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Seed dormancy and dormancy-breaking conditions of 12 West African woody species with high reforestation potential in the forest-savanna ecotone of Côte d'Ivoire

Milène N. Koutouan-Kontchoi[1,2,3a*], Shyam S. Phartyal[1,4,5b*], Sergey Rosbakh[1c], Edouard K. Kouassi[3] and Peter Poschlod[1d]

[1] Ecology and Conservation Biology, University of Regensburg, D-93040 Regensburg, Germany (E-mail: [a]milydege@yahoo.fr; [b]shyamphartyal@gmail.com; [c]sergey.rosbakh@ur.de; [d]peter.poschlod@ur.de)
[2] WASCAL Graduate Research Program on Climate Change and Biodiversity, Université Félix Houphouët-Boigny, Campus of Bingerville, BP 582 Abidjan 22, Côte d'Ivoire
[3] Laboratoire de Botanique, UFR Biosciences, Université Félix Houphouët-Boigny, 22 BP 582, Abidjan 22, Côte d'Ivoire (E-mail: kouasedward@yahoo.fr)
[4] H.N.B. Garhwal University, Department of Forestry and NR, Srinagar-Garhwal, India
[5] School of Ecology and Environment Studies (SEES), Nalanda University, Rajgir, Nalanda, India
*Authors for correspondence

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Abstract

Information on the regeneration ecology of native woody species of the forest-savanna ecotone of West Africa is scarce, which is a major impediment to their optimal utilization in large-scale restoration programmes. The scattered information that is available for some of these species reveals that freshly matured seed are dormant. However, environmental heterogeneity among different habitats may results in inter-population seed dormancy variation. Thus, our objective was to re-examine the dormancy of 12 species from the forest-savanna ecotone that have been targeted for reforestation. Specifically, we aimed to examine the water-permeability of the seeds and explore the effectiveness of acid scarification and heat treatment to alleviate dormancy. Four species belonging to families other than Fabaceae and Malvaceae had water-permeable seeds. Two of them had non-dormant (ND) seeds, and seeds of the other two species had a mixture of ND and other kinds of dormancy (possibly physiological dormancy, PD). Most species of Fabaceae and Malvaceae had water-impermeable seeds. All seeds of three species had physical dormant (PY), and some seeds of the remaining species had PY, while others were ND or had PD. Acid-scarification was effective in breaking PY and in augmenting imbibition and germination of non-PY seeds, while heat treatment was moderately effective in breaking dormancy. In general, acid scarification for 1-30 minutes and heat treatment for one hour at 55-75°C were optimal to enhance seed germination, depending on species. The present study has wide practical implications for park conservationists and restoration ecologists interested in producing bulk quantities of high-quality planting stocks of native woody species for large-scale restoration programmes.

Keywords: biodiversity conservation, climate mitigation, heat treatment, imbibition, native woody species, regeneration ecology, restoration, scarification, seed dormancy

Introduction

In West Africa, the forest-savanna ecotone occupies a vast territory across the Sudanian (dry) and Guinean (humid) regions (White, 1983; Groombridge and Jenkins, 2002). This ecosystem is usually represented by forest islands embedded in savannas that are suggested to be relicts of formerly continuous forests that have been degraded during a past arid period and/or degradation of the forest by human activities (Abbadie *et al*., 2006). The ecotone is characterised by unique landscapes that host high biodiversity (Holland *et al*., 1991). It also serves as an important natural source of ecosystem services for local communities (Weltzin and McPherson, 2000). Further, many forest islands in the savanna are protected at the regional and national levels (e.g. Pendjari and Comoé National Park in Benin and Côte d'Ivoire, respectively).

Global change has been affecting this valuable ecosystem for the last five decades. In regions with relatively low anthropogenic pressure (e.g. protected areas), increased precipitation has led to the expansion of woody species from the wet forests into the dry savannas (Fagan *et al*., 2003; Koulibaly *et al*., 2016; Atsri *et al*., 2018; Axelsson and Hanan, 2018). The low frequency of forest fires and low herbivore pressure (Andela *et al*., 2017; Hempson *et al*., 2017) accelerate this process considerably. In areas with high anthropogenic pressure (e.g. Lamto Reserve region in Côte d'Ivoire; Koulibaly *et al*., 2016), forest expansion is levelled out by regional common land-use practices, including deforestation for plantation establishment, grazing and logging. The existing studies suggest that in such regions the forest-savanna ecotone is not stable and could disappear if no urgent preventative measures are undertaken (Koulibaly, 2008; N'Da *et al*., 2008; Barima *et al*., 2010; Myster, 2012; Oliveras and Malhi, 2016).

To mitigate these negative effects, one solution would be to develop some degraded areas into protected areas for natural recovery, although this plan does not take into account the needs of local communities (Lopoukhine *et al*., 2012; Belle *et al*., 2016). Alternatively, land-use in the region could be changed to sustainable agriculture such as agroforestry (Vodouhe *et al*., 2011; Somarriba and Lopez-Sampson, 2018) with "timber trees as crops", including teak (*Tectona grandis* L. f., Lamiaceae) or cashew (*Anacardium occidentale* L., Anacardiaceae; Koné *et al*., 2007). This solution, on the one hand, would positively affect farmer's well-being, but at the same time, it may result in very low biodiversity in the region (Liu *et al*., 2018). The only 'remedy' that includes benefits for local people, nature conservation and mitigation of climate change effects is the reforestation of degraded lands using native species. Native species are better adapted to local ecological conditions in which they have evolved, and thus they are more suitable for the natural re-establishment of native flora and fauna species than introduced species (FAO, 2015). Moreover, the reforestation of native species at large spatial scales via seeds is a beneficial option due to the relatively low cost of seeds compared with plants propagated from cuttings (Palmerlee and Young, 2010; Merritt and Dixon, 2011). However, knowledge on the use of seeds for regeneration of native species is still scarce, and this hampers the massive use of seeds in large scale restoration programs (Thomas *et al*., 2014). Specifically, data on seed germination of tropical savanna species are very limited (Daibes *et al*., 2019).

The majority of tree species in our study ecosystem (forest-savanna ecotone) belong to the Fabaceae or Malvaceae that are known to have many species with water-impermeable seeds, i.e. physical dormancy (PY; table 1). However, published literature on PY within a species indicates that heterogeneous environments (relative humidity, precipitation, temperature during seed development) among different habitats play an important role in inter-population variability in presence/absence, degree and pattern of dormancy loss (Baskin *et al.*, 2000; Lacerda *et al.*, 2004; Tozer and Ooi, 2014; Liyanage and Ooi, 2015; Hudson *et al.*, 2015; Jaganathan, 2016; Ferreras *et al.*, 2017). Thus, depending on environmental conditions, seeds of the same species produced in different locations can vary in the proportion of non-dormant vs. dormant seeds (Jaganathan, 2016). Similarly, species with water-permeable seeds (e.g. seed with physiological dormancy; PD) can vary in depth of PD (and PD vs. ND) among populations, within populations and even between seed samples of different years from the same population (Andersson and Milberg, 1998). Given the intraspecific variability in seed dormancy, the aim of the present study was, therefore, to examine the seed dormancy pattern in 12 native woody species with high reforestation potential in the forest-savanna ecotone in Côte d'Ivoire (Dayamba *et al*., 2016). More specifically, we addressed the following questions: (1) Do the majority of study species belonging to Fabaceae and Malvaceae have seeds with a water-impermeable seed-coat (PY)? (2) Does scarification improve imbibition of species in families other than Fabaceae and Malvaceae? (3) How effective are acid-scarification and heat treatments on alleviating PY and in breaking PD?

Material and methods

Study site

The forest-savanna ecotone we studied is located in the Lamto Reserve in the central part of Côte d'Ivoire (6°13N and 5°02W), West Africa (figure 1). This reserve is 2617 ha in size, belongs to the Guinean savanna and has ferruginous soil. It mainly has a sub-humid climate (Diawara *et al.*, 2014), with mean annual precipitation of about 1200 mm and a mean annual temperature of 28.5°C. The area has four main seasons (two rainy and two dry; figure 2). To maintain a balance between savanna and forest species, a control fire is performed in the middle of the long dry season (January) by forest officials to minimise the possibility of large-scale fires in the peak of the summer season. Outside the reserve, forests and savannas are subjected to human activities and have been reduced to fragments. The main ethnic group of people, the Baoulé Swamlin (Akan), has been intensively using the savanna for cultivating their main food crop, yam (*Dioscorea* spp., Dioscoreaceae), and forests for their main cash crop, cacao (*Theobroma cacao* L., Malvaceae). Additionally, intensive logging has led to a drastic reduction and disruption of the natural ecosystem. Hence, there is an urgent need to implement an ecologically viable reforestation programme.

Table 1. Information of the study species.

Family	Scientific name (The Plant List, 2019)	Local name (Baoulé)	Collection habitat	Fire tolerance	Fruiting time	Dormancy		
						Kind of dormancy	Dormancy-breaking treatments	References
Apocynaceae	*Holarrhena floribunda* (G. Don) Dur. and Schinz	Cébé	Df	–	Jan-Mar	ND	*	Ayisire *et al*. (2012)
Ebenaceae	*Diospyros mespiliformis* Hochst. ex A.DC.	Adjoblé	Df / S	–	Dec-Mar	PD, ED	H_2SO_4 (2 hours) + W (1 day), CW (1 day), HW (60°C), HCl (5 minutes)	Mensbruge (1966); Wallnöfer (2001); Jegede *et al*. (2015); Dayamba *et al*. (2016)
Fabaceae	*Afzelia africana* Pers.	Kpakpah	Df	+	Dec-Feb	ND, PY	H_2SO_4, HW, HS (70°C), NaCl; KNO_3 (0.1%, 6 hours or 0.2%, 3 hours)	Mensbruge (1966); Amusa (2011); Ogbu *et al*. (2016); Peter-Onoh *et al*. (2017)
	Albizia ferruginea (Guill. and Perr.) Benth.	Koli kpangban / Kindron	Df	+	Jan-Feb	ND	*	Mensbruge (1966)
	Bauhinia thonningii Schum.	Diamla	S	+	Nov-Mar	PY	H_2SO_4 (2 hours) + W (1 day), H_2SO_4 (15 minutes)	Ayisire *et al*. (2009); Dayamba *et al*. (2016)
	Dialium guineense Willd.	Kpliman, Moyé	Df	+	Feb-Mar	PY	CW (1 day), HW (75°C, 6 hours)	Mensbruge (1966); Olajide *et al*. (2014); Ogbu and Otah (2017)
	Erythrophleum suaveolens Guill. and Perr.	Alui	Df	+	Nov-Feb	PY	MS, H_2SO_4 (95%, 40 minutes)	Mensbruge (1966); Ziba *et al*. (2017); Douh *et al*. (2018)
	Lonchocarpus sericeus (Poir.) DC.	Boma	Df / S	+	Jan-Feb	ND, PY	H_2SO_4 (15 minutes)	Mensbruge (1966); Lima and Meiado (2017)
	Pterocarpus erinaceus Poir.	Kpégou	S	+	Dec-Feb	PD	NT, W (12-24 hours), H_2SO_4 (30-60 minutes), MS	Zida *et al*. (2005); Duvall (2008); Akpona *et al*. (2017); N'golo *et al*. (2018)
Malvaceae	*Ceiba pentandra* (L.) Gaertn.	Nié	Df	–	Feb-Mar	ND, PY, PD	RM (12 hours), Na_2SO_4 (0.2 M, 36 hours)	Agboola (1998); Ojo (2019)
Moraceae	*Ficus sur* Forssk.	Aloma kangan	S	–	Dec-Jan	PD	*	Teketay (1993) cited by Baskin and Baskin (2014)
Rubiaceae	*Crossopteryx febrifuga* (Afzel. ex G. Don) Benth.	Crocro	Df	+	Dec-Jan	*	*	*

Abbreviation: Df = deciduous forest; S = savanna; + indicates 'Yes'; – indicates 'No'; ND = no dormancy; PY = physical dormancy; PD = physiological dormancy; ED = epicotyl dormancy; W = water; CW = cold water; HW = hot water; HCl = hydrochloric acid; HS = heat scarification; MS = mechanical scarification; NT = no treatment needed; RM = rabbit manure; * indicates no data available.

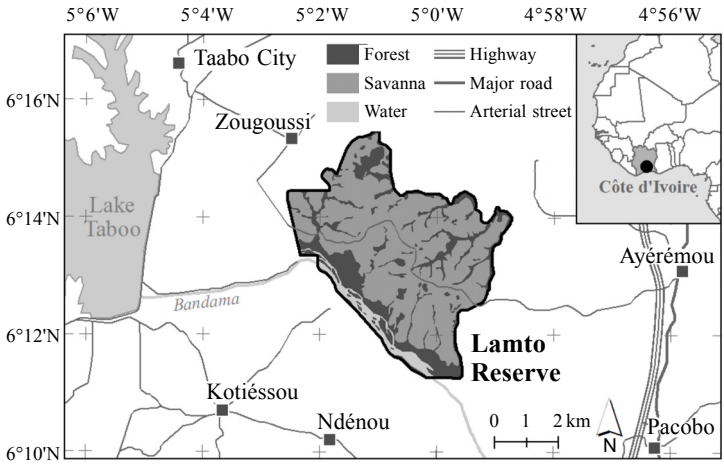

Figure 1. Seed collection site (Lamto Reserve, Côte d'Ivoire, West Africa). Source: Digital Globe 2012, open street map 2019.

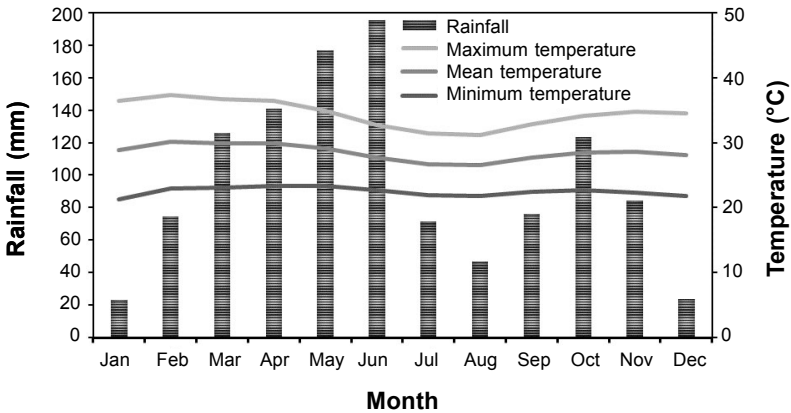

Figure 2. Climate of Lamto Reserve (means over 2009-2017). Data source: Lamto Geophysical Station.

Study species and seed collection

Mature fruits from the 12 woody species with potential for use in reforestation were collected from November 2018 to February 2019 (table 1). Immediately after collection, seeds were removed from their fruits, cleaned, dried and placed in paper bags. Two batches of seeds were transported to the laboratory of the Institute of Plant Sciences, University of Regensburg (UR), Germany, in January and late-February 2019, respectively for seed germination experiments (from March to July 2019). Seeds in paper bags were kept dry on laboratory shelves at ambient room temperature until the beginning of experiments. Seeds of all species were tested for imbibition of water and subjected to dormancy-breaking treatments, if needed, to promote germination.

Effect of mechanical scarification on water imbibition

Seeds of the 12 species were mechanically scarified by blade/nail cutter and another set of non-scarified seeds was the control. Ten seeds per species for each test were treated individually. Each individual seed was weighed before arranging the seeds on double filter papers moistened with water in Petri dishes. In addition, the large seeds of *Afzelia africana* were covered with a moistened filter paper so that most of the seed surface was in contact with water. Individual seeds were re-weighed (after blotting them dry) after 2, 4 and 6 hours and then at 24 hour intervals for a total of 120 hours. After weighing, the seeds were returned to the moist filter papers in the Petri dishes. All seeds were maintained in 12/12 hours light/dark regime at a diurnal fluctuating temperature regime of approximately 35/25°C that closely matches the temperatures of the rainy season in the habitat. The increase in seed mass was calculated as the difference between the wet (imbibed) and dry seed masses using the following formula (Baskin *et al*., 2004):

$$I_w = [(W_i - W_d) / W_d] \times 100$$

I_w is the water imbibition percentage; W_i is the mass of imbibed seed; and W_d is the mass of dry seed (at the start of the experiment).

If scarified seeds imbibed more water than intact seeds, then the seeds have an impermeable seed-coat, hence physical dormancy (PY). If this is not the case, it means that the seeds are non-dormant or could have another kind of dormancy.

Effect of acid scarification on seed dormancy-break and germination

Seeds of nine species that imbibed high amounts of water when scarified compared with non-scarified seeds in the previous experiment were soaked in concentrated 95-97% sulphuric acid for each of 1, 5, 10, 15, 20, 30, 40, 50, and 60 minutes, after which seeds were rinsed thoroughly with distilled water several times. Non-scarified seeds were used as the control. Seeds were tested for germination (see below).

Effect of heat treatment on seed dormancy-break and germination

We selected 10 temperatures for heat treatments: 50, 55, 60, 65, 70, 75, 80, 85, 90 and 95°C. Seeds of seven species that had a strong or weak positive response to acid-scarification in the previous experiments were heated for one hour at each temperature in a pre-heated hot-air oven. These treatments were chosen by considering the potential soil surface temperatures that can be found in the forest-savanna ecotone during the dry season and/or also when a fire occurs (Abbadie *et al*., 2006; Gorgone-Barbosa *et al*., 2016).

After each pretreatment, four replicates of 10-25 seeds from each sub-treatment, depending on size and number of available seeds of each species, were randomly arranged on top of two layers of moistened filter paper in Petri dishes. The Petri dishes with acid-scarified and heat-treated seeds were incubated at 35/25°C in daily 14/10 hours light/dark regime for 5 and 6 weeks, respectively. Seed germination was monitored three times a week, and seeds with the radicle protruded at least 1 mm were considered as germinated. The germination percentages were based on the number of seeds placed in the dishes, since no viability tests were done at the end of the experiment.

Data analysis

Final water imbibition percentages of scarified and non-scarified intact seeds were compared using Mann-Whitney U-tests ($P < 0.05$), while seed germination percentages after different dormancy-breaking treatments were compared using either an independent sample Kruskal–Wallis test (if data failed to meet the assumptions of parametric test) or a one-way ANOVA (if data met the assumptions of parametric test). All statistical analyses were performed using IBM SPSS Statistics version 16.

Results

Effect of mechanical scarification on water imbibition

Based on increase in mass during imbibition, two distinct groups of species were identified (figure 3). The first group of five species (*Crossopteryx febrifuga*, *Diospyros mespiliformis*, *Ficus sur*, *Holarrhena floribunda*, and *Pterocarpus erinaceus*) was characterised by more or less a similar imbibition capacity (Mann-Whitney U-test, $P > 0.05$) of both intact and scarified seeds. In the second group of species, scarification significantly increased the imbibition of water (Mann-Whitney U-test, $P < 0.05$). The mass of mechanically-scarified seeds of the latter group of species increased by 3- to 26-times more than that of intact seeds after 120 hours of incubation on moist filter paper. Seeds of most of species in the first group (*C. febrifuga*, *F. sur*, *H. floribunda* and *P. erinaceus*) germinated to a high percentage (approximatively 70%) without any additional treatments (data not shown).

Effect of acid scarification on seed dormancy-break and germination

There were differences among the nine species in how the seeds responded to different periods of acid scarification, with germination ranging from 0 to 100% depending on species and treatment (figure 4). Seeds of some species only had increased germination when they remained in the acid for more than 50 minutes, such as *Erythrophleum suaveolens* (40%), while those of other species had better germination relative to the above category of species even without acid scarification, such as *Lonchocarpus sericeus* (50%) and *Pterocarpus erinaceus* (65%). For the majority of the remaining species, the highest values of median germination percentage were obtained when they were soaked for 5-30 minutes.

There was no significant effect of acid scarification on seed germination of *Albizia ferruginea*, *Ceiba pentandra* and *Lonchocarpus sericeus* (figure 4). However, the increase in time of the acid scarification treatment resulted in an augmentation in the percentage of germination compared with non-treated seeds. On the other hand, the germination percentage of the remaining species, with a few exceptions, differed significantly from one treatment to another. As for the species on which the acid scarification had a positive effect, non-treated seeds had low germination percentages (*Bauhinia thonningii* and *Dialium guineense*), and others (*Afzelia africana* and *Diospyros mespiliformis*) had moderately high percentages but lower than with treatment. Seeds of the latter two species treated for 5-10 minutes had the highest germination (50 and 100%, respectively), while non-treated seeds of these two species germinated to only 40 and 47%, respectively.

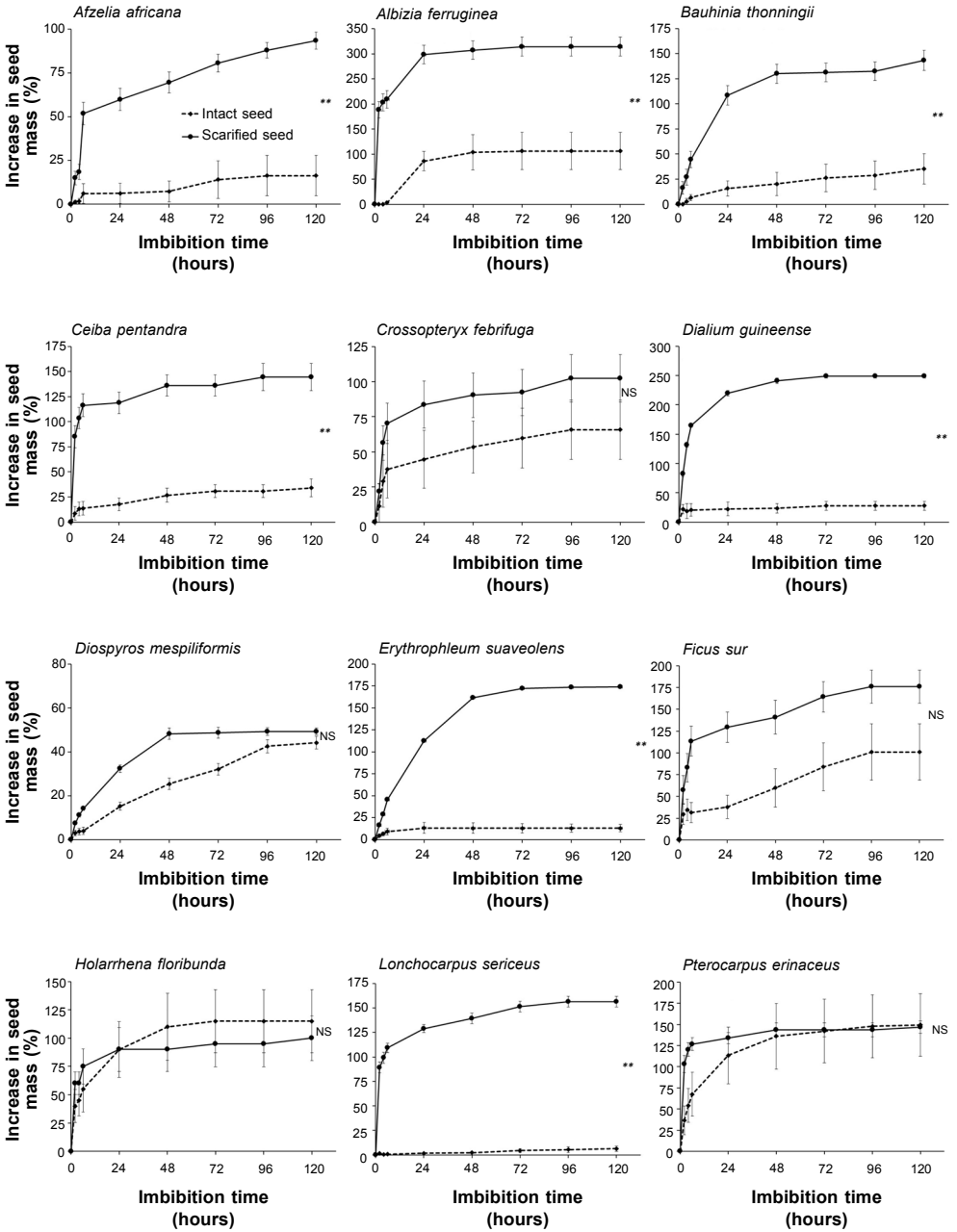

Figure 3. Time course of increase in mass (%) of seeds of different West African woody species from the forest-savanna ecotone that were kept on moist filter paper on Petri dishes intact (control) or after mechanical scarification for 120 hours. Bars indicate standard error. Asterisks or 'NS' represent significance (Mann-Whitney U-test, $P < 0.05$) levels.

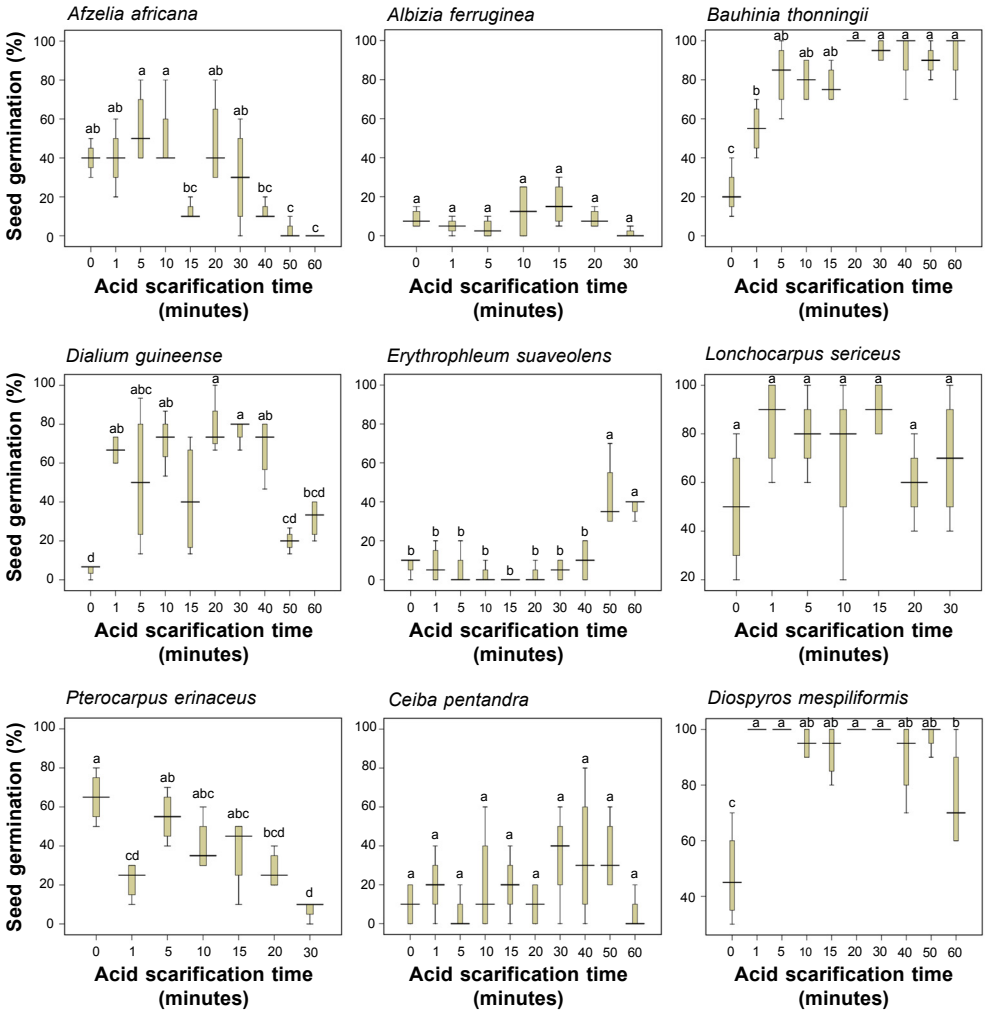

Figure 4. Box plot showing seed germination of different West African woody species from the forest-savanna ecotone incubated at alternative temperature (35/25°C) and normal daylight (14/10 hours L/D) condition after subjected to different periods of acid (H_2SO_4) scarification. Different letters represent subsets with significant ($P < 0.05$) differences. Box plot span covers the interquartile range, horizontal line is the median and whiskers (vertical line) represent the highest and lowest values.

Effect of heat treatment on seed dormancy-break and germination

Heat treatment had a significant effect on seed germination for the six tested species, except *Erythrophleum suaveolens* (figure 5). However, the majority of the study species showed no consistent decrease or increase in seed germination percentage with an increase in treatment temperature. Seed germination increased significantly from 40 to 70% in *Afzelia africana*, 9 to 43% in *Albizia ferruginea*, 22 to 55% in *Bauhinia thonningii*, 5 to 25% in *Dialium guineense* and 47 to 90% in *Diospyros mespiliformis* from the control to one of the heat treatment temperatures.

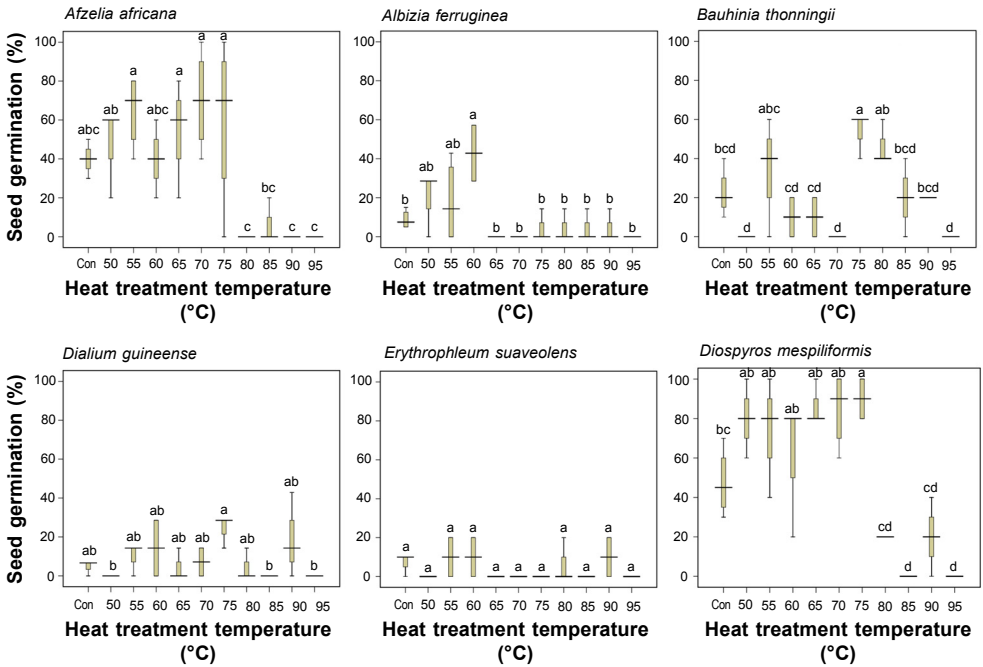

Figure 5. Box plot showing seed germination of different West African woody species from forest-savanna ecotone incubated at alternative temperatures (35/25°C) and normal daylight (14/10 hours L/D) conditions after subjected to different heat treatments for one hour. Different letters represent subsets with significant ($P < 0.05$) differences. Box plot span covers the interquartile range, horizontal line is the median and whiskers (vertical line) represent the highest and lowest values. Con = control (no heat treatment).

Discussion

The comparison of increases in seed mass of scarified and non-scarified seeds revealed that seeds of four species (*Crossopteryx febrifuga*, *Diospyros mespiliformis*, *Ficus sur* and *Holarrhena floribunda*) belonging to families other than Fabaceae and Malvaceae had a water-permeable seed coat. However, scarification increased the rate of water imbibition and germination percentage in seeds of most of these species as hypothesised.

This indicates that these species are either non-dormant or may have dormancy other than PY. Our results support findings of previous research that reported PD in seeds of *D. mespiliformis* (Mensbruge, 1966; Wallnöfer, 2001) and *F. sur* (Baskin and Baskin, 2014), and no dormancy (ND) in seeds of *H. floribunda* (Ayisire *et al.*, 2012). Other species of *Holarrhena*, such as *H. africana* (Mensbruge, 1966) and *H. pubescens* (Thapliyal and Phartyal, 2005), have also been reported to have ND seeds (Baskin and Baskin, 2014). Indeed, families to which these species belong cannot have PY because their seed coat does not possess a water-impermeable palisade layer of cells in the seed coat (Baskin *et al*., 2000; Wallnöfer, 2001; Smýkal *et al*., 2014). In these species, the duration from seed sowing to radicle and/or cotyledon emergence can help us to determine if seeds are ND (germinate within one month) or exhibit another kind of dormancy (PD, require > one month to germinate). Our results suggest that a cohort of *C. febrifuga*, *D. mespiliformis*, *F. sur* and *H. floribunda* seeds was ND, as > 50% of the seeds germinated within four weeks (data not shown); the remaining non-geminated cohort may have PD. Although no information is available on seed dormancy of *C. febrifuga*, the Royal Botanic Gardens Kew (2020) reports that the seeds germinated to > 85% within a month at a temperature range of 20-30°C, also confirming ND as reported in the present investigation. Both acid scarification and heat treatment significantly enhanced germination percentage of *D. mespiliformis* seeds as we hypothesised, providing further evidence that water-permeable seeds of this species have PD (Mensbruge, 1966; Albrecht, 1993; Prins and Maghembe, 1994; Baskin and Baskin, 2014). In addition to breaking PY, scarification is also known to weaken PD (especially non-deep PD), and it promotes germination of water-permeable seeds (or fruits) of various species. This suggests that embryos of some water-permeable seeds of *D. mespiliformis* lack sufficient growth potential to break the seed coat for radicle protrusion.

A high percentage of seeds of the majority of the other group of species (*Afzelia africana*, *Albizia ferruginea*, *Bauhinia thonningii*, *Ceiba pentandra*, *Dialium guineense*, *Erythrophleum suaveolens* and *Lonchocarpus sericeus*) belonging to Malvaceae and Fabaceae had a water-impermeable seed coat except *P. erinaceus*, as their scarifed seeds imbibed water to a significantly high percentage compared with intact seeds. Hence, they have a high possibility of PY, as in their congeners (Baskin *et al*., 2000; Baskin and Baskin, 2014). The non-scarified seeds of *P. erinaceus* germinated relatively well (65%) compared with scarified seeds (maximum 55% when immersed in acid for five minutes). Germination within a month suggests that the major cohort of *P. erinaceus* seeds was ND and a small portion might have had PD. Zida *et al*. (2005) also reported PD in a Burkina Faso population of *P. erinaceus.*

The germination tests of scarified and non-scarified seeds did not fully confirm PY in some of these species (*Afzelia africana*, *Albizia ferruginea*, *Ceiba pentandra* and *Lonchocarpus sericeus*). Their seeds either germinated to a substantial percentage without any scarification treatments (*A. africana* and *L. sericeus*; i.e. both ND and PY in same seed lot), or they did not respond significantly to the scarification treatments (*A. ferruginea* and *C. pentandra*; indicating PY and PD seeds). There is a possibility that either the scarification treatments were not optimal to break PY fully for the latter category of species or these species may have had more than one kind of dormancy.

For examples some seeds of a species may have PY and others have PD. Since most of the species with a water-impermeable seed coat attained maximum germination in less than four weeks, we conclude that the majority of the species had a high percentage of PY seeds except in the case of *C. pentandra.* There is a possibility that a high percentage of *C. pentandra* seeds have PD, which needs further investigation. In contrast to earlier reports (Mensbruge, 1966; Baskin and Baskin, 2014), some seeds of *A. africana*, *A. ferruginea*, *C. pentandra* and *L. sericeus* have PY, while other seeds in the same seed cohort have ND and/or PD. Baskin and Baskin (2014) also mentioned that seeds of *A. africana*, *C. pentandra* and *L. sericeus* have a mixture of dormancies (i.e. different percentages of ND, PY and PD). Nevertheless, acid scarification allowed a considerable increase in seed germination in *A. africana*, *C. pentandra* and *L. sericeus*. Our results also suggest that seeds of the remaining species with a water-impermeable seed coat (*B. thonningii*, *D. guineense*, *E. suaveolens*) may be considered as having 100% PY seeds, as reported in earlier studies (Ayisire *et al.*, 2009; Baskin and Baskin, 2014; Ziba *et al.*, 2017; Douh *et al.*, 2018).

Unlike, seeds of *Bauhinia thonningii* and *Dialium guineense*, those of *Erythrophleum suaveolens* seem to require a longer duration of acid scarification, since 50-60 minutes soaking in acid resulted in only about 40% germination; whereas, heat treatment was ineffective in breaking PY. These results are similar to those reported by Ziba *et al.* (2017), who described a high percentage of PY in *E. suaveolens* seeds. Heat treatment was found to be equally or relatively less effective than acid scarification to enhance seed germination in *A. africana* and *A. ferruginea.*

Conclusion and implications for reforestation

The results presented here confirm that the majority of study species from Fabaceae and Malvaceae have water-impermeable seeds and hence have PY, and others have water-permeable ND or PD seeds, as in natural populations elsewhere. We also found that most of the 12 West African woody species from the forest-savanna ecotone have a mixed cohort of both non-dormant and dormant seeds at maturity. In the majority of the species with PY, acid scarification was an effective pre-treatment compared with heat treatment, which also weaken PD in some water-permeable seeds. Collectively, the results of this study have wide practical implications for restoration practitioners like nurserymen, forest officials, park conservationists, restoration ecologists, and botanists interested in producing bulk quantities of high-quality planting stocks of these native woody species for large scale reforestation and restoration programmes of the forest-savanna ecotone of West Africa.

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