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Population Structure in Natural Stands, Seed Germination and Seedling Growth of *Sterculia setigera* under Nursery Conditions in Burkina Faso (West Africa)

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Authors' contributions

This work was carried out in collaboration between all authors. Author PB conducted the study, compiled the data, conceived the ideas of this manuscript, conducted the analysis and submitted the first draf. Author AO deepened the ideas of the paper, provided guidance for data analysis and contributed to the writing. Authors AT and AML initiated the project UNDESERT, scientifically supervised the implementation of the research and data collection and provided comments on the manuscript. All authors read and approved the final manuscript.

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ABSTRACT

The present study aimed at evaluating *S. setigera* population structure in natural stands and estimating the effect of pretreatment methods on seeds' germination capacity and seedling establishment. Dendrometrical measurements were performed on 504 *S. setigera* trees for population structure assessment. The bell shaped structure obtained indicates that the population of *S. setigera* is unstable and under threat due to lack of recruitments under threat due to lack of recruitments. An experimental design with four randomized blocks corresponding to four replicates

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of 25 seeds in each pretreatment (sulphuric acid, boiling water, water at room temperature and the control) was used. Seeds were sown in a medium of clay and dung in the ratio 2:1, in polythene plastic pots measuring 7.5 x 25.5 cm. A total of 400 plastic pots were used in this experiment and kept moist. Forty days after sowing, germination rate was assessed. The results showed that sulphuric acid produced the highest (75%) cumulative germination while boiling water had the lowest (8%). Seeds under control pretreatment gave an impressive germination, which did not differ significantly (p= 0.000) from the results of sulphuric acid. The high rate of germination in the control can be taken as an indicator that *S. setigera* has the ability to produce seedlings but these seedlings face difficulties of establishment in natural areas. Seedlings growth in term of height were significantly (p=0.016) affected by the type of pretreatment used. Acid pretreatment technique showed the highest seedlings performance. Based on the natural population pattern and the germination traits, we could hypothesize that the lack of *S. setigera* recruitment is primarily caused by water regime in the soil.

Keywords: Pretreatment; germination capacity; growth rate; sylviculture; seedling growth.

1. INTRODUCTION

The rapid rate of forest loss and degradation across the tropics has continued to increase fragmentation of many populations and risk of species' extinction [1]. The high demand for plant resources raises concerns about the impact of exploitation on biodiversity and ecosystem processes [2]. Number of studies in West Africa [3,4,5] have reported unstable populations of *S. setigera* in different sites. In Senegal, *S. setigera* populations are threatened due to gum overexploitation inducing intensive mortality and lack of natural regeneration [6]. This is an indication that the species is under threat not only in the study area but also in several geographical locations in the region of its distribution. To assess the impact of human activities on the population structure and to estimate their resilience to human activities, knowledge on the population structure is required. The use of population structures as a tool to understand the demographic health of harvested populations can be the basis for strong management decisions if it is combined with information related to species specific growth rate and spatial distribution [7].

The resource stocks have been depleted, as *S. setigera* is in high demand by traditional healers and craftsmen for its bark and fibers [4,5]. It is among the most commonly used species by the local people in West Africa [4,5,8,9]. One of the most important is that branches are cut for livestock and bark is highly used for traditional medicine.

Highly variable precipitation, frequent dry periods, seed infertility, loss of seeds and mortality in young seedlings are major barriers for establishment and regrowth in natural stands [10,11]. Furthermore, young trees are fed on by livestock. Ouédraogo [3] reported that most of the trees have stems in the 25-40 cm-diameter class, reflecting old population across *S. setigera* distribution range to the East of Burkina Faso. To enhance rapid sustainable production of *S. setigera,* there is a need for an understanding of the basic sivilcutural requirements of the species.

Germination process is considered as the most important and crucial factor in a plant life cycle as it seriously affects successful execution of afforestation and reforestation programs [12,13]. Thus, there is a necessity to make research on germination and seedling establishment of *S. setigera.* The growth and management of *S. setigera* is necessary to improve the regeneration capacity of the species. Nursery phases are an important part of the operation in the cultivation of many tropical tree crops. Keeping the seedlings growing in the nursery until they are big enough and more vigorous reduces the risk of plant damage. The findings of Aiyeloja and Azeez [14] showed that *S. setigera* seedlings in nurseries respond positively to added urea and NPK fertilizer and perform best when watering is done daily.

This study aims at analyzing the population structure of *S. setigera* in natural stands and investigating possibilities to enhance seed germination, and the early seedlings growth. Such a research will make it possible to highlight reasons for poor population structure and provide basis for adequate approaches for conservation of this threatened species.

2. MATERIALS AND METHODS

2.1 Study Area

The study area is located in Namoungou (31P 894854 UTM 1331216) in eastern Burkina Faso. Phytogeographically, the study site is situated in the north soudanian zone [15]. The rainy season lasts from June to October (Fig. 1). The vegetation is savanna with a grass layer dominated by annual grasses and scattered trees and shrubs. Mimosaceae and Combretaceae are dominant woody species' families.

The region is a livestock-farming and agricultural area with extensive land use. Livestock pasture is increasing, and for over 85% of the farmers, natural pasture is the main source of fodder [16].

2.2 Population Structure

As *S. setigera* trees are scattered, sampling for dendrometrical measurements were taken for all available individuals. For each *S. setigera* tree diameter at breast height (DBH) was measured. A measuring tape was used to measure girth at breast height (GBH, at height 1.3 m), which was then converted to DBH. To establish the size-class distributions, diameters of all trees were used to construct histograms with size classes of 5 cm interval.

The structure was adjusted with the 3-parameter Weibull theoretical distribution because of its flexibility [17].

$$f(x) = \frac{a}{b}\left[\frac{x-a}{b}\right]^{c-1} e^{-[x-a/b]c},$$

where x = tree diameter, a = location parameter represents, the threshold trees diameter structure, b = scale parameter linked to the central value of diameters, and c = shape parameter of the structure.

2.3 Seed Collection and Processing

The seeds of *S. setigera* were collected directly from standing trees during February 2013 in Namoungou located in eastern of Burkina Faso. Seeds were collected from individuals with clear bole, well developed and abundant seeds. Seeds were thus transported in the Laboratory of Biology and Ecology of the University of Ouagadougou, Burkina Faso for processing and germination tests.

Seeds were extracted manually; infected seeds were discarded, while intact seeds were stored at room temperature (24 to 26°C) to keep the seeds viable for the germination experiments.

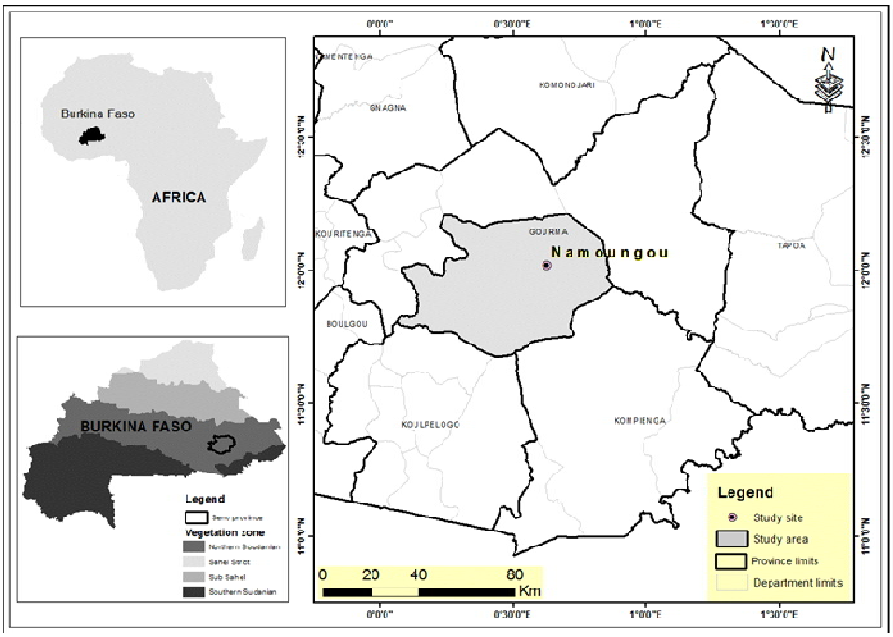

Fig. 1. Location of study site

2.4 Germination Experiment

A germination experiment was conducted in March 2013 at the nursery of Ouagadougou University one month after seeds collection. The experimental design was four randomized blocks with four replicates and 25 seeds in each pretreatment. Seeds were sown in a medium of clay and dung in the ratio 2:1, in polythene plastic pots measuring 7.5 x 25.5 cm. A total of 400 plastic pots were used in this experiment and kept moist. Conditions were similar to those of the surrounding environment (temperature = 25-38°C). The physical and chemical characteristics of substratum are mentioned in Table 1. The germination process was monitored every day during 40 days and germinated seeds were counted when the seedling emerged from the medium [18]. We considered in this study that the germination termination is the emergence of seedling from the substratum because seed germination involves the imbibitions of water, a rapid increase in respiratory activity, the mobilization of nutrient reserves and the initiation of growth in the embryo [19]. The four pretreatments were:

1. Acid pretreatment: The seeds were randomly selected and soaked in 98% concentrated sulphuric acid (H_2S0_4) during ten minutes and rinsed immediately after removal under tap water during five minutes.
2. Boiling water pretreatment: Water was boiled to approximately 100°C, the heat source removed and then the seeds were soaked into the boiling water until the water got cold and seeds were following left in water for 24 hours.
3. Room temperature water pretreatment: The seeds were soaked in water for 24 hours at room temperature.
4. The seeds were sown without any pretreatment (control).

A total of eight hundred seeds were used in this experiment. The seeds were watered every day and germinated seeds were counted every morning. The experiments were carried out between April and July 2013.

After germination, seedling assessments were carried out at monthly intervals beginning from the 30 days after sowing (DAS). The seedlings in the nursery were monitored for four months from April to July. A total of 40 seedlings (10 per pretreatment) were selected at random for growth parameters measure.

Table 1. Physical and chemical characteristics of the substrate used in this experiment (mean±standard deviation, n = 3)

Parameters	Quantities
Granulometry	
Clay fraction (%)	9.8±0.00
Silt fraction (%)	26.14±1.13
Sand fraction (%)	64.05±1.13
Water constants	
pF 2.5 (%)	10.87±0.22
pF 3.0 (%)	6.43±0.02
pF 4.2 (%)	3.19±0.14
Nutriments	
Total organic matter (%)	0.70±0.02
Total organic carbon (%)	0.40±0.01
Total organic nitrogen (%)	0.05±0.00
Total phosphorus (ppm)	70±0.00
Available phosphorus (ppm)	0.44±0.04
Total potassium (ppm)	395±0.00
Available potassium (ppm)	81.08 3.45

2.5 Seedlings Growth Parameters

Seedling assessments were carried out at monthly intervals beginning from the 30 days after sowing (DAS). The seedlings in the nursery were monitored for five months from May to September. Growth parameters of the seedlings of *S. setigera* that were investigated were: total height, collar diameter and number of leaves. Seedling height was measured as the distance between the root collar diameter and the apical meristem using a graduated ruler (in cm), stem diameter at the collar was measured using a vernier caliper (in mm) and the number of leaves was counted manually.

2.6 Data Analysis

The germination rates were calculated for each pretreatment method. Daily germination percentages were summed up, over the 40 days monitoring period to obtain cumulative germination percentage for each pretreatment. The effects of pretreatment were tested on *S. setigera* seeds. Germination rate mean, values of seedlings height and basal stem diameter were calculated and tested for differences among pretreatment by one-way analysis of variance (ANOVA) using JMP version 9 Statistical Software [20]. Data were tested for normality and homogeneity of variance. Data on germination

rates were log transformed to ensure normality and homogeneity of variance. Differences among species were tested using Tukey HSD test at 5% significant level.

3. RESULTS

3.1 Population Structure

The stem diameter distribution of *S. setigera* showed a bell shape population structure, which revealed unstable demographic pattern (Fig. 2). The histogram showed a predominance of adult individuals. In the overall stand, trees with 35-40 cm stem diameter were more abundant.

3.2 Effect of Seed Pretreatment on Germination

Initial germination in both pretreatments showed that the seeds do not germinate quickly. Less than 10% germination was observed after sixteen days of sowing (Fig. 3). It was however observed that germination of few seeds started twelve days for the seeds pre-treated in sulphuric acid and room temperature water pretreatments.

Cumulative germination rate 40 days after sowing showed that more than 65% germination could be achieved without pretreatment (control). Sulphuric acid had the highest cumulative germination (75%), soaking in room temperature water and control had an average cumulative germination (67%) while boiling water pretreatment had the lowest cumulative germination (8%).

The cumulative germination percentage was not significantly different between sulphuric acid and room temperature water pretreatment methods (F=0.07; P=0.79), between sulphuric acid and the control (F=0.70; P=0.40), between the control and the room temperature water pretreatment (F=1.14; P=0.28). The cumulative germination percentage was significantly different between the two pretreatment (sulphuric acid and room temperature) and the boiling water pretreatment, between the control and the boiling water pretreatment.

3.3 Seedlings Growth under Nursery

Growth of seedlings, in terms of collar diameter, stem height, and number of leaves produced varied between seeds pretreatment method. The total heights of *S. setigera* seedling were significantly affected by the type of pretreatment used, whereas diameter and leaf production were not significantly affected by the pretreatment method (Table 2). The data in Table 1 also show high variability in growth as indicated by standard deviations.

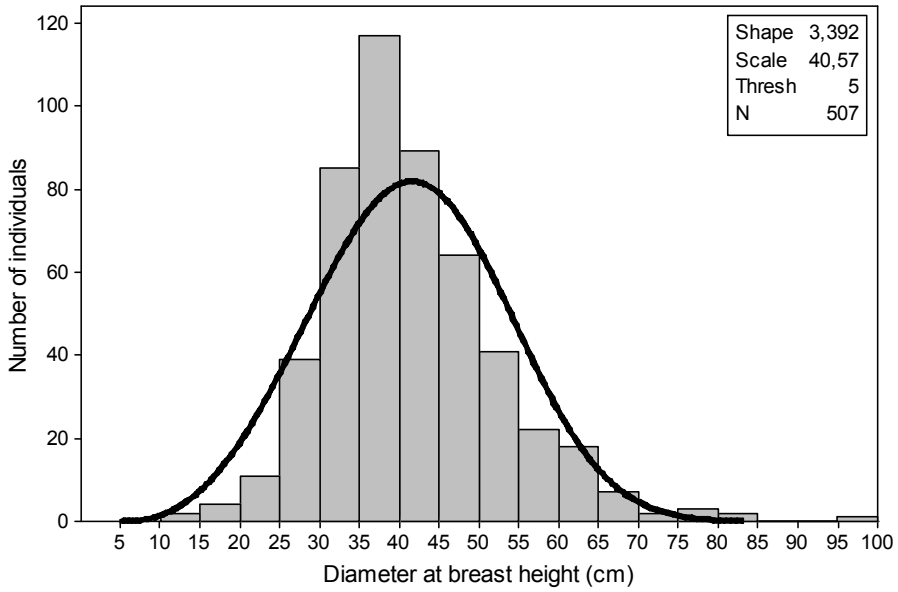

Fig. 2. Population structure of *S. setigera* in Eastern (Namoungou, Burkina Faso)

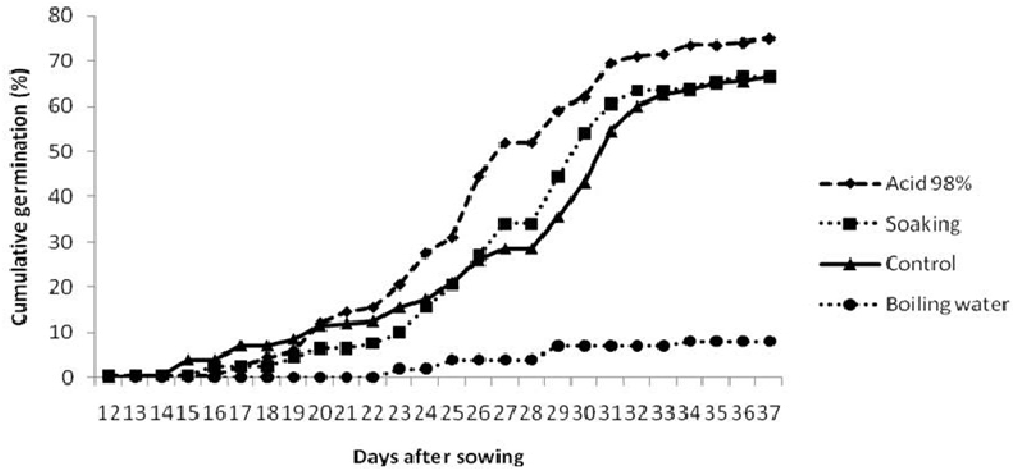

Fig. 3. Cumulative germination rate of *S. setigera* seeds according to pre-sowing treatment

Table 2. Summary of the results of the one-way ANOVA investigating the effects of pretreatment on the seedlings growth traits

Sources of variation	Height			Collar diameter			Number of leaves		
	df	F	P	df	F	p	df	F	p
Pretreatment	3	11.8	<0.0001	3	1.40	0.24	3	6.57	<0.0001

At 5 months after sowing, it was observed that highest plant were recorded on seedlings germinated from sulphuric acid while the lowest height was recorded on seeds germinated from boiling water pretreatment (Fig. 4). The number of leaves recorded was higher on the seedlings from H_2SO_4 treated seeds. The collar diameter remains relatively the same at the end of 5 months in all the seedling growth was therefore influenced by pretreatment method.

4. DISCUSSION

4.1 Population Structure

The population structure of *S. setigera* showed a bell shape form, which revealed unstable demographic pattern and under threat due to lack of recruitments. The stem diameter distribution of individuals showed the predominance of adult individuals. The species population showed a strongly declining trend characterized by aging trees and lack of regeneration. The lack of regeneration and the absence of intermediate stage individuals of *S. setigera* prove its population decline. The observed population structure of *S. setigera* in this study was similar to ones reported in the South Sudanian zone [4], the eastern of Burkina Faso [11] and the Sudanian zone of Togo [5]. According to Traoré et al. [4] the species population showed a J-shaped population structure in both protected and unprotected forests in the North Sudanian sector and this is a typical trend for a declining species with aging populations as evidenced by the lack of individuals in the small diameter classes. The few young individuals indicates a weak regeneration potential [21] of the species. This is an evidence that the species is under threat as reported in several geographical locations of its distribution range. In Burkina Faso, Ouédraogo [3] showed that most of the trees have stems in the 25-40 cm-diameter class, reflecting old populations.

4.2 Effect of Pretreatment on Seeds Germination

The seeds required a long time of humidity for best germination result. Ouédraogo [3] observed similar situation with the seeds of the same species. The germination rate (66.5%) obtained in the control showed that our results were different from those of Ouédraogo [3] who found a higher percentage (78%) without pretreatments of seeds six months after harvesting. The high germination rate in the control can be taken as an indicator that *S. setigera* has the ability to recruit by seedlings but these seedlings face difficulties of establishment. The capacity of germination of the species without pretreatments is a mean to mitigate the environmental aridity in natural habitats. Since it is possible to produce

seedlings of *S. setigera* easily, *ex-situ*, the poor regeneration of the species *in situ* that was reported by Ouédraogo and Thiombiano [11] may be attributed to the possible high predation of seeds by birds and rodents.

Our results indicated that seeds pretreatment affect the germination of *S. setigera*. Sulphuric acid was most effective but its applicability in rural context is questionable. Indeed, sulphuric acid presents the risk to burn the operator and the seeds. Sowing without any pretreatment (control) or soaking in room temperature water are suitable for rural people use since neither sophisticated equipment nor special techniques are required.

Compared to the control, the boiling water pretreatment gives qualified result contrary to what would be expected in nature. This showed that boiling water is not an appropriate pretreatment method for *S. setigera* seeds. It probably leads to the seed embryo being killedbecause of the contact with boiled water.

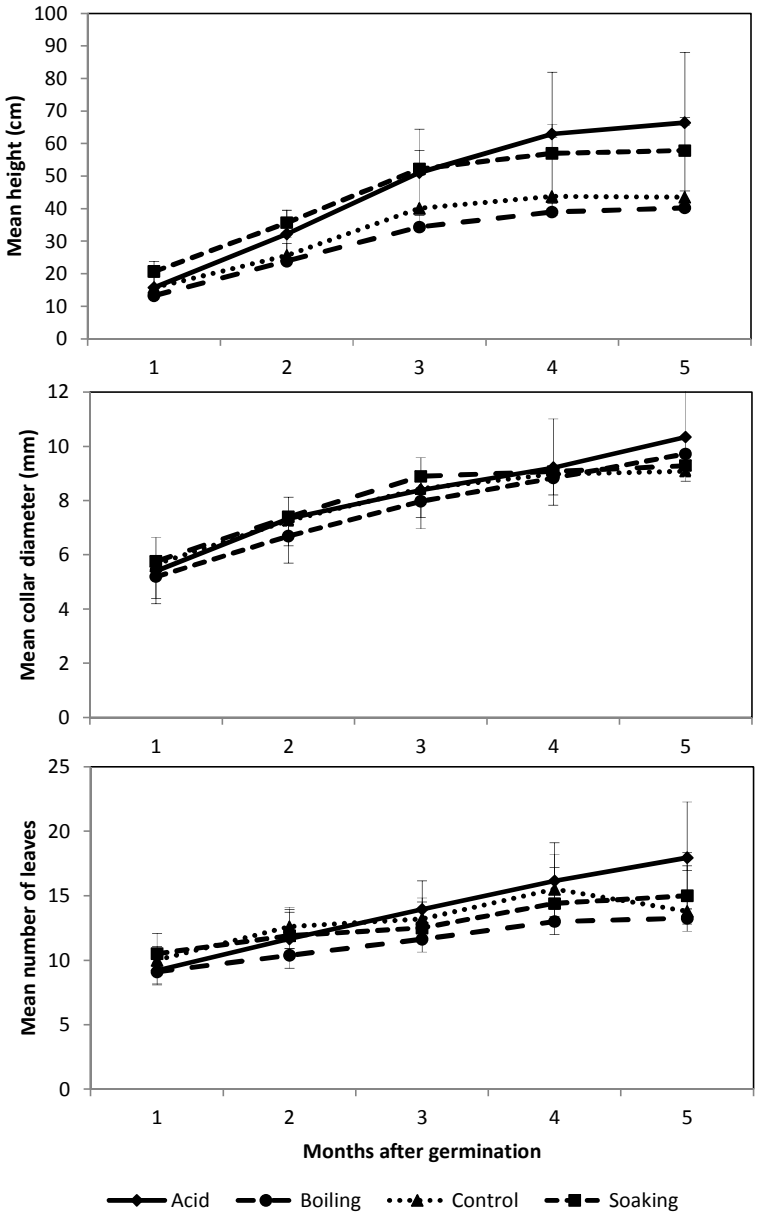

Fig. 4. Trend in *S. setigera* seedlings traits over the time

Aliero [22] reported that seed germination of *P. biglobosa* decreases when seeds were soaked in hot water for more than 4 s, suggesting that embryo may get destroyed on contact with boiling water for a prolonged period.

The seeds had a long delay of germination (average 12 days) and they would require a long time of humidity to assure a good germination. In this case the irregular distribution of rainfall in time and space is one the main factors that affect the species regeneration capacity.

4.3 Seedlings Growth under Nursery

The observed variations in the seedling growth, related to plant height, collar diameter and number of leaves, can be attributed to the effect of the pretreatments. Seedling from soaking seeds pretreatment and the control showed the lowest growth rates compared to those from the sulfuric-acid experiment where the higher performance was observed. This may be the result of the earlier germination. Seedlings in sulfuric-acid pretreatment have good growth characteristics what might later be exploited in sylviculture program. The good growth rates in nursery reveal forestry good sylvicultural aptitude of the species. The rapid growth of seedlings is a major asset that might help to assist the species regeneration in natural area.

According to Dauro et al. [23], enfranchisement of the majority of tree recruits depends on their survival and growth aptitudes in the natural stands facing drought, fire and pasturage.
There was high positive relationship between the different growth characters of seedling ($r>0.70$), which might make it possible to select group of parameters in a sylviculture program.

These parameters may be considered in the promotion of rapid production of vigorous seedlings for afforestation and reforestation programs.

5. CONCLUSION

The population structure illustrated that *S. setigera* was under threat due to lack of recruitment. Experiments revealed that germination of seeds and seedling growth varied according to the pretreatment method. The best germination rate, seedling growth were obtained with sulphuric acid while the lowest values were observed with boiling water pretreatments. Based on the natural population pattern and the germination traits, we could hypothesize that natural regeneration of *S. setigera* is primarily caused by the fact that seeds are mature long time before the rainy season and could be attack by pests or loose their germination capacity.

It is recommended to use sulphuric acid for seeds pretreatment before sowing. However the best germination and growth are best in areas with a high water regime in the soil. Soudanian zones could be the best zones for afforestation using *S. setigera*. In the dry areas, plantation of *S. setigera* should be supported by soil treatments which can improve soil moisture.

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COMPETING INTERESTS

Authors have declared that no competing interests exist.

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