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Mixed Effect of Provenance and Stand Age on the Germination of Teak (*Tectona grandis*) Seeds in Ghana

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Abstract: Teak (*Tectona grandis* L. f.) plantations developers in Ghana have difficulty in selecting teak seeds from ecological sources and maternal ages that could guarantee optimum germination rates. To fill this knowledge gaps and contribute knowledge on germination characteristics of teak seeds in Ghana, we studied the effects of age of the maternal tree, the ecological zone of the mother tree, and the combination of the two on germination rates of teak seeds. We collected teak seeds from 10, 15, and 20-year-old healthy teak stands in the Savannah Zone (SZ), Transitional Zone (TZ), and the High Forest Zone (HFZ) of Ghana for this study. Fifty seeds from each maternal age for each ecological source were pretreated and sown in nine replicates using a completely randomized design in a factorial experiment with 2-factor treatment combination (age and ecological source). Our findings show that germination rate of seeds from the three maternal ages in the SZ was not different. The SZ also recorded the lowest overall germination rate among the three ecological zones studied. In the TZ, germination rate was not different between 10 years (47.33%) and 15 years (45.33%) maternal stands but both were significantly ($p<0.01$) higher than 20 years old (34.22%) maternal stands. The TZ recorded intermediate overall germination rates, which are higher than SZ but lower than HFZ. Germination rate was not different between 15 years old (88.00%) and 20 years old (94.44%) in the HFZ but was significantly ($p<0.05$) higher than 10 years old (41.56%). Moreover, the HFZ recorded the highest overall germination rate among the three ecological zones studied. Our findings further show that seed source (ecological zone), the age of the maternal teak tree, and the interaction of both, have significant ($p<0.01$) effects on germination rate of teak seeds. More importantly, the effects of age of maternal tree on germination rate was found to be dependent on the ecological zone in which it is located as same maternal age trees recorded different germination rates in different ecological zones. Interaction plot of age and the ecological zone of maternal teak plant produced the highest germination rate at the combination of HFZ with 15 and 20-year-old teak stands. We recommend that teak plantation developers in Ghana select teak seeds from 15 years and above in the High Forest Zone for optimum germination rates.

Keywords: Provenance, Nurseries, Climatic Conditions

1. Introduction

With the high rate at which the tropical forest is being lost [19] of which Ghana is not excluded, it is expected that the indigenous tree species be able to reproduce quickly to repopulate the degraded forest covers. However, the long gestation period of these indigenous species [1] poses a challenge to foresters who in turn substitute these with fast growth exotic species, which can perform well under tropical climate. One such example of these fast growth exotic species is *Tectona grandis* [11].

Tectona grandis commonly known as 'Teak' is a deciduous tree species of Southeast Asia [30] origin, which has become one of the most successful exotic species [18] performing extremely well on the soils of Ghana since its introduction. It is valued as an important commercial tree species because of its strength, aesthetic qualities [14] durability, and stability [30] even after natural disasters such as wildfire, which happens to be prevalent in most areas the species grows in Ghana [11].

To establish a successful plantation, however, the quality and quantity of seeds sown are paramount. The quality of seed is known to be affected by maternal identities [9] such as maternal age [25] and the maternal environment [5], both of which influence the natural regeneration processes. Several studies involving different species have shown significant effects of maternal age on seed production [31], which subsequently affects the quality of plantations established.

In most plantations in Ghana, selection of seed source and age of mother stands from which seeds are collected is mostly done at random often depending on the availability of seeds and easiness of collection. This usually compromises the quality of the plantation being established. According to [21] the importance of age of mother stands from which seeds are collected for germination is an essential factor influencing plantation development. A study conducted by [19] revealed that seed germination depends on abundance as well as viable seed supply, suitable medium, and favorable environmental conditions, which determine the output of nurseries, established to produce the stock for planting.

Knowledge of germination characteristics of species and the variation in the desired traits of the species are therefore pivotal to successful nursery establishment, especially when it is well known that germination of teak seeds is a critical problem in plantation programs [18]. It is in this light that seed sources and maternal age from which seeds are collected have become important issues in plantation programs. There is, however, a little knowledge and a lack of documented information concerning provenances and stand age groups, which could yield the optimum teak germination rate. This study, therefore, aimed to assess the effects of seed sources, ages of mother stands, and the interaction between these factors on the germination rate of teak seed. The results of this study shall provide guidance to plantation developers on where to collect seeds and the ages of tree stands, they should target for seed collection in order to achieve optimum results in plantation programs.

2. Materials and Methods

2.1. Study Area

Ghana lies between latitudes 5°N and 11°N and between longitudes 1°E and 3°N. According to [16], there are nine ecological zones in Ghana. These have been further regrouped into three distinct vegetation zones to include the High Forest Zones (HFZ), transitional zone (TZ) and the Savannah Zones (SZ) [3]. The country has a tropical climate with varying climatic conditions depending on the season. The various vegetation zones have distinct climatic conditions and soil types, which are mostly influenced by rainfall amount and pattern.

The HFZ consists of argillaceous sediments metamorphosed into phyllite type soil [29], which was developed from rocks of the Birrimian system [2]. The forest types in the HFZ are wet evergreen and moist evergreen [15] with an annual average temperature and rainfall of 27°C and 2092mm respectively [10].

The TZ consist of the Savannah Gleisols and Ochrosols whiles the Savannah zones are mainly lixisols, Luvisols and Plinthosols developed over voltaian sandstones, granite, phyllite and schists [4]. The TZ is delineated by [24] as being farther north (about 7.5-8.5° North) with an average annual total rainfall of 1,301 mm with rain occurring an average of 101 days/year and average annual temperature of 29°C. The vegetation present in the TZ is a mosaic of medium to tall grasses and tall tropical tree species [10].

Luvisols dominate the SZ of Ghana. Luvisols are defined as having a mixed mineralogy, high nutrient content and good drainage [6]. Average annual temperature in the SZ is in the region of 35°C with limited average annual rainfall of 1000mm. Moreover, hot and dry continental winds that blow from the northeast across the Sahara desert known as harmattan causes extremely hot, dry days, and cool nights in the SZ [28]. It is prudent to state here that soil organic matter varies among the various vegetation zones per their rainfall amount and distribution; hence, the forest zones are usually rich in organic matter content than the other zones [27] under study.

2.2. Seed Collection, Pretreatment and Nursery Site Conditions

High quality fresh drupe seeds, which were disease free and not malformed, were collected from 10, 15, and 20 years old healthy teak plantation stands each from the Savannah Zone, Transitional Zone, and the High Forest Zone. Seed collection took place during the latter part of December 2015. For each age at all provenances, 50 seeds were collected and replicated nine times. Seeds were initially dried with open air for three days, soaked in water for another three days, soaked in hot water (95°C) for 2 minutes, and finally exposed to sunlight for another three days before sowing on the germination beds to a depth of 0.5 cm.

The germination seed experiment was conducted at the Faculty of Renewable Natural Resources of the Kwame Nkrumah University of Science and Technology Nursery site (06°41′5.67″N, 01°34′13.87″W). The nursery site has an average temperature of 23°C, a relative humidity of 70% throughout the year and an annual rainfall between 1250mm and 1500mm [12] with a bimodal pattern and soils developed over granite, lower Birimian, and coarse-grained Votaian sandstone.

2.3. Experimental Design

The experiment was map out based on Completely Randomized Design (CRD) in a factorial experiment. 2-factor treatment combinations, namely Seed Source (SS) and Age (A) were employed in this study. The Seed Source

(SS) consisted of seeds collected from Assin Fosu in the High Forest Zone (HFZ), Kintampo in the Transitional Zone (TZ), and Tamale in the Savannah Zone (SZ). The three different ages (A) considered in this study were 10, 15 and 20-year-old stands. In total, nine treatment combinations labeled HFZ10, HFZ15, HFZ20, TZ10, TZ15, TZ20, SZ10, SZ15, and SZ20 were employed in the study, each replicated nine times.

2.4. Data Collection and Analysis

Counting of germinated seeds started from the first day of germination, which happened to be the 6th day of sowing. Counting was carried out after every three days for 12 weeks. Data were initially captured into excel tables and later imported and analyzed with R programming software (Version 3.2.4.). One Way Analysis of Variance (ANOVA) was used to test within source variation in germination from the three age groups. Two-Way Analysis of Variance (ANOVA) was also used to test the combined effect of age and provenance on seed germination. Where differences were significant (at 95% confidence level), Tukey posthoc test was conducted to reveal differences found by ANOVA.

3. Results

This section presents the distribution of germination within each of the three ecological zones and lastly highlights the interactive effects of combined ecological zone and age of parent stands from which seeds were collected on germination of seeds.

3.1. Germination Distribution in the Savannah Zone (SZ)

We tested the difference in germination from the three tree ages within the Savannah Zone of Ghana. Mean germination recorded in the SZ was 16.22% (*SD=2.33*) for 10-year-old Teak trees, 18.89% (*SD=2.03*) for 15 years old trees, and 16.22% (*SD=3.53*) for 20-year-old trees. From the ANOVA (Table 1) below, the three tree ages in the SZ did not differ significantly [F (2, 24) = 2.9091, p = 0.07] in germination. We, therefore, do not reject the null hypothesis that means germination is not different among the three tree ages in the SZ.

Table 1. *ANOVA Table for germination in SZ.*

Treatment: Age	df	Sum of squares	Mean squares	F value	Sig.(p-value)
Age	2	42.67	21.33		
Residuals	24	176.00	7.33	2.9091	0.07^{ns}
Total	26	218.67	28.66		

^{ns}Not Significant at 95% confidence level (p<0.05)

3.2. Germination Distribution in the Transitional Zone (TZ)

Mean germination recorded in the Transitional Zone was 47.33% (*SD=7.68*) for 10-year-old trees, 45.33% (*SD=8.72*) for 15-year-old trees, and 34.22% (*SD=8.80*) for 20-year-old trees. ANOVA test conducted (Table 2) showed a significant effect of age on germination (p<0.05) among the three tree age groups in the TZ [F (2, 24) = 6.34, p = 0.006].

Table 2. *ANOVA Table for germination in TZ.*

Treatment: Age	df	Sum of squares	Mean squares	F value	Sig (p-value).
Age	2	898.1	449.0	6.341	
Residuals	24	1699.6	70.8		0.006**
Total	26	2597.7	519.8		

**Significant at 99% confidence level (p<0.01)

Tukey multiple comparisons of means (95% family-wise confidence level) was conducted to reveal where the reported significant difference (p=0.006) in germination rate among the 10, 15, and 20-year-old Teak trees lies. The results are presented in Table 3 below.

Table 3. *Tukey multiple comparisons of means in TZ (95% family-wise confidence level).*

Age pairs	Mean difference	Lower bound	Upper bound	Sig.(p-value)
15-10	-2.000000	-11.90659	7.906592	0.87
20-10	-13.11111	-23.01770	-3.204519	0.01
20-15	-11.11111	-21.01770	-1.204519	0.03

Sig. (p-value) = Level of significance; p-value is significant at 95% confidence level (p<0.05)

It must be noted from Table 3 that germination of seeds from 20-year-old Teak trees was significantly lower (p<0.05) than both 15 and 10 years old Teak. Germination of seeds from 10-year-old trees and 15 years old trees was not significantly different (p=0.87). The distribution of germination of seeds from the three age groups in TZ is further displayed in Figure 1 below.

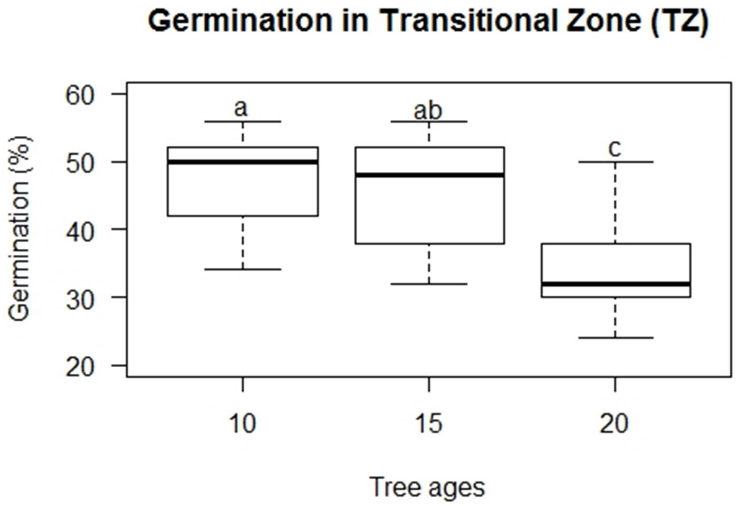

Figure 1. *Distribution of germination in the Transitional Zone.*

3.3. Germination Distribution in the High Forest Zone (HFZ)

Mean germination recorded in the High Forest Zone was 41.56% (*SD=3.43*) for 10-year-old trees, 88.00% seeds (*SD=13.19*) for 15-year-old trees, and 94.44% (*SD=5.17*) for 20-year-old trees. ANOVA test (Table 4) shows significant difference [F (2, 24) = 105.8, p = 0.00] in means among the three tree age groups in the High Forest Zone (HFZ).

Table 4. *ANOVA Table for germination in HFZ.*

Treatment	df	Sum of squares	Mean square	F	Sig.
Age	2	14988	7494		
Residuals	24	1700	71	105.8	0.000***
Total	26	16688	7565		

***Significant at 99.99% confidence level (p<0.001)

Tukey multiple comparisons of means (95% family-wise confidence level) was conducted to reveal the significance differences [F (2, 24) = 105.8, p = 0.00] in germination among the three age groups in the HFZ as found by ANOVA table (Table 5) and the results is presented below in Table 5 and also in Figure 2.

Table 5. *Tukey multiple comparisons of means in HFZ (95% family-wise confidence level).*

Age pairs	Mean difference	Lower bound	Upper bound	Sig.
15-10	46.444444	36.535262	56.35363	0.00
20-10	52.888889	42.979706	62.79807	0.00
20-15	6.444444	-3.464738	16.35363	0.26

Sig.(p-value) = Level of significance; p-value is significant at 95% confidence level (p<0.05)

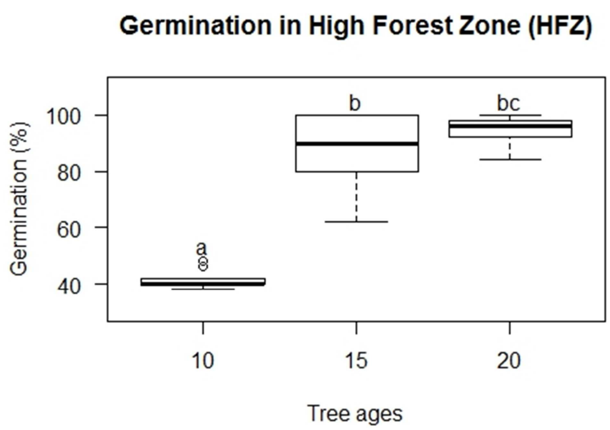

Figure 2. *Distribution of germination in the High Forest Zone.*

Germination of seeds from 10-year-old trees in the HFZ was significantly different (p<0.05) from 15 and 20 years old Teak trees. However, germination of seeds from 15 and 20 years old seeds was not significantly different (p>0.05)

3.4. Interactive Effects of Seed Source and Age on Teak Seed Germination

ANOVA was conducted to test the combined effect of seed source and age of teak stands on seeds germination. From Table 6 below, seed source (ecological zone) had significant effects [F (2, 75) = 274.41, p = 0.00] on seed germination. In addition, age of plantation trees also have significant effects [F (1, 75) = 28.98, p = 0.00] on seeds germination. More importantly, the combined effects of seed source and age of teak trees had significant effects [$F_{(2, 75)} = 67.073$, $p = 0.00$] on seed germination. An interactive plot (Figure 3) displays highest seed germination from the High Forest Zone (HFZ), followed by Transitional zone (TZ), and lastly Savannah zone (SZ). Tukey multiple comparisons of mean germination from all seed sources (Table 7) showed a significant difference ($p<0.05$) in germination among all the seed sources. HFZ was the significantly highest ($p<0.05$) with TZ also significantly higher ($p<0.05$) than SZ.

Table 6. *ANOVA Table for combined effects of seed source and age on seed germination.*

Treatment	df	Sum of squares	Mean of squares	F value	Sig.(p-value)
Seed source	2	44953	22476.5	274.408	0.00**
Age	1	2373	2373.4	28.976	0.00*
Seed source: Age	2	10988	5493.9	67.073	0.00*
Residuals	75	6143	81.9		

**Significant at 99% confidence level ($p<0.01$); *Significant at 95% confidence level ($p<0.05$)

Table 7. *Tukey multiple comparisons of means of germination based on seeds source (95% family-wise confidence level).*

Source pairs	Mean difference	Lower bound	Upper bound	Sig.(p-value)
TZ - HFZ	-16.62963	-21.97712	-11.282140	0.00
SZ - HFZ	-29.22222	-34.56971	-23.874733	0.00
SZ - TZ	-12.59259	-17.94008	-7.245103	0.00

Sig. (p-value) = Level of significance; p-value is significant at 95% confidence level ($p<0.05$)

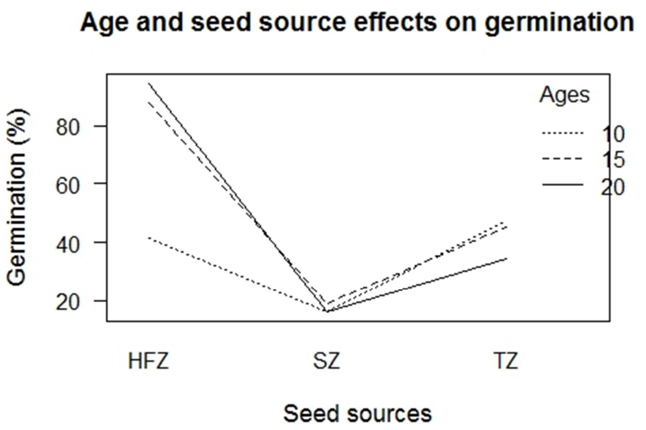

Figure 3. *Interactive effects of seed source and tree age on germination.*

4. Discussion

Seed source, the age of the mother stand [31] from which seeds are collected as well as the prevailing site conditions the mother stand dwells [26] are very influential when it comes to seed germination. Seeds collected from different sources with varying environmental conditions differ in the ease with which they can germinate [35].

It was very surprising that germination of seeds from the 10, 15, and 20-year old teak stands in the Savannah Zone was not significantly different. This could be due to peculiar dormancy of the seeds resulting from drought stress imposed on the parent plants [36] by the prevailing annual rainfall of 1000mm and temperature of 35°C in Ghana's Savannah Zone [10]. The optimal rainfall and temperature for teak are in the range of 1250-3000mm and 25-32°C [37]. Though seeds of teak are generally known to have strong dormancy attribute even after treatment [18], its dormancy is particularly strong in seeds from dry conditions and require a higher amount of pretreatment to break dormancy compared with seeds from high rainfall areas with moist areas [20]. The pretreatment employed was perhaps inadequate to break the dormancy of seeds from a dry and hot Savannah Zone [32] to achieve higher germination rates, which could have revealed any differences in germination among the three age groups. Moreover, the viability of seeds from such dry Savannah Zone to germinate regardless of the age of parent tree could also be the issue of plants responding to water stress by investing resources into root development at the expense of production of viable seeds [7]. However, [22] asserted that viable seeds might fail to germinate because they went into a state of secondary dormancy when they were exposed to the presumed unfavorable environmental factors present at the nursery site, which is different from the seeds main provenance.

For the Transition Zone, germination rate was observed to be higher in young (10 years) to middle (15) aged trees and falls drastically as the stands grow older (age 20). Germination rate in the TZ was comparatively better than the SZ. This could be due to the better site conditions (soils, temperature, and rainfall) at TZ relative to SZ, which stimulated rigorous photosynthetic activities, plant growth, and production of quality seeds [23] among the younger teak stands. Another reason could be attributed to the fact that at age 10, the plants had acquired all the necessary photosynthetic requirements needed for producing viable seeds. Plants in the TZ then turns to lose this photosynthetic requirement as they grow older which subsequently affects the viability of seeds such older stands produces. However, with increasing age and size, relative leaf growth and photosynthetic rates in woody perennials tend to slow down which could affect the production of viable seeds [23]. One possible explanation for the low germination rate among the 20-year-old teak stands in the TZ could be temporal increase in the competition for limited resources in the TZ, which could trigger a shift in resource allocation from reproduction to survival and growth [13].

For the HFZ, older stands turn to produce viable seeds than younger ones. The observed higher germination rate among the 15 years and 20 years stands confirms assertion by [17] that the fertility of teak seeds in a favorable site increases with age of mother stands from 15 years. With teak trees in the HFZ, not drought stressed, they might have shifted resource allocation to growth and survival in the early years [7] for quality seeds production later.

As observed in Table 6, this study further proves that seed sources, the age of mother stands, and the interaction of the two have a significant effect on teak seed germination rate [34]. [8] also confirm that local environmental conditions present where the mother stands grew could largely influence germination timing and success. The local microclimatic conditions at the site of the mother trees could affect seed viability through a change in resource allocation [13] or peculiar dormancy [32] which eventually determine germination success.

However, the effects of age on the germination were found to be dependent on the seed provenance as depicted in Figure 3. For example, while 10-year-old teak stands recorded the highest mean germination rate in the TZ, it recorded the lowest in the HFZ. The interactive effects of HFZ and older teaks stand (15 and 20 years) which recorded the highest overall germination confirm previous studies [17, 31]. The HFZ, therefore, has the microclimatic conditions optimal for breaking the worrying dormancy of teak seeds [20] to achieve higher germination rates. Even Though sown seeds could be fertile and viable, local environmental conditions present at the nursery site could change the genetic constitutions of the species, rendering the seed dormancy to germinate [33].

5. Conclusion

Our study shows that germination rate of teak seeds from Ghana's Savannah Zone is the lowest (<20%) among the three ecological zones studied and does not differ with age of mother stands. The Transition Zone recorded intermediate overall germination (34.22∓8.80% - 47.33∓*7.68*) with higher germination rates among 10 and 15 year old stands. The High Forest Zone recorded the highest overall germination rate (41.56∓3.43% - 94.44∓5.17%) with 15 and 20 years old stands significantly higher than 10-year-old stands. We also found that age of mother trees, seed source, and the combination of the two has a significant influence on germination rate of teak. However, the influence of age of mother stands on germination rate is dependent on the source in question.

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