Regular Article
pISSN: 2288-9744, eISSN: 2288-9752
Journal of Forest and Environmental Science
Vol. 35, No. 2, pp. 69-77, June, 2019
https://doi.org/10.7747/JFES.2019.35.2.69

JFES
Journal of Forest and Environmental Science

Seed Quality, Germinability and Initial Growth of *Pterocarpus erinaceus* (African Rosewood). How Important are Mother Tree Size, Source and Timing of Fruit Harvest?

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Abstract

Pterocarpus erinaceus is a multipurpose tree species indigenous to semi-arid and Guinean-savanna woodlands of Africa. Natural regeneration on the savanna is being hampered by higher fire frequencies and other land use changes. Simultaneously, demand for timber from the species on the international market is on the rise, raising conservation concerns. To ensure sustainability, good quality seeds, sources of which have not received much research focus, are needed for afforestation. This study investigated how seed quality, germinability and initial seedling growth of *P. erinaceus* might be influenced by land-use type, mother tree size as well as source and timing of fruit harvest, using both correlational and experimental approaches. The results showed that up to 94.6% of all harvested fruits contained seeds, with no differences found between fruits harvested from cultivated and non-cultivated lands. Percentage of (sound) unblemished seeds was found to be higher for fruits harvested early March (47.3%) than fruits from late April (39.5%). Percentage sound seeds was 41.4% for dispersed fruits (i.e. detached fruits picked from under mother trees) which was not found to differ from undispersed fruits (i.e. fruits harvested while still attached to mother trees) at 45.5%. Also, the influence of fruit harvest time was not found to be different for dispersed and undispersed fruits. Correlations between seed set (proportion of fruits containing seeds) and mother tree size (both tree height and DBH) were found to be very low and non-significant for both dispersed and undispersed fruits. Across mother trees, mean emergence percent was 79.7%, and mean seedling height at three weeks following emergence was 5.32 cm. Both emergence percentage and seedling height were not found to differ among mother trees, but seeds from dispersed fruits had a higher emergence percent (85%) than seeds from undispersed fruits (74%). Implications of findings are discussed.

Key Words: *Pterocarpus erinaceus*, rosewood tree, seed sources, germination, seedling growth

Introduction

In many parts of Africa, it is increasingly being recognized that plantation development or the incorporation of multipurpose tree species in agroforestry systems is needed to ensure the sustainability of the multiple use values of the many species for which there is overreliance on wild populations. One such species with enormous potential is

Received: November 17, 2017. Revised: May 26, 2019. Accepted: May 29, 2019.

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Pterocarpus erinaceus.

Pterocarpus erinaceus is a leguminous woody perennial of the family *Fabaceae* which grows naturally in West and Central Africa (Ouédraogo et al. 2006; Orwa et al. 2009). In Ghana, it occurs predominantly in the forest-savanna transitional and northern savanna woodland ecological zones (Dumenu and Bandoh 2016). *P. erinaceus* has several uses. The leaves are an important source of fodder for livestock in the dry season (Duvall 2008). Locally, various parts of the tree are important in traditional medicine and the wood is highly preferred for charcoal production, for carving mortars and pestles, manufacture of musical instruments (such as xylophones, guitars, violins), and for furniture making and building construction (Bonkoungou 1999; Duvall 2008; Bosu 2013; Dumenu and Bandoh 2016). Ecologically, it is important in traditional agroforestry systems by forming symbiotic relations with Rhizobium to fix nitrogen into the soil (Bonkoungou 1999).

Locally, the multiple use benefits of *P. erinaceus* account for the high pressure on populations of this species. Internationally, pressure comes from particularly China, which is the largest importer of rosewood from Africa due to increased demand for rosewood furniture (Winfield et al. 2016). Logging of the species is currently done without proper regulations, making exploitation unsustainable (Ouédraogo et al. 2006; Bosu 2013; Novinyo et al. 2015; Dumenu and Bandoh 2016). Additionally, agricultural extensification, excessive livestock grazing and increasing fire frequencies are reported to hamper natural regeneration of the species on the savanna in some places (Doungyotha and Owens 2002; Ouédraogo et al. 2006; Nacoulma et al. 2011), although natural regeneration is still sufficient in other places (Novinyo et al. 2015). These changes in the habitat of the species coupled with unsustainable exploitation in the native ranges of the species are raising conservation concerns.

Planting programmes have been initiated in some places across Africa (Diakité 1991; Duvall 2008) and seedlings have been reported to be very slow growing with large differences also reported among provenances (Duvall 2008). The success of any afforestation/reforestation programme depends on availability of viable and superior propagating material (Baskin and Baskin 1998). The capacity for flowering and fruiting of a tree has long been known to be generally associated with tree vigour (Kozlowski 1971). Also, seed viability and superiority of any planting stock depend in part on the mother trees from which seeds are collected due to the potential for desirable heritable traits to be passed on from parent trees. Consequently, selecting seeds from superior mother trees has been an age-long forestry practice. Information on sources of good quality seeds for *P. erinaceus* needs to be made available to assist foresters and plantation developers, but not much data are currently available. There are some data available on phenology, methods of breaking seed dormancy (Duvall 2008 and references there in), germination, growth rates and survival of seedlings (Issifu et al. 2015; Dumenu and Bandoh 2016), but it is unclear how seed quantity, quality, germinability and the initial growth of seedlings are influenced by mother tree, land use type, seed harvest source and time of fruit harvest.

Pterocarpus erinaceus is known to flower and fruit copiously, such that while fruits are green, trees appear like they have been covered by leaves (Duvall 2008), but number of flowers or fruits cannot accurately predict number of sound seeds in many genera of forest trees. In genus Tectona for example, number of sound seeds per fruit was reported to vary between 0 and 4 (Kamra 1973). This could be due to parthenocarpy; a phenomenon whereby fruits are formed without feritlisation of an ovule, known to occur in many genera of forest trees (Kozlowski 1971). For example, *Detarium microcarpum*, a savanna tree, often produces seedless fruits (Duvall 2008). It could also be due to site factors (edaphic and climatic) which influence seed set.

It is also often unclear to seed collectors whether to collect dispersed fruits under canopy of mother trees or harvest fruits still attached to mother trees. As pre-dispersal predation is lower than post-dispersal predation in some species (Castro et al. 1999), dispersed *P. erinaceus* fruits are more likely to be damaged than undispersed ones. Additionally, timing of fruit harvest is crucial as too early harvest may lead to physiologically immature seeds while too late harvest may render poor quality seeds as a result of deterioration by microbes, predators and pests (Copeland and McDonald 1995). The present study was therefore carried out to investigate the influences of mother tree, land use type (habitat of mother tree), fruit harvest source (dispersed or undispersed) and harvest time on seed set (determined in this study as the proportion of fruits containing seeds), seed quality, germinability and the initial growth of seedlings.

Materials and Methods

Study area

The study employed both field survey and greenhouse experimental approaches. The field survey was carried out in Langbinsi, a farming community, about three kilometers from Daboya (09° 31' 49" N and 01° 22' 56" W) (Fig. 1), the capital of the North Gonja District of the Northern Region of Ghana. The area has a unimodal rainfall pattern with average annual rainfall of 1044 mm, occurring between May and October with peaks occurring in August and September. The dry season lasts for a period of six months (September-April). Average anuual temperature is 28.3°C with maximum temperatures experienced in March, while the lowest temperatures are experienced in December when the north east-trade winds push the Inter Tropical Convergence Zone further south (Meteorological Station, Tamale, 2006). The vegetation is generally guinea savanna vegetation with *Vitellaria paradoxa*, *Adansonia digitata*, *Azadiracta indica*, *Parkia biglobosa Pterocarpus erinaceus* and *Afzelia africana* being the dominant woody species. The district was selected for this study because it is one of the districts affected by the recent spike in rosewood felling in northern Ghana (Bosu 2013).

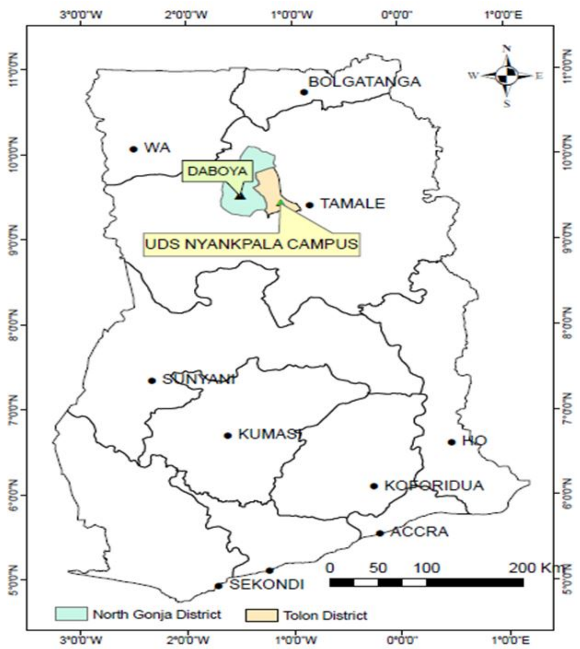

Fig. 1. Map of Ghana showing sites where field survey and greenhouse experiment were carried out.

The green house experiment (which followed the field survey) was carried out at the plant house of the University for Development Studies, Nyankpala Campus (9° 24' 0" N, 0° 59' 0" W) (Fig. 1) in the Tolon District of the Northern Region of Ghana. The area is located within the Guinea savanna Agro-ecological zone. The study was conducted from January to May, 2016.

Data collection

Sampling design

Field survey was done on both farm lands and bush fallows. On fallow lands, twenty fruiting *P. erinaceus* trees were selected by walking five transects, each of ca. 500 m long. In some places, cultivated areas were found very close to fallow lands. In such places, farms were skipped before walking the next transect on fallow lands. This resulted in a wide inter-transect distance range of ca. 100 to 500 m. On each transect, the criterion for selecting a mother tree for inclusion in the study was the presence of both dispersed (i.e. presence of fruits underneath tree) and undispersed fruits (i.e. fruits on top of tree). Also, where fruiting trees were next to one another and it was difficult to determine source of dispersed fruits, such mother trees were excluded from the study.

In cultivated lands, *P. erinaceus* trees were fewer compared with bush fallows. Therefore, several farms (10) were visited, and any fruiting *P. erinaceus* tree encountered which met the criterion for inclusion was selected for data collection. This approach was used until twenty individuals were obtained on farm lands. For all the 40 trees on both land use types, mother tree girth (cm) and height (m) were measured. The girth was measured with measuring tape and later converted to DBH using the formula $C=\frac{\pi}{D}$. (Where, C=circumference, D=diameter and $\pi=3.14386$). Tree height was measured using the Haga altimeter.

Seed collection

For each mother tree, as many fruits as possible were collected from the ground underneath mother tree and also harvested from the tree and put separately in sacks. Sacks (containing fruits) were labeled with both mother tree identification and seed harvest source (i.e. undispersed or dispersed). Fruits were collected in the first week of March and in the last week of April, 2016 from the same mother trees. For each mother tree, 100 fruits were randomly picked from sacks containing dispersed fruits and from sacks containing undispersed fruits. Sampled fruits were cracked opened and number of fruits that contained seeds out of the total number of fruits sampled (100) were recorded for dispersed and undispersed fruits and for each mother tree (40 individuals). Also, number of fruits that contained sound unblemished seeds were recorded.

Germination and growth experiment

Six mother trees were randomly selected from the 40 sampled trees from the field survey for the germination and seedling growth experiment in the greenhouse. The experiment was a fully crossed-factored two factor experiment; with six mother trees crossed with dispersed and undispersed fruits and replicated three times in completely randomized design (CRD). Thus, 36 seed boxes measuring 50 cm×15 cm×10 cm filled with top soil from a mango plantation near the plant house were used. To eliminate all other confounders so as to reveal the effects of mother tree and fruit harvest source on germination and seedling height growth, seeds were used instead of fruits. Seeds were not pre-treated prior to sowing.

One hundred seeds were planted in each box by burying seeds in a thin layer of soil. Seed boxes were watered lightly twice a day, morning and late afternoon. For this species, germination has been reported to take between 6-10 days (Roussel 1995). Therefore, count of seedlings that emerged each day was done per seed box until the 11th day. Seedlings were then thinned to ten in each box to reduce competition. Three weeks after planting, seedling height was measured of each seedling and pooled per seed box (i.e. an average height of 10 seedlings per seed box was obtained).

Data analysis

Number of fruits that contained seeds were analyzed for differences between cultivated lands and bush fallows by fitting a Poisson model using the generalized linear models (GLM) procedure. For data on counts of healthy seeds (i.e. number of healthy- unblemished- seeds per 100 fruits), an overdispserd Poisson was fitted in GLM to determine main and interactive effects of fruit harvest time and harvest source (i.e. whether seeds were dispersed or undispersed). The overdispersed model was fitted by including in the model, a scale weight variable, calculated as 1/ (Pearson's Chi-square divided by its degrees of freedom).

Correlations between mother tree size and proportion of fruits containing seeds were tested using non-parametric Kendall's tau_b as a result of non-normality of data and also because this is a better test for when sample sizes are small with many scores having the same rank (Howell 1997). Tree height and DBH correlations to seed set proportions were analysed separately for dispersed fruits (i.e. fruits picked under mother trees) and undispersed fruits (i.e. fruits harvested while still attached to mother trees).

Prior to analysis of seedling emergence, proportion data on seedling emergence were arcsine-square root transformed to stabilize variances and improve normality (Sokal and Rohlf 1995). A two-way ANOVA was used to test differences in percentage seedling emergence, and also absolute height of seedlings among mother trees and between dispersed and undispersed seeds. Mother tree was specified as a random factor in the analysis. Adjustments for multiple comparisons were done using SIDAK. The interactive effect of mother tree and harvest source in the two-way analysis allowed for it to be shown whether effects (if any) of fruit harvest source (dispersed or undispersed) were unique to particular mother trees or there existed a general pattern.

Results and Discussion

Effect of land use on seed set

Overall, proportion of fruits that contained seeds was found to be very high (mean=0.946±0.04, N=80) for trees in the study area and did not differ significantly (Poisson log linear, Wald Chi-Square=0.069; df=1, N=80, p=0.30) between cultivated lands (mean=0.936±0.03 N=40) and bush fallows (mean=0.956±0.06 N= 40).

Seed set is very high for trees in the study area perhaps due to a high pollination (and fertilization) success which is perhaps also helped by the bisexual nature of the flowers of this species (Orwa et al. 2009). *P. erinaceus* flowers between December and February (up to April) (Duvall 2008) during which period food crops are not in cultivation, thus making a flowering tree one of few sources of nectar for insect pollinators. Bees are largely seen as key agents pollinating the species because of their high visitation rates to *P. erinaceus* trees (Duvall 2008). Also, the proximity of cultivated areas to bush fallows allows for pollinators to easily reach trees in both land use types, and thus explaining the similarity in seed set between the two land use types. It is however recognized that uncultivated areas have more trees and higher flowering plant diversity and may tend to attract more pollinators than less diverse habitats (e.g. cultivated lands) (Nicholls and Alteiri 2013).

The implication of this finding is that a large supply of *P. erinaceus* seeds is available in the study area and it makes no difference whether fruits are collected from trees on farmlands or in bush fallows.

Effect of time of fruit harvest on seed quality

The goodness of fit statistic (value/df for Pearson's Chi-square) for the fitted overdispersed Poisson model was 1.0, indicating the model was a good fit to the data. The analysis revealed that fruits collected early March had significantly higher (Poisson log linear, Wald Chi-Square=4.693, df=1, N=40, p=0.03) number of unblemished seeds than fruits collected late April (mean=47.25±15.34, N=20 and mean=39.45±16.53, N=20 respectively). However, number of unblemished seeds did not significantly differ (Poisson log linear, Wald Chi-Square=1.195, df=1, N=40, p=0.274) between dispersed (mean=41.40±15.39=20) and undispersed (mean=45.45±17.17, N=20) fruits. Also, the interaction effect of time of fruit collection and fruit harvest source (dispersed or undispersed) was not found to be significant (Poisson log linear, Wald Chi-Square=0.033, df=1, N=40, p=0.856) (Fig. 2).

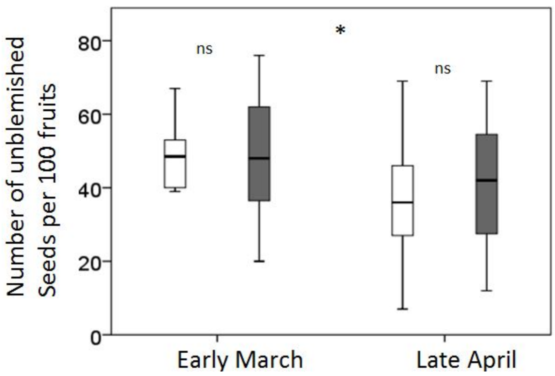

Fig. 2. Median number of unblemished seeds compared between dispersed (open bars) and undispersed fruits (gray-filled bars) and between early March and late April fruit harvests. Significant difference (Poisson log linear, $p<0.05$) between the two fruit harvest periods is indicated by asterisks, while "ns" indicates no significant differences between dispersed and undispersed fruits.

Fruits from early March were of a higher quality than late April seeds because delayed harvesting may lead to a decline in proportion of healthy seeds as a result of adverse environmental factors such as high temperature, high humidity, rainfall, over drying and attack by pathogens or predation by pests (Copeland and McDonald 1995). However, it is also important not to harvest too early as this may also lead to a greater proportion of immature seeds or seeds with higher moisture content, leading to poor viability of harvested seeds (Copeland and McDonald 1995). Thus, sound, unblemished seeds may not necessarily mean viable seeds. Although, seeds from dispersed fruits were not found to have significantly lower quality than undispersed fruits not even during the late April harvest in this study, the effect of environment and predation on seed quality may depend on how long seeds are exposed to such adverse factors. Therefore, significant interactive effect of harvest source and time of fruit harvest could have been found had fruits been sampled much later than April.

Relationship between seed set and mother tree size

Sampled mother trees varied both in height (Coefficient of Variation=7.3) and particularly in DBH (Coefficient of

Table 1. Descriptive statistics for all mother trees (N=40) for DBH (cm) and height (m)

Size	Minimum	Maximum	Range	Mean	Std. Deviation
DBH	20	62	40	33.175	11.573
Height	15	21	6	18.050	1.3195

Variation=34.9). Descriptive statistics on mother trees are summarised in Table 1. There were no significant correlations found between mother tree DBH and proportion of fruits containing seeds for both dispersed (Kendall's tau_b, r=-0.04, N=40, p=0.76) and undispersed (Kendall's tau_b, r=-0.17, N=40, p=0.14) fruits (Fig. 3a and 3b). Similarly, correlations between seed set and mother tree height were found to be very poor and non-significant for both dispersed (Kendall's tau_b, r=-0.006, N=40, p=0.96) and undispersed (Kendall's tau_b, r=-0.053, N=40, p=0.67) fruits (Fig. 3c, d).

P. erinaceus are typically small trees growing up to 15 m-25 m in height and 75 cm-100 cm in diameter, depending on site conditions (Duvall 2008). Sizes of trees found in this study are therefore comparable to sizes described in the literature, but are slightly taller, perhaps due to the higher amount of rainfall this study site receives relative to the Sahelian regions.

No evidence was found for any relationship between size of fruiting trees and seed set in this study suggesting that factors responsible for seed set are not influenced by size (as measured in this study; height and diameter) of fruiting individuals of *P. erinaceus*. For example, pollination is important for seed set (Ollerton et al. 2011), but pollination may not depend on tree size as *P. erinaceus* trees at age of flowering and fruiting produce copious, showy and attractive masses of golden yellow flowers which cover the entire canopy (Bonkoungou 1999). Thus, every flowering tree, regardless of size, could attract pollinators. Tree size (which is also positively correlated to tree age for trees in their growth phase) effect on seed quality and quantity has often been studied and often with mixed results. For example, enhanced seed production has been reported for older and larger beech and oak species (Fennessy 2002). Also, trunk diameter effectively predicted seed production in *Garcinia lucida* (Guedje et al. 2003). By contrast, in an old study on *Pinus pongence*, normal and vigorous seeds were produced irrespective of age of fruiting individuals (McIntyre 1928 cited in Espahbodi et al. 2007). Our finding in this study suggests that *P. erinaceus* may be one of those species for which tree size does not predict fruit/seed quality.

The significance of this finding in forestry practice is that seed collectors may not have to consider mother tree size during fruit harvest, if the searching criterion is fruits with sound seeds.

Germination and initial seedling height growth: influences of mother tree and seed source

Overall (averaged over all mother trees and seed sources), seeds from the study area recorded a high seedling

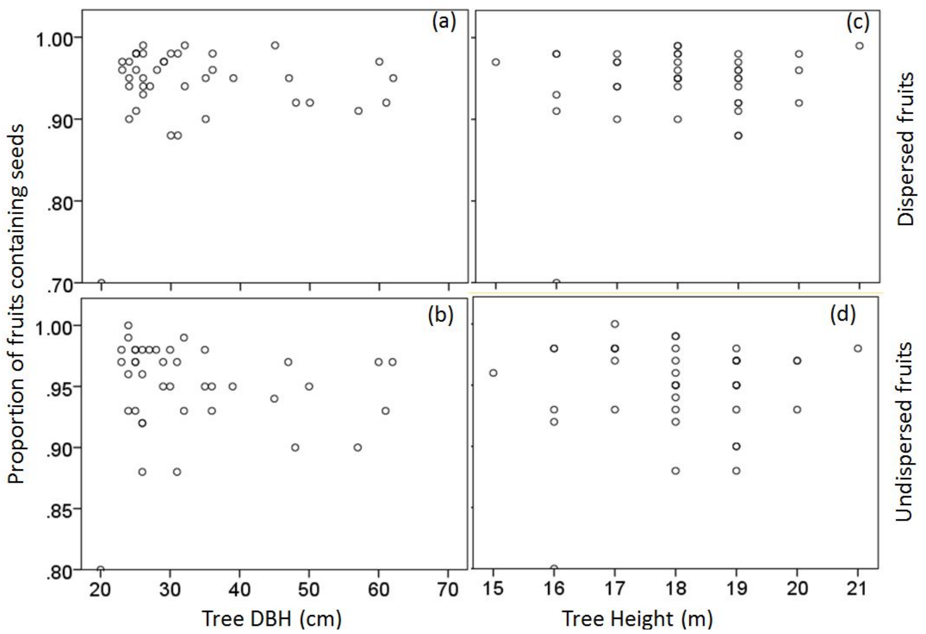

Fig. 3. Relationships between seed set and mother tree DBH (a, b) and tree height (c, d), for dispersed fruits (a, c) and undispersed fruits (b, c).

emergence percentage (mean=79.72±15.02%, N=36). There was a pattern of higher emergence percent for dispersed seeds for nearly all mother trees (Fig. 4). Although the difference was significant (p=0.011) for only one mother tree, the overall pattern culminated in significant main effect of harvest source (ANOVA, $F_{5,36}$=4.917, p=0.03) with seeds from dispersed fruits having a higher emergence percent that those from undispersed fruits (mean=85.0±14.65, N=18 and mean=74.4±13.82, N= 18 respectively). However, emergence percentage did not differ significantly (ANOVA, $F_{5,36}$=0.761, p=0.58) among mother trees.

Overall, seedling height after three weeks was 5.32±1.01 cm (N=36) and was not found to significantly differ among mother trees (ANOVA, $F_{5,36}$=1.256, p=0.315) or between the two seed harvest sources (ANOVA, $F_{5,36}$=0.065, p=0.80) (Fig. 5).

A high emergence percent was recorded for seeds from the study area. In a pre-treatment experiment, Duval (2008) found that germination after sulphuric acid and cold water pretreatments was over 70%, while mechanical scarification gave 100% germination. Therefore, an emergence percent of 79.72% (averaged over mother trees and seed sources) in this study using seeds is comparable with available data on germinability of the species. The focus of this part of the study was to make clear influences of mother tree and seed harvest source on germination. Therefore, seeds were used to avoid planting fruits which might not contain viable seeds. No influence of mother tree was found, suggesting that seeds from any tree will germinate well under the right conditions. This result could be different if fruits were used instead of seeds as differences in pod characteristics as influenced by mother tree could in turn influence seedling emergence. By contrast, Espahbodi et al. (2007) reported that in *Sorbus torminalis*, higher seed germination rates were found only for mother trees between 25 cm and 35 cm DBH.

Seeds from dispersed fruits had a higher emergence percent possibly because fruits with physiologically mature seeds are also those more easily dispersed (Schmidt 2007). Another possibility was that as dispersed seeds were in contact with the ground and hence with microbes and soil moisture they could have been more conditioned for germination than undispersed seeds. Both moisture and scarification have been used as methods of breaking seed dormancy in this species (Duvall 2008).

Seedling height, three weeks after sowing, did not differ among mother trees and harvest sources perhaps due to uniform emergence of seedlings for all mother trees and both harvest sources. Height recorded in the study is considered high because the species is reported to be slow growing, reaching only 9 cm after three months in Côte d'Ivoire and 15 cm after one year in Mali (Duvall 2008).

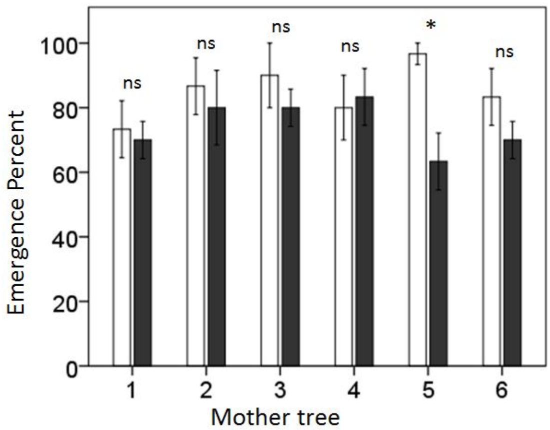

Fig. 4. Mean emergence percent compared between dispersed (open bars) and undispersed (gray-filled bars) fruits. Significant difference (ANOVA, $p < 0.05$) between the two fruit harvest periods is indicated by asterisks, while "ns" indicates no significant differences. Error bars represent ±1 standard error of mean.

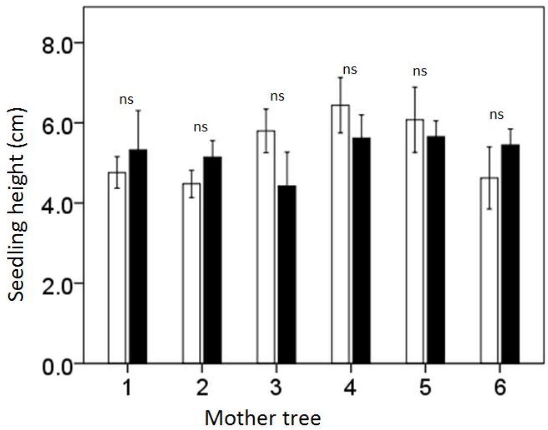

Fig. 5. Mean seedling height (cm) compared between dispersed (open bars) and undispersed (gray-filled bars) fruits for each mother tree. Statistical comparisons (ANOVA, $p < 0.05$) are indicated by "ns" (not significant). Error bars represent ±1 standard error of mean.

These findings have important forestry applications. Firstly, seeds of sufficient quality from any mother tree in the study area will germinate well, but it may be better to collect dispersed seeds for nursey operations as that may guarantee a higher emergence percentage.

Conclusion

This study investigated how mother tree size and habitat (related to land use) sources and time of fruit harvest influence seed set, quality and germinability. It was shown that, fruits are largely filled with seeds regardless of whether fruits are picked from farmlands or in bush fallows in the study area. Also, fruits collected early in the season (first week of March) have a higher proportion of sound, unblemished seeds than fruits collected later (last week of April), regardless of whether fruits are dispersed (collected on the ground beneath mother trees) or undispersed (harvested while still on mother trees).

There was no correlation between seed set and mother tree size (both height and DBH) in this study, an indication that seed set is high among mother trees in the study area regardless of mother tree size. Germination and initial seedling growth are also high regardless of mother tree from which seeds were harvested. However, seeds from dispersed fruits have a higher emergence percent than those from undispersed fruits.

Findings are expected to improve efficiency of seed collection to aid in *P. erinaceus* reforestation efforts.

Acknowledgement

The authors wish to acknowledge the support of Technicians and all others, especially Samuel Nana Ocran, for the support they provided during field work and also in the plant house, during the greenhouse experiment.

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