Soil seed bank characteristics of *Canarium schweinfurthii* (Engl.): implications for its natural regeneration

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Soil seed bank characteristics of *Canarium schweinfurthii* (Engl.): implications for its natural regeneration.

Abstract — Introduction. *Canarium schweinfurthii*, a tree species in the rainforest of Nigeria whose fruits are intensively gathered and eaten, is seriously endangered because of poor seed germinability and usage. Our study examined the pattern of seed distribution of *C. schweinfurthii* in the soil from the stem base of the parent plant and through the soil profile, and it assessed the seed level of germinability. **Materials and methods**. Four stands of *C. schweinfurthii* were selected from a study area in Southeastern Nigeria. Soils were collected from six distances from each trunk base (1 m, 5 m, 10 m, 15 m, 20 m and 25 m) and at four soil depths (0–5 cm, 5–10 cm, 10–20 cm and 20–30 cm); then seeds of *C. schweinfurthii* were isolated from the cores. Moreover, the percentage of viability and germinability of the seeds collected from each distance and depth were determined. **Results**. The maximum number of seeds occurred at 1 m from the trunk base (82.3 seeds·30 cm^{-2}), which was 55% of the total collected seeds, and no seed occurred beyond 20 m from the trunk base. The mean number of *C. schweinfurthii* seeds occurring at 0–5 cm soil depth was 51.3 seeds·30 cm^{-2}, which was the highest from any profile. No seeds occurred below 20 cm. Sixty-seven percent of the total 148 seeds collected were considered viable, with about 80% of them occurring at the 0–5 cm soil depth. Even with the pre-sowing treatment (cutting the hard endocarp), only 30.8% of viable seeds collected from 0–5 cm soil depth were able to germinate, while 10% of those collected from 5–10 cm depth germinated. **Conclusion**. The localization of over 80% of *C. schweinfurthii* seeds within a 5-m radius from the stem base and 65% within 0–5 cm soil depth encourages easy fruit gathering by local sellers and leads to depletion of the seed bank. Seedling multiplication, protection of stands and domestication need to be initiated to lift *C. schweinfurthii* out of endangered status, considering the demand for the fruit and poor seed germination due to the hard endocarp.

Nigeria / *Canarium schweinfurthii* / seed stands / gene banks / germinability

Caractéristiques de la réserve du sol en graines de *Canarium schweinfurthii* (Engl.) : implications pour sa régénération naturelle.

Résumé — Introduction. *Canarium schweinfurthii*, une espèce forestière de la forêt tropicale du Nigéria dont les fruits sont intensivement recueillis et consommés, est sérieusement mis en danger en raison de la faible faculté germinative de ses graines et de leur usage. Nous avons étudié la répartition des graines de *C. schweinfurthii* dans le sol à partir de la base du tronc de la plante-mère, ainsi que de leur distribution dans l'épaisseur du sol ; puis nous avons évalué le taux de germination de ces graines. **Matériel et méthodes**. Quatre peuplements de *C. schweinfurthii* ont été choisis au sud-est du Nigéria. Des prélèvements de sols ont été effectués à six distances de la base des troncs (1 m, 5 m, 10m, 15 m, 20 m et 25 m) et à quatre profondeurs du sol (0–5 cm, 5–10 cm, 10–20 cm et 20–30 cm) ; les graines de *C. schweinfurthii* ont alors été récupérées dans chacun des prélèvements. Par ailleurs, les pourcentages de viabilité et de germination des graines collectées à chaque distance et dans chaque profil de sol ont été déterminés. **Résultats**. Le nombre maximum de graines, soit 55 % du total des graines récupérées, a été trouvé à 1 m de la base des troncs (82,3 graines·30 cm^{-2}) ; aucune graine n'a été trouvée à plus de 20 m de la base des troncs. Le nombre moyen de graines de *C. schweinfurthii* présentes à une profondeur de sol de 0–5 cm a été de 51,3 graines·30 cm^{-2}, cela représente le maximum de graines obtenues par profil. Aucune graine n'a été trouvée en dessous de 20 cm. Soixante-sept pour cent des graines parmi les 148 récupérées dans l'ensemble des prélèvements ont été considérées comme viables ; environ 80 % d'entre elles ont été localisées dans le profil de sol de 0–5 cm. Même avec un traitement avant semis (coupe de l'endocarpe coriace), seules 30,8 % des graines viables parmi celles récupérées dans la couche 0–5 cm ont pu germer ; il y en a eu 10 % pour celles collectées entre (5 et 10) cm. **Conclusion**. La localisation de plus de 80 % des graines de *C. schweinfurthii* dans un rayon inférieur à 5 m de la base des troncs et de 65 % dans la couche de sol de 0–5 cm facilite le ramassage par les vendeurs locaux et donc conduit à un appauvrissement de la réserve du sol en graines. La multiplication, la protection des peuplements et la domestication de la plante ont besoin d'être entrepris pour placer l'espèce *C. schweinfurthii* hors du statut de plante menacée lié à la demande du fruit et à la germination difficile de la graine dû à son endocarpe coriace.

Nigéria / *Canarium schweinfurthii* / peuplement semencier / banque de gènes / faculté germinative

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Figure1.
Fruits of *Canarium schweinfurthii* boiled and wrapped in polyethylene material as sold in the local market (Nigeria).

1. Introduction

The rainforests of Nigeria, which originally had high plant species richness, have been greatly decimated because of human activities [1]. The huge resources existing in the rainforest provided a medium for genetic improvement and a source of food, fiber and medicinal plants. Inherently, a significant proportion of the plant species occurring in the rainforest of Nigeria have difficulty in seed production and germination. Among such species is *Canarium schweinfurthii*, a climax species in the rainforest, whose fruits are edible after softening the pulp with hot water, and oils extracted from the fruits and leaves can be used in soap, paint and polish productions [2, 3]. In local markets, a wrap of twenty *C. schweinfurthii* boiled fruits (*figure 1*) is sold for fifty Nigerian Naira (US$0.5)

Canarium schweinfurthii has the status of an endangered species [4] because of the combined impact of forest destruction, intense fruit collection for eating and poor germinability of the seeds. The process of preparing the fruits for sale through boiling and softening of the pulp affects the seed viability. Also, the fruit of *C. schweinfurthii* has a thick and very stony endocarp (*figure 1*), which is a serious obstacle to germination as it prevents water penetration and imbibition by the embryo [5]. In a preliminary study, a germination test using 250 seeds extracted from fruits bought from five different local sellers gave 100% failure. Conservation of *C. schweinfurthii* is therefore necessary and could be realized if the processes surrounding the soil seed bank are understood.

The soil seed bank is an important facility in the dynamics of plant population because plant species maintain their population status largely through seeds buried in the soil and vegetative stumps [6, 7]. When a gap is created in mature forest or a forest is cleared, new seedlings spring up to replace the destroyed plant community. A colonizing community of plant species develops from a store of forest seeds which constituted the seed bank lying in the soil beneath mature forest [5, 8].

The size and quality of the existing seed bank and the number of seeds that germinate depend on viable seed deposit and the number that persist in the soil seed bank. It has been reported that seeds in the soil can germinate to recruit seedlings anytime during the growing season and seeds that fail to germinate immediately after dispersal may remain in the seed bank only to germinate under favorable conditions [9]. There is a need to understand the processes that go on concerning seeds of *C. schweinfurthii* on the forest floor, particularly in the presence of threatening forest disturbances and intense demand for the fruits as a local delicacy. This will be useful in developing an appropriate strategy for its conservation.

The objectives of this study were therefore to investigate the pattern of occurrence of seeds of *Canarium schweinfurthii* at various soil depths and distances away from the tree stand; and to assess the viability and germinability of the seeds.

2. Materials and methods

2.1. Study area

The study area was in Olokoro, Umuahia Abia State, Southeastern Nigeria (lat. between 05° 16' N and 05° 33' N; long. between 7° 32' E and 7° 41' E, alt. 122 m above sea level). The mean maximum daily temperature is 27 °C and the mean soil temperature 22 °C. There are two seasons in the area: a wet and a dry season. The wet season starts in March and

ends in November, with an annual total mean rainfall reaching 2035 mm. The area has lowland rainforest vegetation but most of the natural forest has been destroyed, mainly because of agriculture [4, 10]. The topography presents a gentle slope, except in some valleys and watersheds where the slope ranges from 30° to 75°. The soil in the area is deep reddish well-drained loam to moderately deep sandy clay loam.

2.2. Sample collection

The experiment was done using four separate stands of *C. schweinfurthii* found in three protected sacred forests (groves) within the study area in Olokoro and these stands were regarded as blocks. The use of three different sacred forests (groves) is to assess if location differences may exist in the results obtained. Under each *C. schweinfurthii* stand, two treatment factors were created, namely: distances away from the stem base; and soil depth.

Six distances (0 m, 5 m, 10 m, 15 m, 20 m and 25 m) were established under each stand with four soil depths (0–5 cm, 5–10 cm, 10–20 cm and 20–30 cm) which were prepared at each of the six distances, giving a total of 24 treatments. A 30 cm × 30 cm quadrat was laid on each sampling position to ensure that the correct volume of soil was collected. Soils were collected carefully using a hand trowel and measurement tape from the quadrats on these sampling distances and depths. The collected soil was put in a labeled polythene bag to indicate soil depth, sampling distance and the specific block (tree stand), and was subsequently taken to the laboratory where the seeds contained in the collected soils were isolated from each polythene bag and counted carefully. Viability of *C. schweinfurthii* seeds was tested using the simple flotation method in water. A 1000-mL glass container was filled with tap water and all the seeds collected at each soil depth were separately soaked in the water. Those *C. schweinfurthii* seeds that floated on the water were regarded as 'non-viable' seeds while the remaining, which were on the bottom of the glass container, were assumed to be 'viable' seeds. In order to uniformly assess their germinability, the seeds were given an angular cut to expose the embryos and enable them to easily imbibe moisture (*figure 2*). An angular cut on each seed was made by firmly holding the seed on a clamp and making an incision towards one end using a small hand saw.

The data obtained were subjected to analysis of variance (two factorials in a Randomized Complete Block Design) and the means were separated using Duncan's Multiple Range Test [11].

3. Results and discussion

3.1. Pattern of occurrence of *C. schweinfurthii* at distances from stem base

The highest number of seeds of *C. schweinfurthii* was found at 1 m from the trunk base. The mean total number of seeds collected for the four stands at 1 m distance was 82.33 seeds·30 cm^{-2}, which represented 55% of the total seeds collected whatever the distance (*table I*). The total number of seeds collected declined as distance away from the stem base increased. However, beyond 20 m from the stem base, in all four stands, no seed of *C. schweinfurthii* was observed. The mean numbers of seeds found at the six distances investigated were 82.33 seeds at the trunk base, 36.34 seeds at a 5-m distance, 16.0 seeds at 10 m, 13.33 seeds at 15 m, 1.63 seeds at 20 m, and no seed at 25 m.

The canopy size of *C. schweinfurthii* contributed immensely to the limitation of its seed within this area of coverage. The canopy size of most stands of *C. schweinfurthii* terminated at 6.5 m radius from the trunk base. When tree species shed their seeds at maturity, most of them are left on the soil surface below the tree canopy, particularly those not dispersed by wind and water [12].

Seed dispersal by agents such as gravity, wind and water over various distances is affected by the seed weight and shape. Small, light seeds are dispersed over a longer distance by wind.

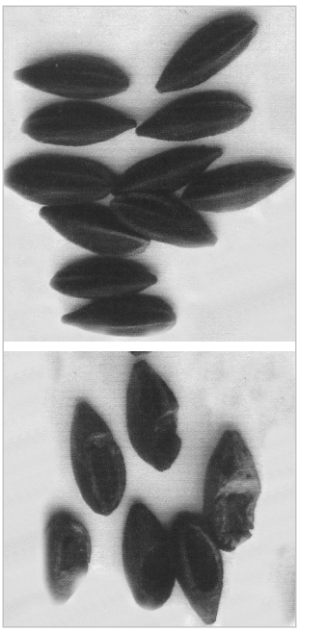

Figure 2.
Seeds of *Canarium schweinfurthii* showing the thick hard endocarp and pointed ends (top); cuts on their endocarp to facilitate water absorption by the embryo and germination (at the bottom).

The seed weight and shape constitute influential factors that could limit the dispersal processes [13]. In the case of *C. schweinfurthii*, its seeds are relatively heavy and this might be responsible for the limited dispersal range of the seeds.

3.2. Pattern of occurrence of *C. schweinfurthii* at different soil depths

The highest number of *C. schweinfurthii* seeds occurred at 0–5 cm soil depth. At 1 m from the trunk base, which was the distance where most seeds were deposited, it was observed that the mean number of seeds occurring at this depth was 51.3 seeds·30 cm^{-2}.

Depth significantly affected the distribution of the seeds at various soil levels because most of the *C. schweinfurthii* seeds were buried at the top layer depth of 0–5 cm. Similar reports of decreasing seed density with soil depth were made for *Cecropia obtuse* and *Cecropia sciadophylla* [14], and *Acacia salingna* [7].

About 11.3% of the mean total seeds of *C. schweinfurthii* occurred at 10–20 cm soil depth. It appears that, if fruits remain on the floor for a long time after shedding, they gradually become covered by the soil with each incidence of rainfall through displacement of soil particles, considering the seed weight, thereby moving deeper into the soil. Also, *C. schweinfurthii* seeds have pointed anterior and posterior ends with a streamlined shape, which could facilitate seed movement into the soil.

Seeds of *C. schweinfurthii* were not encountered below 20 cm soil depths. It is not common to find seeds, particularly grasses, sedges and legumes, below 10 cm soil depth [15–18]. The existence of *C. schweinfurthii* below 10 cm is largely attributable to the relatively heavy seed weight and streamlined shape.

3.3. Occurrence of viable seeds of *C. schweinfurthii* at various soil depths

Through the simple viability test conducted, it was observed that 67.9% of the seeds were viable (*table I*). The greatest quantity of viable seeds of *C. schweinfurthii* was collected from 0–5 cm soil depth. The viable seeds occurring at 0–5 cm depth constituted about 54.5% of the total seeds collected, while at 10–20 cm depth, the viable seeds made up only 3% of the total seeds collected. Thus, the viability of *C. schweinfurthii* seeds occurring on the floor below the canopy sharply declined below 5 cm soil depth.

The soil depth where the seeds are located is largely determined by the period during which the seeds remain on the soil after shedding from the parent plant. Seeds that stay for the longest time on the floor are more likely to displace more soils and penetrate deeper into the soil. However, seed viability generally becomes reduced with age, and so, most seeds found at higher soil depth become more unlikely to retain viability. This could be responsible for the low percentage of number of viable seeds occurring below 5 cm depth. Other reports have also shown that the number of viable seeds in the soil may decrease due to certain agencies such as predation by animals, fungal attacks, ageing, chemical content and other natural causes [7, 17, 19, 20].

Viable seeds have the potential to germinate under favorable conditions. Perennial plants retain their viability only for a brief period and germinate immediately. Annuals and biennials have seeds that remain viable in the soil for a longer period, while in a dormancy state, especially when buried deep in the soil from where they germinate when favorable conditions are available, and even when the parent species may become extinct locally. The loss of seed viability by plant species whose seed were located below 5 cm depth has been attributed to changes in soil temperatures and water relations [21–23].

In our experiments, only 30.8% of 81 viable seeds collected from 0–5cm soil depth were able to germinate, while 10% of those collected from 5–10 cm depth germinated. The low percentage of germination of *C. schweinfurthii* seeds occurred in this trial despite the pre-sowing treatment (*i.e.*, cutting the hard endocarp), a process that rarely takes place naturally. This evidently shows the extent of the physical and physiological barrier that needs to be managed

Table I.
Mean number of seeds of *Canarium schweinfurthii* occurring at various depths and their percentage viability (Southeastern Nigeria).

Distance to the trunk (m)	Depth (cm)	Mean number of collected seeds	Mean percentage of viable seeds
0	0 to 5	51.33 a	95.5 a
	5 to 10	19.00 b	57.8 c
	10 to 20	12 c	33.3 d
	20 to 30	0	0
5	0 to 5	23 b	82.6 a
	5 to 10	9.67 ce	31.2 d
	10 to 20	3.67 d	27.7 d
	20 to 30	0	0
10	0 to 5	12.67 c	39.7 d
	5 to 10	3.33 d	0
	10 to 20	0	0
	20 to 30	0	0
15	0 to 5	8 e	87.5 a
	5 to 10	4 ef	25 d
	10 to 20	1.33 f	0
	20 to 30	0	0
20	0 to 5	1.3 f	76.9 b
	5 to 10	0.33 f	0
	10 to 20	0	0
	20 to 30	0	0
25	0 to 5	0	0
	5 to 10	0	0
	10 to 20	0	0
	20 to 30	0	0
30	0 to 5	0	0
	5 to 10	0	0
	10 to 20	0	0
	20 to 30	0	0

Figures followed by different letter(s) in the same column are significantly different from each other.

in order to achieve successful conservation of *C. schweinfurthii*. This barrier is in addition to the limitation imposed by frequent gathering and boiling of the fruits for a local delicacy by people living in nearby settlements.

4. Conclusion

The *C. schweinfurthii* tree does not have the mechanism to disperse the seeds farther away from the parent plant. Over 80% of the total seed-rain remains within 5 m from the

trunk base, making predation by animals and gathering for selling and eating by people easy.

Also, 65% of the seeds are located within 0–5 cm soil depth and over half of them retain their viability but with very slim chances of germination without deep scarification of the seed endocarp. Only 13% of the seeds occurring below 5 cm soil depth retain viability and much less can germinate.

Seedling multiplication of *C. schweinfurthii* should be entrusted to Forestry agencies, and the plant should be used as a candidate species in afforestation programs. In addition, stands of *C. schweinfurthii* occurring in some areas could be protected in order to encourage the building up of the soil seed bank and the seedling recruitment. The existence of stands of *C. schweinfurthii* in the sacred groves used in our study shows the effectiveness of the proposed strategy. Since *C. schweinfurthii* fruit has significant economic value among the local people, it is an incentive to encourage domestication of the plant species in farms around their settlements if the seedlings are multiplied.

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Características de la reserva del suelo en semillas de *Canarium schweinfurthii* (Engl.): implicaciones para su regeneración natural.

Resumen — Introducción. *Canarium schweinfurthii*, una especie forestal de la selva tropical de Nigeria cuyos frutos se recogen y consumen, se encuentra seriamente en peligro debido a su débil facultad de germinación de sus semillas y de su uso. Estudiamos la repartición de las semillas de *C. schweinfurthii* en el suelo a partir de la base del tronco de la planta madre, así como a partir de su distribución en el espesor del suelo; a continuación evaluamos el índice de germinación de estas semillas. **Material y métodos**. Se eligieron cuatro poblaciones de *C. schweinfurthii* en el sur de Nigeria. Se efectuaron muestreos de suelo a seis distancias de la base de los troncos (1 m, 5 m, 10m, 15 m, 20 m, y 25 m) y a cuatro profundidades del suelo (0–5 cm, 5–10 cm, 10–20 cm y 20–30 cm); se recuperaron después las semillas de *C. schweinfurthii* en cada uno de los muestreos. Por otro lado, se determinaron los porcentajes de viabilidad y de germinación de las semillas recogidas a cada distancia y en cada perfil de suelo. **Resultados**. El número máximo de semillas, es decir el 55 % del total de las semillas recogidas, se encontró a 1 m de la base de los troncos (82,3 semillas·30 cm^{-2}); ninguna semilla se encontró a más de 20 m de la base de los troncos. El número medio de semillas de *C. schweinfurthii* presentes a una profundidad de suelo de 0–5 cm fue de 51,3 semillas·30 cm^{-2}, esto representa el máximo de semillas obtenidas por perfil. Ninguna semilla se encontró por debajo de 20 cm. Sesenta y siete por ciento de las semillas de las 148 recogidas en el conjunto de los muestreos se consideraron viables; de las cuales cerca del 80% se localizaron en el perfil de suelo de 0–5 cm. Incluso con un tratamiento antes de la siembra (corte del endocarpio coriáceo), únicamente el 30,8 % de las semillas viables de aquellas recogidas en la capa 0–5 cm pudieron germinar ; hubo el 10 % para aquellas que se recogidas entre (5 y 10) cm. **Conclusión**. La localización de más del 80 % de las semillas de *C. schweinfurthii* en un radio inferior a 5 m de la base de los troncos y del 65 % en la capa de suelo de 0–5 cm facilita la colecta por parte de los vendedores locales y conduce por lo tanto a un empobrecimiento de la reserva del suelo en semillas. La multiplicación, la protección de los poblaciones y la domesticación de la planta necesitan tomarse en cuenta para situar la especie *C. schweinfurthii* fuera del estatus de planta en peligro relacionado con la demanda del fruto y con la difícil germinación de la semilla debido a su endocarpio coriáceo.

Nigeria / *Canarium schweinfurthii* / rodal semillero / banco de genes / poder germinativo