), *A. microsperma* (IF>IN 50 days, *t*-test, *p*<0.01), *H. glabra* (IF>IN 26 days, *t*-test, *p*=0.02), *M. azedarach* (IF>IN 38 days, *t*-test, *p*<0.01), *S. pinnata* (IF>IN 79 days, *t*-test, *p*<0.01) and *S. albiflorum* (IF>IN 10 days, *t*-test, *p*=0.01). Three species exhibited the opposite result; *A. fraxinifolious* (IF<IN 90 days, *t*-test, *p*=0.04), *B. variegata* (IF<IN 5 days, *t*-test, *p*<0.01) and *C. axillaris* (IF<IN 157 days, *t*-test, *p*<0.01, Figure 4.18).

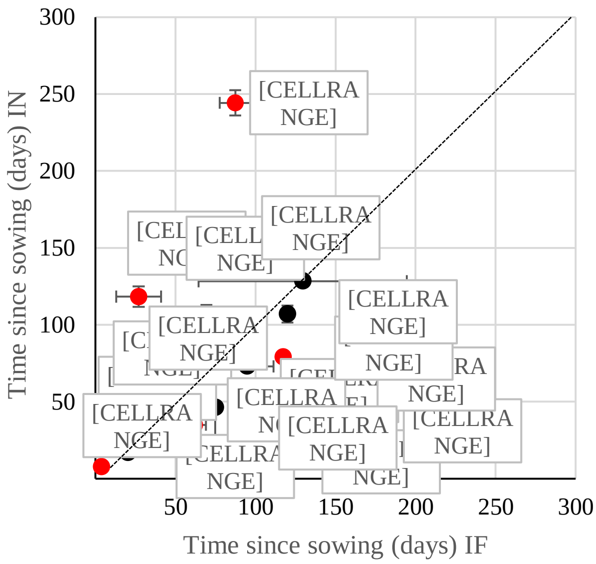


Figure 4.18 Comparison of mean (± SE) MLD's of 17 tree species, seeds sown at collection time, in the field (IF) and in the nursery (IN) (N=3). Red circles indicate significant difference between the two bars within each species (t-test, p < 0.05). Dashed line indicates axis X equals axis Y. AF=*A. fraxinifolius,* AM=*A. microsperma*, AK=*A. kurzii,* AL=*A. lacucha,* BV=*B. variegata,* CA=*C. axillaris,* DL=*D. longan,* DG=*D. glandulosa*, GA=*G. arborea*, HG=*H. glabra*, HD=*H. dulcis*, MA= *M. azedarach*, MG=*M. garrettii*, PE=*P. emblica*, PC=*P. cerasoides*, SP=*S. pinnata*, SA=*S. albiflorum.*

Comparing MLD after seed storage between the nursery experiments and the field trials, 5 species had longer mean MLD in the field than in the nursery; *A. microsperma* (SF>SN 10 days, *t*-test, *p*<0.01), *B. variegata* (SF>SN 3 days, *t*-test, *p*=0.01), *M. azedarach* (SF>SN 20 days, *t*-test, *p*<0.01), *P. cerasoides* (SF>SN 3 days, *t*-test, *p*=0.01) and *S. pinnata* (SF>SN 10 days, *t*-test, *p*<0.01, Figure 4.19).

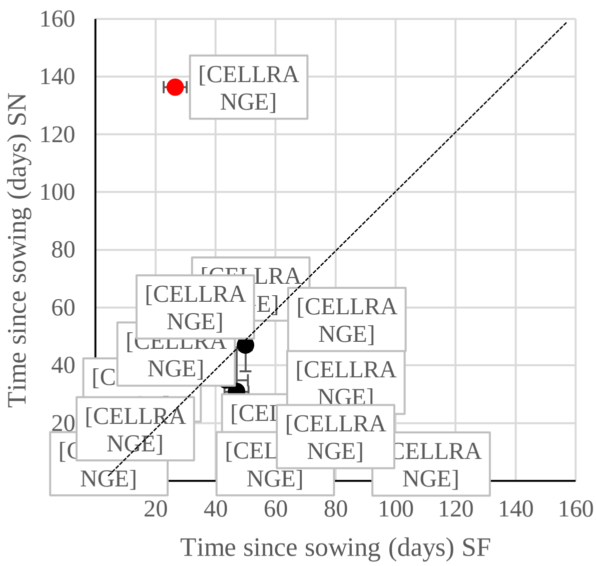


Figure 4.19 Comparison of mean (± SE) MLD's of 13 tree species between two sowing conditions after seed storage, in the field (SF) and in the nursery (SN), (N=3). Red circles indicate significant difference between the two bars within each species (t-test, p < 0.05). Dashed line indicates axis X equals axis Y. AF=*A. fraxinifolius*, AM=*A. microsperma*, AK=*A. kurzii*, AL=*A. lacucha*, BV=*B. variegata*, CA=*C. axillaris*, DL=*D. longan*, DG=*D. glandulosa*, GA=*G. arborea*, HG=*H. glabra*, HD=*H. dulcis*, MA= *M. azedarach*, MG=*M. garrettii*, PE=*P. emblica*, PC=*P. cerasoides*, SP=*S. pinnata*, SA=*S. albiflorum.*

In the field, seeds of most species, sown at collection time (IF), had significantly longer MLD than those stored and sown at beginning of rainy season (SF): *A. microsperma* (IF > SF 46 days, seeds stored 112 days, *t*-test, *p*<0.01), *H. glabra* (IF > SF 61.8 days, seeds stored 24 days, *t*-test, *p*<0.01), *H. dulcis* (IF > SF 78 days, seeds stored 112 days, *t*-test, *p*=0.01), *M. azedarach* (IF > SF 97 days, seeds stored 159 days, *t*-test, *p*<0.01), *P. emblica* (IF > SF 93 days, seeds stored 166 days, *t*-test, *p*<0.01) *P. cerasoides* (IF > SF 57 days, seeds stored 62 days, *t*-test, *p*<0.01) and *S. pinnata* (IF > SF 76 days, seeds stored 79 days, *t*-test, *p*<0.01, Figure 4.20).

B. variegata seeds were the only ones with significantly longer dormancy when stored and sown at the start of the rainy season (SF, 28 days' storage), compared with IF, but the difference was only 4 days (*t*-test, $p<0.01$, Figure 4.20).

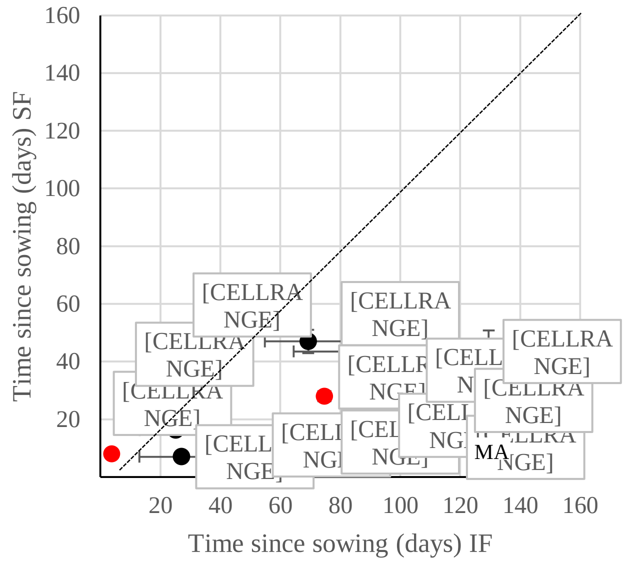


Figure 4.20 Comparison of mean (± SE) median length of dormancy of 13 tree species between two sowing times in the field condition, at collection time (IF) and at the beginning of rainy season after storage (SF), (N=3). Red circles indicate significant difference between the two bars within each species (t-test, p < 0.05). Dashed line indicates axis X equals axis Y. AF=*A. fraxinifolius*, AM=*A. microsperma*, AK=*A. kurzii*, AL=*A. lacucha*, BV=*B. variegata*, CA=*C. axillaris*, DL=*D. longan*, DG=*D. glandulosa*, GA=*G. arborea*, HG=*H. glabra*, HD=*H. dulcis*, MA= *M. azedarach*, MG=*M. garrettii*, PE=*P. emblica*, PC=*P. cerasoides*, SP=*S. pinnata*, SA=*S. albiflorum*.

For seeds sown in the field at collection time (IF), most seeds germinated just before the start of the rainy season (using median date of germination). The exceptions were *D. longan*, *D. glandulosa* and *M. garrettii* whose median germination dates fell in October, December and March respectively (Table 4.5 and Figure 4.21a). For seeds sown after storage (sowing date 12/06/16), all species had median germination dates within the rainy season (June to August 2015, Table 4.5 and Figure 4.21 b).

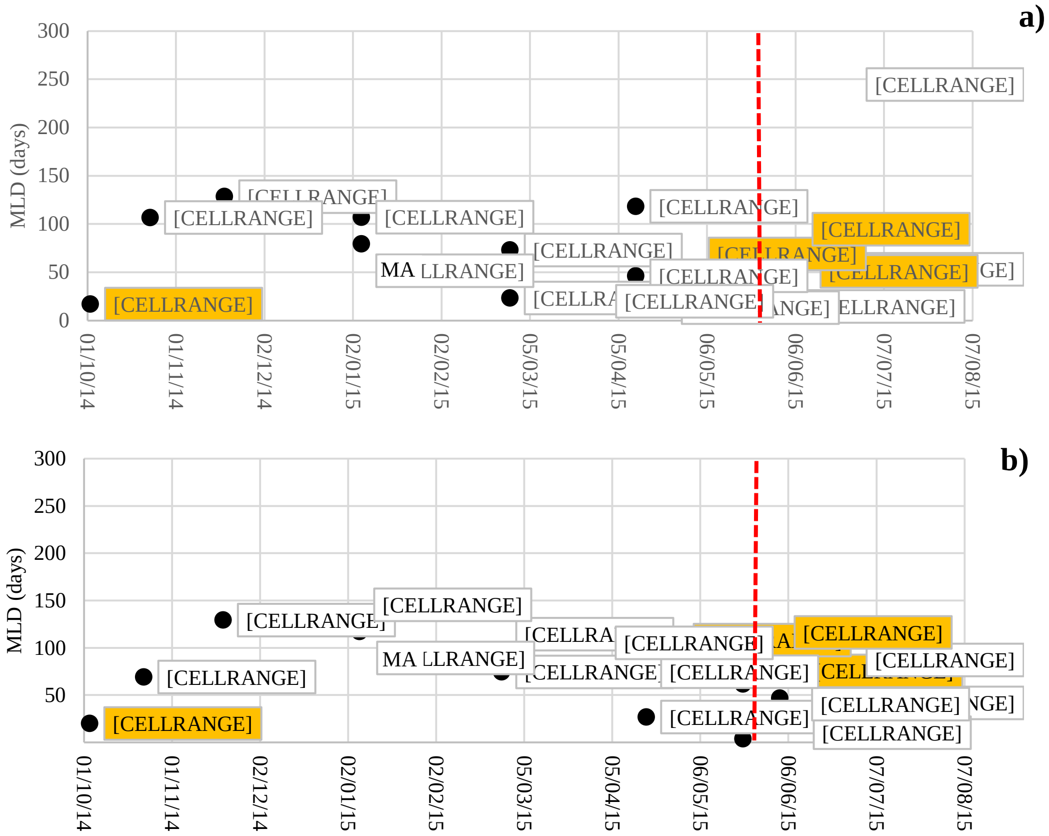
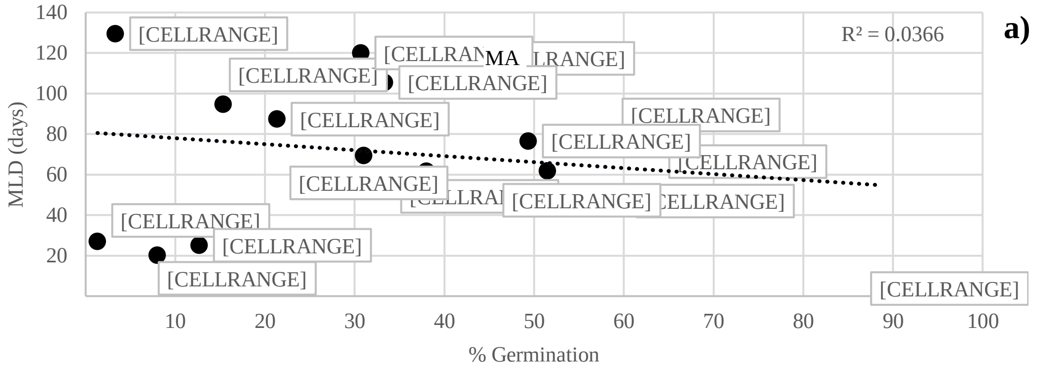


Figure 4.21 Sowing date and median length of dormancy (MLD) of 17 tree species in a) nursery and b) field. Red line is a starting point of rainy season (22 May 2015). Orange boxes are recalcitrant species and white are orthodox. AF=*A. fraxinifolius*, AM=*A. microsperma*, AK=*A. kurzii*, AL=*A. lacucha*, BV=*B. variegata*, CA=*C. axillaris*, DL=*D. longan*, DG=*D. glandulosa*, GA=*G. arborea*, HG=*H. glabra*, HD=*H. dulcis*, MG=*M. garrettii*, MA= *M. azedarach*, PE=*P. emblica*, PC=*P. cerasoides*, SP=*S. pinnata*, SA=*S. albiflorum.*

Table 4.5 Sowing, median length of dormancy (MLD) and median date of germination of 17 tree species in two sowing condition; sown at collection time (IF) and sown after storage at the beginning of rainy season (SF). Species were ordered from sowing date in IF.

Species	IF			SF		
	Sowing date	MLD (days)	Median date of germination	Sowing date	MLD (days)	Median date of germination
Dimocarpus longan	03/10/14	20.2	23/10/14	-	-	-
Manglietia garrettii	22/10/14	69.3	30/12/14	12/06/15	47.0	29/07/15
Diospyros glandulosa	19/11/14	129.5	28/03/15	12/06/15	43.5	25/07/15
Melia azedarach	06/01/15	117.3	03/05/15	12/06/15	20.0	01/07/15
Phyllanthus emblica	06/01/15	120.0	05/05/15	12/06/15	26.5	08/07/15
Adenanthera microsperma	25/02/15	74.7	10/05/15	12/06/15	28.0	10/07/15
Hovenia dulcis	25/02/15	94.7	30/05/15	12/06/15	17.9	29/06/15
Spondias pinnata	01/04/15	105.4	15/07/15	12/06/15	28.9	10/07/15
Acrocarpus fraxinifolius	17/04/15	27.0	14/05/15	12/06/15	7.0	19/06/15
Prunus cerasoides	17/04/15	74.9	30/06/15	12/06/15	17.9	29/06/15
Bauhinia variegata	21/05/15	3.8	24/05/15	12/06/15	8.0	20/06/15
Horsfieldia glabra	21/05/15	61.8	21/07/15	12/06/15	-	-
Gmelina arborea	27/05/15	25.1	21/06/15	12/06/15	16.2	28/06/15
Artocarpus lacucha	03/06/15	46.9	19/07/15	12/06/15	50.0	01/08/15
Syzygium albiflorum	03/06/15	76.5	18/08/15	-	-	-
Alangium kurzii	15/07/15	61.7	14/09/15	-	-	-
Choerospondias axillaris	15/07/15	87.3	10/10/15	-	-	-

Regression analysis showed no significant correlation between MLD and percent germination, neither for seeds sown at collection time (r=0.19, *p*=0.46, N=17, Figure 4.22 a) nor for seeds sown after storage (r=0.54, *p*=0.07, N= 12, Figure 4.22 b). A similar trend was detected when combining data from the two treatments and applying the same analysis (r=0.17, *p*=0.50, N= 17, Figure 4.22 c).



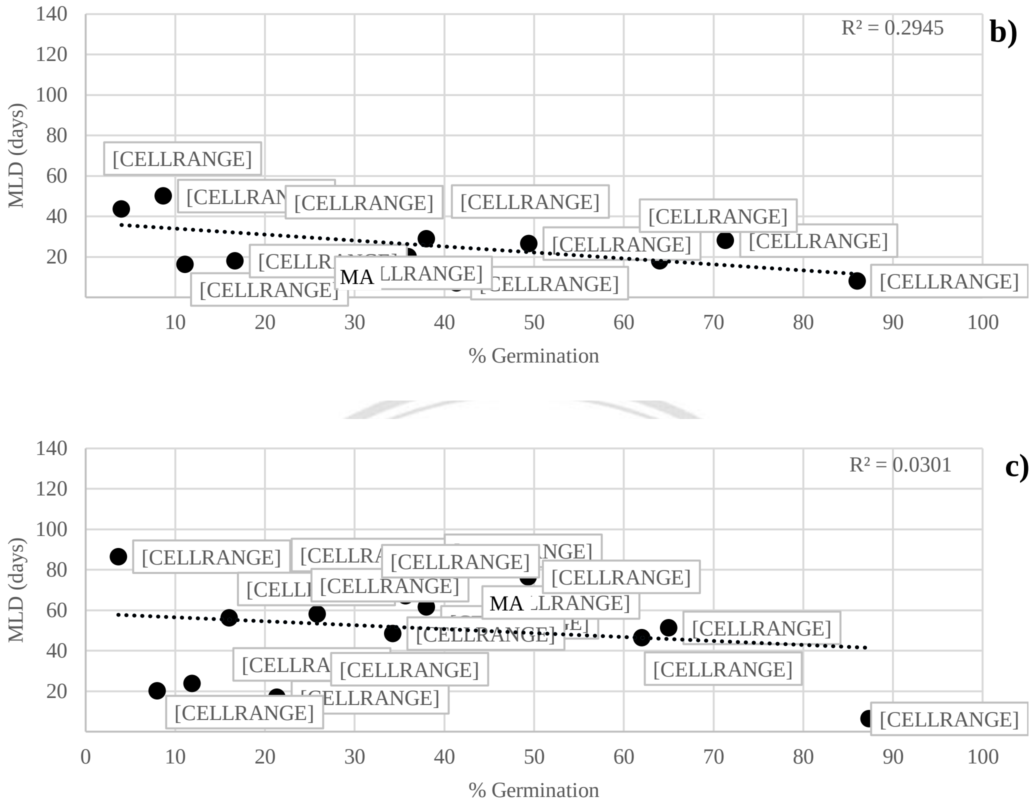


Figure 4.22 Relationships between mean percent seed germination and median length of dormancy (MLD) of 17 tree species in the field at two sowing times; a) collection time (N=17) b) at the beginning of rainy season after storage (N=12) c) combining the two periods (N=17). The dotted line is the line of best fit. AF=*A. fraxinifolius*, AM=*A. microsperma*, AK=*A. kurzii*, AL=*A. lacucha*, BV=*B. variegata*, CA=*C. axillaris*, DL=*D. longan*, DG=*D. glandulosa*, GA=*G. arborea*, HG=*H. glabra*, HD=*H. dulcis*, MG=*M. garrettii*, MA= *M. azedarach*, PE=*P. emblica*, PC=*P. cerasoides*, SP=*S. pinnata*, SA=*S. albiflorum*.

4.3.3 Seedling Survival and Seedling Yield

Seedling survival was defined as the number of surviving seedlings, expressed as a percentage of the seeds that germinated after 12 months. *B. variegata* achieved the highest percent survival (69.7 ± 9.1 %), followed by *P. emblica* (51.1 ± 10.2 %). *A. fraxinifolius*, *G. arborea* and *H. dulcis* had low survival percentages in the field (1.1 ± 1.1 %, 3.3 ± 2.2 % and 3.3 ± 3.3 %, respectively, Figure 4.23). In general, percent survival was not significantly different between the two sowing periods.

A. fraxinifolius seedlings from immediate sowing did not survive, while all of *G. arborea* seedlings from seed stored treatment died in the field (Table 4.6). These two species presented low percent seedling survival when compared with the other species (Figure 4.23).

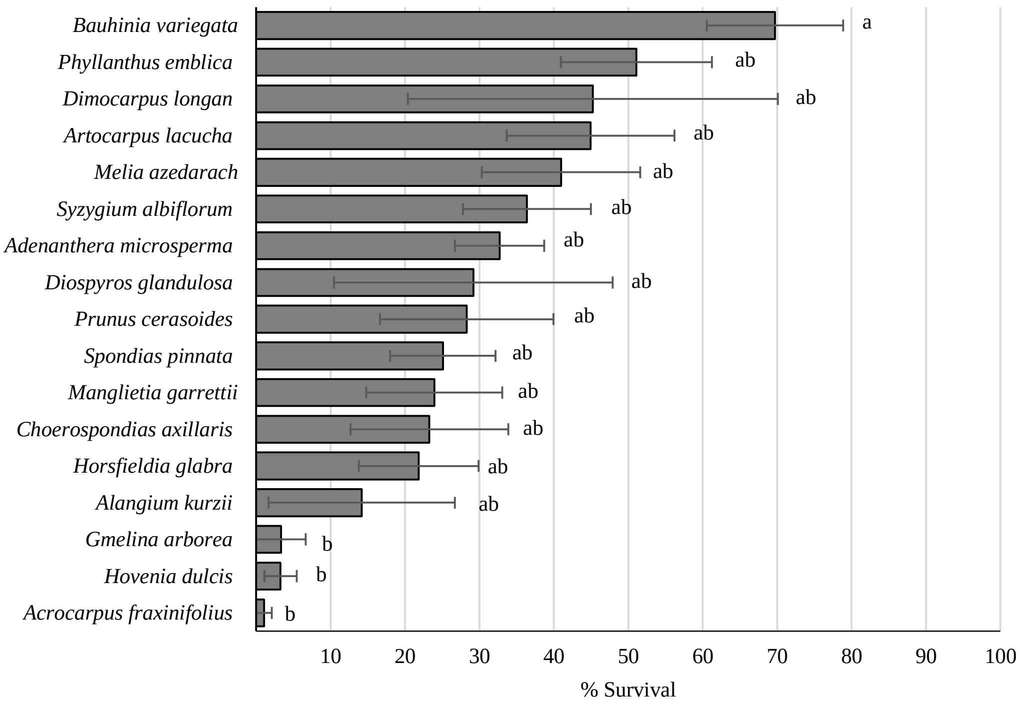


Figure 4.23 Comparison of mean (± SE) seedling survival, over one year, of direct-seeded seedlings in the field, calculated as a percent of the number of seeds that germinated, using combined data from two seed sowing times, collection time and beginning of rainy season after storage (N=6). Columns not sharing the same superscript letters are statistically different, among species (mean differentiation using Turkey's HSD, α= 0.05).

Table 4.6 Comparison of mean seedling survival, over one year, of direct-seeded seedlings of 17 tree species in the field, at two sowing periods, IF = sown at collection time and SF = seeds stored and sown at the beginning of rainy season (N=3). The t-tests indicated no significant differences between the 2 sowing times. Therefore, data were pooled for Figure 4.23.

Species	Storage duration (days)	IF		SF		*t-test, p-value*
		Mean	SE	Mean	SE	
Bauhinia variegata	28	67.1	16.9	72.3	11.2	0.83
Phyllanthus emblica	166	46.6	16.7	55.6	14.7	0.70
Dimocarpus longan	-	45.2	24.9	-	-	-
Artocarpus lacucha	11	44.2	8.4	45.7	23.8	0.85
Syzygium albiflorum	-	36.4	8.6	-	-	-
Diospyros glandulosa	209	33.3	33.3	25.0	25.0	0.79
Melia azedarach	159	32.4	11.6	49.5	18.9	0.51
Adenanthera microsperma	112	25.1	5.6	40.3	9.6	0.24
Spondias pinnata	79	24.9	12.5	25.3	9.7	0.81
Prunus cerasoides	62	23.9	19.9	32.7	16.3	0.60
Choerospondias axillaris	-	23.3	10.6	-	-	-
Horsfieldia glabra	24	21.8	8.1	-	-	-
Manglietia garrettii	236	19.5	9.8	28.3	17.4	0.79
Alangium kurzii	-	14.2	12.5	-	-	-
Gmelina arborea	22	6.7	6.7	0.0	0.0	0.42
Hovenia dulcis	112	2.4	2.4	4.2	4.2	0.85
Acrocarpus fraxinifolius	62	0.0	0.0	2.1	2.1	0.42

Seedling yield was defined as the number of seedlings that survived to reach 1-year-old, expressed as a percent of the number of seeds sown. *B. variegata* achieved the highest yield in the field (60.7 ± 8.7 %). Species mostly presented low percent yield of less than 20 percent. *A. fraxinifolius* and *H. dulcis* had lowest yield: only 0.3 ± 0.3 % (Figure 4.24). Percent yield of most species were not significant different between two sowing periods. All *A. fraxinifolius* seedlings from immediate sowing died in the field (Table 4.7). *A. lacucha* was the only species, for which percent yield from immediately sown seeds was significant higher (22 %) than for those from stored seeds (*t*-test, *p*=0.04, Table 4.7).

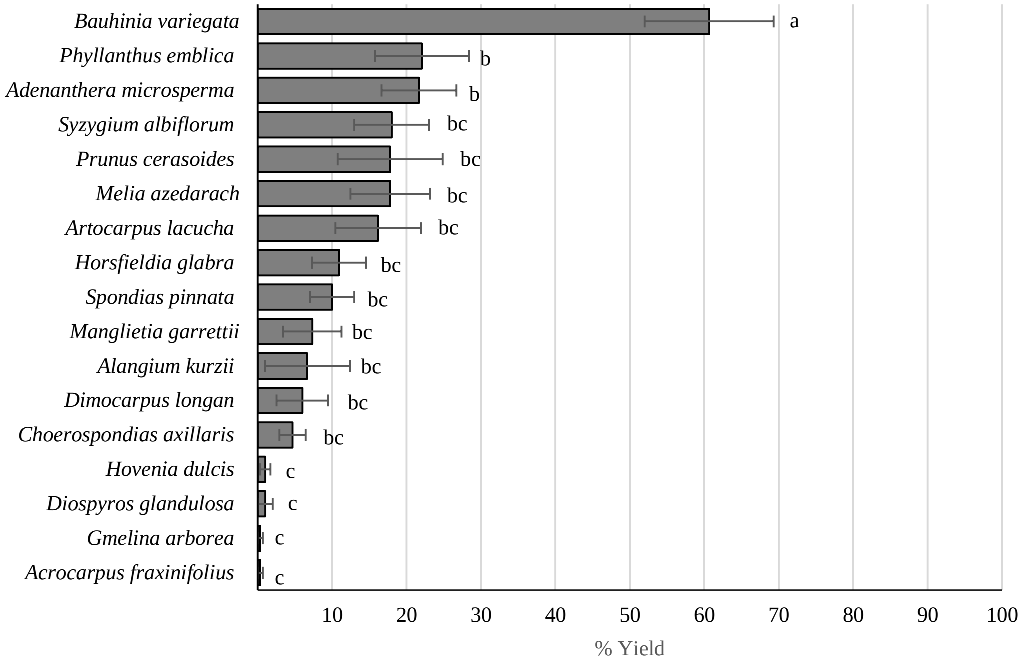


Figure 4.24 Comparison of mean (± SE) percent seedling yield over one year of direct-seeded seedlings in the field, calculated from two seed sowing times, at collection time and beginning of rainy season after storage (N=6). Columns not sharing the same superscript letters are statistically different among species (mean differentiation using Turkey's HSD, α= 0.05).

Table 4.7 Seedling yield, over one year, of direct-seeded seedlings of 17 tree species in the field at two sowing periods, IF = sown at collection time and SF = seeds stored and sown at the beginning of rainy season (N=3). T-tests indicated no difference between IF and SF. Therefore, data were pooled for Figure 4.24.

Species	Storage duration (days)	IF		SF		*t-test, p-value*
		Mean	SE	Mean	SE	
Bauhinia variegata	28	57.3	13.7	64.0	13.3	0.72
Artocarpus lacucha	11	27.0*	6.4	5.3	2.7	0.04
Syzygium albiflorum	-	18.0	5.0	-	-	-
Phyllanthus emblica	166	17.3	10.5	26.8	8.1	0.46
Adenanthera microsperma	112	15.3	4.7	28.0	8.1	0.23
Prunus cerasoides	62	14.7	11.8	20.9	10.0	0.56
Melia azedarach	159	14.0	5.0	21.6	10.2	0.67
Horsfieldia glabra	24	10.9	3.6	-	-	-
Manglietia garrettii	236	10.7	7.9	4.0	2.0	0.61
Spondias pinnata	79	10.0	5.3	10.0	4.0	0.86
Alangium kurzii	-	6.7	5.7	-	-	-
Dimocarpus longan	-	6.0	3.5	-	-	-
Choerospondias axillaris	-	4.7	1.8	-	-	-
Gmelina arborea	22	0.7	0.7	0.0	0.0	0.42
Hovenia dulcis	112	0.7	0.7	1.3	1.3	0.82
Acrocarpus fraxinifolius	62	0.0	0.0	0.7	0.7	0.42
Diospyros glandulosa	209	0.0	0.0	2.0	2.0	0.42

Asterisk (*) indicates statistical difference among treatments ($p < 0.05$)

4.2.4 Seedling Growth Performance

Differences in height, crown width (CW) and root collar diameter (RCD) of 1-year-old seedlings, between those grown from immediately sown seeds and those grown from stored seeds were not significant within species (Figure 4.25) and sowing periods (*t*-tests, height, p=0.85, CW, p=0.78 & RCD, p=0.92, Table 4.8). *P. cerasoides* seedlings grew the tallest (87.4 ± 22.1 cm), followed by *M. azedarach* (46.9 ± 13.4 cm) and *B. variegata* (30.4 ± 2.7 cm). The remaining species grew to less than 30 cm tall. *A. fraxinifolius* seedlings were the smallest, only 4.3 ± 4.3 cm tall (Figure 4.26 a).

A similar pattern was found with crown width. *P. cerasoides* achieved the greatest mean crown expansion (47.9 ± 12.2 cm), followed by *M. azedarach* (31.7 ± 8.8 cm) and *B. variegata* (19.6 ± 1.8 cm). *A. fraxinifolius* seedlings had the smallest crowns (3.3 ± 3.3 cm) (Figure 4.26 b).

P. cerasoides achieved the widest stems after 1 year (RCD, 6.5 ± 1.5 mm) followed by *M. azedarach* (5.9 ± 1.0 mm), whilst of *A. fraxinifolius* and *H. dulcis* were less than 1 mm (0.6 ± 0.6 mm and 0.7 ± 0.5 mm, respectively, Figure 4.26 c).

Table 4.8 Comparison of mean size variables (height, crown width and root collar diameter) and relative growth rate (RGR) of one year direct-seeded seedlings across 17 species in the field, between two sowing periods, IF=sown at collection time, SF= seeds stored and sown at the beginning of rainy season (N=3).

Variables	**IF**		**SF**		***t*-test, *p-value***
	Mean	SE	Mean	SE	
Height (cm)	19.4	3.8	20.6	4.6	0.85
Crown width (cm)	13.6	2.4	14.7	2.7	0.78
Root collar diameter (mm)	2.7	0.4	2.7	0.4	0.92
Height RGR (%/year)	57.8	8.2	54.8	10.9	0.83
Crown width RGR (%/year)	46.6	9.6	36.1	10.9	0.48
Root collar diameter RGR (%/year)	58.8	8.9	57.4	9.5	0.92

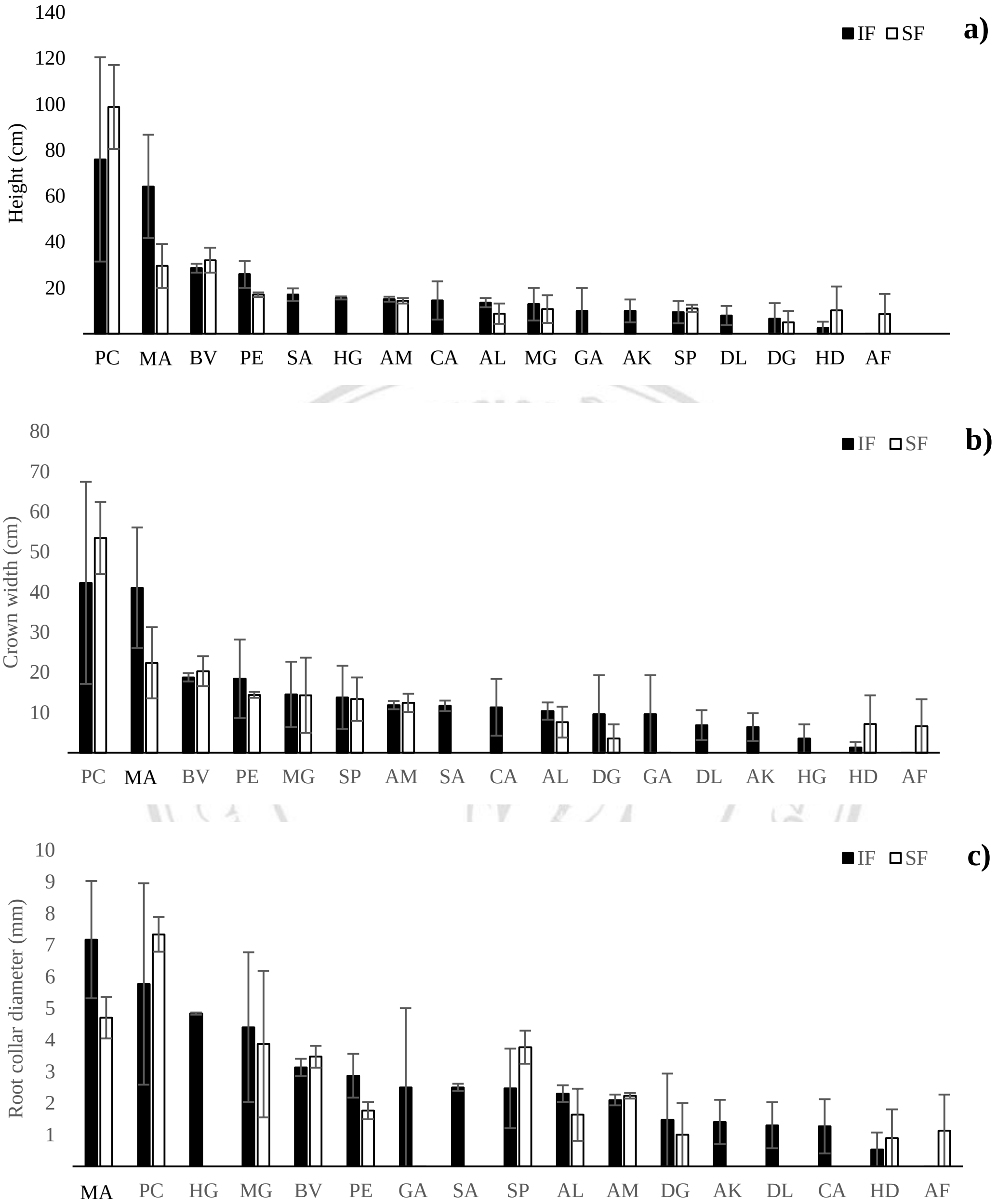


Figure 4.25 Comparison of mean (± SE) growth variables of 1 year direct-seeded seedlings of 17 tree species in the field between two sowing periods, IF = sown at collection time, SF=Stored and sown at the beginning of rainy season (N=3). a) Height, b) Crown width and c) Root collar diameter. Species; AF=*A. fraxinifolius,* AM=*A. microsperma*, AK=*A. kurzii*, AL=*A. lacucha*, BV=*B. variegata*, CA=*C. axillaris*, DL=*D. longan*, DG=*D. glandulosa*, GA=*G. arborea*, HG=*H. glabra*, HD=*H. dulcis*, MG=*M. garrettii*, MA= *M. azedarach*, PE=*P. emblica,* PC=*P. cerasoides,* SP=*S. pinnata,* SA=*S. albiflorum.*

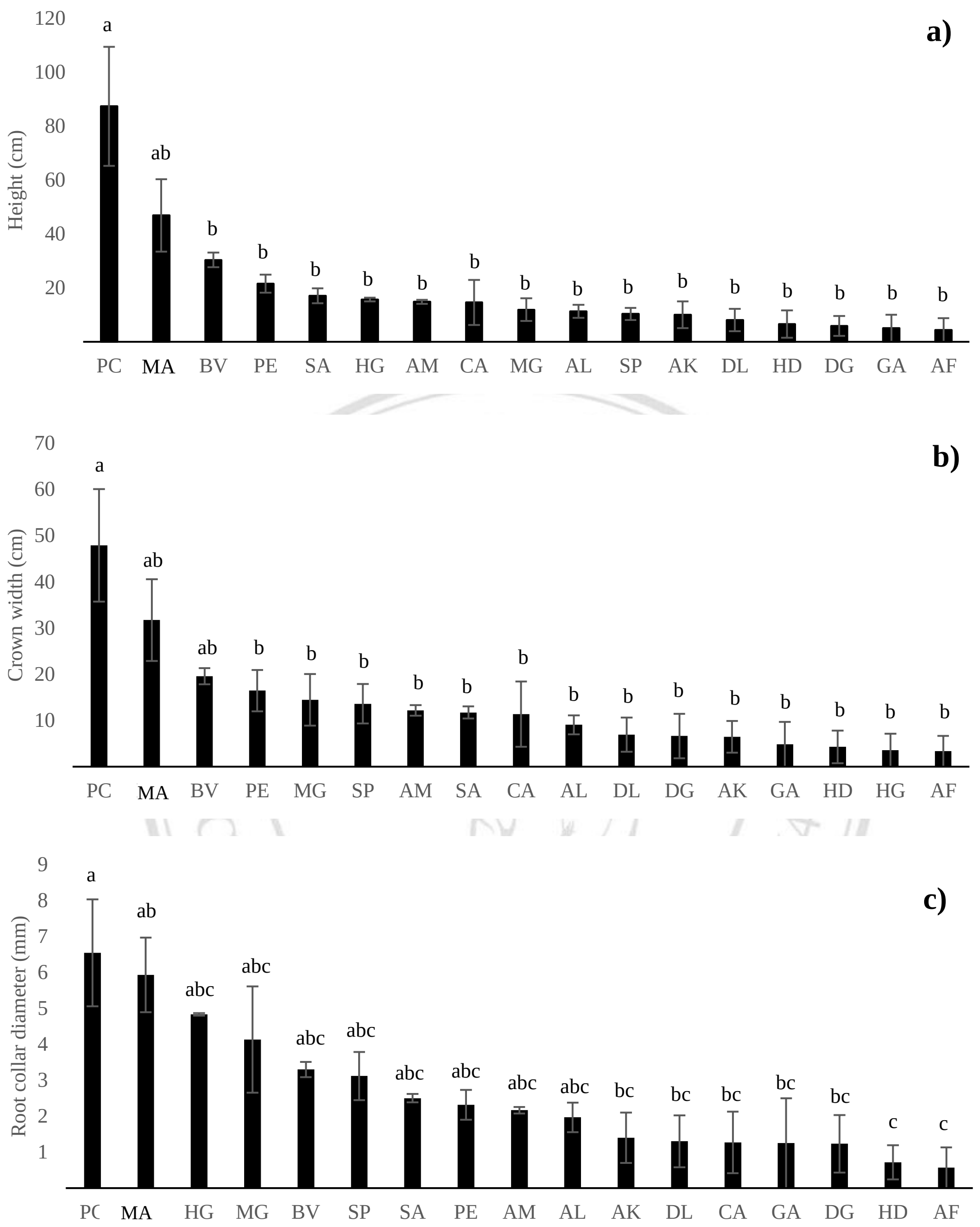


Figure 4.26 Comparison of mean (± SE) seedlings performance of 1 year direct-seeded seedlings in the field, calculated from two seed sowing times, at collection time and beginning of rainy season after storage, N=6. a) Height, b) M Crown width c) Root collar diameter. Species; AF=*A. fraxinifolius,* AM=*A. microsperma*, AK=*A. kurzii,* AL=*A. lacucha*, BV=*B. variegata*, CA=*C. axillaris*, DL=*D. longan*, DG=*D. glandulosa*, GA=*G. arborea*, HG=*H. glabra*, HD=*H. dulcis*, MG=*M. garrettii*, MA= *M. azedarach,* PE=*P. emblica*, PC=*P. cerasoides,* SP=*S. pinnata,* SA=*S. albiflorum*. Columns not sharing the same superscript letter are significantly different (Turkey's HSD, α= 0.05).

Differences in relative growth rate (RGR) of 1-year-old seedlings, compared between the two sowing periods, were not significant (*t*-test, height RGR, p=0.83, Crown width RGR, p=0.48 and RCD RGR, p=0.92, Table 4.9) across all species and at the individual species level (Figure 4.27). *P. cerasoides* seedlings grew the fastest (height RGR (171.7 ± 37.9 %/year), followed by *M. azedarach* (127.3 ± 27.9 %/year). Conversely, *G. arborea*, *S. pinnata* and *H. dulcis* grew the slowest, with height RGR values of 15.6 ± 15.6, 17.6 ± 12.1 and 17.7 ± 17.7 %/year, respectively, Figure 4.28 a).

P. cerasoides also achieved the highest rate of crown expansion (crown width RGR, 130.4 ± 30.4 %/year) without statistical significant difference (ANOVA, p=0.12, Figure 4.28 b).

P. cerasoides also achieved highest root collar diameter RGR (121.1 ± 28.1 %/year), followed by *M. azedarach* and *P. emblica* (119.0 ± 14.2 %/year and 109.2 ± 20.6 %/year, respectively). In contrast, root collar diameter RGR of *S. pinnata*, *H. glabra* and *C. axillaris* seedlings was low (21.7 ± 11.7 %/year, 22.2 ± 12.3 %/year and 24.2 ± 61.8 %/year, respectively, Figure 4.28 c).

The average seedling health score (from 0=dead to 3=perfect health) across all species was 1.9 ± 0.1. Seedlings of both two sowing treatments had average health scores of above 1.5. *P. emblica* and *A. microsperma* seedlings were the healthiest (scoring 2.8 on average), whilst, seedlings of *A. fraxinifolius*, *D. glandulosa*, *G. arborea*, and *H. dulcis* were unhealthy scoring less than 1.0 on average (0.5, 0.9, 0.5 and 0.7, respectively, Figure 4.29).

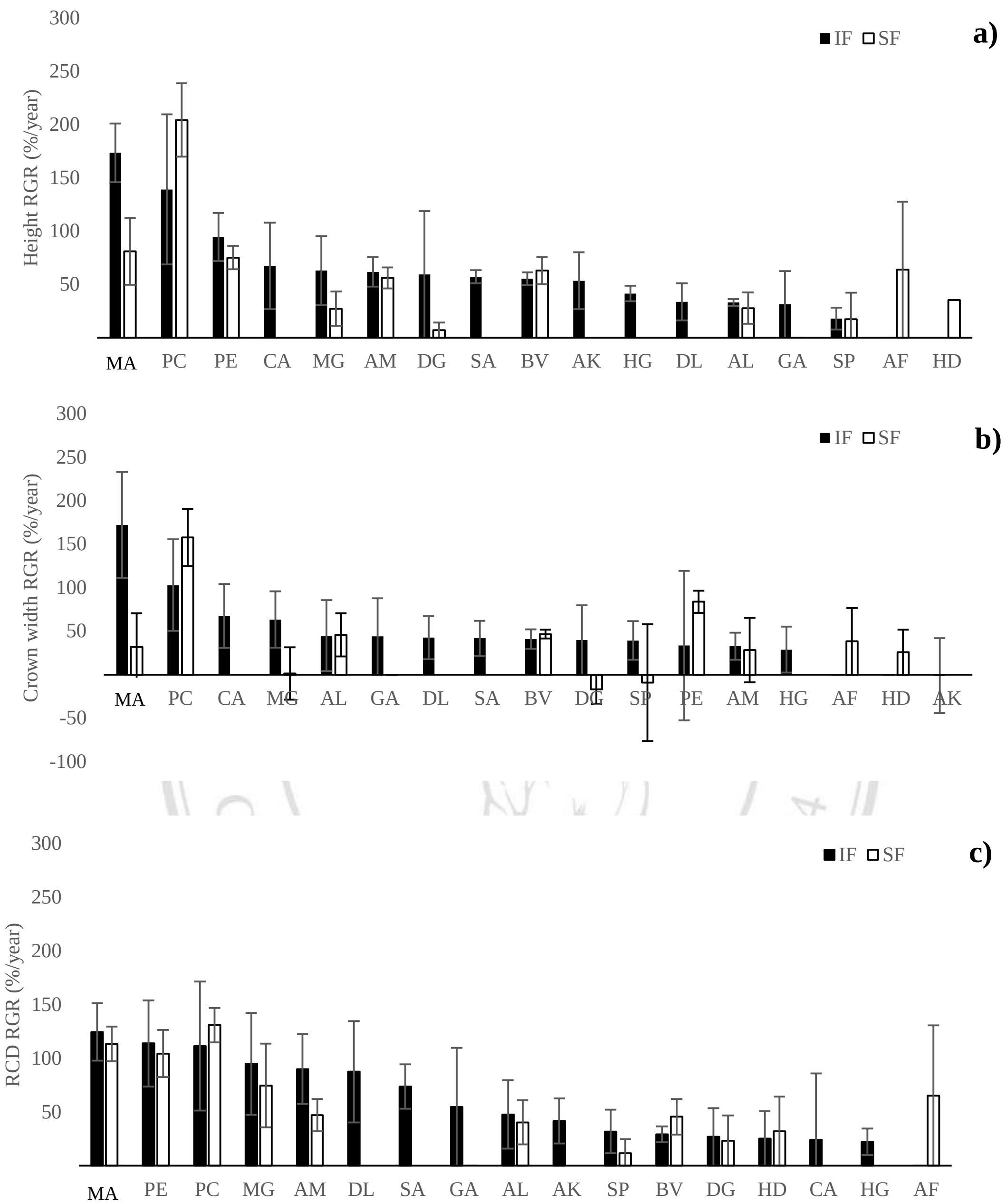


Figure 4.27 Comparison of mean (± SE) height, crown width and root collar diameter relative growth rate (RGR) of 1 year direct-seeded seedlings in the field by species between two sowing periods, IF = sown at collection time, SF=Stored and sown at the beginning of rainy season (N=3). a) Height RGR, b) Crown width RGR and c) Root collar diameter (RCD) RGR. Species; AF=*A. fraxinifolius*, AM=*A. microsperma*, AK=*A. kurzii*, AL=*A. lacucha*, BV=*B. variegata*, CA=*C. axillaris*, DL=*D. longan*, DG=*D. glandulosa*, GA=*G. arborea*, HG=*H. glabra*, HD=*H. dulcis*, MG=*M. garrettii*, MA= *M. azedarach*, PE=*P. emblica*, PC=*P. cerasoides*, SP=*S. pinnata*, SA=*S. albiflorum.*

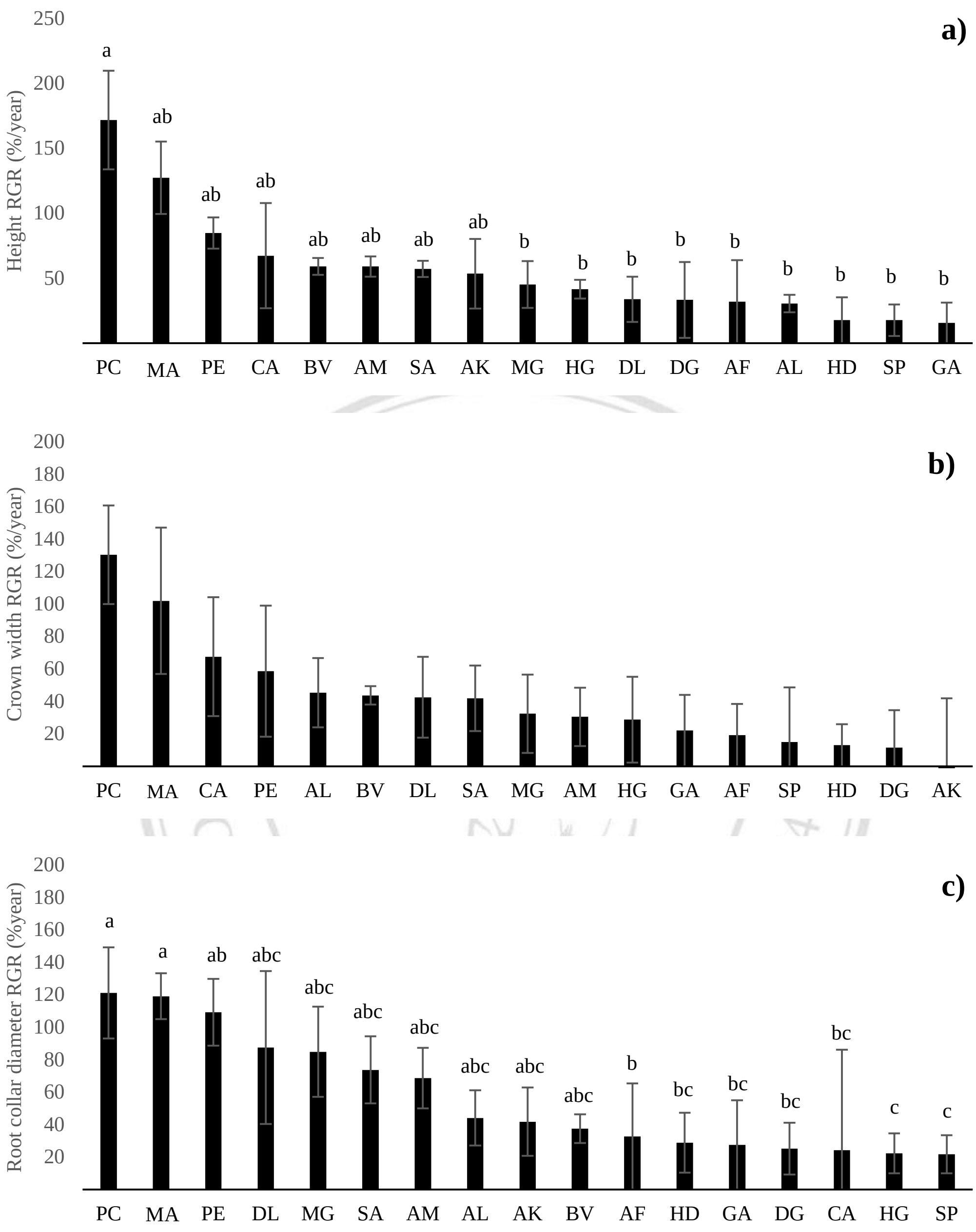


Figure 4.28 Comparison of mean (± SE) relative growth rate (RGR) of one year direct-seeded seedlings in the field. a) Height RGR, b) Crown width RGR and c) Root collar diameter RGR, calculated from two seed sowing times, at collection time and beginning of rainy season after storage (N=6). Species; AF=*A. fraxinifolius*, AM=*A. microsperma*, AK=*A. kurzii*, AL=*A. lacucha*, BV=*B. variegata*, CA=*C. axillaris*, DL=*D. longan*, DG=*D. glandulosa*, GA=*G. arborea*, HG=*H. glabra*, HD=*H. dulcis*, MG=*M. garrettii*, MA= *M. azedarach*, PE=*P. emblica*, PC=*P. cerasoides*, SP=*S. pinnata*, SA=*S. albiflorum.* Columns not sharing the same superscript letter are significantly different (Turkey's HSD, α= 0.05).

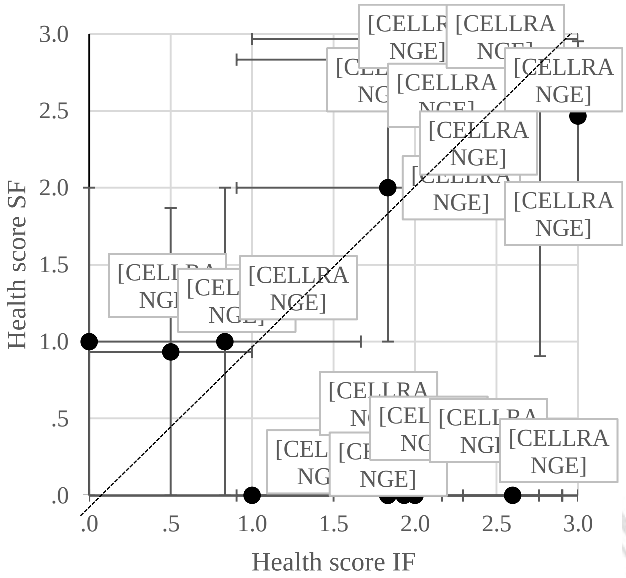


Figure 4.29 Comparison of mean (±SE) health score of one year direct-seeded seedlings in the field between two sowing periods, IF = sown at collection time, SF= Stored and sown at the beginning of rainy season (N=3). Dashed line indicates axis X equals axis Y. AF=*A. fraxinifolius*, AM=*A. microsperma*, AK=*A. kurzii*, AL=*A. lacucha*, BV=*B. variegata*, CA=*C. axillaris*, DL=*D. longan*, DG=*D. glandulosa*, GA=*G. arborea*, HG=*H. glabra*, HD=*H. dulcis*, MA= *M. azedarach*, MG=*M. garrettii*, PE=*P. emblica*, PC=*P. cerasoides*, SP=*S. pinnata*, SA=*S. albiflorum.*

4.3.5 Relationship between Seed Size and Other Factors

Correlations between dry seed mass or seed size of studied species and tested factors (germination, MLD, percent yield, height RGR, crown width RGR and RCD RGR) were very low or non-existent (r^2 =0.0015, 0.017, 0.0056, 0.1119, 0.0605 and 0.1356 respectively, Figures 4.30 and 4.31).

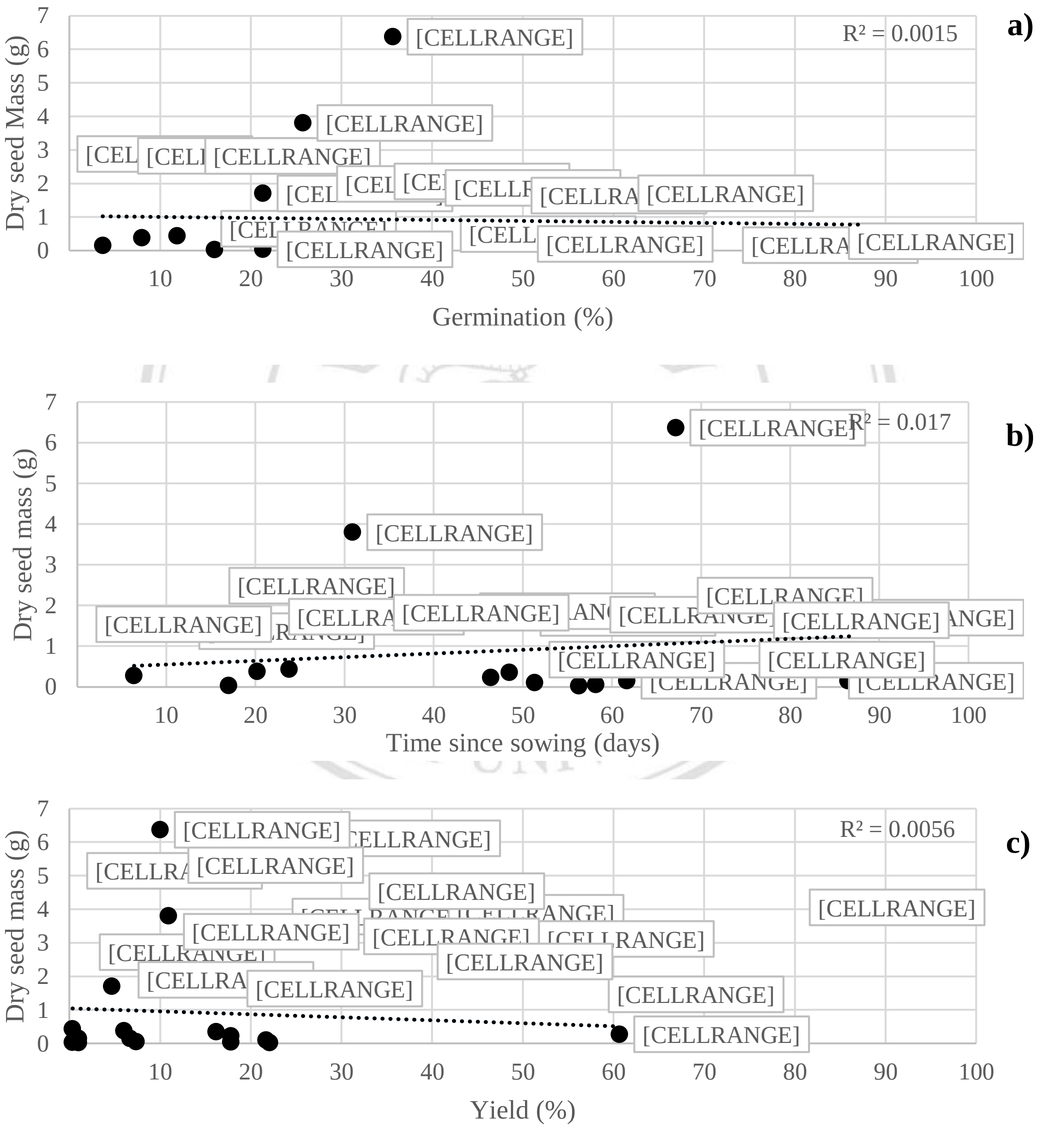


Figure 4.30 Relationship between dry seed mass (g) and a) percent germination, b) median length of dormancy (days) and c) percent yield; AF=*A. fraxinifolius*, AM=*A. microsperma*, AK=*A. kurzii*, AL=*A. lacucha*, BV=*B. variegata*, CA=*C. axillaris*, DL=*D. longan*, DG=*D. glandulosa*, GA=*G. arborea*, HG=*H. glabra*, HD=*H. dulcis*, MA= *M. azedarach*, MG=*M. garrettii*, PE=*P. emblica*, PC=*P. cerasoides*, SP=*S. pinnata*, SA=*S. albiflorum.*

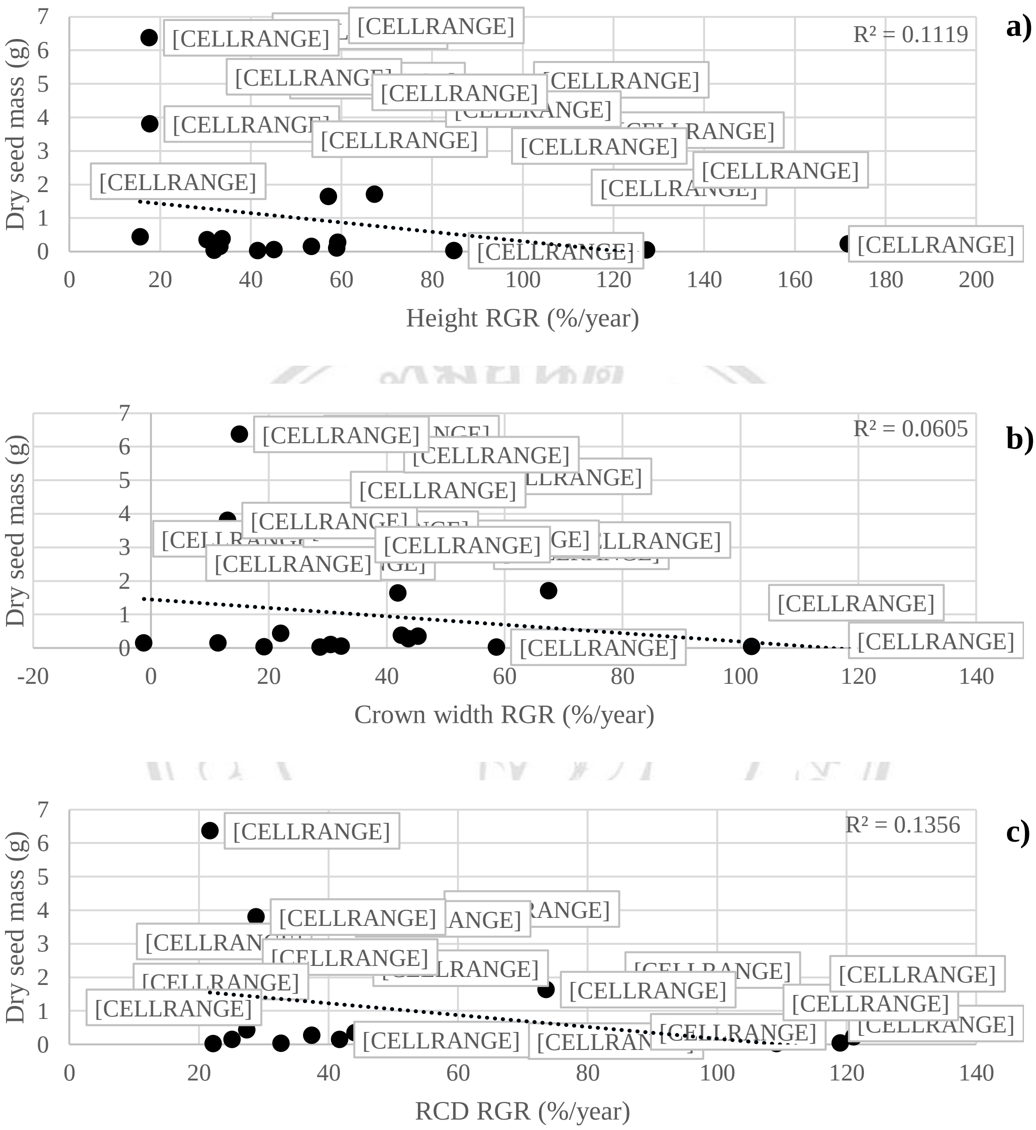


Figure 4.31 Relationship between dry seed mass (g) and a) height RGR (%/year), b) crown width (%/year) and c) RCD RGR (%/year),; AF=*A. fraxinifolius*, AM=*A. microsperma*, AK=*A. kurzii*, AL=*A. lacucha*, BV=*B. variegata*, CA=*C. axillaris*, DL=*D. longan*, DG=*D. glandulosa*, GA=*G. arborea*, HG=*H. glabra*, HD=*H. dulcis*, MA= *M. azedarach*, MG=*M. garrettii*, PE=*P. emblica*, PC=*P. cerasoides*, SP=*S. pinnata*, SA=*S. albiflorum.*

4.3.6 Relative Species Performance Indices (RSPI's)

Firstly, correlation analysis was performed to determine inter-relationships among the size and RGR measurements for height, CW and RCD, to identify the most appropriate variable to use for the SI calculation. Absolute height, crown width and root collar diameter (1 year after sowing) were all strongly and significantly correlated: i) height and crown width (r=0.96, p<0.01, N=17, Figure 4.32 a), ii) height and root collar diameter (r=0.80, p<0.01, N=17, Figure 4.32 b) and iii) crown width and root collar diameter (r=0.80, p<0.01, N=17, Figure 4.32 c). RGR values were also correlated, but slightly less strongly than the absolute size variables: i) height and crown width RGR (r=0.90, p<0.01, N=17, Figure 4.33 a), ii) height and root collar diameter (r=0.76, p<0.01, N=17, Figure 4.33 b) and iii) crown width and root collar diameter (r=0.73, p=0.01, N=17, Figure 4.33 c). Therefore, the SI results could be performed using any of these growth indicators.

In this study, 1-year seedling height was selected as the main factor since it was strongly correlated with the other parameters and also measuring height could be done with less error in the field, compared with the other parameters. A *relative* species performance index RSPI was calculated from the absolute 1-year seedling height multiplied by seeding yield, expressed as a per cent of the highest score, i.e. *B. variegata* = 100, followed by *P. cerasoides*, *M. azedarach*, *P. emblica* and *A. microsperma* (SI=84, 45.3, 25.8 and 17.4, respectively, Table 4.9).

In addition, another RSPI was calculated replacing absolute height with RGR height. Using this substitution did not change the order of the top five species compared with the RSPI using absolute height. *B. variegata* showed the highest (100) followed by *P. cerasoides, M. azedarach*, *P. emblica* and *A. microsperma* (RSPI = 85.2, 63.1, 52.1 and 35.6, respectively, Table 4.10).

A third calculation method was based on i) seedling volume increment (calculated by combining relative growth rate data using height, crown width and RCD) and ii) percent yield. The proportion of these two factors were equally weight. This calculation method produced a slightly different result. The top five species remained the same but in a different order. *P. cerasoides* exhibited the highest species performance (SI=64.7), followed by *B. variegata*, *M. azedarach*, *P. emblica* and *A. microsperma* (SI=51.6, 50.5, 38.3 and 23.3, respectively). The remaining species had RSPI values of less than half that

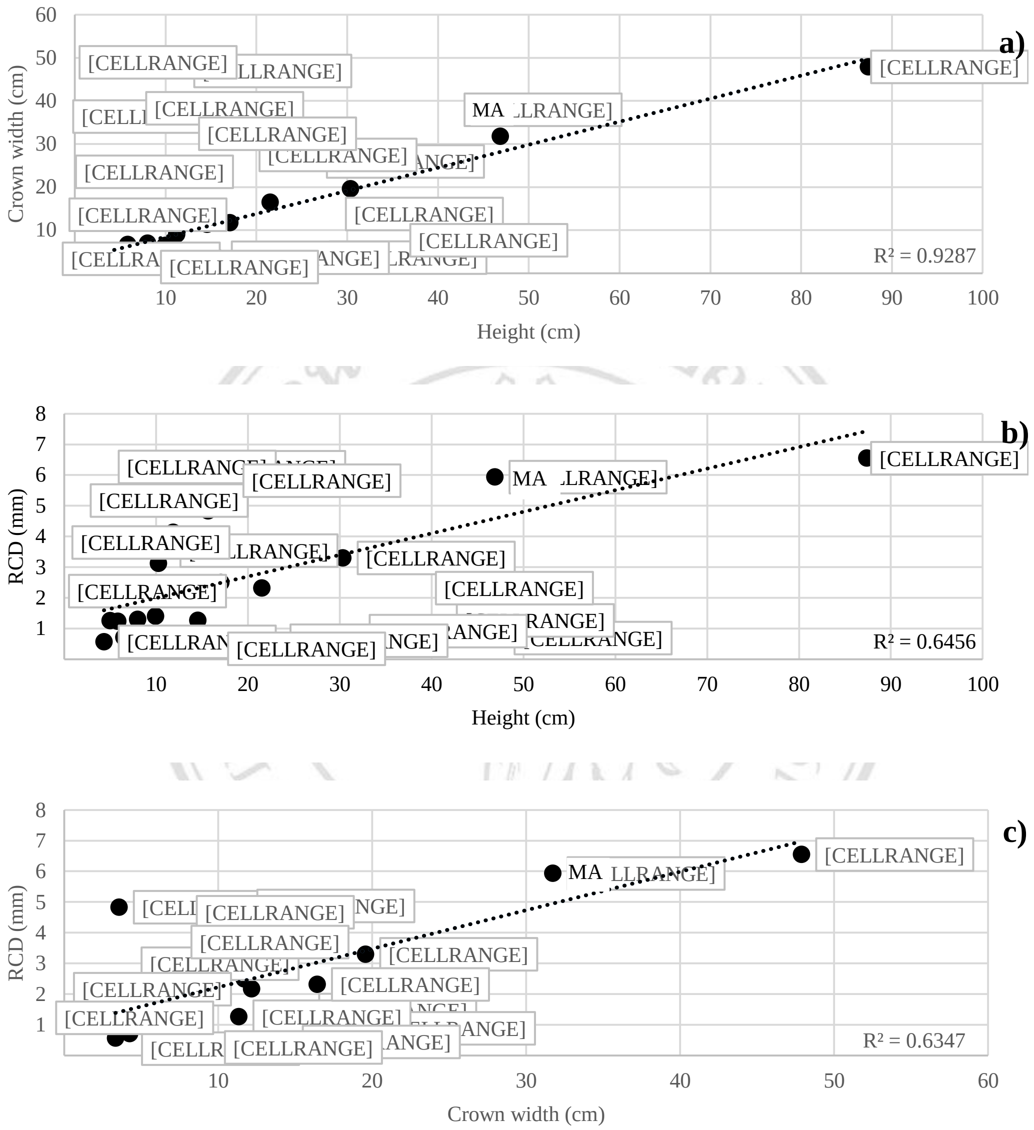


Figure 4.32 Relation of mean height, crown width and root collar diameter of one year direct-seeded seedlings in the field. Plotted from 17 species, three replicates in two sowing treatments (N=17). a) Height and crown width, b) Height and root collar diameter and c) Crown width and root collar diameter. Dotted line indicates trend of relation. Species; AF=*A. fraxinifolius*, AM=*A. microsperma*, AK=*A. kurzii*, AL=*A. lacucha*, BV=*B. variegata*, CA=*C. axillaris*, DL=*D. longan*, DG=*D. glandulosa*, GA=*G. arborea*, HG=*H. glabra*, HD=*H. dulcis*, MG=*M. garrettii*, MA= *M. azedarach*, PE=*P. emblica*, PC=*P. cerasoides*, SP=*S. pinnata*, SA=*S. albiflorum.*

of the best performing species, with *G. arborea* having the lowest (SI= 0.5, Table 4.11).

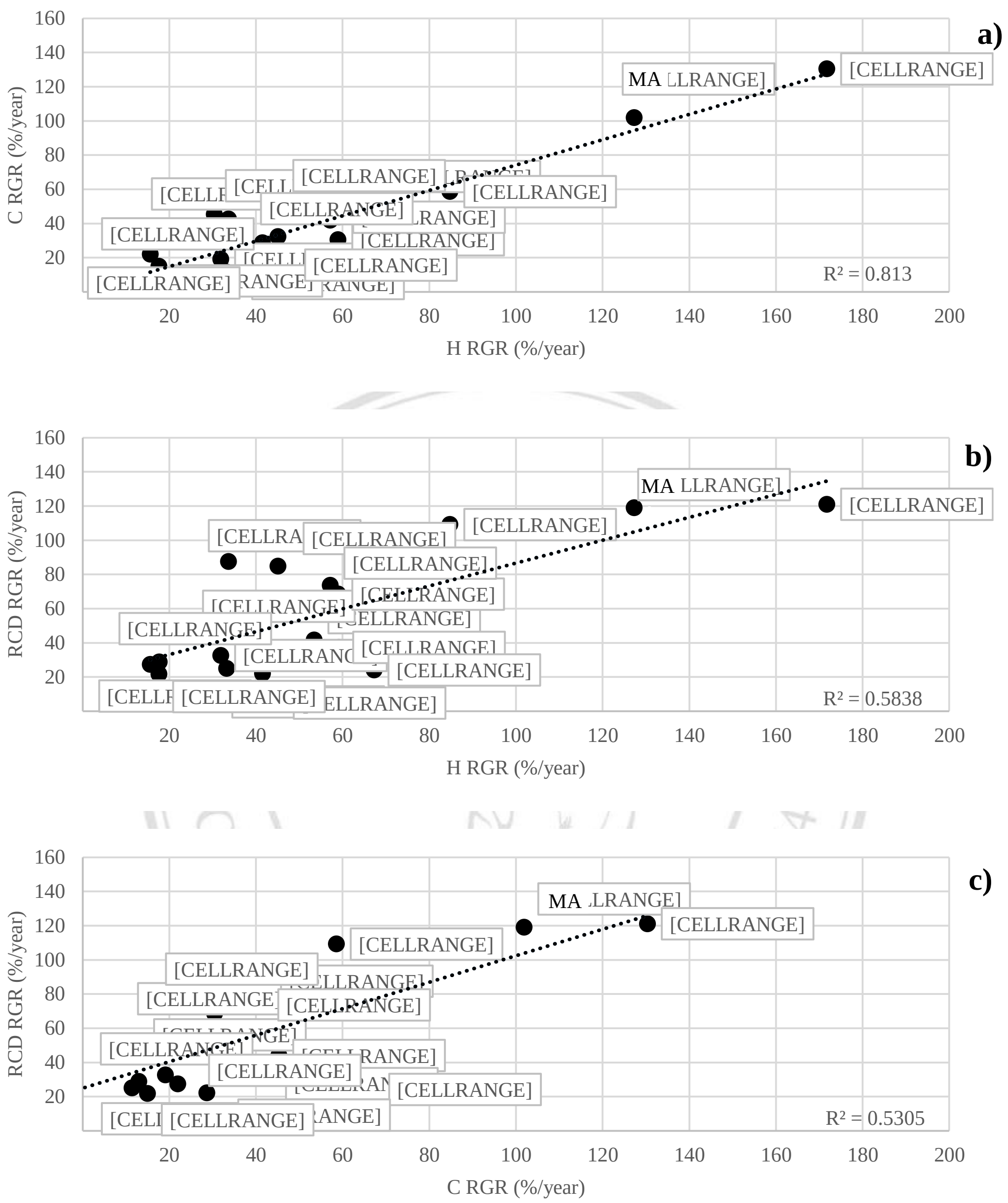


Figure 4.33 Relation of mean height, crown width and root collar diameter relative growth rate (H RGR, C RGR and R RGR, respectively) of one year direct-seeded seedlings in the field. Plotted from 17 species, three replicates in two sowing treatments (N=17). a) H RGR and C RGR, b) H RGR and R RGR and c) R RGR and C RGR. Dotted line indicates trend of relation. Species; AF=*A. fraxinifolius*, AM=*A. microsperma*, AK=*A. kurzii*, AL=*A. lacucha*, BV=*B. variegata*, CA=*C. axillaris*, DL=*D. longan*, DG=*D. glandulosa*, GA=*G. arborea*, HG=*H. glabra*, HD=*H. dulcis*, MG=*M. garrettii*, MA= *M. azedarach*, PE=*P. emblica*, PC=*P. cerasoides*, SP=*S. pinnata*, SA=*S. albiflorum.*

Table 4.9 Relative Species Performance Index (RSPI), calculation of growth index of height of direct-seeded seedlings over one year in the field.

Species	% Yield (Y)	Mean Height (cm) (H)	Y x H	RSPI
Bauhinia variegata	60.7	30.4	1841.2	100.0
Prunus cerasoides	17.8	87.4	1555.7	84.5
Melia azedarach	17.8	46.9	834.5	45.3
Phyllanthus emblica	22.1	21.5	474.8	25.8
Adenanthera microsperma	21.7	14.8	320.3	17.4
Syzygium albiflorum	18.0	17.1	307.2	16.7
Artocarpus lacucha	16.2	11.2	181.6	9.9
Horsfieldia glabra	10.9	15.7	170.8	9.3
Spondias pinnata	10.0	10.3	102.8	5.6
Manglietia garrettii	7.3	11.9	87.1	4.7
Choerospondias axillaris	4.7	14.6	68.0	3.7
Alangium kurzii	6.7	10.0	66.4	3.6
Dimocarpus longan	6.0	8.0	48.0	2.6
Hovenia dulcis	1.0	6.5	6.5	0.4
Diospyros glandulosa	1.0	5.8	5.8	0.3
Acrocarpus fraxinifolius	0.3	4.3	1.4	0.1
Gmelina arborea	0.3	5.0	1.7	0.1

Table 4.10 Relative Species Performance Index (RSPI), calculation of growth index of height relative growth rate of direct-seeded seedlings over one year in the field.

Species	% Yield (% E)	Mean H RGR (H)	% E x H	RSPI
Bauhinia variegata	60.7	59.2	3,588.4	100.0
Prunus cerasoides	17.8	171.8	3,057.2	85.2
Melia azedarach	17.8	127.3	2,265.9	63.1
Phyllanthus emblica	22.1	84.8	1,871.3	52.1
Adenanthera microsperma	21.7	59.0	1,277.3	35.6
Syzygium albiflorum	18.0	57.1	1,028.4	28.7
Artocarpus lacucha	16.2	30.4	491.5	13.7
Alangium kurzii	6.7	53.4	356.2	9.9
Manglietia garrettii	7.3	45.1	330.6	9.2
Choerospondias axillaris	4.7	67.3	314.1	8.8
Dimocarpus longan	6.0	33.7	202.2	5.6
Horsfieldia glabra	10.9	17.7	192.6	5.4
Spondias pinnata	10.0	17.6	176.0	4.9

Hovenia dulcis	1.0	41.5	41.5	1.2
Diospyros glandulosa	1.0	33.2	33.2	0.9
Acrocarpus fraxinifolius	0.3	31.9	10.6	0.3
Gmelina arborea	0.3	15.6	5.2	0.1

Table 4.11 Relative Species Performance Index (RSPI), calculation of growth index of relative growth rate (RGR) of direct-seeded seedlings over one year in the field.

Species	**% Yield**	**Relative Yield**	**Growth Index (GI)***	**Relative Growth Index**	**RSPI****
Prunus cerasoides	17.8	29.3	659,021.8	100.0	64.7
Bauhinia variegata	60.7	100.0	21,693.1	3.3	51.6
Melia azedarach	17.8	29.3	472,071.4	71.6	50.5
Phyllanthus emblica	22.1	36.4	264,658.4	40.2	38.3
Adenanthera microsperma	21.7	35.7	72,515.3	11.0	23.3
Syzygium albiflorum	18.0	29.7	81,098.2	12.3	21.0
Artocarpus lacucha	16.2	26.6	15,480.6	2.3	14.5
Manglietia garrettii	7.3	12.1	84,830.3	12.9	12.5
Dimocarpus longan	6.0	9.9	67,556.6	10.3	10.1
Horsfieldia glabra	10.9	18.0	5,396.6	0.8	9.4
Spondias pinnata	10.0	16.5	2,183.6	0.3	8.4
Alangium kurzii	6.7	11.0	24,350.4	3.7	7.3
Choerospondias axillaris	4.7	7.7	10,380.7	1.6	4.6

Diospyros glandulosa	1.0	1.6	5,490.0	0.8	1.2
Hovenia dulcis	1.0	1.6	3,847.3	0.6	1.1
Acrocarpus fraxinifolius	0.3	0.5	8,926.5	1.4	1.0
Gmelina arborea	0.3	0.5	3,097.3	0.5	0.5

*Growth Index was calculated from Seedling volume (1/3 π x r^2 x H) + RCR Crown width, r= RGR Root collar diameter divided by 2, H= RGR height.
** Species Performance Index calculated from (Relative Yield + Relative Growth Index)/2

4.3.7 Seedling Sturdiness

Seedling sturdiness was calculated from seedling height (cm) divided by root collar diameter (mm). Good quality planting stock, raised in a nursery, is considered sturdy if this index is <10. The mean sturdiness quotient, across all species, was 5.3 ± 0.5, ranging from 0.7 in *G. arborea* to 12.9 in *C. axillaris* (Figure 4.34). The sturdiness quotient was mostly did not differ significantly between the two sowing periods. While, *M. azedarach* seedlings from seeds sown at collection time were more sturdy than those sown after storage (sturdiness quotient lower by 3.5, *t*-test, *p*=0.04, Figure 4.35).

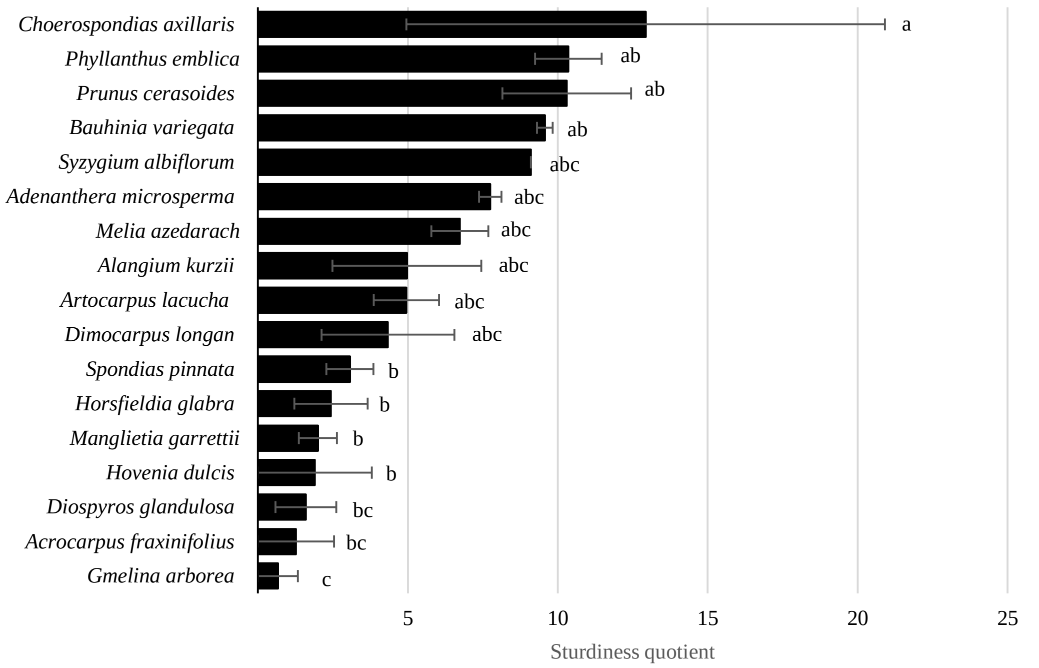


Figure 4.34 Sturdiness quotient of one year direct-seeded seedlings in the field, calculated from two seed sowing times, at collection time and beginning of rainy season after storage. Columns not sharing the same superscript letter are significantly different (Turkey's HSD, α= 0.05).

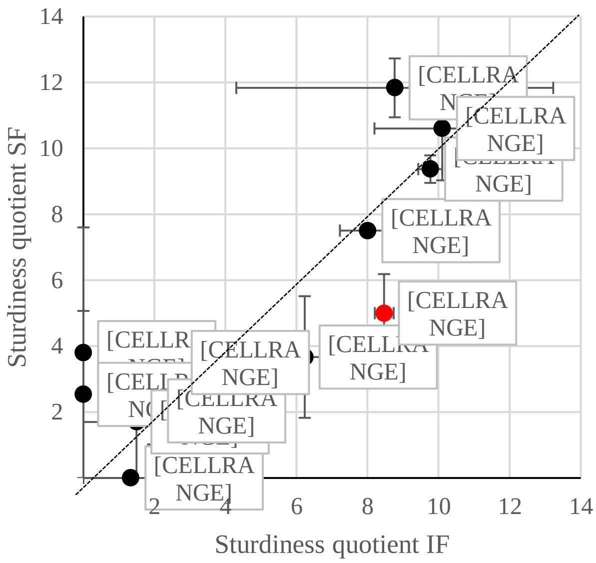


Figure 4.35 Comparison of mean (± SE) sturdiness quotient of one year direct-seeded seedlings in the field between two sowing periods, IF = sowing immediately at collecting time, SF=Stored and sown in the field (N=3). Red circles indicate significant difference between the two bars within each species (t-test, p < 0.05). Dashed line indicates axis X equals axis Y. AF=*A. fraxinifolius,* AM=*A. microsperma*, AK=*A. kurzii,* AL=*A. lacucha,* BV=*B. variegata*, CA=*C. axillaris,* DL=*D. longan,* DG=*D. glandulosa*, GA=*G. arborea,* HG=*H. glabra*, HD=*H. dulcis,* MA= *M. azedarach,* MG=*M. garrettii*, PE=*P. emblica,* PC=*P. cerasoides,* SP=*S. pinnata,* SA=*S. albiflorum.*

4.3.8 Nursery-raised seedlings

Seedling survival

The mean (± SE) percent seedlings survival, across species, was 40.9 ± 3.5 %. *H. glabra* and *A. kurzii* presented the lowest percent seedling survival (3.3 ± 1.7 % and 10.1 ± 1.8 % respectively). In contrast, *M. azedarach, A. microsperma* and *D. longan* survived well in the field with high percentages (72.7 ± 10.5 %, 78.6 ± 6.6 % and 79.7 ± 4.6 %, respectively, Figure 4.36).

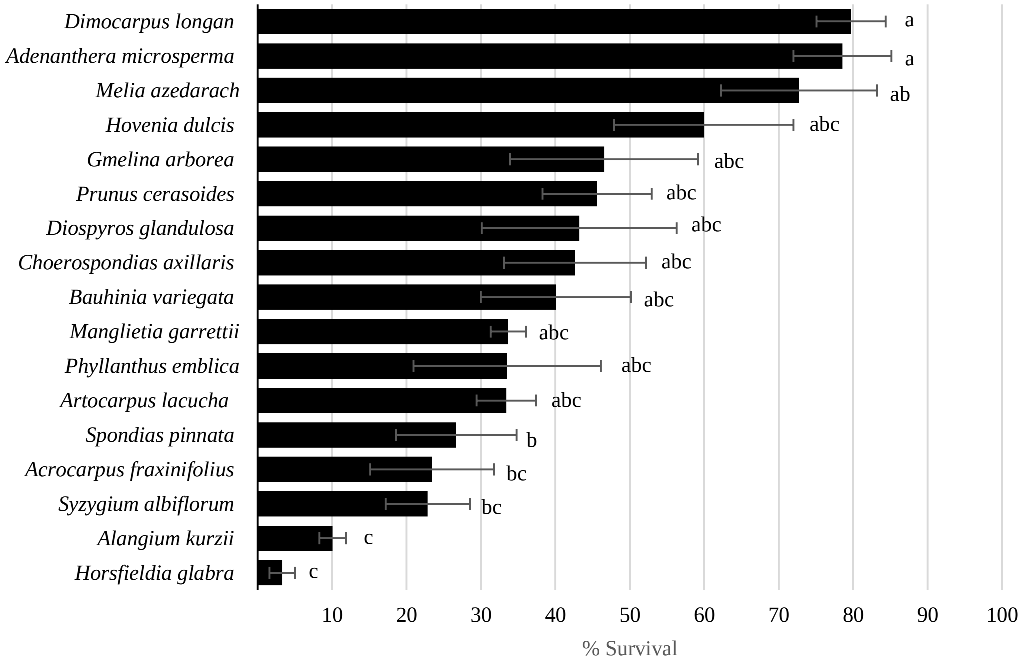


Figure 4.36 Comparison of percent survival of nursery raised-seedlings over one year in the field. Columns not sharing the same superscript letter are significantly different (Turkey's HSD, α= 0.05).

Seedling Growth

Seedling height, averaged across all species, one year after planting was 82.7 ± 9.9 cm. *M. azedarach* seedlings were the tallest (268.0 ± 60.8 cm), whilst *D. longan* seedlings were the shortest (21.3 ± 1.4 cm, Figure 4.37 a). Mean crown width, averaged across species, was 57.0 ± 5.5 cm. *M. azedarach* also showed the greatest crown expansion (142.5 ± 28.2 cm), whilst *H. glabra* achieved the least (18.3 ± 9.9 cm, Figure 4.37 b). Mean RCD averaged across species was 12.5 ± 1.2 mm. *G. arborea* presented the largest root collar diameter (28.3± 4.8 mm), whilst *H. glabra* presented the smallest (4.5 ± 2.3 mm, Figure 4.37 c).

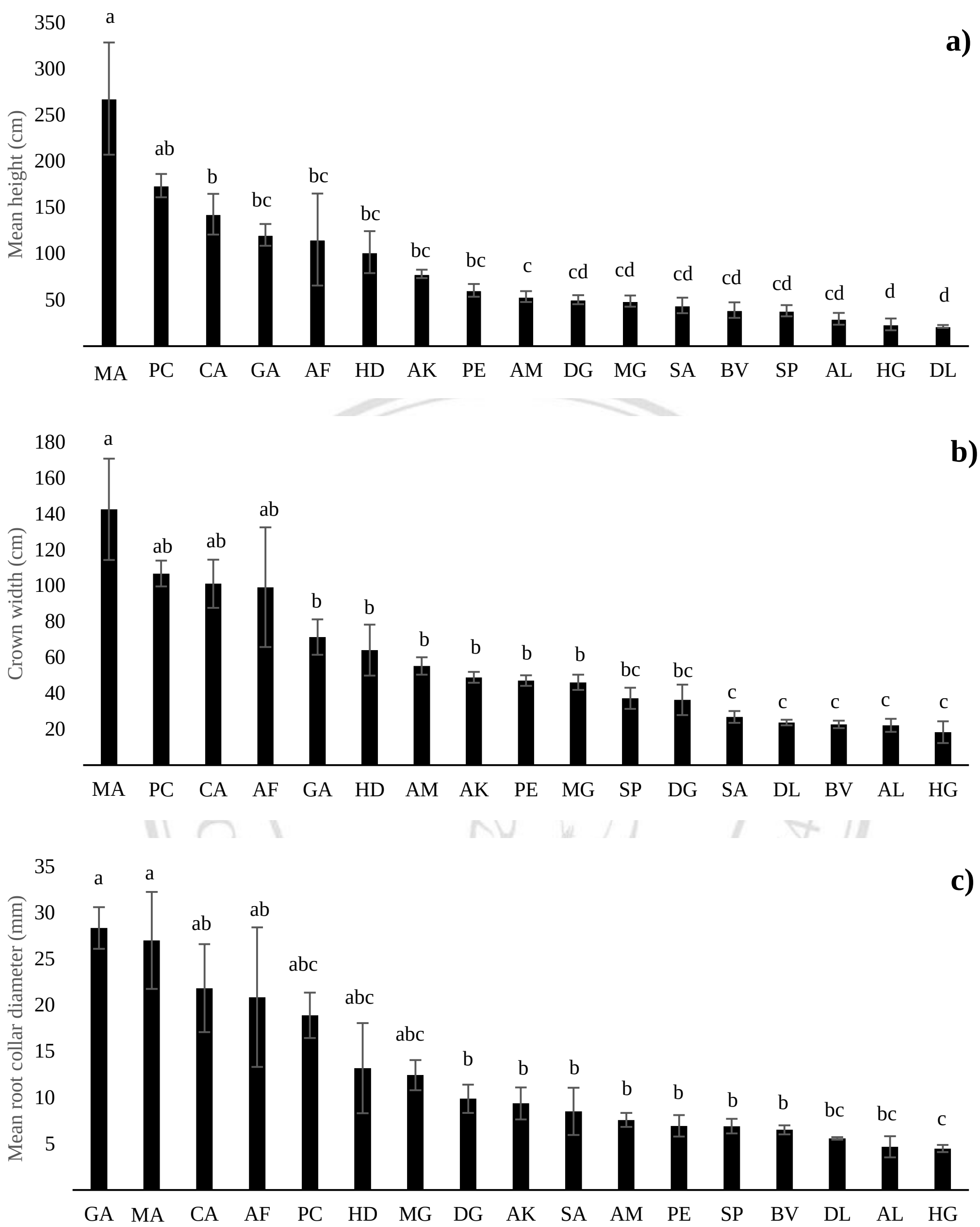


Figure 4.37 Comparison of seedlings performance of 1-year nursery-raised seedlings in the field, N=3. a) Mean seedling height b) Mean seedling crown width c) Mean root collar diameter. Species; AF=*A. fraxinifolius*, AM=*A. microsperma*, AK=*A. kurzii*, AL=*A. lacucha*, BV=*B. variegata*, CA=*C. axillaris*, DL=*D. longan*, DG=*D. glandulosa*, GA=*G. arborea*, HG=*H. glabra*, HD=*H. dulcis*, MG=*M. garrettii*, MA= *M. azedarach*, PE=*P. emblica*, PC=*P. cerasoides*, SP=*S. pinnata*, SA=*S. albiflorum*. Columns not sharing the same superscript letter are significantly different (Turkey's HSD, α= 0.05).

Relative growth rates (RGR) of nursery-raised seedlings were calculated 1 year after planting. The mean height RGR, averaged across species, was 126.7 ± 16.8 %. *M. azedarach* achieved the highest growth rate (290.6 ± 50.5 %/year) and other five species exceeded 200 %/year; *G. arborea* (286.4 ± 37.9 %/year), *C. axillaris* (248.6 ± 11.4 %/year), *P. cerasoides* (227.8 ± 75.0 %/year), *M. garrettii* (223.0 ± 23.6 %/year) and *A. fraxinifolius* (211.7 ± 22.6 %/year). Conversely, two species showed negative height RGR, indicating damage or die back of the above-ground seedling parts: *B. variegata* (-2.0 ± 34.1 %/year) and *H. glabra* (-38.4 ± 38.1 %/year, Figure 4.38 a). The mean crown width RGR across species was 181.1 ± 25.4 %/year. *H. dulcis* presented the highest (438.4 ± 113.5 %/year) followed by *M. azedarach* (385.8 ± 9.2 %/year) and *G. arborea* (347.8 ± 46.0 %/year). Three species presented negative values; *S. pinnata* (-2.2 ± 33.4 %/year), *B. variegata* (-11.5 ± 118.4 %/year) and *H. glabra* (-68.7 ± 91.0 %/year, Figure 4.38 b). The mean root collar diameter RGR, averaged across species, was 157.9 ± 17.1 %/year. *G. arborea* achieved the highest RCR RGR (368.3 ± 59.8 %) with *P. cerasoides*, *C. axillaris*, and *M. azedarach* all exceeding 300 %/year (323.1 ± 11.1, 315.7 ± 17.7 and 307.1 ± 22.5 %/year, respectively). *A. lacucha* had the slowest RGR RCD (25.9 ± 30.9 %/year, Figure 4.38 c).

Seedlings generally maintained good health throughout their first year. The mean seedling health score was 2.9 ± 0.1. Most species had health scores higher than 2.5, whilst *H. glabra* was the lowest (2.0 ± 1.0, Figure 4.39).

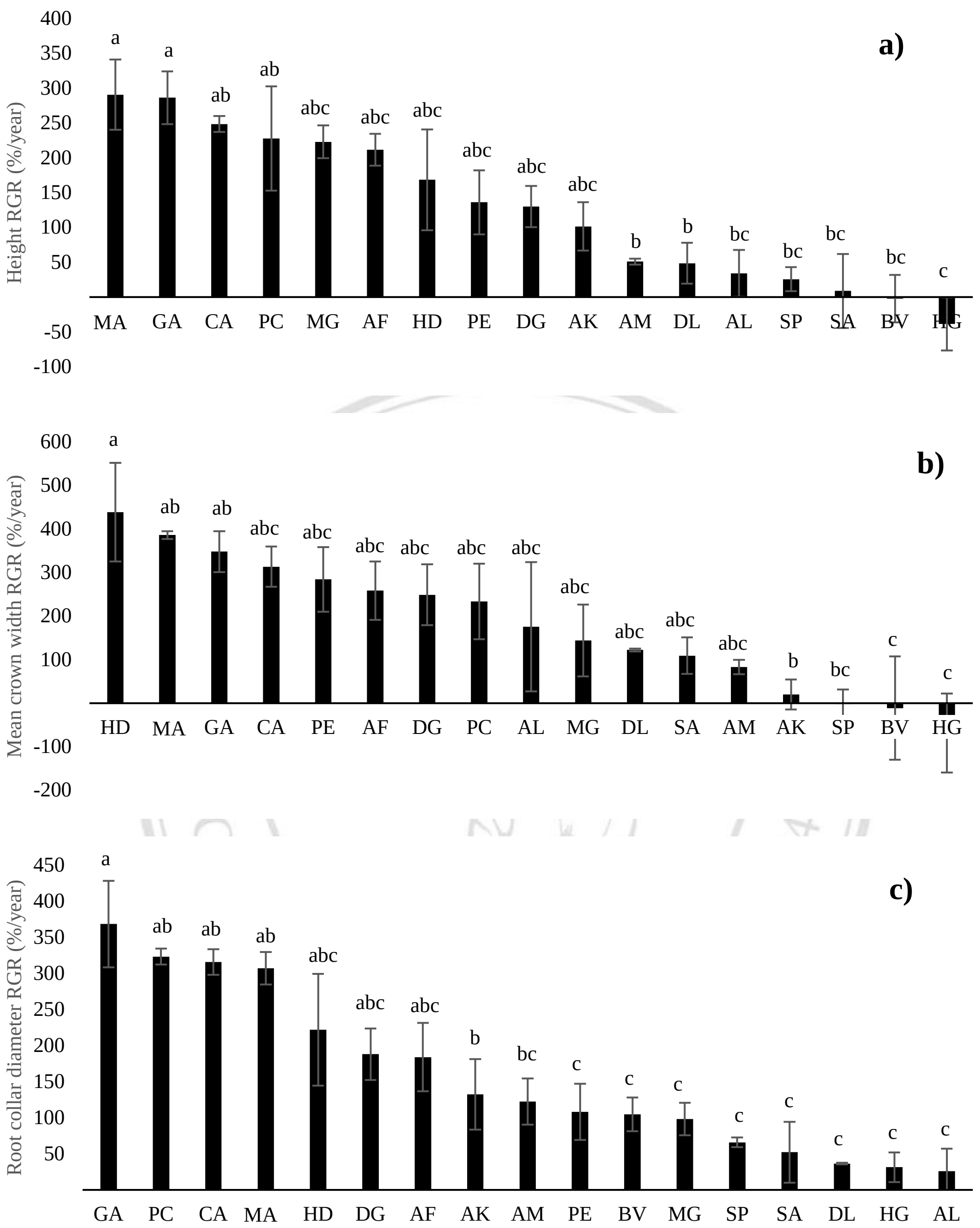


Figure 4.38 Comparison of relative growth rate (RGR) of nursery raised-seedlings in the field. a) Mean seedling height RGR b) Mean seedling crown width RGR and c) Mean root collar diameter RGR. Species; AF=*A. fraxinifolius*, AM=*A. microsperma*, AK=*A. kurzii*, AL=*A. lacucha*, BV=*B. variegata*, CA=*C. axillaris*, DL=*D. longan*, DG=*D. glandulosa*, GA=*G. arborea*, HG=*H. glabra*, HD=*H. dulcis*, MG=*M. garrettii*, MA= *M. azedarach*, PE=*P. emblica*, PC=*P. cerasoides*, SP=*S. pinnata*, SA=*S. albiflorum*. Columns not sharing the same superscript letter are significantly different (Turkey's HSD, α= 0.05).

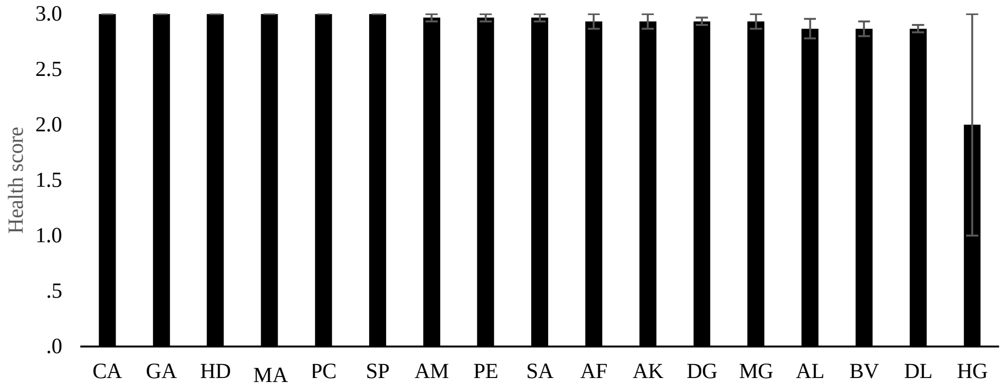


Figure 4.39 Health score of nursery raised-seedlings over one year in the field. Species; AF=*A. fraxinifolius,* AM=*A. microsperma*, AK=*A. kurzii*, AL=*A. lacucha*, BV=*B. variegata,* CA=*C. axillaris,* DL=*D. longan,* DG=*D. glandulosa*, GA=*G. arborea,* HG=*H. glabra,* HD=*H. dulcis*, MG=*M. garrettii*, MA= *M. azedarach,* PE=*P. emblica*, PC=*P. cerasoides,* SP=*S. pinnata,* SA=*S. albiflorum.*

Seedling Sturdiness

Mean seedling sturdiness quotient, averaged across species was 6.9 ± 0.4, which is well within the limit of <10, recommended for nursery-raised planting stock. *A. kurzii* was the least sturdy species (10.4 ± 2.1) followed by *H. dulcis* (10.0 ± 2.3). *H. glabra* was the sturdiest (3.5 ± 1.8, Figure 4.40).

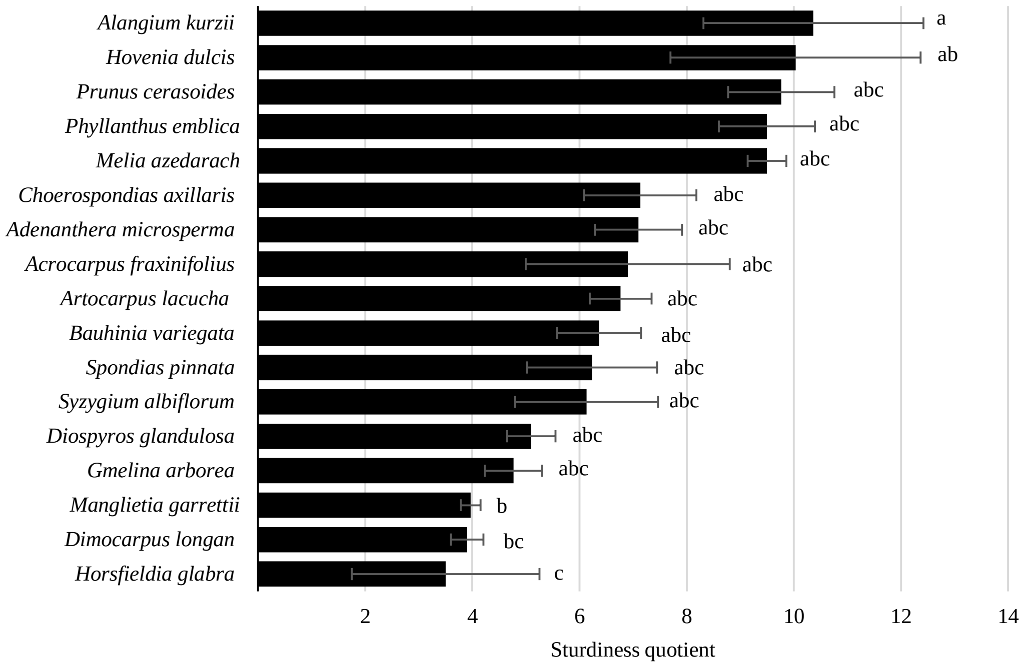


Figure 4.40 Sturdiness quotient of one year nursery raised-seedlings in the field. Columns not sharing the same superscript letter are significantly different (Turkey's HSD, α= 0.05).

Relative Species Performance Indices (RSPI's)

Size variables (height, crown width and root collar diameter) were strongly correlated with each other: i) height and crown width (r=0.96, p<0.01, N=17, Figure 4.41 a), ii) height and root collar diameter (r=0.86, p<0.01, N=17, Figure 4.41 b) and iii) crown width and root collar diameter (r=0.87, p<0.01, N=17, Figure 4.41 c), as were relative growth rates (RGR): i) height and crown width RGR (r=0.80, p<0.01, N=17, Figure 4.42 a), ii) height and root collar diameter RGR (r=0.86, p<0.01, N=17, Figure 4.42 b) and iii) crown width and root collar diameter RGR (r=0.72, p<0.01, N=17, Figure 4.42 c).

Relative Species Performance Index (RSPI) was calculated by two method, based on height RGR and growth index (combining all growth parameters) as previously described. Both indices produced similar results. Using the RGR height-based index, *M. azedarach* performed the best (SI= 100) followed by *G. arborea* (SI=63.1) and *C. axillaris* (SI=50.1) respectively. While *A. microsperma* had lowest performance (SI=49.1, Table 4.12). Similarly with the growth-based index, once again *M. azedarach* performed the best (SI= 80.9) followed by *G. arborea* (SI=79.2) and *C. axillaris* (SI=58.6) respectively. While *A. microsperma* had lowest performance (SI=7.3, Table 4.13).

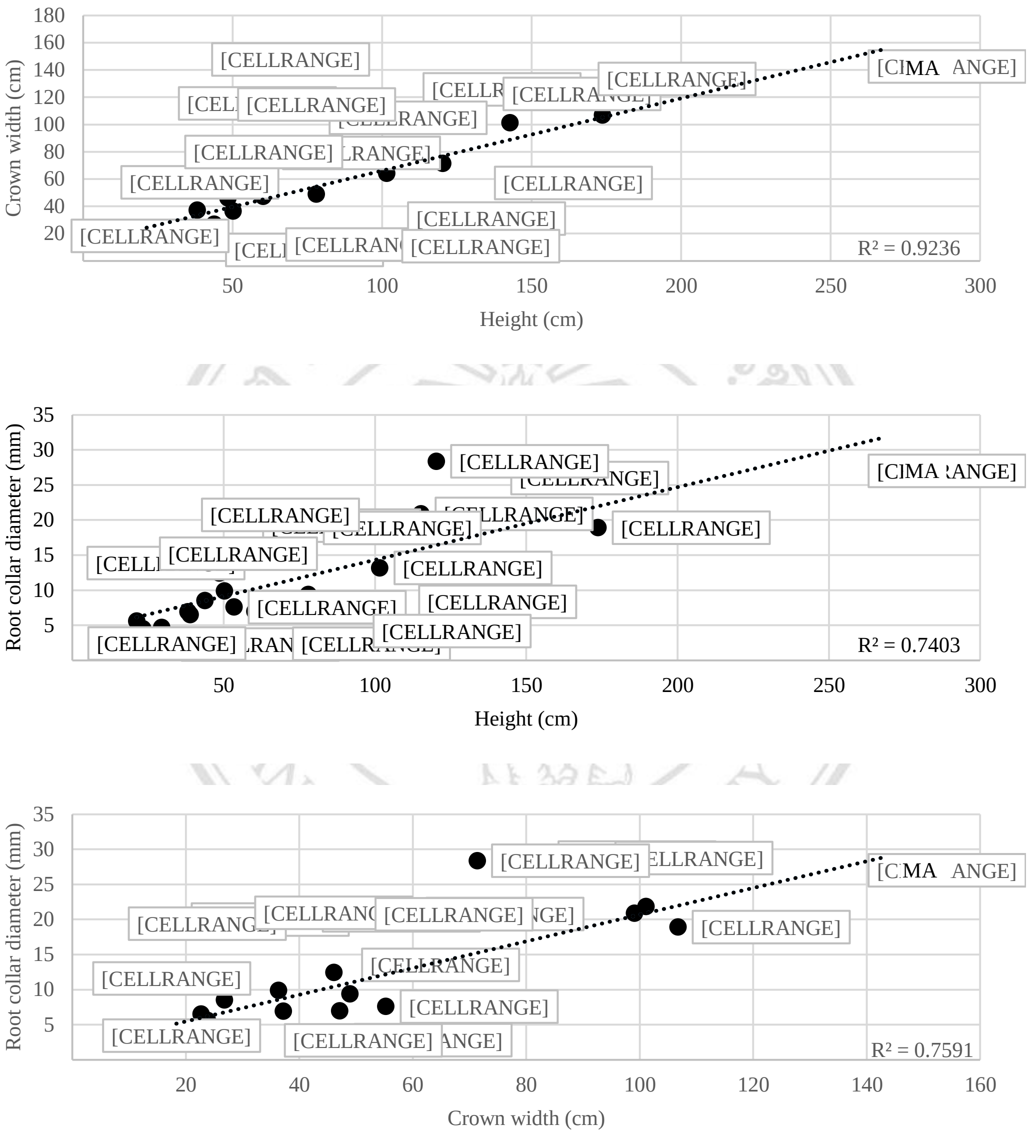


Figure 4.41 Relation of mean height, crown width and root collar diameter of one year nursery raised-seedlings in the field. Plotted from 17 species, three replicates in two sowing treatments (N=17). a) Height and crown width, b) Height and root collar diameter and c) Crown width and root collar diameter. Dotted line indicates trend of relation. Species; AF=*A. fraxinifolius*, AM=*A. microsperma*, AK=*A. kurzii*, AL=*A. lacucha*, BV=*B. variegata*, CA=*C. axillaris*, DL=*D. longan*, DG=*D. glandulosa*, GA=*G. arborea*, HG=*H. glabra*, HD=*H. dulcis*, MG=*M. garrettii*, MA= *M. azedarach*, PE=*P. emblica*, PC=*P. cerasoides*, SP=*S. pinnata*, SA=*S. albiflorum.*

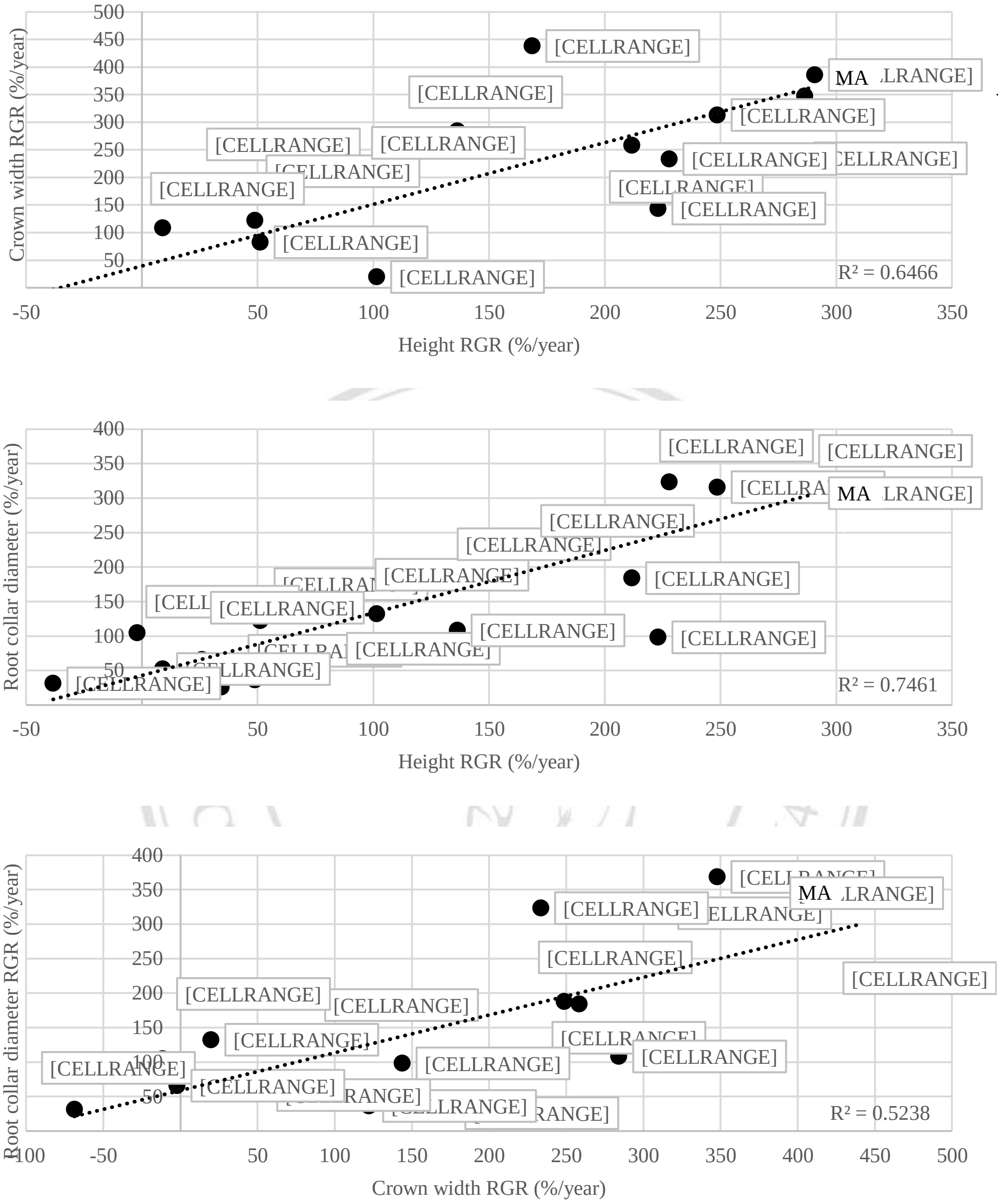


Figure 4.42 Relation of mean height, crown width and root collar diameter relative growth rate (H RGR, C RGR and R RGR, respectively) of one year nursery raised-seedlings in the field. Plotted from 17 species, three replicates in two sowing treatments (N=17). a) H RGR and C RGR, b) H RGR and R RGR and c) R RGR and C RGR. Dotted line indicates trend of relation. Species; AF=*A. fraxinifolius,* AM=*A. microsperma,* AK=*A. kurzii,* AL=*A. lacucha,* BV=*B. variegata,* CA=*C. axillaris,* DL=*D. longan,* DG=*D. glandulosa,* GA=*G. arborea,* HG=*H. glabra,* HD=*H. dulcis,* MG=*M. garrettii,* MA= *M. azedarach,* PE=*P. emblica,* PC=*P. cerasoides,* SP=*S. pinnata,* SA=*S. albiflorum.*

Species	% Yield (Y)	Mean H RGR (H)	Y x H	RSPI
Melia azedarach	72.7	290.6	21,136.1	100.0
Gmelina arborea	46.6	286.4	13,330.6	63.1
Choerospondias axillaris	42.6	248.6	10,599.5	50.1
Diospyros glandulosa	79.7	130.2	10,382.5	49.1
Prunus cerasoides	33.5	227.8	7,630.2	36.1
Manglietia garrettii	33.7	223.0	7,506.7	35.5
Phyllanthus emblica	45.6	136.2	6,210.5	29.4
Acrocarpus fraxinifolius	23.4	211.7	4,960.1	23.5
Alangium kurzii	33.4	101.5	3,388.4	16.0
Artocarpus lacucha	78.6	34.3	2,692.2	12.7
Dimocarpus longan	43.2	48.8	2,106.2	10.0
Spondias pinnata	22.8	25.9	590.6	2.8
Hovenia dulcis	3.3	168.5	555.2	2.6
Adenanthera microsperma	10.1	51.1	514.7	2.4
Syzygium albiflorum	26.7	9.0	240.0	1.1
Bauhinia variegata	40.1	- 2.0	-81.5	-0.4
Horsfieldia glabra	59.9	-38.4	-2,299.8	-10.9

Table 4.13 Relative Species Performance Index (RSPI) based on calculation of growth index of nursery-raised seedlings over one year in the field.

Species	% Seedling Yield	Relative Yield	Growth Index (GI)*	Relative Growth Index	RSPI**
Melia azedarach	72.7	91.2	7,172,603.4	70.6	80.9
Gmelina arborea	46.6	58.4	10,166,413.5	100.0	79.2
Choerospondias axillaris	42.6	53.5	6,483,651.7	63.8	58.6
Diospyros glandulosa	79.7	100.0	1,202,983.8	11.8	55.9
Prunus cerasoides	33.5	42.0	6,223,266.3	61.2	51.6
Artocarpus lacucha	78.6	98.6	6,174.6	0.1	49.3
Horsfieldia glabra	59.9	75.2	9,883.2	0.1	37.6
Phyllanthus emblica	45.6	57.2	416,849.5	4.1	30.6
Dimocarpus longan	43.2	54.2	16,936.6	0.2	27.2

Bauhinia variegata	40.1	50.3	-5,825.4	-0.1	25.1
Acrocarpus fraxinifolius	23.4	29.4	1,873,372.9	18.4	23.9
Manglietia garrettii	33.7	42.2	561,315.9	5.5	23.9
Alangium kurzii	33.4	41.9	464,974.1	4.6	23.2
Syzygium albiflorum	26.7	33.5	6,509.6	0.1	16.8
Spondias pinnata	22.8	28.6	29,213.8	0.3	14.5
Hovenia dulcis	3.3	4.1	2,166,667.4	21.3	12.7
Adenanthera microsperma	10.1	12.6	200,318.8	2.0	7.3

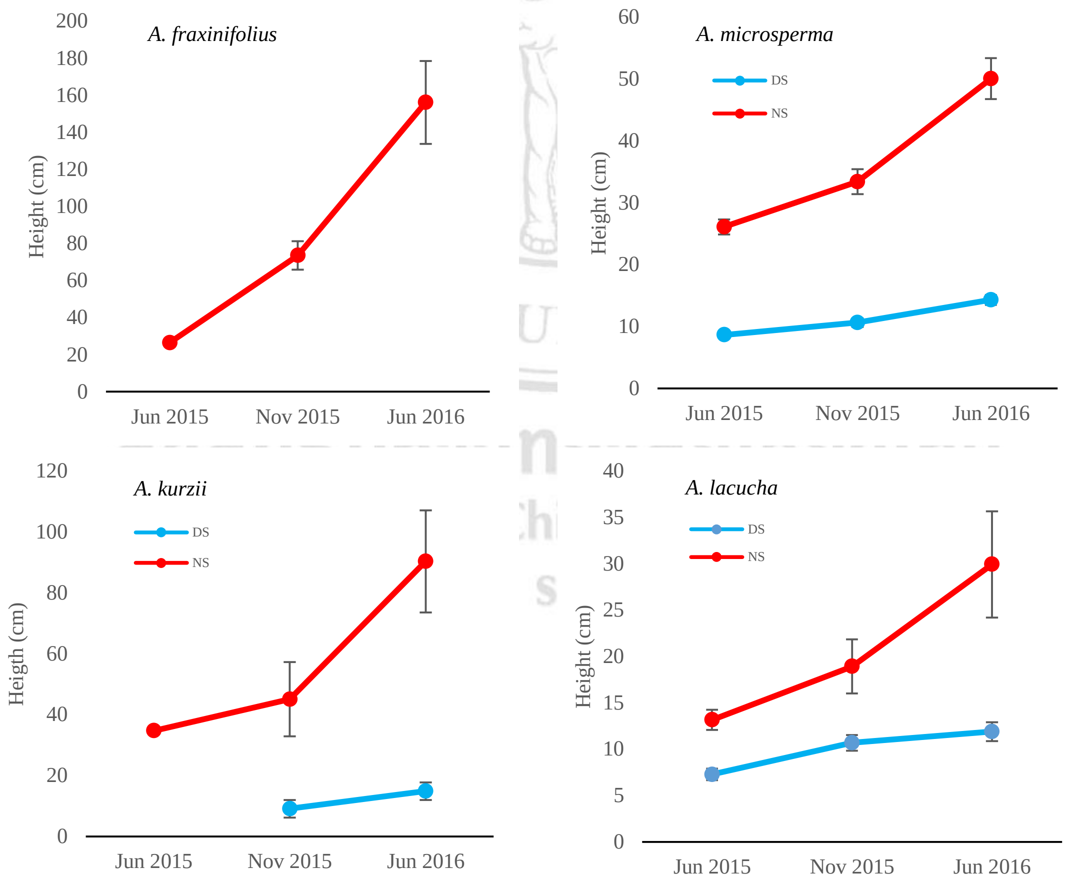
*Growth Index was calculated from seedling volume (1/3 π x r^2 x H) + RCR Crown width, r= RGR Root collar diameter divided by 2, H= RGR height.
** Species Performance Index calculated from (Relative Yield + Relative Growth Index)/2

4.3.9 Growth Comparison of Direct Seeded and Nursery-raised seedlings

Since size variables (height, CW and RCD, after 1 year) were strongly correlated (as shown in the previous sections), only one variable – height – was used in the following analysis. Direct-seeded seedlings grew less tall than nursery-raised seedlings (averaged across species), one year after planting. The mean heights of 1-year-old direct-seeded seedlings (DS) were close to the initial planting heights of nursery-raised seedlings (NS) of 7 species: *A. lacucha* (DS ages 12 Months = 11.9 cm and NS age 8 months = 13.2 cm), *B. variegata* (DS ages 12 months = 28.0 cm and NS ages 10 months = 27.1 cm), *C. axillaris* (DS ages 8 months = 24.0 cm and NS ages 8 months = 24.1 cm), *D. longan* (DS ages 12 months =13.0 cm and NS ages 9 months = 13.6 cm), *H. glabra* (DS ages 12 months = 19.5 cm and NS ages 13 months = 25.3 cm), *P. emblica* (DS ages 12 months = 25.4 cm and NS ages 14 months = 30.7 cm) and *S. albiflorum* (DS ages 12 months = 18.5 cm and NS ages 15 months = 22.1 cm)

For three species, 1-year-old direct-seeded seedlings were about twice as tall as the initial height of nursery-raised seedlings; *M. garrettii* (DS ages 12 months = 24.4 cm and NS ages 14 months = 13.5 cm), *M. azedarach* (DS ages 12 month = 61.2 cm and NS = 37.5 cm) and *P. cerasoides* (DS ages 12 months = 95.9 cm and NS ages 5 months = 35.7, Figure 4.43)

For *A. fraxinifolius*, *D. glandulosa*, *G. arborea* and *H. dulcis* results were available only from nursery-raised seedlings, since germination and seedling establishment from direct seeding was unsuccessful.



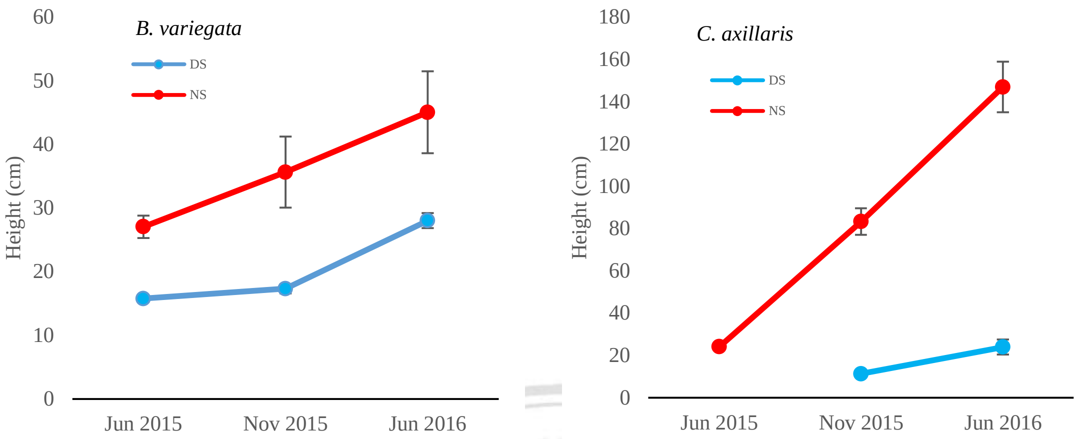
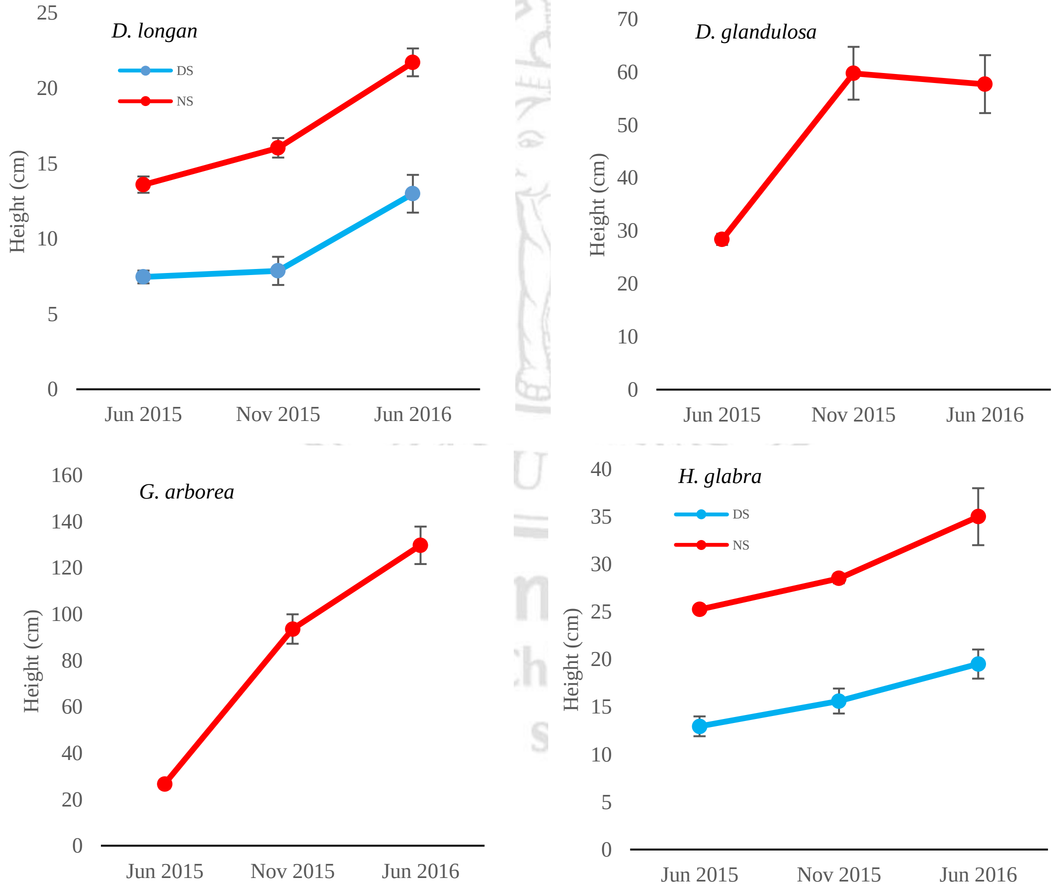


Figure 4.43 Comparison of mean height (±SE) of direct seeded and nursery-raised seedlings of 17 tree species in the field, monitored at 3 periods.



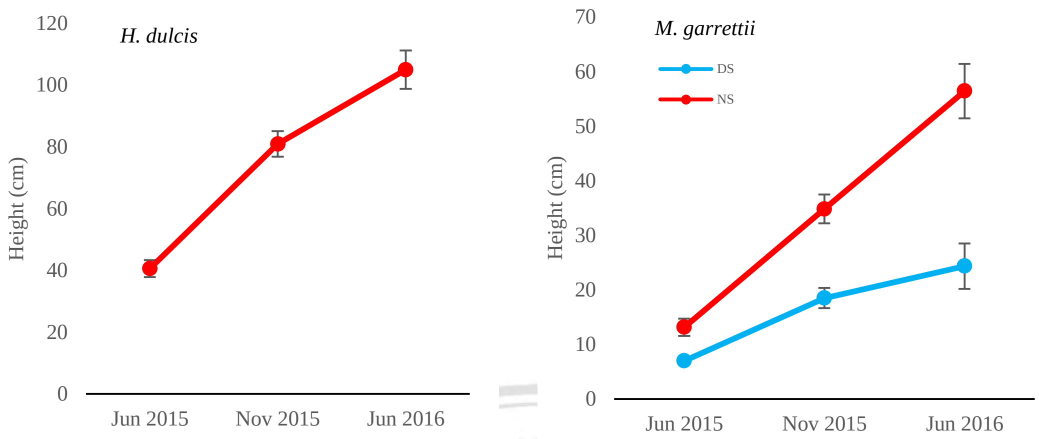
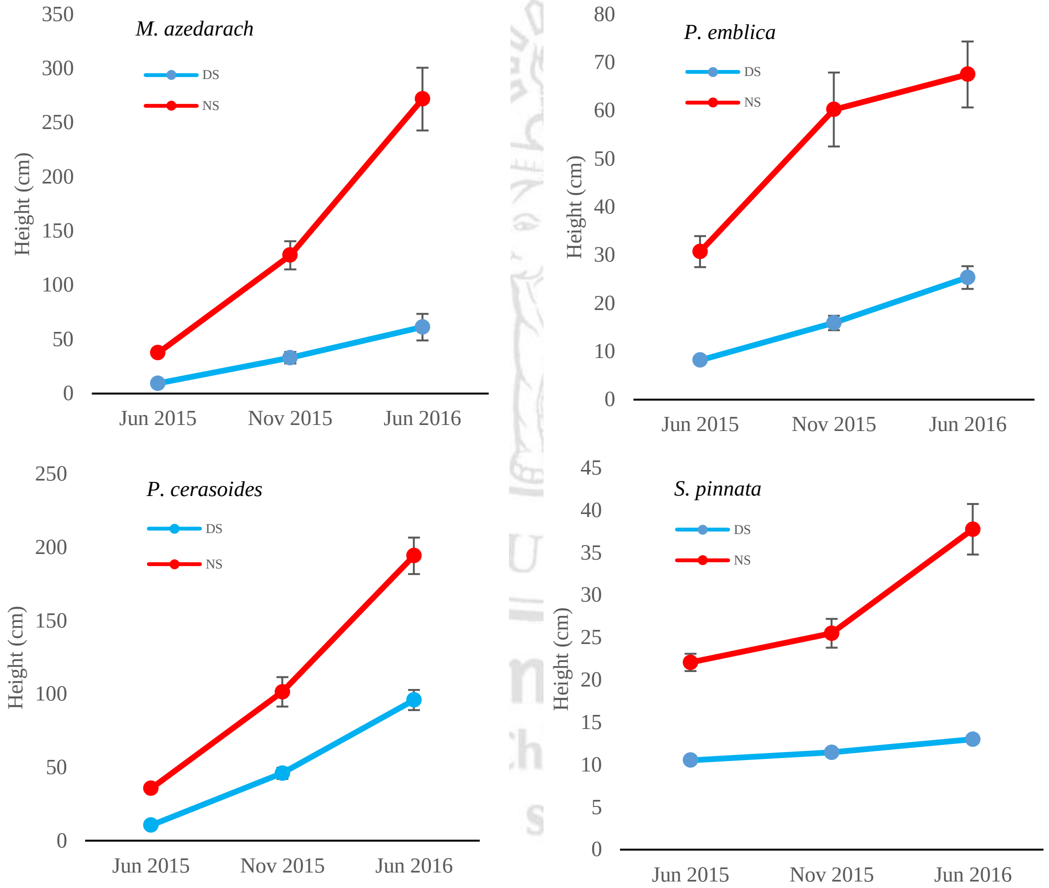


Figure 4.43 Continued.



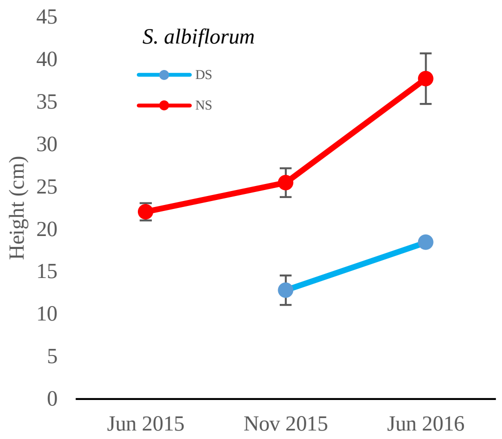


Figure 4.43 Continued.

Paired t-tests were performed, since each nursery raised seedling was planted next to direct seeded seedling. The mean height-RGR's of nursery-raised seedlings were significantly higher than those of direct-seeded seedlings in four studied species; *M. azedarach* (121.1 %/year higher, *t*-test, p=0.02, N=12), *P. cerasoides* (64.2 %/year higher, *t*-test, p=0.01, N=14), *D. longan* (130.4 %/year higher, *t*-test, p<0.01, N=8) and *M. garrettii* (71.6 %/year higher, *t*-test, p=0.04, N=9). In contrast, the mean height-RGR of *B. variegata* nursery-raised seedlings was 35.5 %/year lower than that of direct-seeded seedlings (*t*-test, p<0.01, N=15, Figure 4.44).

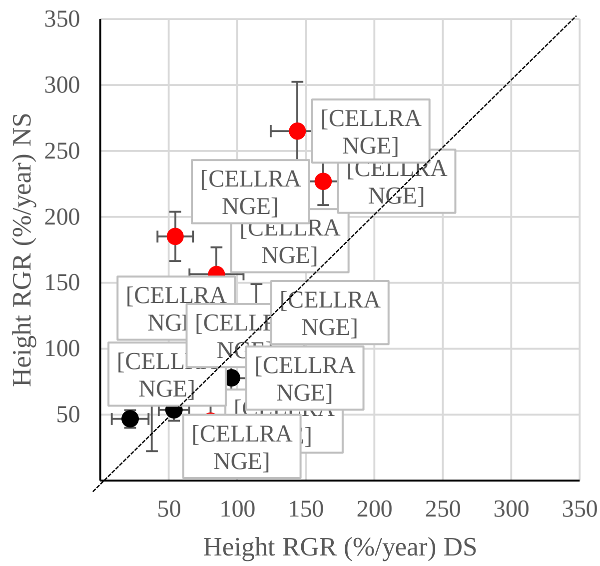


Figure 4.44 Comparison of mean (± SE) height relative growth rate (RGR) of 11 tree species seedlings, between nursery-raised seedlings (NS) and direct-seeded seedlings (DS). Red circles indicate significant difference between the two bars within each species (t-test, p < 0.05). Dashed line indicates axis X equals axis Y. AF=*A. fraxinifolius*, AM=*A. microsperma*, AK=*A. kurzii*, AL=*A. lacucha*, BV=*B. variegata*, CA=*C. axillaris*, DL=*D. longan*, DG=*D. glandulosa*, GA=*G. arborea*, HG=*H. glabra*, HD=*H. dulcis*, MA= *M. azedarach*, MG=*M. garrettii*, PE=*P. emblica*, PC=*P. cerasoides*, SP=*S. pinnata*, SA=*S. albiflorum*.

The mean CW-RGR's of nursery-raised seedlings were significant higher than those of directed-seeded seedlings for 6 species; *M. azedarach* (306.8 %/year higher, *t*-test, *p*<0.01, N=12), *A .lacucha* (280.3 %/year higher, *t*-test, *p*=0.03, N=9), *D. longan* (127.1 %/year higher, *t*-test, *p*=0.01, N=8), *P. emblica* (125.0 %/year higher, *t*-test, *p*=0.01, N=14) and *B. variegata* (31.0 %/year higher, *t*-test, *p*=0.04, N=15). *C. axillaris* was the only species for which CW-RGR was significantly lower (by 42.1 %/year) for nursery-raised seedlings (*t*-test, *p*=0.03, N=6 Figure 4.45).

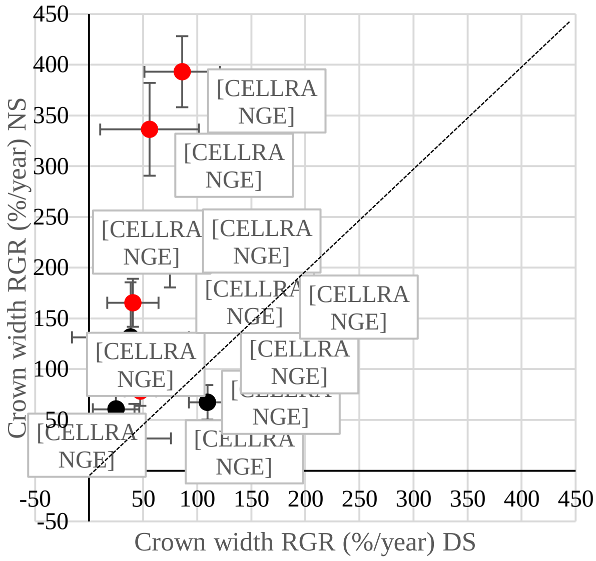


Figure 4.45 Comparison of mean (± SE) crown width relative growth rate (RGR) of 11 tree species seedlings, between nursery-raised seedlings (NS) and direct-seeded seedlings (DS). Red circles indicate significant difference between the two bars within each species (t-test, $p < 0.05$). Dashed line indicates axis X equals axis Y. AF=*A. fraxinifolius*, AM=*A. microsperma*, AK=*A. kurzii*, AL=*A. lacucha*, BV=*B. variegata*, CA=*C. axillaris*, DL=*D. longan*, DG=*D. glandulosa*, GA=*G. arborea*, HG=*H. glabra*, HD=*H. dulcis*, MA= *M. azedarach*, MG=*M. garrettii*, PE=*P. emblica*, PC=*P. cerasoides*, SP=*S. pinnata*, SA=*S. albiflorum.*

The mean RCD-RGR did not differ significantly between nursery-raised seedlings and direct-seeded seedlings, except for *M. azedarach*, for which nursery-raised seedlings achieved a mean RCD-RGR 235.5 %/year higher than that of direct-seeded seedlings (*t*-test, $p<0.01$, N=12, Figure 4.46).

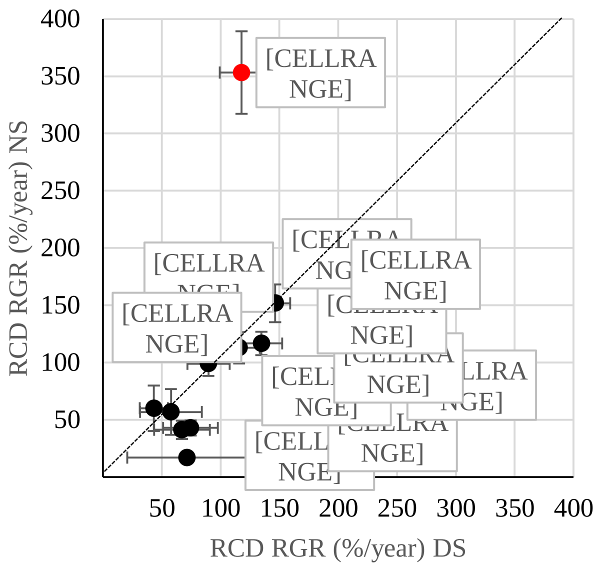


Figure 4.46 Comparison of mean (± SE) root collar diameter relative growth rate (RCD RGR) of 11 tree species seedlings, between nursery-raised seedlings (NS) and direct-seeded seedlings (DS). Red circles indicate significant difference between the two bars within each species (t-test, $p < 0.05$). Dashed line indicates axis X equals axis Y. AF=*A. fraxinifolius*, AM=*A. microsperma*, AK=*A. kurzii*, AL=*A. lacucha*, BV=*B. variegata*, CA=*C. axillaris*, DL=*D. longan*, DG=*D. glandulosa*, GA=*G. arborea*, HG=*H. glabra*, HD=*H. dulcis*, MA= *M. azedarach*, MG=*M. garrettii*, PE=*P. emblica*, PC=*P. cerasoides*, SP=*S. pinnata*, SA=*S. albiflorum.*

4.4 Hydrogel Experiment

Germination and dormancy of *A. fraxinifolius, A. lacucha, C. axillaris, G. arborea, P. emblica,* and *P. cerasoides* seeds were tested with mixture of hydrogel and forest soil in the nursery and the field. Statistical analyses were performed on the nursery data of all species and on the field data of *A. fraxinifolius, C. axillaris* and *P. emblica.* In the field, predators completely removed *A. lacucha, G. arborea* and *P. cerasoides* seeds (of all treatments) in replicate 1. Therefore, data from these species were insufficient for statistical analysis.

4.4.1 Seeds Germination and MLD

4.4.1.1 *Acrocarpus fraxinifolius*

Gel treatments did not significantly affect *A. fraxinifolius* seed germination or dormancy. Differences in mean percent germination and MLD were not significant, among all hydrogel treatments, both in the nursery and in the field (for germination ANOVA, *p*=0.45 and 0.07, Figure 4.47 a and b respectively and for dormancy ANOVA, *p*=0.38 and 0.75, Figure 4.47 c and d, respectively).

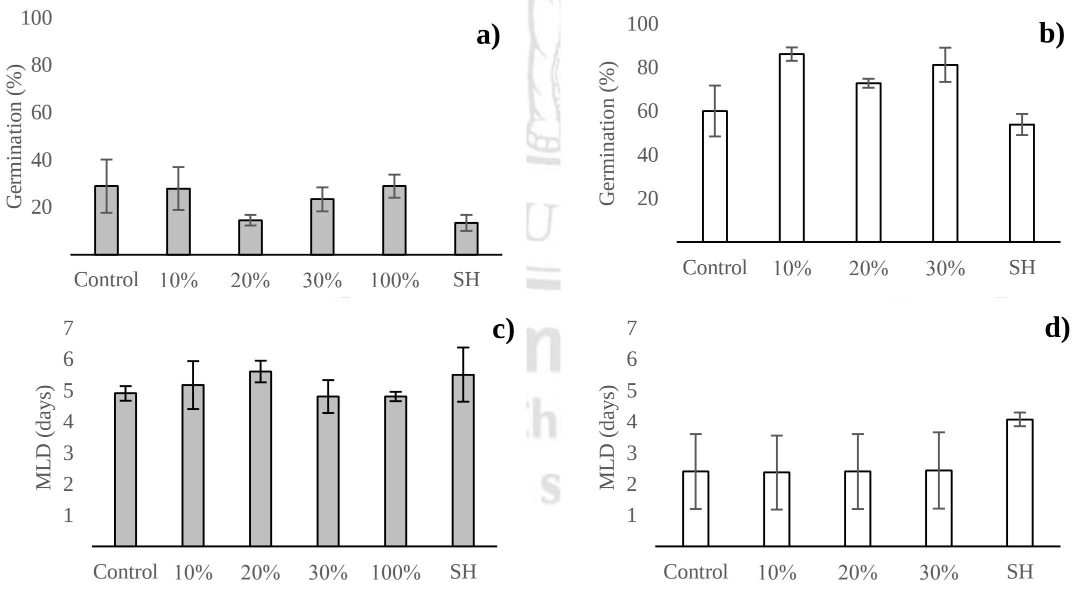


Figure 4.47 Mean (± SE) percent germination and MLD of *Acrocarpus fraxinifolius* a) germination in nursery, b) germination in field, c) MLD in nursery and d) MLD in field (3 replicates of 30 seeds each; control (forest soil); 10%, 20% and 30% hydrogel (by volume) mixed with forest soil; 100% (pure hydrogel, nursery only) and SH half layer of forest soil and hydrogel). See methods.

Consequently, to compare germination and dormancy between nursery and field conditions, data for all treatments (except 100% in the nursery) were combined for each location. Mean percent germination in field was significantly higher than in the nursey (by 64.0%). In contrast, dormancy showed no significantly differences (Table 4.14).

Table 4.14 Comparison of germination and median length of dormancy (MLD) of *Acrocarpus fraxinifolius* seeds between nursery and field (*t*-test on 15replicates; 30 seeds per replicate).

Parameters	Nursery		Field		*t*-test, *p*-value
	Mean	SE	Mean	SE	
Germination (%)	94.0	1.1	30.0	7.4	$p<0.01$
MLD (days)	32.6	0.0	29.5	6.6	0.63

4.4.1.2 *Choerospondias axillaris*

Differences in mean percent germination and MLD of *Choerospondias axillaris* were not significant, among all hydrogel treatments, both in the nursery and in the field, except that, germination in 100% hydrogel in the nursery was significantly lower than that of all other nursery treatments (germination ANOVA, $p<0.01$, Figure 4.48 a and $p=0.88$, Figure 4.468b and dormancy $p=0.80$ and 0.90, respectively, Figure 4.48 c and d).

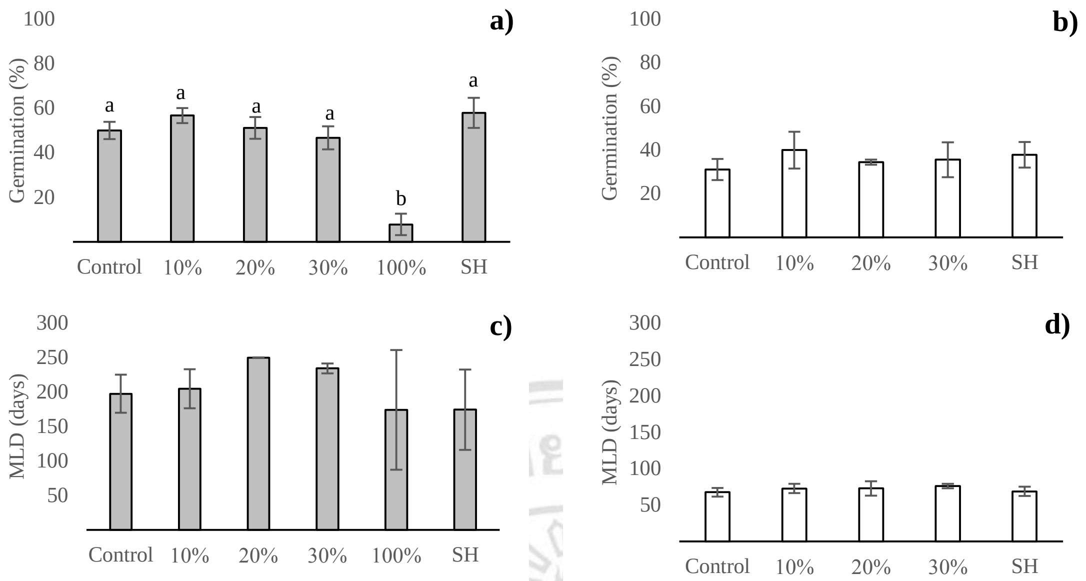


Figure 4.48 Mean (± SE) percent germination and MLD of *Choerospondias axillaris* a) germination in nursery, b) germination in field, c) MLD in nursery and d) MLD in field (3 replicates of 30 seeds each; control (forest soil); 10%, 20% and 30% hydrogel (by volume) mixed with forest soil; 100% (pure hydrogel, nursery only) and SH half layer of forest soil and hydrogel). See methods. Column not sharing the same superscript letters are statistically different among treatments (mean differentiation using Turkey's HSD, α= 0.05).

Consequently, to compare germination and dormancy between nursery and field conditions, data for all treatments (except 100%) were combined for each location. Mean percent germination in nursery was significantly higher in the nursery than in field (by 16.6%) but dormancy was significantly prolonged in the nursery (by 140.5 days, Table 4.15).

Table 4.15 Comparison of germination and median length of dormancy (MLD) of *Choerospondias axillaris* seeds between nursery and field, (*t*-test on 15 replicates; 30 seeds per replicate).

Parameters	Nursery		Field		*t*-test, *p*-value
	Mean	SE	Mean	SE	
Germination (%)	52.4	2.2	35.8	2.5	$p<0.01$
MLD (days)	212.1	14.0	71.6	2.7	$p<0.01$

4.4.1.3 *Phyllanthus emblica*

Differences in mean percent germination and MLD of *Phyllanthus emblica* were not significant, among all hydrogel treatments, both in the nursery and in the field (germination ANOVA, p=0.47 and 0.69, respectively, Figure 4.49 a and b; dormancy p=0.30 and 0.91, respectively, Figure 4.49 c and d)

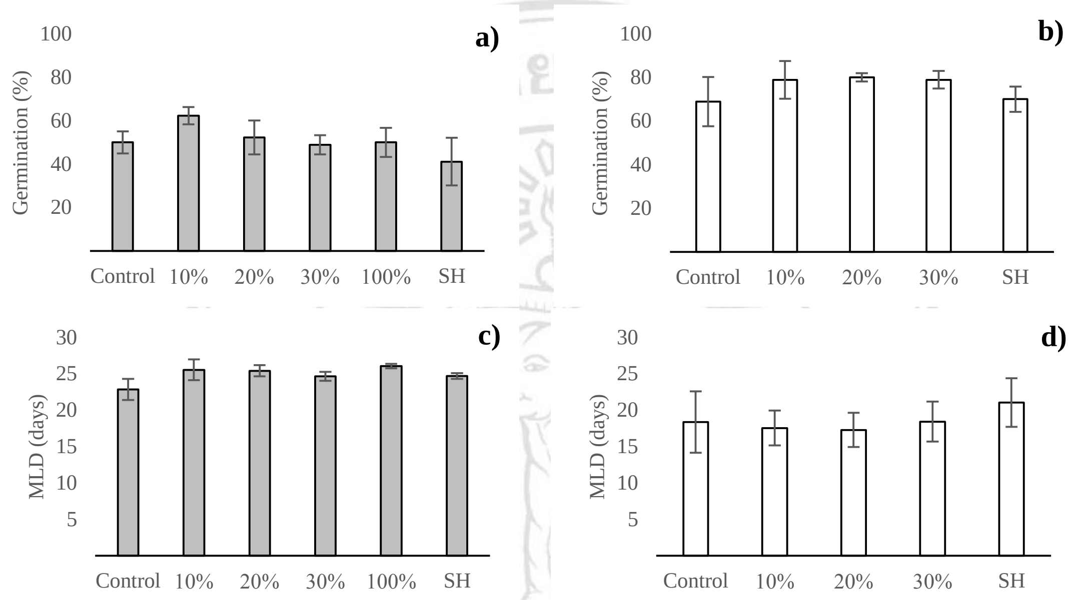


Figure 4.49 Mean (± SE) percent germination and MLD of *Phyllanthus emblica* a) germination in nursery, b) germination in field, c) MLD in nursery and d) MLD in field (3 replicates of 30 seeds each; control (forest soil); 10%, 20% and 30% hydrogel (by volume) mixed with forest soil; 100% (pure hydrogel, nursery only) and SH half layer of forest soil and hydrogel). See methods.

Consequently, to compare germination and dormancy between nursery and field conditions, data for all treatments (except 100%) were combined for each location. Mean percent germination was significantly higher (by 24.4%). and more rapid (by 6.1 days) in the field than in the nursery (Table 4.16).

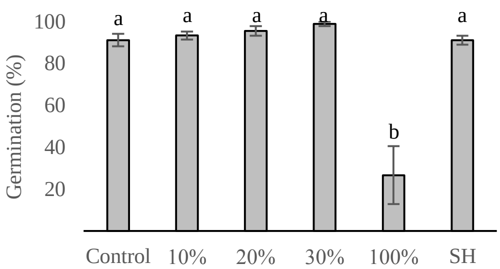
Table 4.16 Comparison of germination and median length of dormancy (MLD) of *Phyllanthus emblica* seeds between nursery and field, (t-test on 15 replicates; 30

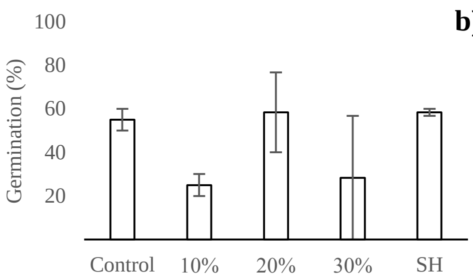
seeds per replicate).

Parameters	Nursery		Field		*t*-test, *p*-value
	Mean	SE	Mean	SE	
Germination (%)	50.9	3.2	75.3	3.0	p<0.01
MLD (days)	24.6	0.5	18.5	1.2	p<0.01

4.4.1.4 *Artocarpus lacucha*

As previously mentioned, only nursery data were analyzed statistically for this species. The 100% hydrogel treatment significantly decreased (by 64.5%), and delayed (by 6.5 days) germination, compared with all other treatments in the nursery (germination 22.6 ± 3.9%, ANOVA, p<0.01, Figure 4.50 a and dormancy 39.1 ± 1.0 days, ANOVA, p<0.01, Figure 4.50 c). In the field, mean percent germination ranged from 10 to 58.4% across (Figure 4.50 b) whilst MLD ranged from 22.0 days to 57.6 days.





b)

c)

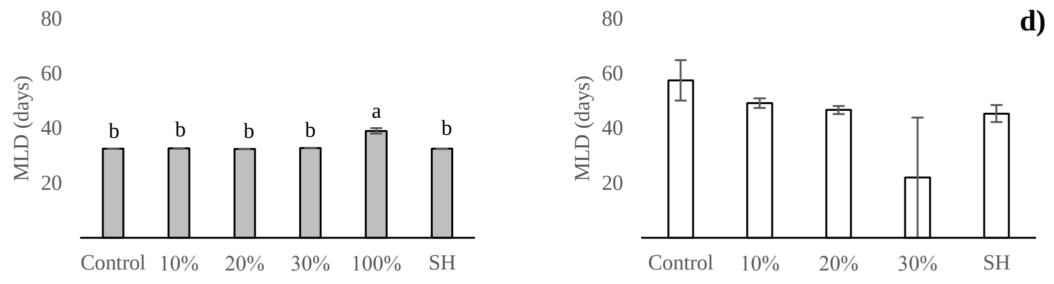
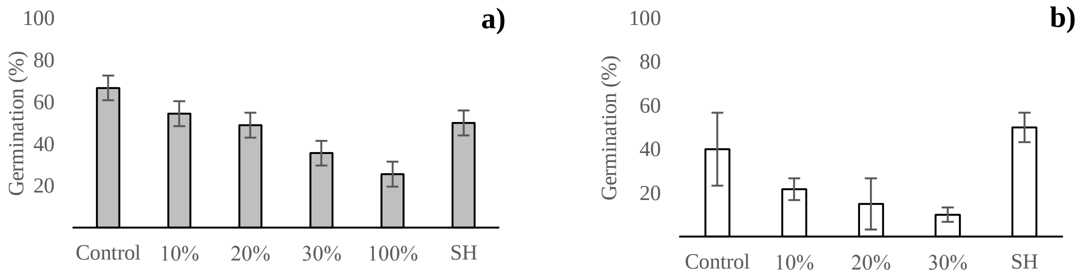


Figure 4.50 Mean (± SE) percent germination and MLD of *Artocarpus lacucha* a) germination in nursery, b) germination in field, c) MLD in nursery and d) MLD in field (3 replicates of 30 seeds each; control (forest soil); 10%, 20% and 30% hydrogel (by volume) mixed with forest soil; 100% (pure hydrogel, nursery only) and SH half layer of forest soil and hydrogel). See methods. Column not sharing the same superscript letters are statistically different among treatments (mean differentiation using Turkey's HSD, α= 0.05).

Germination of this species appeared to be higher (by 49.0%) and more rapid in the nursery (by 11.6 days) than in the field, but statistical analysis could not be performed to determine if this result was significant.

4.4.1.5 *Prunus cerasoides*

As previously mentioned, only nursery data were analyzed statistically for this species. In the nursery, differences in mean percent germination among treatments were not significant (ANOVA, p=0.05, Figure 4.51 a). However, the mean MLD of seeds, sown in 100% hydrogel, was slightly, but significantly, longer than that of seeds sown in 20% hydrogel (by 7.0 days) differences compared with other treatments were insignificant (ANOVA, p=0.03, Figure 4.51 c). In the field, mean germination ranged from 10.0 to 50% across treatments (Figure 4.51 b), whilst mean MLD ranged from 25.3 to 36.9 days (Figure 4.51 d).



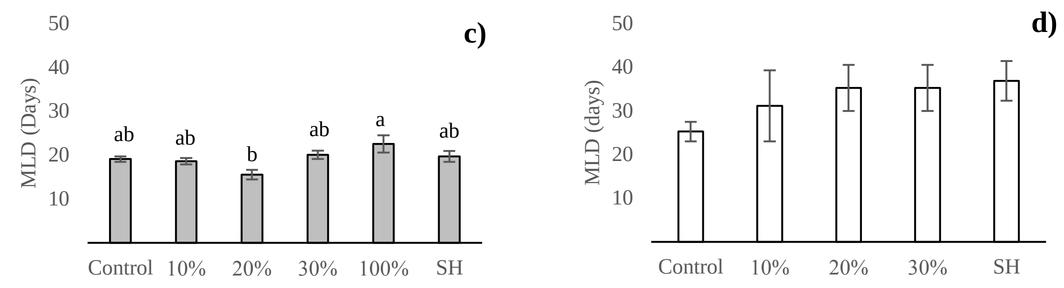
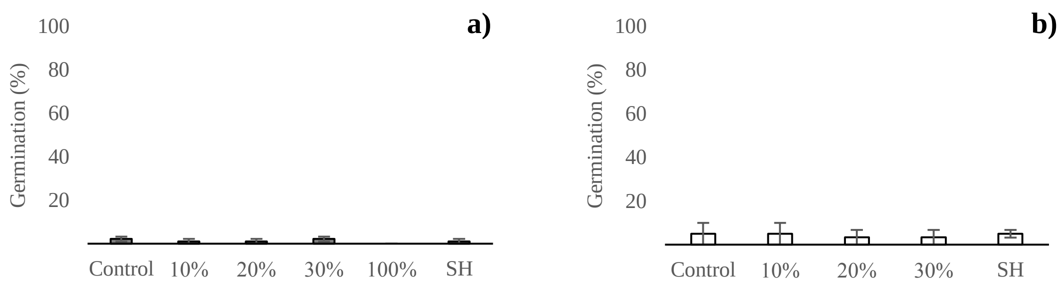


Figure 4.51 Mean (± SE) percent germination and MLD of *Prunus cerasoides* a) germination in nursery, b) germination in field, c) MLD in nursery and d) MLD in field (3 replicates of 30 seeds each; control (forest soil); 10%, 20% and 30% hydrogel (by volume) mixed with forest soil; 100% (pure hydrogel, nursery only) and SH half layer of forest soil and hydrogel). See methods. Column not sharing the same superscript letters are statistically different among treatments (mean differentiation using Turkey's HSD, α= 0.05).

It appeared that germination was substantially higher (by 23.8%) and more rapid (by 14.2 days) in the nursery than in the field, but it was not possible to confirm the significance of this result statistically.

4.4.1.6 *Gmelina arborea*

Germination of *G. arborea* seeds was very low (generally less than 10%) and zero in 100% hydrogel. In the nursery differences in mean percent germination and MLD were not significant (ANOVA, p=0.65, Figure 4.50 a; ANOVA, p=0.60, Figure 4.52 c). In the field, mean percent germination ranged from 3.4 to 5% across treatments (Figure 4.52 b). Whereas mean dormancy ranged from 8.5 to 17.0 days (Figure 4.52 d).



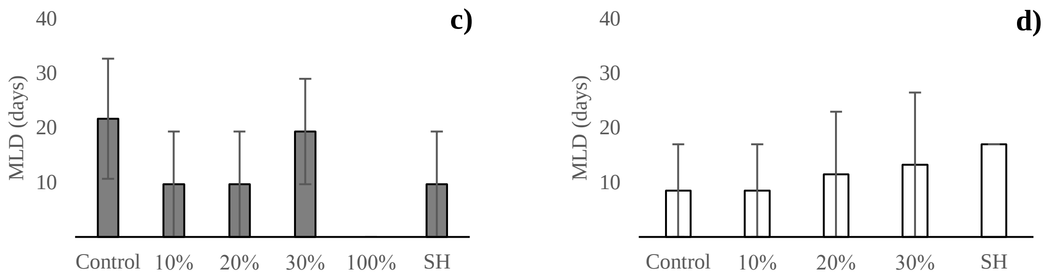


Figure 4.52 Mean (± SE) percent germination and MLD of *Gmelina arborea* a) germination in nursery, b) germination in field, c) MLD in nursery and d) MLD in field (3 replicates of 30 seeds each; control (forest soil); 10%, 20% and 30% hydrogel (by volume) mixed with forest soil; 100% (pure hydrogel, nursery only) and SH half layer of forest soil and hydrogel). See methods.

It appeared that germination may have been slightly higher (by 2.8%) and slightly more rapid (by 2.3 days) in the field than in the nursery, but it was not possible to confirm the significance of this result statistically.

4.4.2 Seedling Survival

Gel treatments did not significantly affect *A. fraxinifolius* and *P. emblica* seedling survival (defined as the number of seedlings at the monitoring time, as a percentage of the number of seedlings that germinated) (Table 4.17). In contrast, *C. axillaris* seedlings survived significantly better in 20% hydrogel, compared with 30% hydrogel and the SH treatment (43.1% and 42.1%, respectively).

In general, it appeared that gel treatments may have increased survival of *P. cerasoides* seedlings, but decreased that of *A. lacucha*, but it was not possible to prove this statistically. So few seedlings of *G. arborea* germinated that calculation of mean survival rates became meaningless.

The 30% hydrogel treatment substantially reduced seedling survival of *A. lacucha* from 81.1% (control) to 38.3%.

No seedlings of *G. arborea* survived the 20% and 30% hydrogel treatments. All hydrogel treatments appeared to substantially increase survival of *P. cerasoides* seedlings (compared with the control) except the soil/hydrogel layered treatment (Table 4.17).

Table 4.17 Percent seedling survival in the field over 231 days (09/12/15 to 27/07/16) after 1st dry season of tested species with various hydrogel (H) treatments applied (3 replicates of 30 seeds). SH indicates a half layer of soil and hydrogel.

species	Control		10% H		20% H		30% H		SH		*p*-value
	Mean	SE	Mean	SE	Mean	SE	Mean	SE	Mean	SE	
Acrocarpus fraxinifolius	49.0	7.6	49.1	5.0	29.9	2.7	46.0	4.0	32.0	8.4	0.11
Choerospondias axillaris	42.2[ab]	9.3	35.8[ab]	8.0	66.5[a]	6.2	23.4[b]	3.5	24.4[b]	6.7	0.01
Phyllanthus emblica	81.1	8.5	86.9	4.7	73.8	4.5	82.8	6.8	66.3	5.2	0.21
*Artocarpus lacucha**	81.1	7.8	61.2	5.6	70.5	12.2	38.3	38.3	51.8	12.9	-
*Prunus cerasoides**	49.2	8.0	87.5	12.5	87.5	12.5	62.5	37.5	42.8	4.3	-

- An asterisk (*) above species indicates mean percent calculated from 2 replicates.
- Mean values of the first three species, not sharing the same superscripts are statistically different (Turkey's HSD, α=0.05).

4.4.3 Seedling Yield

Gel treatments did not significantly affect seedling yield (defined as the number of seedlings at the monitoring time, as a percentage of the number of seed sown) of tested species (Table 4.18).

Table 4.18 Percent seedling yield in the field over 408 days (15/06/15 to 27/07/16) after passed 1st dry season of tested species in different amount of hydrogel (H) applied in sowing media, testing in field with 3 replicates of 30 seeds. SH indicates a half layer of soil and hydrogel.

species	Control		10% H		20% H		30% H		SH		*p*-value
	Mean	SE	Mean	SE	Mean	SE	Mean	SE	Mean	SE	
Acrocarpus fraxinifolius	31.1	11.1	42.0	3.2	21.1	1.1	36.7	0.0	16.7	5.8	0.07
Choerospondias axillaris	12.2	1.1	14.5	4.0	21.1	1.1	8.9	2.9	10.0	3.9	0.14
Phyllanthus emblica	57.8	14.2	67.8	4.0	58.9	2.2	65.5	7.8	46.7	6.7	0.44
*Artocarpus lacucha**	45.0	8.3	15.0	1.7	43.3	20.0	21.7	21.7	30.0	6.7	-
*Prunus cerasoides**	19.7	3.7	18.4	1.7	11.7	8.4	5.0	1.7	21.7	5.0	-

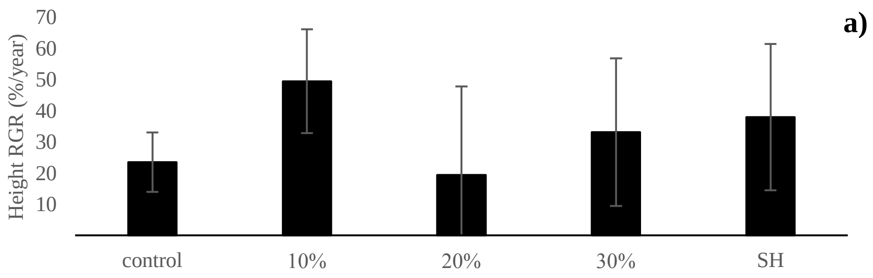
- An asterisk (*) above species indicates mean percent calculated from 2 replicates.

4.4.3 Seedling Growth

Relative growth rate was computed from two monitoring times; December 2015 and July 2016. Growth rate of *A. fraxinifolius*, *C. axillaris* and *P. emblica* were statistically compared among hydrogel treatments. Only mean values for remaining species are presented without statistical analysis (as explained above). *G. arborea* was excluded due to insufficient data for analysis.

4.4.3.1 *Acrocarpus fraxinifolius*

Mean height, crown width and root collar diameter RGR of *A. fraxinifolius* across treatments were 32.7 ± 8.6%/year, -57.8 ± 16.0%/year and 64.5 ± 7.2%/year, respectively. Mean seedling growth rates of 3 parameters did not significantly differ among treatments (ANOVA, Height RGR, *p*=0.86, Crown width RGR, *p*=0.53 and Root collar diameter RGR, *p*=0.68, Figure 4.53). Crown width RGR of all treatments decreased as the mean values were negative (Figure 4.53 b).



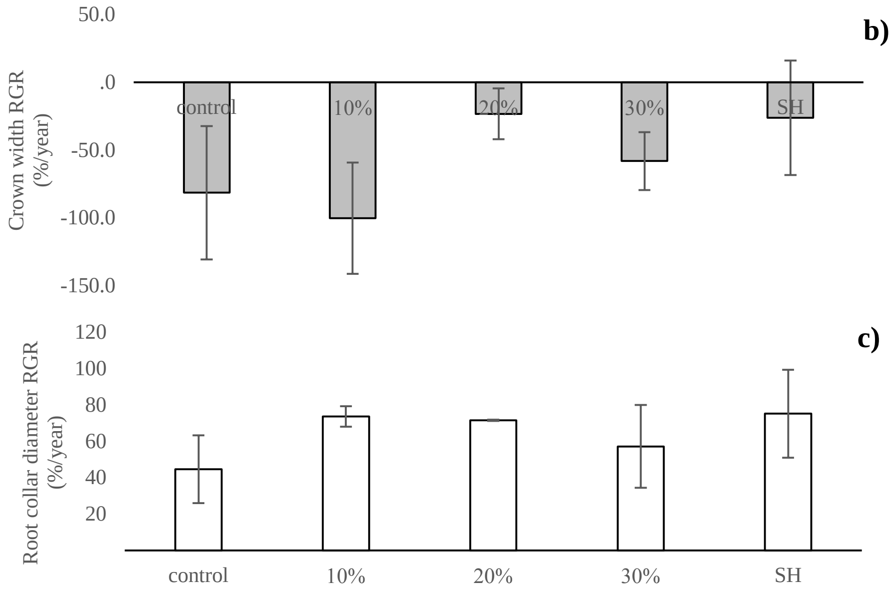
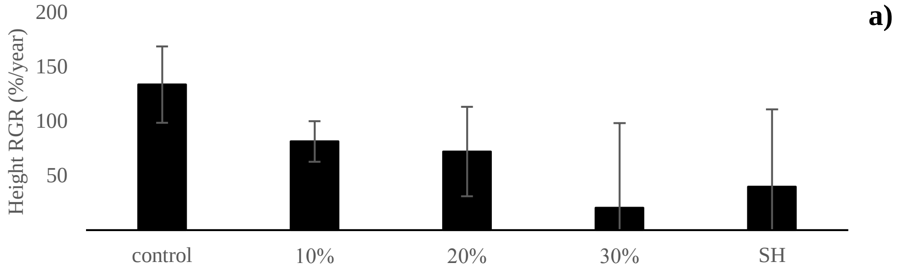


Figure 4.53 Comparison of relative growth rate (RGR) of *Acrocarpus fraxinifolius* among hydrogel treatments in the field (N=3) monitored at December 2015 and July 2016. a) Mean seedling height RGR b) Mean seedling crown width RGR and c) Mean root collar diameter RGR. Control, 10%, 20% and 30% were amount of hydrogel applied in sowing media 0, 10, 20 and 30 volume by volume and SH was a haft layer of forest soil and hydrogel.

4.4.3.2 *Choerospondias axillaris*

Mean height, crown width and root collar diameter RGR of *C. axillaris* across treatments were 69.5 ± 22.8%/year, 3.6 ± 25.2%/year and 51.8 ± 28.1%/year, respectively. Mean growth rate of each parameter (height, crown width and root collar diameter) were not significantly different among treatments (ANOVA, *p*=0.64, 0.67 and 0.25, respectively, Figure 4.54). Crown width shrank in 30% hydrogel and half layer of soil and hydrogel (-39.7%/year and 33.2%/year, respectively, Figure 4.54 b). In addition, root collar diameter of seedlings in 30% hydrogel treatment decreased -63.4%/year (Figure 4.54 c).



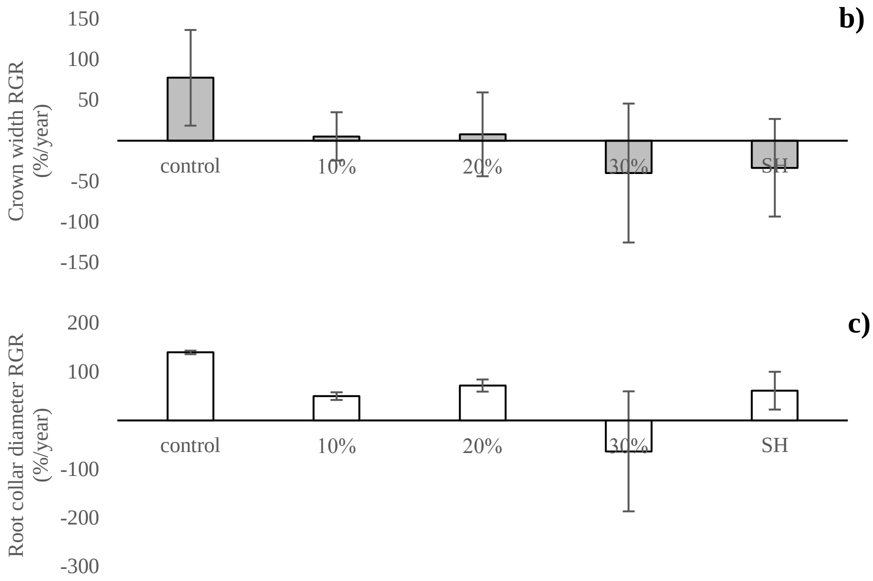
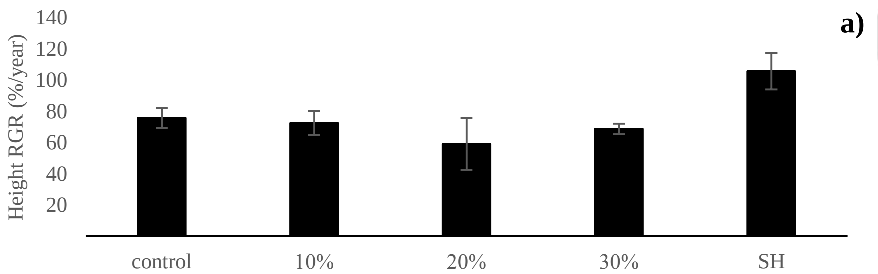
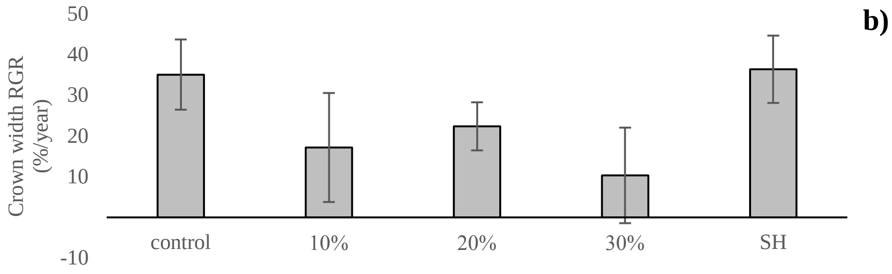


Figure 4.54 Comparison of relative growth rate (RGR) of *Choerospondias axillaris* among hydrogel treatments in the field (N=3) monitored at December 2015 and July 2016. a) Mean seedling height RGR b) Mean seedling crown width RGR and c) Mean root collar diameter RGR. Control, 10%, 20% and 30% were amounts of hydrogel applied in sowing media 0, 10, 20 and 30 volume by volume and SH was a haft layer of forest soil and hydrogel.

4.4.3.3 *Phyllanthus emblica*

Mean height, crown width and root collar diameter RGR of *P. emblica* across treatments were 76.3 ± 5.7%/year, 24.3 ± 4.6%/year and 73.0 ± 3.8%/year, respectively. Mean growth rates of each parameter (height, crown width and root collar diameter) showed no significant differences among treatments (ANOVA, p=0.08, 0.34 and 0.15, respectively, Figure 4.55).





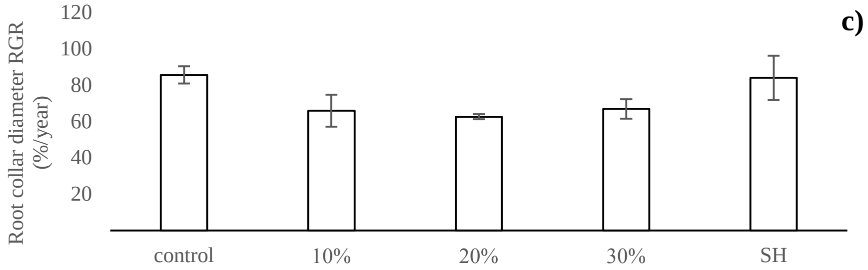
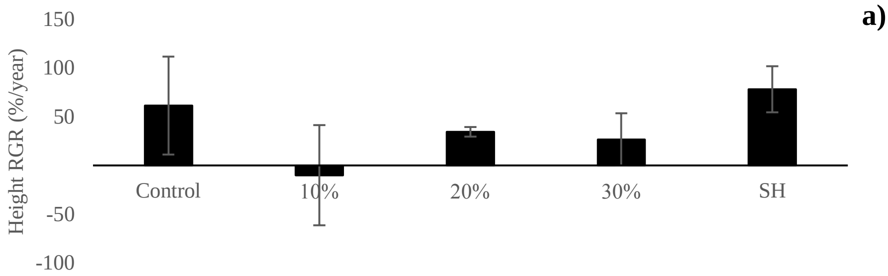


Figure 4.55 Comparison of relative growth rate (RGR) of *Phyllanthus emblica* among hydrogel treatments in the field (N=3) monitored at December 2015 and July 2016. a) Mean seedling height RGR b) Mean seedling crown width RGR and c) Mean root collar diameter RGR. Control, 10%, 20% and 30% were amounts of hydrogel applied in sowing media 0, 10, 20 and 30 volume by volume and SH was a haft layer of forest soil and hydrogel.

4.4.3.4 *Artocarpus lacucha*

Mean height, crown width and root collar diameter RGR of *A. lacucha* across treatments were 38.3 ± 15.7%/year, 36.0 ± 21.4%/year and 34.1 ± 25.0%/year, respectively. Seedlings in 10% hydrogel presented negatively growth in height and crown width (-10.0 %/year, Figure 4.56 a and -13.7%/year, Figure 4.56 b, respectively). In root collar diameter parameter, seedlings positively increased growth rate for all treatments (Figure 4.56 c).



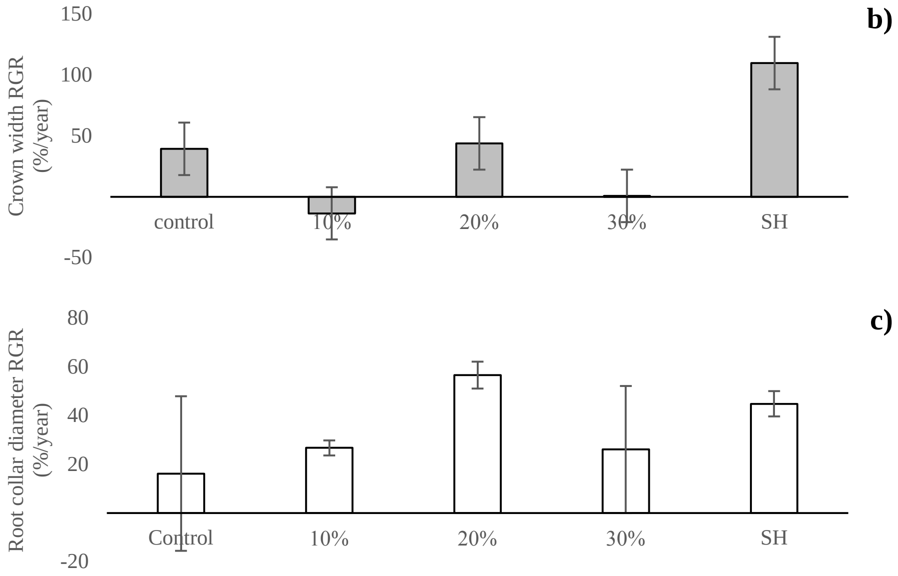
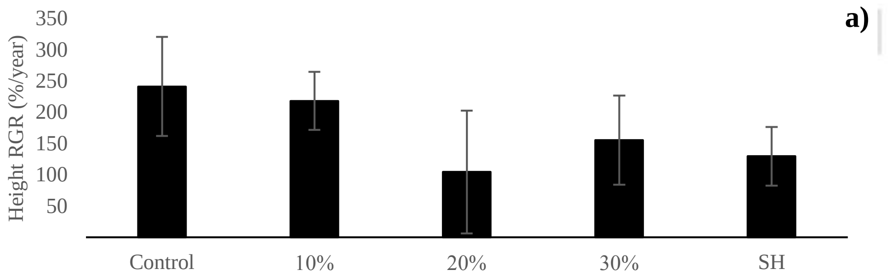


Figure 4.56 Comparison of relative growth rate (RGR) of *Artocarpus lacucha* among hydrogel treatments in the field (N=2) monitored at December 2015 and July 2016. a) Mean seedling height RGR b) Mean seedling crown width RGR and c) Mean root collar diameter RGR. Control, 10%, 20% and 30% were amounts of hydrogel applied in sowing media 0, 10, 20 and 30 volume by volume and SH was a haft layer of forest soil and hydrogel.

4.4.3.5 *Prunus cerasoides*

Mean height, crown width and root collar diameter RGR of *P. cerasoides* across treatments were 169.8 ± 29.4%/year, 105.4 ± 15.8%/year and 121.8 ± 10.4%/year, respectively. Growth rates of all parameters were positive, mostly exceeding 100%/year (Figure 4.57).



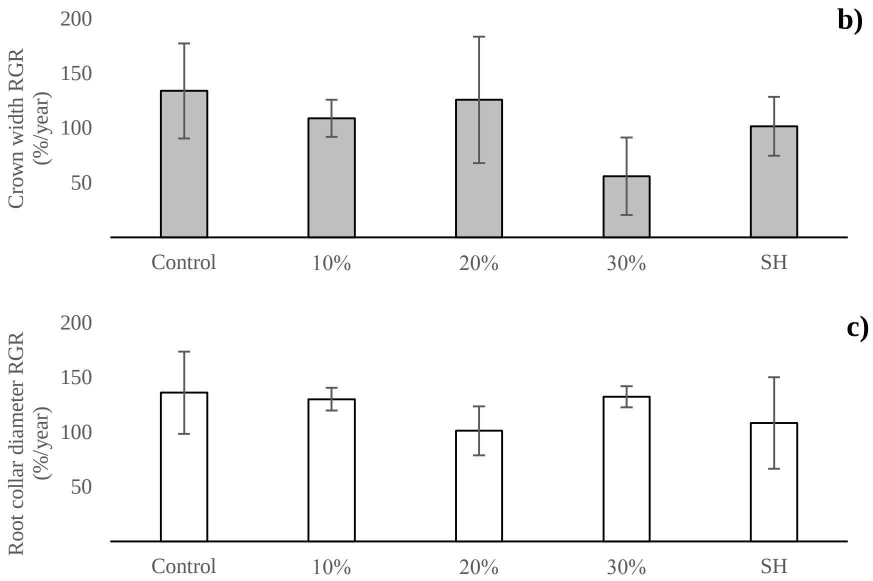


Figure 4.57 Comparison of relative growth rate (RGR) of *Prunus cerasoides* among hydrogel treatments in the field (N=2) monitored at December 2015 and July 2016. a) Mean seedling height RGR b) Mean seedling crown width RGR and c) Mean root collar diameter RGR. Control, 10%, 20% and 30% were amounts of hydrogel applied in sowing media 0, 10, 20 and 30 volume by volume and SH was a haft layer of forest soil and hydrogel.

4.4.4 Relative Species Performance Index (RSPI)

RSPI was calculated based on height RGR and yield of tested species. *P. emblica* performed the best (assigned RSPI = 100). Control treatment of *P. cerasoides, C. axillaris* and *A. fraxinifolius* had index values greater than other treatments.

Performance of *P. emblica* with SH and *A. lacucha* with 10% hydrogel treatment was greater than with other treatments (Table 4.19).

Table 4.19 Relative Species Performance index, calculation of height RGR of tested species in various hydrogel treatments; control (forest soil); 10%, 20% and 30% hydrogel (by volume) mixed with forest soil and SH (half layer of forest soil and hydrogel).

Species	**Treatments**	**% Yield (Y)**	**Height RGR (H)**	**Y*H**	**RSPI**
Phyllanthus emblica	SH	46.7	105.7	4,932.7	100.0
	10%	67.8	72.4	4,906.3	99.5
	30%	65.5	68.7	4,500.0	91.2
	Control	57.8	75.7	4,377.4	88.7
	20%	58.9	59.1	3,483.0	70.6
*Prunus cerasoides**	Control	19.7	241.4	4,742.5	96.1
	10%	18.4	218.3	4,004.9	81.2
	SH	21.7	129.7	2,813.4	57.0
	20%	11.7	104.5	1,216.8	24.7
	30%	5.0	155.4	776.8	15.7
Acrocarpus fraxinifolius	Control	45.0	61.6	2,769.8	56.2
	SH	30.0	78.3	2,349.0	47.6
	20%	43.3	34.6	1,498.2	30.4
	30%	21.7	26.9	582.4	11.8
	10%	15.0	-10.0	- 149.3	-3.0
Choerospondias axillaris	Control	12.2	139.7	1,704.7	34.6
	20%	21.1	71.6	1,510.1	30.6
	10%	14.5	50.2	725.7	14.7
	SH	10.0	61.0	610.3	12.4
	30%	8.9	-63.4	- 561.9	-11.4
*Artocarpus lacucha**	10%	42.0	49.5	2,079.0	42.1
	30%	36.7	33.2	1,217.2	24.7
	Control	31.1	23.5	731.9	14.8
	SH	16.7	38.0	634.0	12.9
	20%	21.1	19.4	409.3	8.3

* Mean percent were calculated from 2 replicates.

4.5 Fertilizer Experiment

Seedlings of 8 native tree species: *A. fraxinifolius*, *A. microsperma*, *A. lacucha*, *H. dulcis*, *H. thorelii*, *P. emblica*, *P. cerasoides* and *S. albiflora* were tested in the nursery with different fertilizer treatments: Osmocote 0.3 g (FORRU's standard fertilizer treatment: Control) and 2 dose sizes (0.15 g and 0.3 g) of new fertilizer developed by NANOTEC (here after referred to as NF).

4.5.1 Relative Growth Rate

In general, fertilizer treatments did not affect seedling relative growth rates. Mean relative growth rate (height, crown width and root collar diameter) of *A. franxinifolius*, *A. microsperma*, *A. lacucha*, *P. emblica*, *P. cerasoides* and *S. albiflora* were not significantly different among fertilizer treatments (Figure 4.56). In contrast, mean RGR of crown width and root collar diameter of *H. glabra* with 0.3 g NF were significantly higher than control (0.3 g Osmocote) by 71.0 and 42.6%/year, respectively (ANOVA, *p*=0.04 and 0.04, respectively, Figure 4.56). In contrast, Mean RGR crown width of *H. dulcis* control was significantly higher than with the 0.15 g NF treatment by 110.0%/year (ANOVA, *p*=0.03, Figure 4.56).

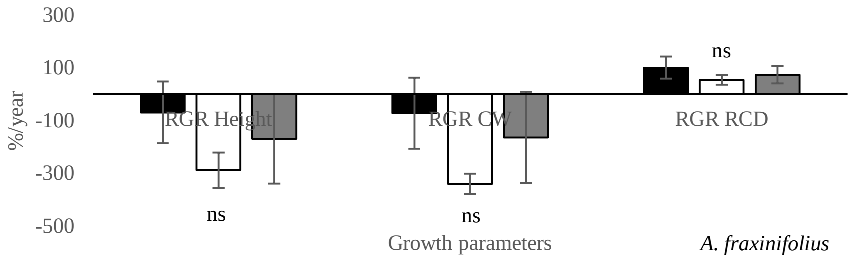
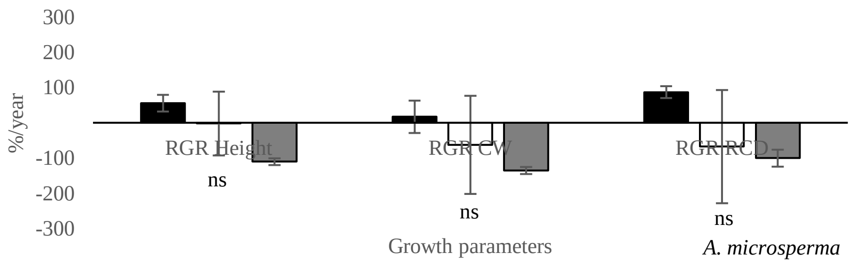


Figure 4.58 Comparison of relative growth rate (RGR) height, crown width (CW) and root collar diameter (RCD) of 8 native tree species between fertilizer treatments (Black, white and grey bars are 0.3 g Osmocote, 0.3 g and 0.15 g NANOTEC, respectively) in the nursery (N=3), monitored on 21/08/16 and 24/02/16. Column not sharing the same superscript letters are statistically different among treatments, ns indicate not significantly different (mean differentiation using Turkey's HSD, α= 0.05).



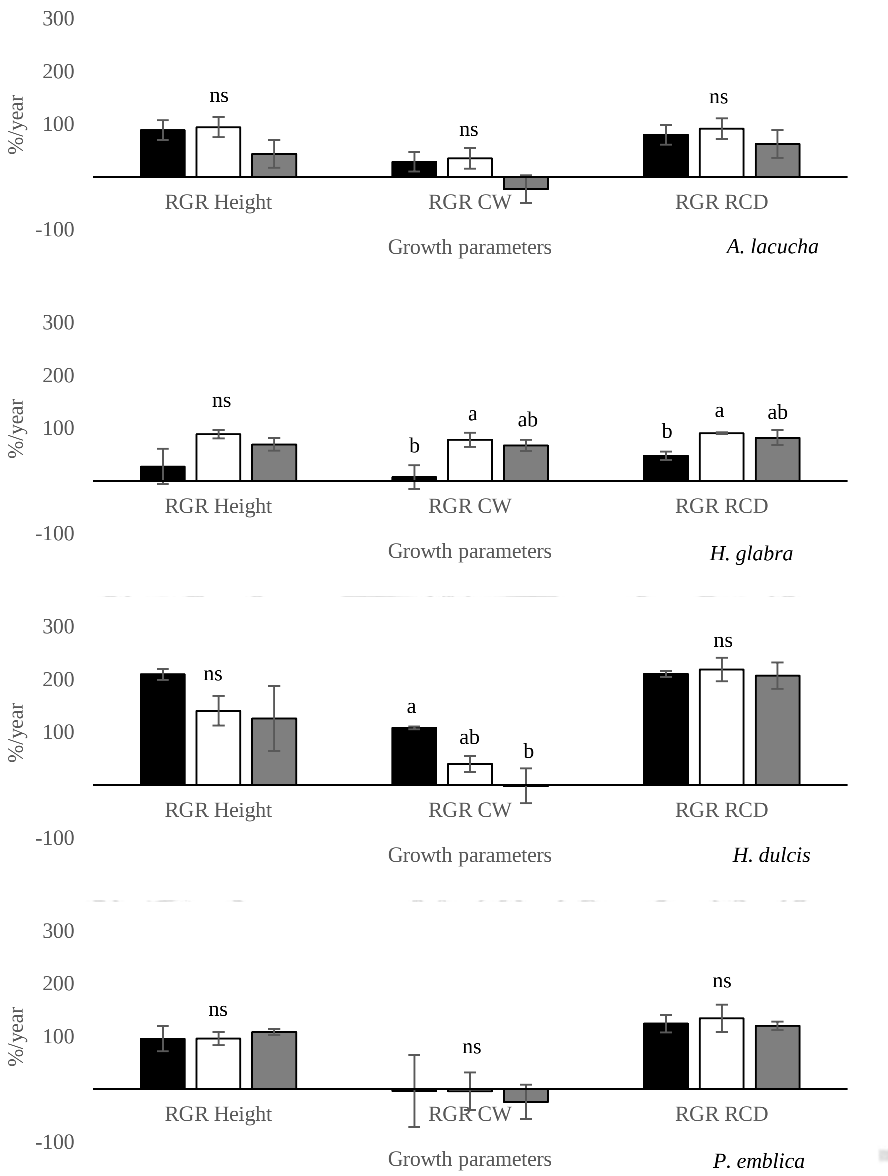
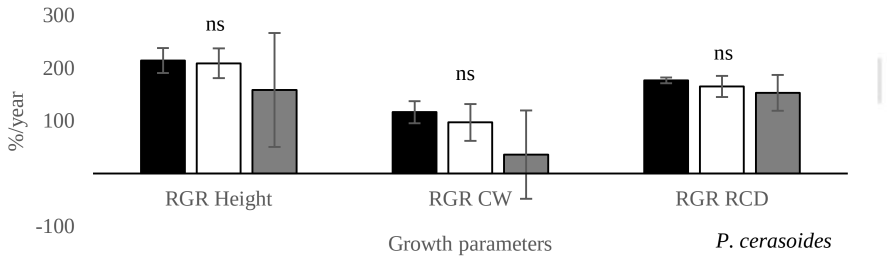


Figure 4.58 Continued.



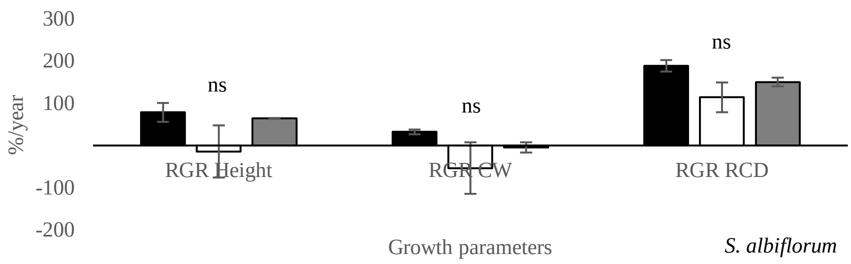


Figure 4.58 Continued.

4.5.2 Seedling Height

Fertilizer treatments did not affect seedling height. Mean seedling height of all species were not significantly different among fertilizer treatments when compared at each monitoring times (0, 56, 112 and 187 days, respectively, Figure 4.57). *P. cerasoides* was the only species for which height exceed 30 cm after being raised in the nursery for 112 days and 187 days (mean across treatments were 41.1 ± 1.5 cm and 44.6 ± 2.6 cm, respectively, Figure 4.59).

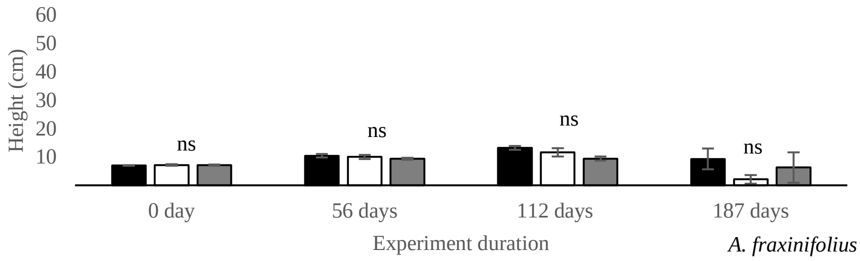
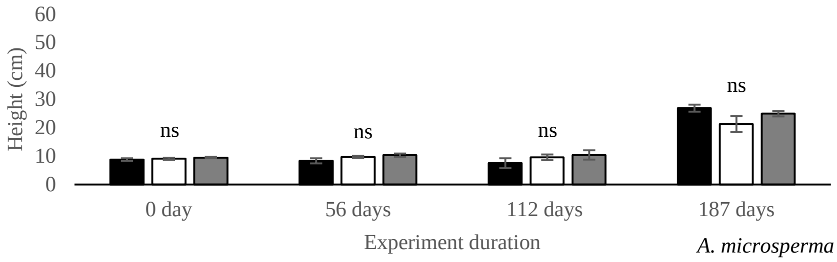
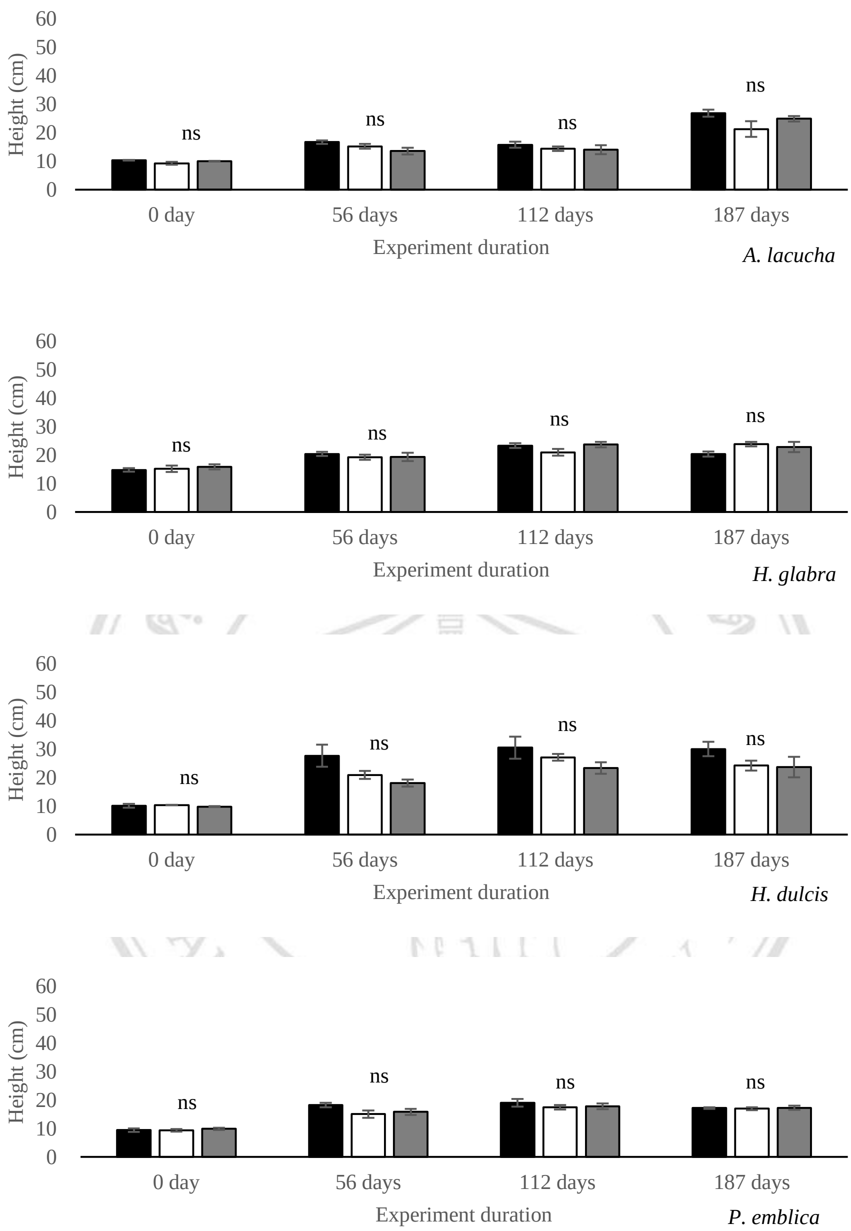


Figure 4.59 Comparison mean height of 8 native tree species between fertilizer treatments (black, white and grey bars are 0.3 g Osmocote, 0.3 g and 0.15 g NANOTEC, respectively) in the nursery (N=3), monitored at monitored at 21/08/16 (0 day), 16/10/15 (56 days), 11/12/15 (112 days) and 24/02/16 (187 days), ns above bar indicate not significantly different among treatments (mean differentiation using Turkey's HSD, α= 0.05).





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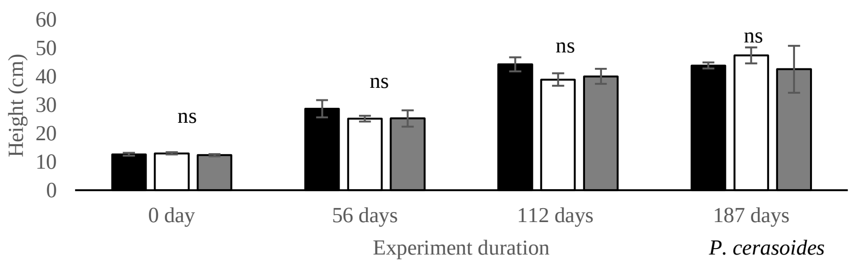


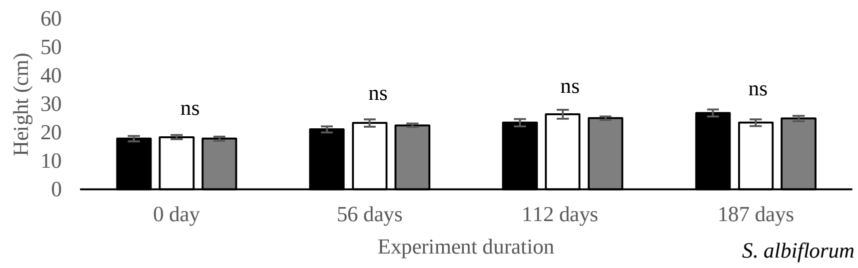
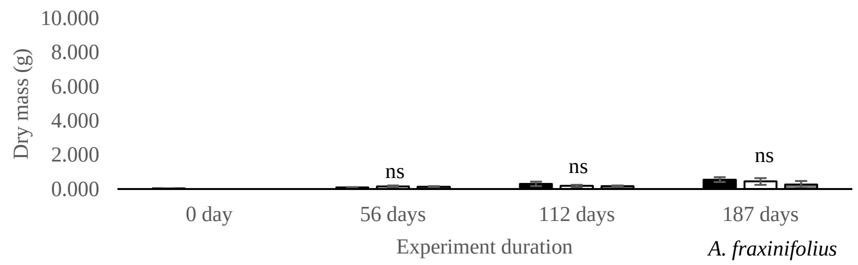


Figure 4.59 Continued.

4.5.3 Seedling Biomass

In general, fertilizer treatments did not affect seedling dry mass. Mean seedling dry mass of most species were not significantly different among fertilizer treatments at each monitoring time (56, 112 and 187 days, Figure 4.60). While, *P. cerasoides* dry mass of control was significantly higher than 0.3 g NF by 3.30 g (ANOVA, *p*=0.01, Figure 4.60). Only *H. glabra* exhibited mean dry mass more than 5 g after being raised for 187 days (means across treatment was 6.17 ± 0.63 g).



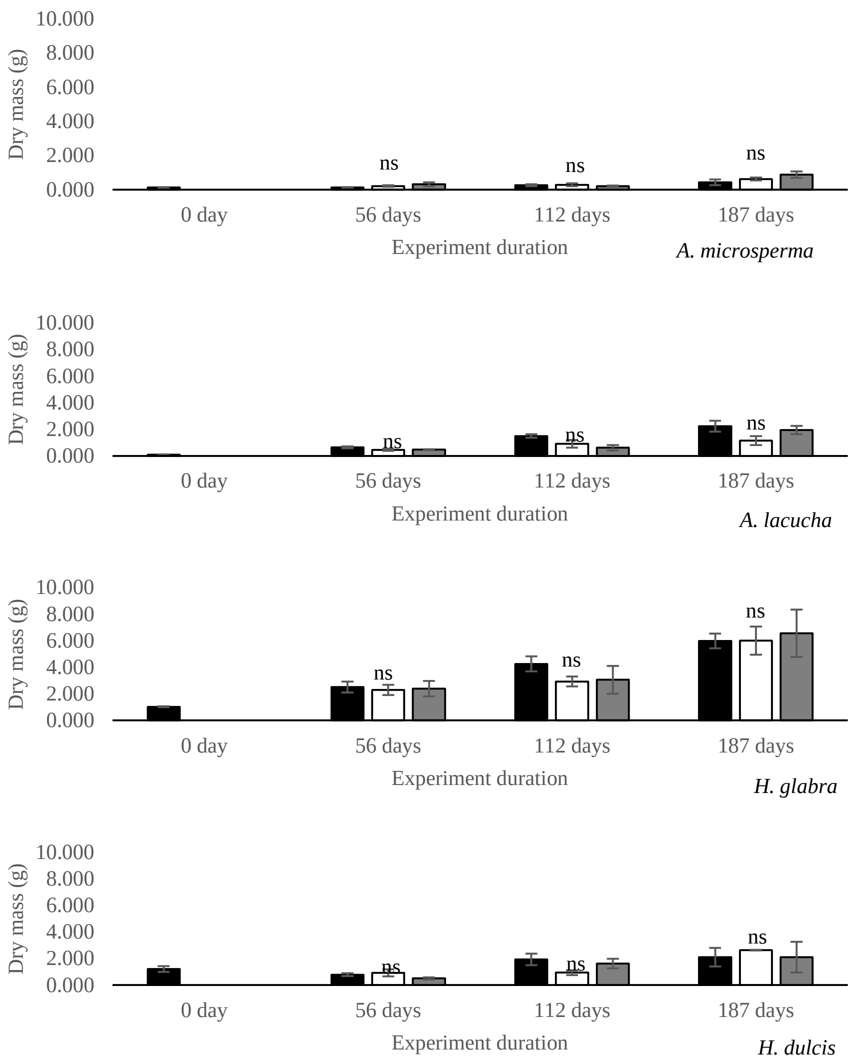
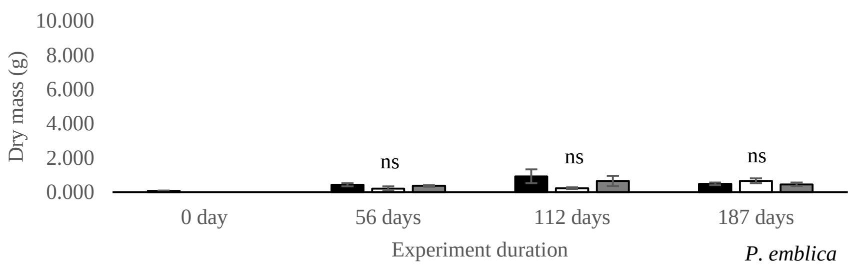


Figure 4.60 Comparison mean dry mass of 8 native tree species between fertilizer treatments (Black, white and grey bars are 0.3 g Osmocote, 0.3 g and 0.15 g NANOTEC, respectively) in the nursery (N=3), monitored at monitored at 21/08/16 (0 day), 16/10/15 (56 days), 11/12/15 (112 days) and 24/02/16 (187 days). Column not sharing the same superscript letters are statistically different among treatments, ns indicate not significantly different (mean differentiation using Turkey's HSD, α= 0.05).



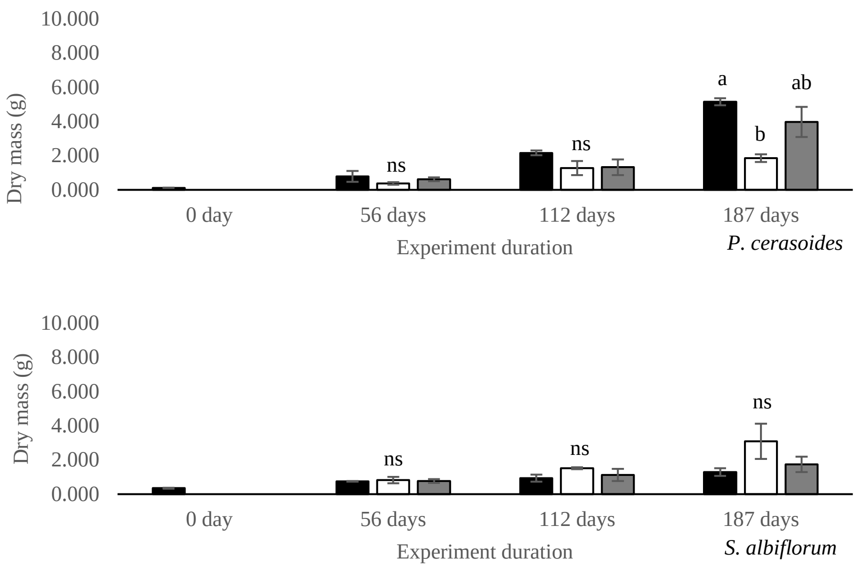
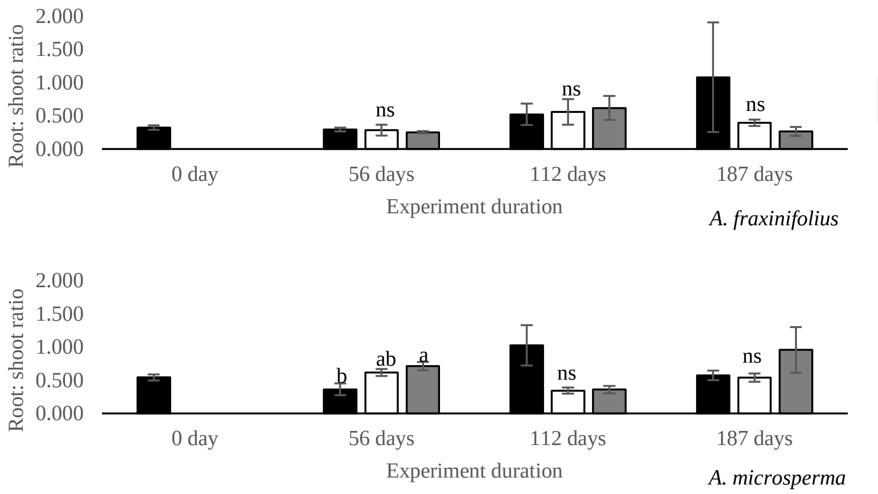


Figure 4.60 Continued.

4.5.4 Root: Shoot Ratio

Fertilizer treatment did not affect root: shoot ratio. In general, mean root: shoot ratios were not significantly different among treatments at different monitoring times (56, 112 and 187 days, Figure 4.61). An exception was *A. microsperma* at 56 days, with 0.15 g NF, for which the ratio was significantly higher than that of the control by 0.03 (ANOVA, p=0.03, Figure 4.61)



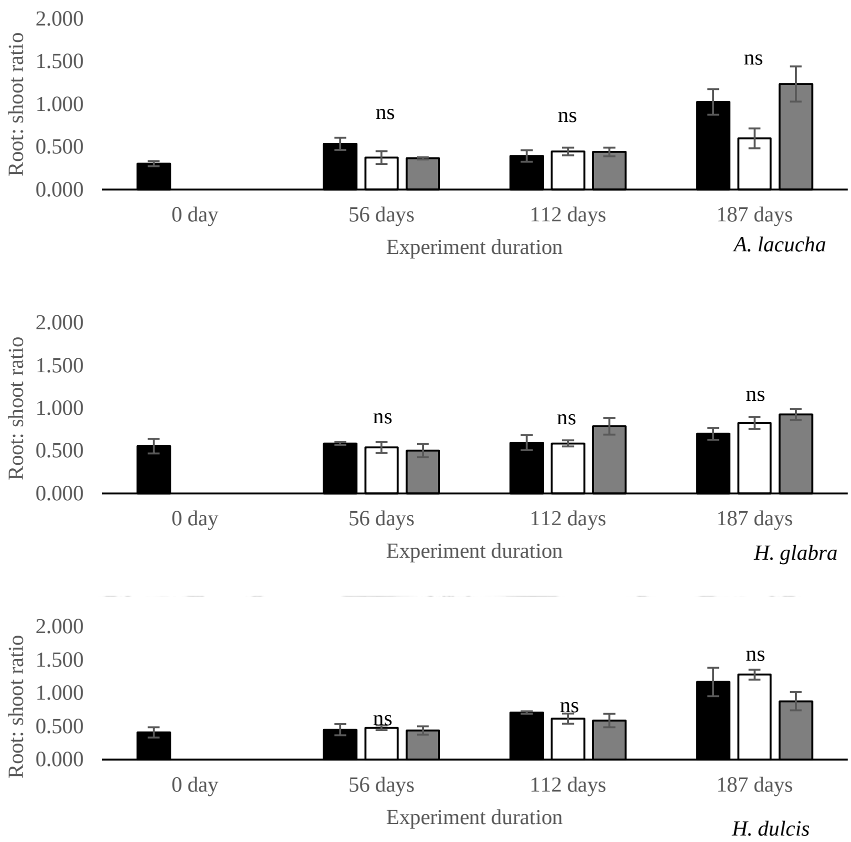
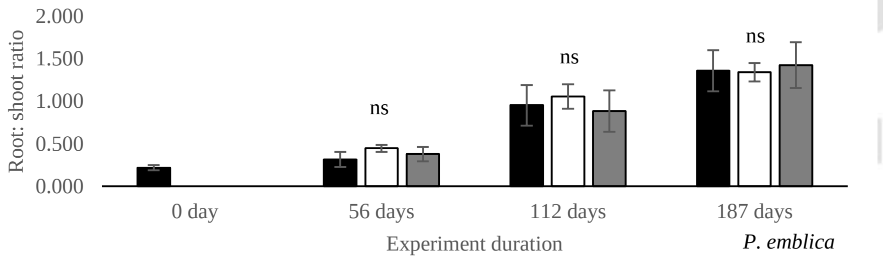


Figure 4.61 Comparison mean root: shoot ratio of 8 native tree species between fertilizer treatments (Black, white and grey bars are 0.3 g Osmocote, 0.3 g and 0.15 g NANOTEC, respectively) in the nursery (N=3), monitored at monitored at 21/08/16 (0 day), 16/10/15 (56 days), 11/12/15 (112 days) and 24/02/16 (187 days). Column not sharing the same superscript letters are statistically different among treatments, ns indicate not significantly different (mean differentiation using Turkey’s HSD, α= 0.05).



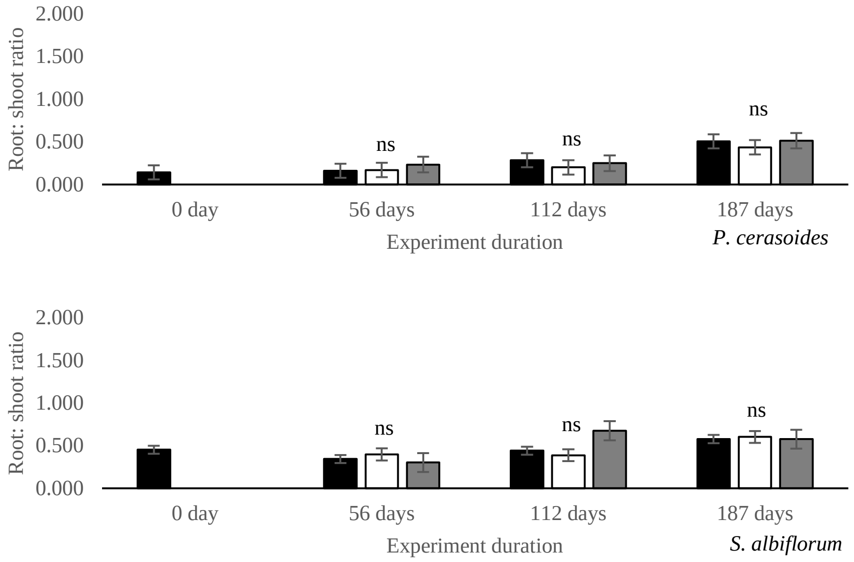
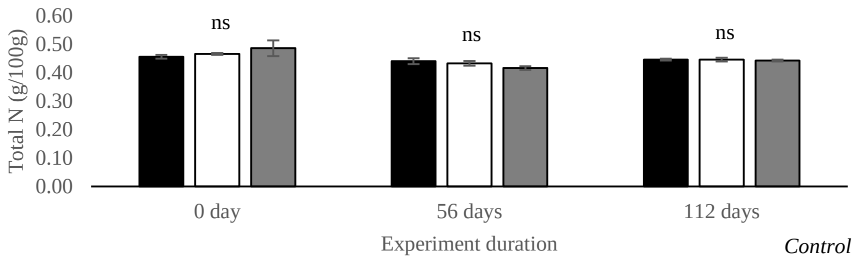


Figure 4.61 Continued.

4.5.5 Fertilizer Remaining

4.5.5.1 Total Nitrogen

Available nutrients (N, P and K) were analysed from planting media at initial stage (0 day), 56 and 112 days. Fertilizer treatments did not affect total nitrogen. Differences in mean total nitrogen among fertilizer treatments were not significant at 0, 56 and 112 days (Figure 4.62). In contrast, mean total nitrogen with 0.15 g NF and with *P. cerasoides* media at 56 days was significantly higher than for 0.3 g NF by 0.065 g/100g (ANOVA, p=0.04, Figure 4.62).



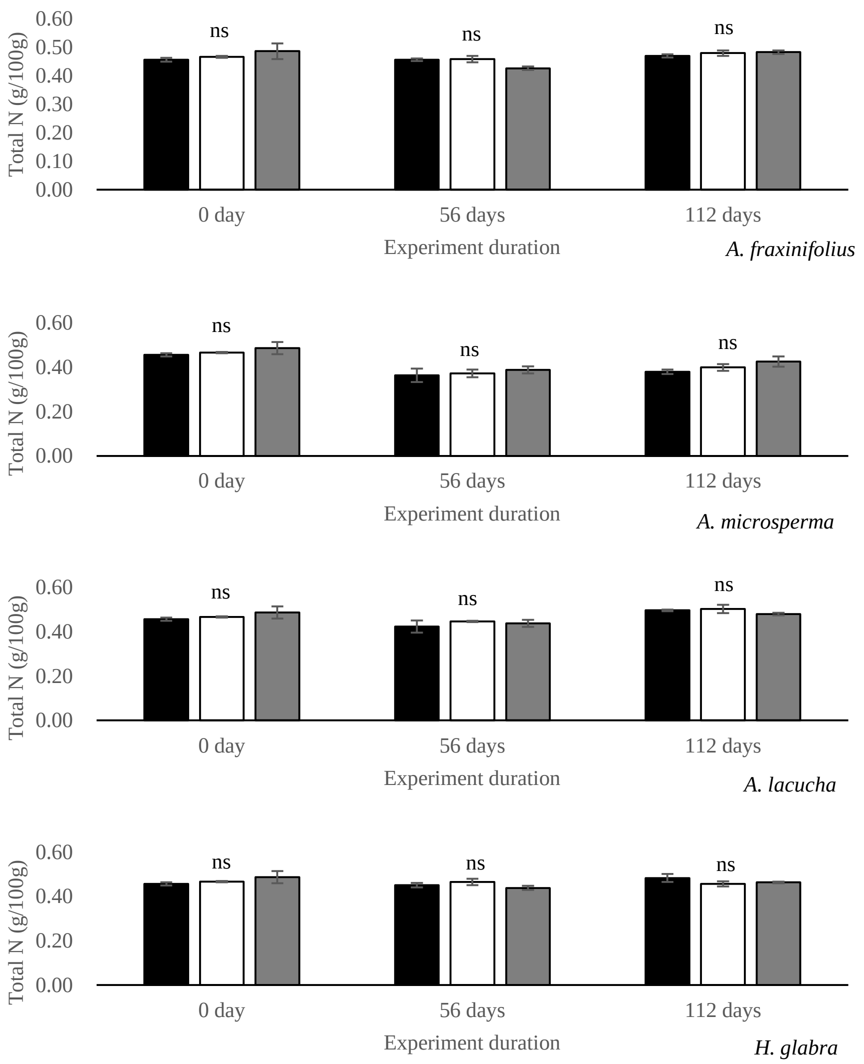
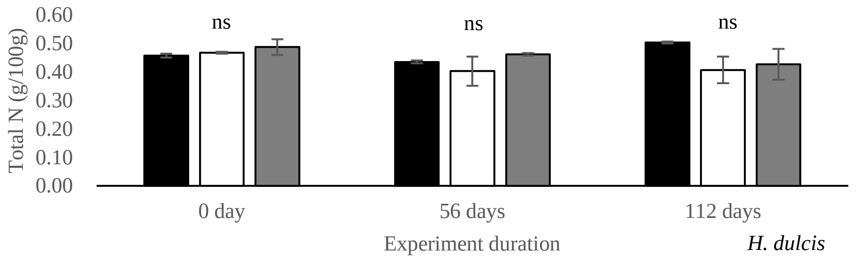


Figure 4.62 Comparison mean total nitrogen of 8 native tree species between fertilizer treatments (Black, white and grey bars are 0.3 g Osmocote, 0.3 g and 0.15 g NANOTEC, respectively) in the nursery (N=3), monitored at monitored at 21/08/16 (0 day), 16/10/15 (56 days) and 11/12/15 (112 days). Column not sharing the same superscript letters are statistically different among treatments, ns indicate not significantly different (mean differentiation using Turkey's HSD, α= 0.05).



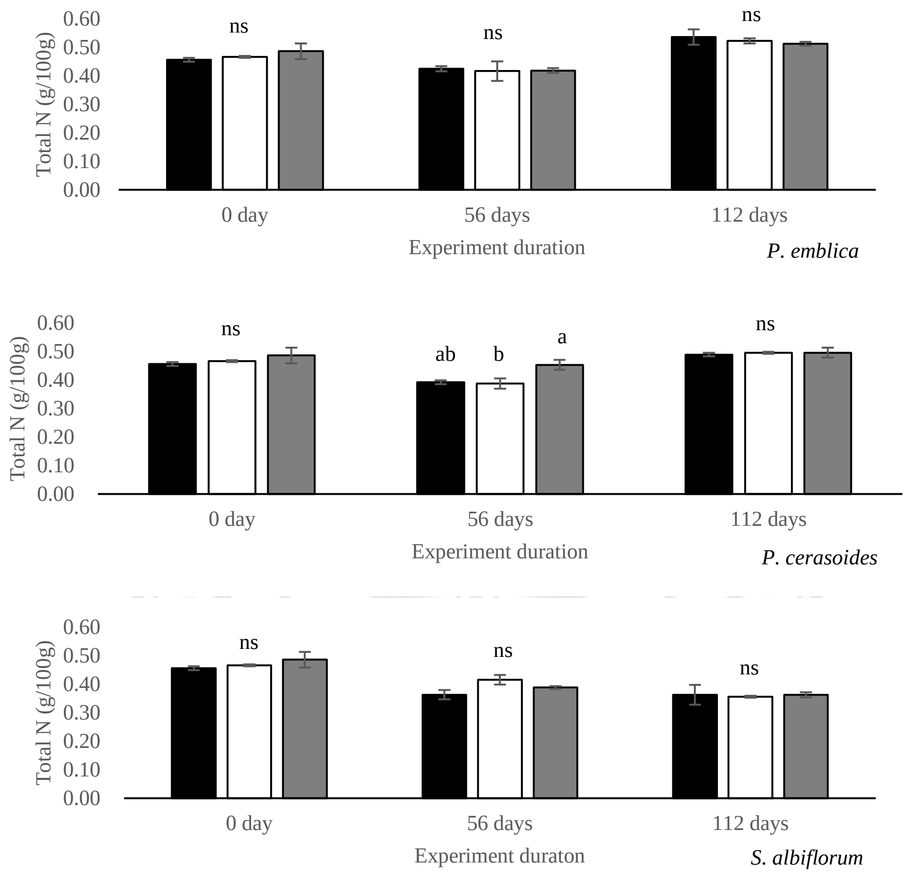


Figure 4.62 Continued.

4.5.5.2 Available Phosphorus

Control media (media without seedling) and *S. albiflorum,* control had slightly but significantly higher phosphorus concentrations than 0.15 NF at all monitoring times 0, 56 and 112 days (Figure 4.63). In contrast, the media of *A. fraxinifolius*, *A. lacucha*, *H. glabra*, *P. emblica* and *P. cerasoides* showed no significant differences among treatments at 56 and 112 days (Figure 4.63). Whereas, control and 0.3 g NF of *A.*

microsperma were significantly higher than 0.15 g NF at 112 days (ANOVA, p=0.03, Figure 4.63). In addition, control and 0.3 g NF of *H. dulcis* were significantly higher than 0.15 g NF at 56 days (ANOVA, p<0.01, Figure 4.63).

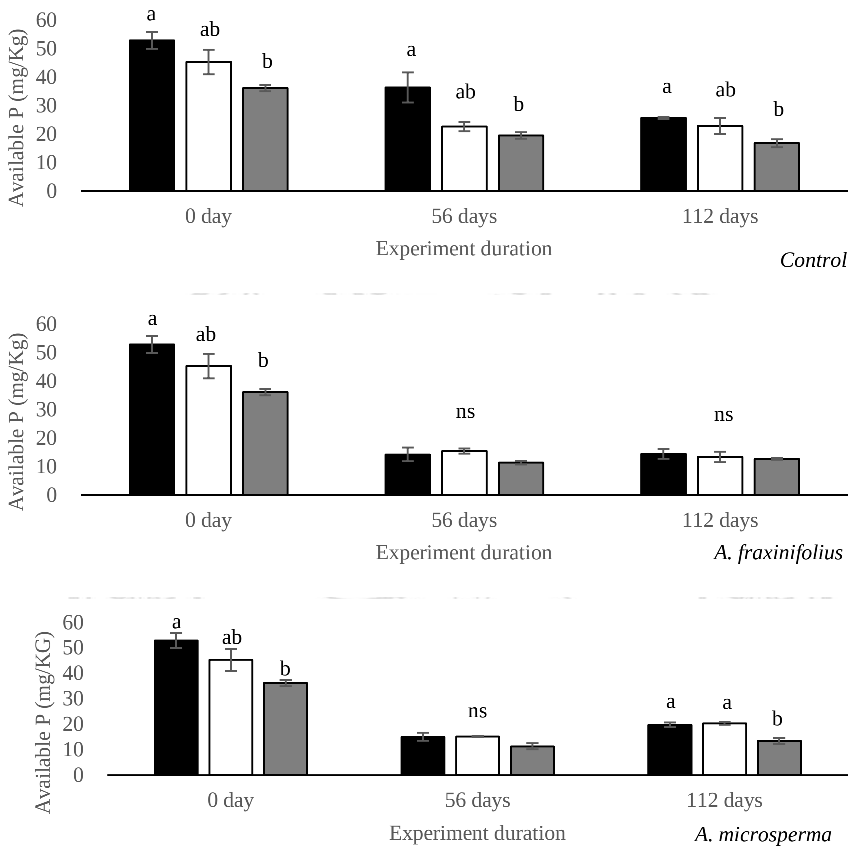
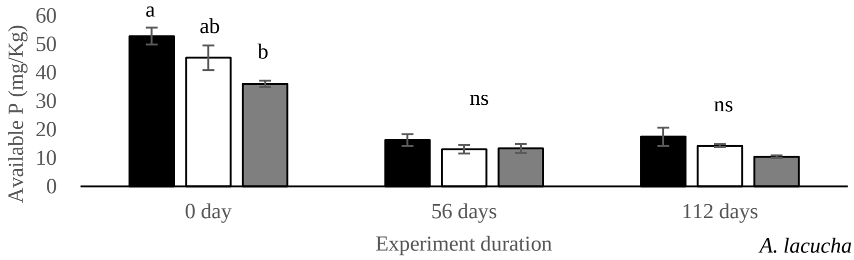
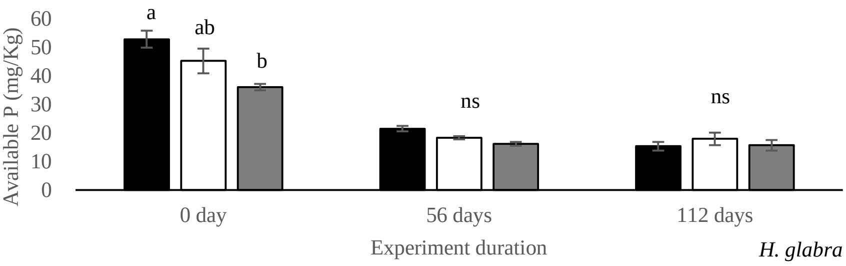
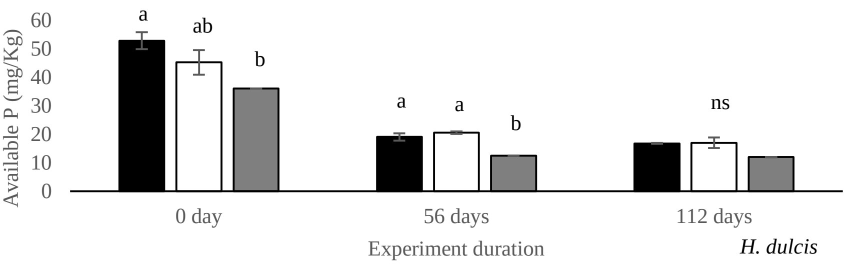
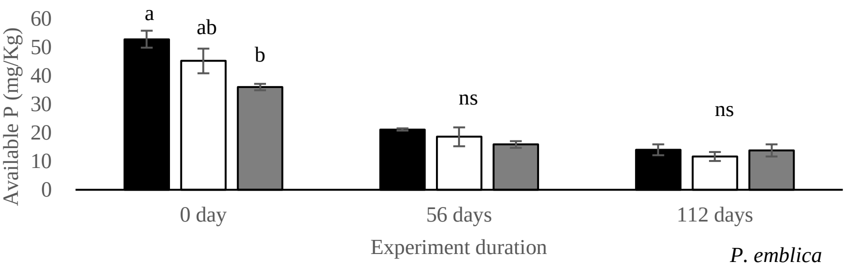


Figure 4.63 Comparison mean available Phosphorus of 8 native tree species between fertilizer treatments (Black, white and grey bars are 0.3 g Osmocote, 0.3 g and 0.15 g NANOTEC, respectively) in the nursery (N=3), monitored at monitored at 21/08/16 (0 day), 16/10/15 (56 days) and 11/12/15 (112 days). Column not sharing the same superscript letters are statistically different among treatments, ns indicate not significantly different (mean differentiation using Turkey's HSD, α= 0.05).









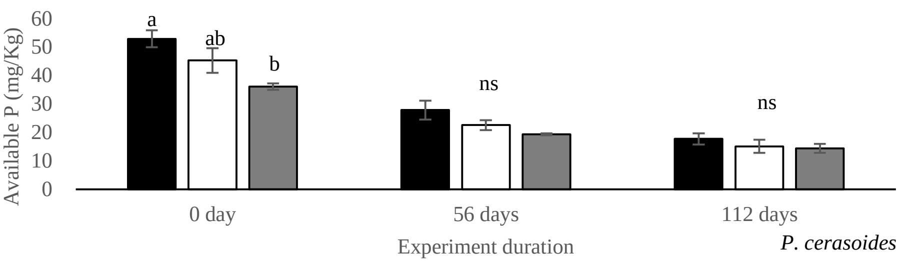


Figure 4.63 Continued.

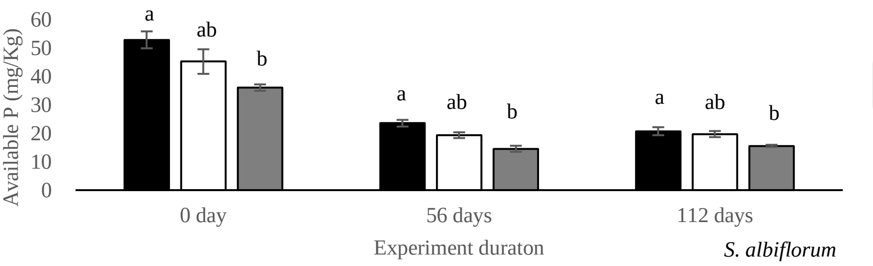
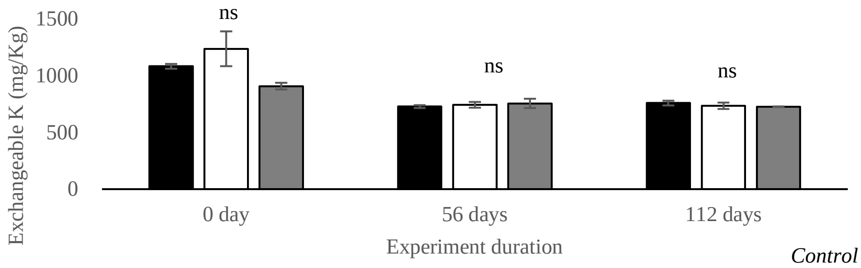


Figure 4.63 Continued.

4.5.5.3 Exchangeable Potassium

Fertilizer treatment did not affect amount of exchangeable Potassium. Mean exchangeable Potassium of most species and control media (without seedling) were not significantly different among treatments at 0, 56 and 112 days (Figure 4.64). While, control of *A. microsperma* and *P. cerasoides* at 112 days were significantly greater than 0.15 g NF (by 111.3 and 59.2 mg/Kg, ANOVA, p=0.16 and 0.04, respectively).



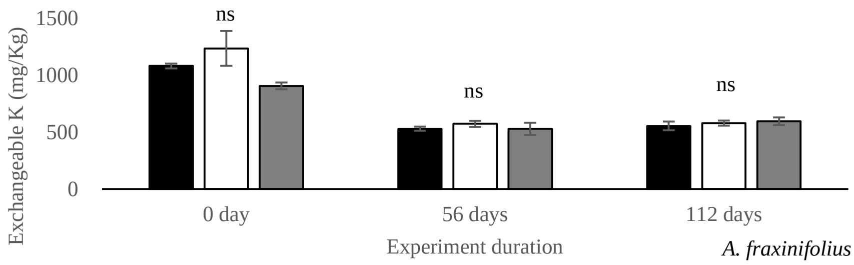
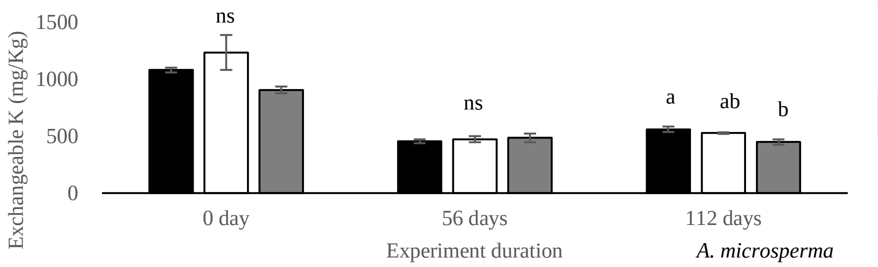
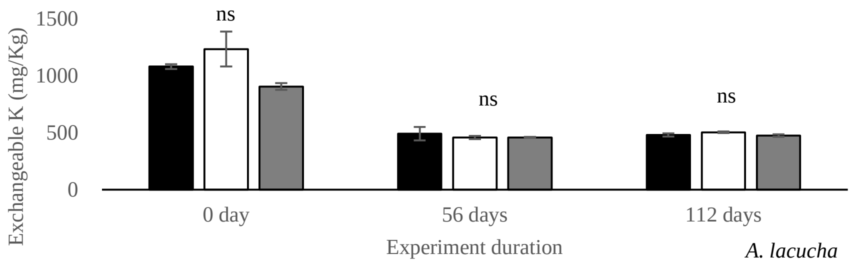
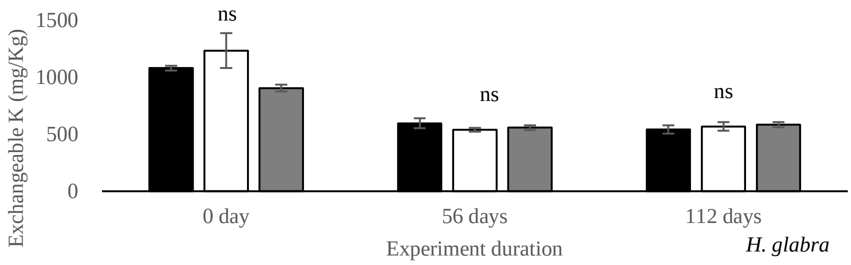
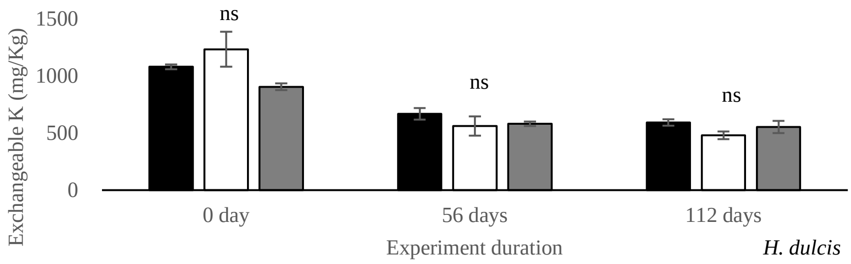


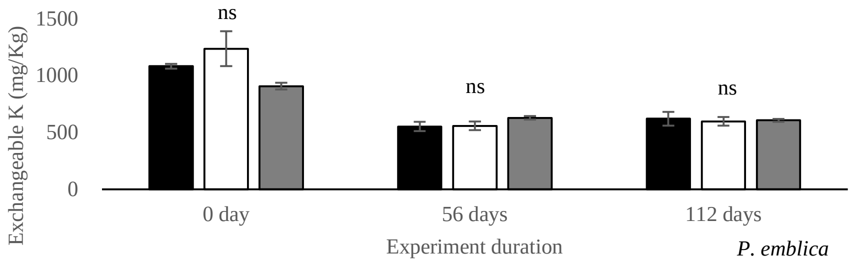
Figure 4.64 Comparison mean exchangeable Potassium of 8 native tree species between fertilizer treatments (Black, white and grey bars are 0.3 g Osmocote, 0.3 g and 0.15 g NANOTEC, respectively) in the nursery (N=3), monitored at monitored at 21/08/16 (0 day), 16/10/15 (56 days) and 11/12/15 (112 days). Column not sharing the same superscript letters are statistically different among treatments, ns indicate not significantly different (mean differentiation using Turkey's HSD, α= 0.05).











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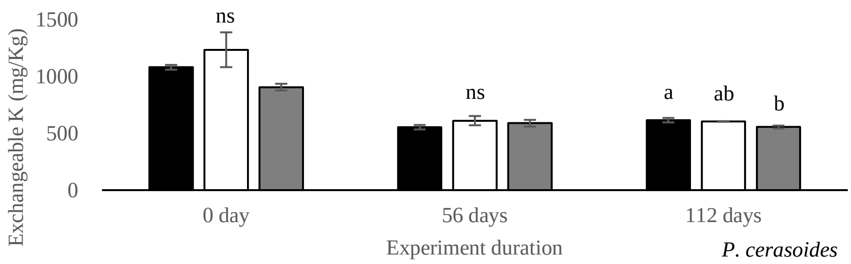

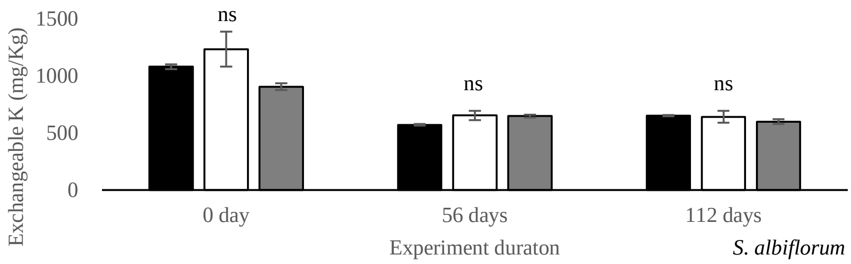

Figure 4.64 Continued.