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Germination Test of Shea Seeds (*Vitellaria paradoxa* C.F. Gaertn) in Nursery on Substrates of Northern Côte d'Ivoire

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Authors' contributions

This work was carried out in collaboration among all authors. Authors AKA and DN designed the study, initiated and conducted the field experiment. Authors AKA and YSDM wrote the protocol, performed the statistical analysis and wrote the first draft of the manuscript. Authors YSDM and DN managed the literature searches, wrote and edited the draft manuscript. All authors read and approved the final manuscript.

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ABSTRACT

Aims: The present study aims to evaluate the effect of some abiotic factors on the quality of seed germination of shea tree, a plant of great economic interest for the rural populations in Northern Côte d'Ivoire.
Study Design: The trials were conducted in a nursery where two factors were considered. These were the substrate, with six modalities and shelter with two modalities. Six small pits, each of size 60 x 60 cm, surface 3600 cm^2 and 15 cm of depth were dug and then filled with different substrates.
Place and Duration of Study: The work was carried out in 2018 in the district of Korhogo in Northern Côte d'Ivoire.
Methodology: Each treatment received 36 seeds of shea tree giving a total of 216 seeds per test. The seeds used were all dark brown, ellipsoid in shape with masses ranging from 10 to 11 g. The

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experiment was carried out with a total of 12 treatments, six under a greenhouse hermetically covered with transparent polyethylene plastic and six under a shade made up of a rack covered with maximum *Panicum* leaves.

Results: The first germination was observed at the level of the organic manure treatment at 6 months of degradation installed under the greenhouse (ManB_G = 28 days). The lowest final germination rate was obtained with the organic fertilization at 3 months of degradation installed under the shade (FGP ManA_S = 2.95%) while the highest was observed in the sawdust installed under the greenhouse (FGP S_G = 64.18%).

Conclusion: It is concluded that for each substrate, soil or biowaste, the seeds of shea tree have a better ability to germinate under a greenhouse than under a shelter covered with straw.

Keywords: Shea tree; seed; germination; substrates; nursery; Côte d'Ivoire.

ABBREVIATIONS

Are_S : Arenosol under greenhouse;
Are_S : Arenosol under shade;
Fer_G : Ferralsol under greenhouse;
Fer_S : Ferralsol under shade;
Flu_G : Fluvisol under greenhouse;
Flu_S : Fluvisol under shade;
ManA_G : Organic manure at 3 months of degradation under greenhouse;
ManA_S : Organic manure at 3 months of degradation under shade;
ManB_G : Organic manure at 6 months of degradation under glass;
ManB_G : Organic manure at 6 months of degradation under glass;
S_G : Sawdust under glass;
Sc_S : Sawdust under shade.

1. INTRODUCTION

Shea tree is native to the arid lands of sub-Saharan Africa. Source of one of the oldest food oils in Africa, the butter of "shea tree" *Vitellaria paradoxa* C.F. Gaertn, (Sapotaceae), is a slow-growing fruit plant. Species are highly appreciated by local communities for their food, financial and environmental contributions. The shea tree has also distinguished itself as a multi-million dollar industry in the international market through the export of nuts and shea butter from Africa to Europe, Japan and other countries, making the plant a strategically important resource for Africa [1]. Shea butter is very popular in the food, cosmetics and pharmaceuticals industries [2,3,4], for its intrinsic properties related to its glyceride composition and its high content of unsaponifiables, which offers many opportunities in international markets. The economic exploitation of Africa's shea butter has become the focus of a vibrant industry, largely due to the spirit of initiative, physical resilience and African women in rural areas [5]. In view of the continuous decline in agricultural production, people are increasingly moving towards the exploitation and marketing of shea fruits. However, land pressure, the various agro-pastoral developments and the development of agricultural areas (cash crops) have caused a major disturbance of vegetation in savannah areas [6]. The annual bushfires and the modernization of farming techniques have led to depredation natural regeneration of the shea tree and the erosion of shea tree parklands [7]. The studies about productivity of shea tree showed the long time to maturity of this species (from 15 to 20 years), the lack of continuity in research and development efforts have left enormous gaps in the understanding of the biological and environmental factors on the productivity of shea tree. Otherwise, shea tree can multiply from seed sowing as most species of plant. Unfortunately, several research studies have shown that the germination of shea seeds is difficult or long because of the rapid loss of their germination capacity and the integument that constitutes a natural barrier. In addition, young shoots from natural seed germination are often cut by the plow during plowing or trampling of cattle [8].

Despite the socio-economic importance of shea butter increasing, until today the parks of shea tree are only established from natural regeneration in Côte d'Ivoire. Therefore, there is an urgent need to focus on the domestication of this high-value species, to improve its *in situ* management and to assess the impacts of land uses and agricultural practices on the natural regenerative dynamic of natural parkland. The present study aims to generate useful knowledges to optimize the germination of the seeds of shea tree for the domestication of this species in Côte d'Ivoire. Specifically, this study evaluates some abiotic factors effects on the

quality of the germination of the seeds of shea tree in the nursery.

2. MATERIALS AND METHODS

2.1 Study Zone

The tests were carried out on the vegetable patch of the botanical garden of the University of Peleforo Gon Coulibaly (UPGC) in the Korhogo district in Northern Côte d'Ivoire (Fig. 1). The site has coordinates (UTM) 210786 N and 1043639 W, on an average altitude of 370 m. The qualified Sudanese climate is characterized each year by a long dry season from November to May and a short rainy season from June to October. The temperature varies from 22 to 35ºC. The average annual rainfall is 1200 mm. Granites and shales are the parent rocks characteristic of the region's substrate. Soils susceptible to leaching, erosion and induration tend to be low in moisture and of medium fertility [9].

2.2 Plant Material and Substrates

The shea seeds used were collected in the same area, under fructiferous shea tree. Only fallen fruits were collected to ensure that they reached physiological maturity (Fig. 2). Two categories of substrate were used for germination tests that are biowaste and soil. The biowaste used comes from a woodworking workshop (sawdust) and the textile industry of the city of Korhogo (decaying seed cotton). The degradation times of seed cotton biowaste were 3 and 6 months. The soil substrates were derived from the natural environment and consisted of samples of three types of soil namely: Arenosol, Ferralsol and Fluvisol, all also used as seedbed (Fig. 3). Soil samples taken from a depth of 0-30 cm were well homogenized.

2.3 Experimental Design

The collected mature fruits were freed of their pulp, then the seeds rinsed with distilled water. The seeds used for the experiment had a mass which varied from 10 to 11 g, an ellipsoid form and the dark brown integument. The two factors considered were the shelter (two levels of modalities) and the substrate (six levels of modalities). The experiment was carried out with a total of 12 treatments, six under a greenhouse hermetically covered with transparent polyethylene plastic and six under a shade made up of a rack covered with maximum *Panicum* leaves. To evaluate shelter factor, the tests were carried out, one under a greenhouse hermetically covered with transparent polyethylene plastic and the other under a shade made up of a rack covered with *Panicum* leaves maximum. The levels of factor substrate were Arenosol, Ferralsol, Fluvisol, also biowaste at 3 months of degradation and biowaste at 6 months of degradation.

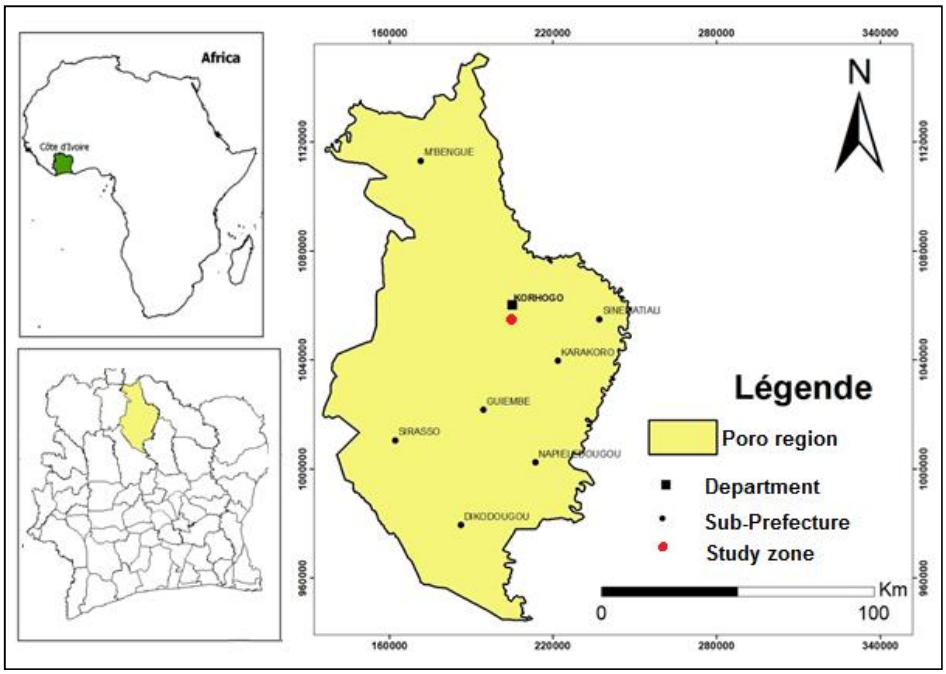

Fig. 1. Geographic location of the study site

Fig. 2. Mature shea seeds used for germination tests

Under each test, six small pits, each 60 x 60 cm in size, 3600 cm^2 in area and 15 cm of depth were dug and filled with different substrates (Fig. 4). The treatments were subdivided into small pots with an area equivalent to 900 cm^2, each separated by bamboo trays (Fig. 4). Non-scarified shea seeds were buried to a depth of 5 cm in each of the substrates. Each treatment received 36 shea seeds giving a total of 216 seeds per test. The experiment was carried out with a total of 12 treatments as mentioned in Table 1. The treatments were watered with tap water at 150 ml / treatment without any loss. The average temperature (substrates, greenhouse and shade) was recorded daily until the end of the experiment.

2.4 Organic Carbon and Total Nitrogen Contents in Biowaste and Soil Types

The organic carbon content (C) of the various substrates was determined by the Walkley-Black method after oxidation with a mixture of sulfuric acid (H_2SO_4) and potassium dichromate (K_2 Cr_2 O_7). Total nitrogen (N) was measured by the Kjeldahl method based on wet oxidation.

2.5 Estimated Germination Parameters

Previously, the germination process was characterized by the kinetics of germination. Since 2005, the germination process has been defined and measured by other parameters [10, 11]. In our experiment six of them have been chosen. They are germination parameters such as latency (L), germination capacity or final germination percentage (FGP), germination velocity coefficient (GVC), uniformity of germination (CVt) and Synchronous germination ($\bar{E}$).

Fig. 3. Substrates basis of biowaste and types of soils used for germination tests

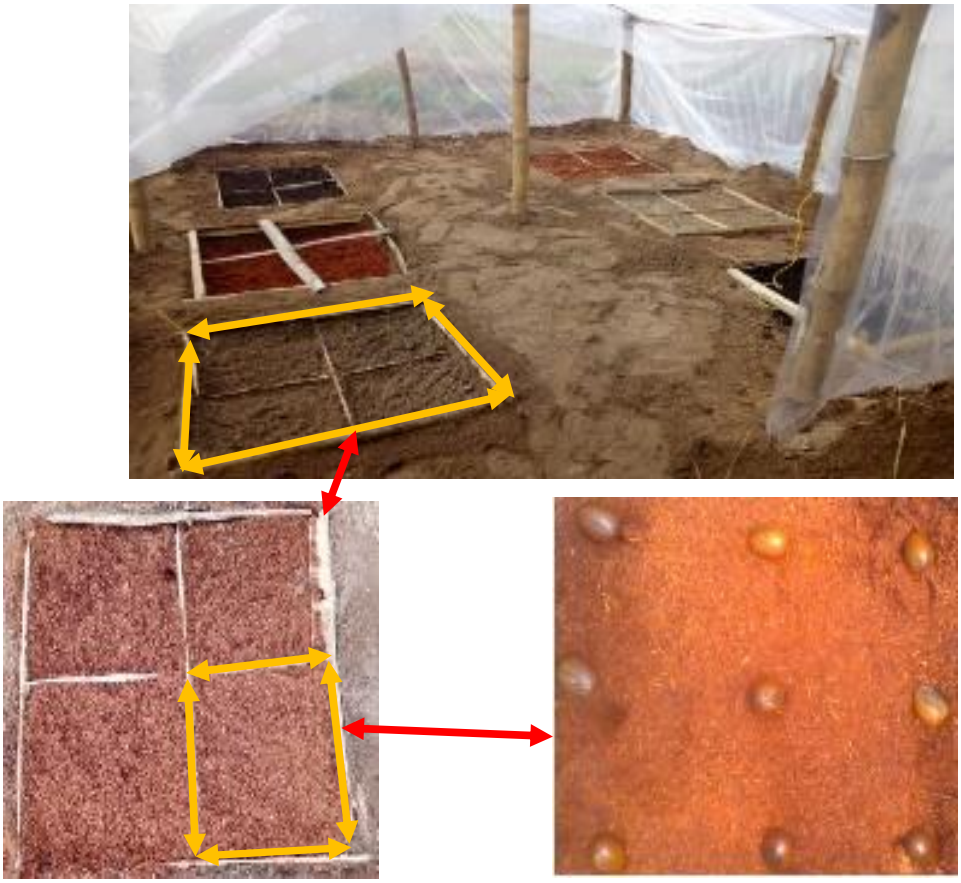

Fig. 4. Experimental design used for germination tests

Table 1. Different treatments and associated codes

Substrates	Greenhouse	Shade
Arenosol	Arenosol under a greenhouse (Are_G)	Arenosol under shade (Are_S)
Ferralsol	Ferralsol under a greenhouse (Fer_G)	Ferralsol under shade(Fer_S)
Fluvisol	Fluvisol under a greenhouse (Flu_G)	Fluvisol under shade (Flu_S)
Organic manure at 3 months of degradation	Organic manure at 3 months of degradation under a greenhouse (ManA_G)	Organic manure at 3 months of degradation under shade (ManA_S)
Organic manure at 6 months of degradation	Organic manure at 6 months of degradation under a greenhouse (ManB_G)	Organic manure at 6 months of degradation under shade (ManB_S)
Sawdust	Sawdust under a greenhouse (S_G)	Sawdust under shade (S_S)

2.5.1 Latency

Latency (L) refers to the time elapsed from the date of sowing to the appearance of the first sprouts.

2.5.2 Germination capacity or final germination rate

The final germination rate (FGR) is the percentage of seeds that germinated during the germination process. The germination capacity is converted in proportion to perform the statistical tests. The mathematical expression of the final germination rate is as follows:

$$FGR\ (\%) = \frac{ni}{N}$$

With ni the cumulative number of seeds germinated at each observation i, and N the total number of seeds germinated.

2.5.3 Germination time

The germination time is measured with the median time corresponding to 50% of the germination (GT50)). This measure makes it possible to take into account the germination behavior of all the seeds in a sample. The median time is expressed as follows:

$$GT50\ (days) = \frac{\mathrm{Tn} + \ (0{,}5 - \mathrm{Gn})}{(\mathrm{Gn} + 1 - \mathrm{Gn})\ \mathrm{x}\ (\mathrm{Tn} + 1 - \mathrm{Tn})}$$

G_n = cumulative percentage of germinated seeds at time Tn, the value of which is the closest to 50% by value lower.

G_{n+1} = cumulative percentage of seeds sprouted at time Tn + 1 whose value is closest to 50% per upper value.

2.5.4 Germination velocity coefficient

The germination velocity coefficient (GVC) is free from the influence of the number of germinated seeds in the samples and corresponds to the reciprocal of the mean germination time. It is noted as follows:

$$CVG\ (\%) = 100\ (\frac{n1 + n2 + \cdots + nx}{n1t1 + n2t2 + \cdots + nxtx})$$

With nx: the number of seeds sprouted for an observation x, tx: the day corresponding to the germination of the seeds.

2.5.5 Uniformity of germination

The uniformity of germination is calculated from the coefficient of variation of the germination time (CVt). This parameter corresponds to a measure of relative dispersion making it possible to quantify the variation of the germination time between each sprouted seed. The coefficient of variation of the germination time is calculated as follows:

$$\mathrm{CV}_t(\%) = (St/\mathrm{AGT})\ \mathrm{x}\ 100$$

With St: the standard deviation of the average germination time (AGT).

2.5.6 Synchronous germination

In general, the germination is asynchronous and it is possible to quantify this characteristic thanks to the synchronization index noted Ē. This parameter makes it possible to see if the number of seeds that sprouts over time is periodic. Ē is expressed as follows:

$$\bar{\mathrm{E}}\ (bit) = -\sum_{i=1}^{k} fi\ log2\ fi, \qquad avec\ fi = ni/\sum_{i=1}^{k} \mathrm{ni}$$

With fi the frequency of germination; ni: number of seeds germinated on day i and k: last day of observation. The germination is all the more synchronous as the values of Ē are close to 0.

2.6 Statistical Analyses of the Data

The averages of the parameters were compared with each other using statistical tests. These tests were applied in the presence of several samples. The ANOVA test was applied in case of normality of the data and Kruskal-Wallis test was used in the absence of normality. All these tests were carried out thanks to the software SPSS version 20 (IBM, USA).

3. RESULTS

3.1 Physicochemical and Chemical Characteristics of the Biowaste

The Table 2 indicates the content of some elements analyzed at the level of the substrates used. The Kruskal-Wallis test showed that the nitrogen (N) and organic matter (OM) contents in different analyzed samples each has a highly significant difference (N: χ^2_{obs} = 16.57**; P <.01, MO: χ^2_{obs} = 16.64 **; P <.01). The highest value at the nitrogen level was found in the organic manure at 6 months of degradation (N = 1.36 g.kg^{-1}). As for organic matter, it was high in sawdust (MO = 94.82 g.kg^{-1}). The C / N ratio, which characterizes the decomposition of the material, indicated that mineralization is good in bio-waste based on seed cotton. This ratio is of the order of 11.87 for seed cotton at 3 months of degradation and 12.46 for that having 6 months of degradation.

3.2 Temperature Values in Substrates under Shade and Greenhouse

The average temperatures observed during the experiment are significantly different (Fig. 5; Fcal = 89.83**; P< .01). The temperatures varied from 25.15 to 25.86ºC in the substrates installed under the shade cover compared to those installed under the greenhouse (34.7 to 38.63ºC). The highest temperature (38.63ºC) was obtained at the level of the organic manure at 6 months of degradation (ManB_G) installed under the greenhouse (Table 3; Fig. 5).

Table 2. Nitrogen (N), carbon (C) and organic matter contents and C/N ratio value in Biowaste and types of soils used for germination tests

Substrates	Mean ± standard deviation			
	N ($g.kg^{-1}$)	C ($g.kg^{-1}$)	MO ($g.kg^{-1}$)	C/N
Arenosol	0.01 ± 0000 d	0.04 ± 0.001 e	0.07 ± 0.001 e	4.1 ± 0.1 c
Ferralsol	0.05 ± 0.0015 c	0.3 ± 0.01 ed	0.51 ± 0.01 d	5.14 ± 0.04 c
Fluvisol	0.08 ± 0.005 c	0.74 ± 0.03 d	1.27 ± 0.06 c	8.71 ± 0.36 bc
Organic manure at 3 months of degradation	0.17 ± 0.0026 b	2.04 ± 0.002 c	3.57 ± 0.004 c	11.87 ± 0.16 b
Organic manure at 6 months of degradation	1.36 ± 0.0153 a	17.03 ± 0.01 b	29.3 ± 0.02 b	12.46 ± 0.15 b
Sawdust	0.14 ± 0.01 b	55.13 ± 4.20 a	94.82 ± 7.22 a	393.72 ± 1.8 a
X^2_{obs}	16.57**	16.64**	16.64**	16.77**
P_{cal}	.005	.007	.007	.004
P_{theor}	≤.01	≤.01	≤.01	≤.01

*The averages followed by the same letter on the same column, are not significantly different at the Probability threshold < 0.05; P_{cal} = P calculed ; Ptheor = P theoretical ; ** = highly significant, N= nitrogen , C = Carbon, C/N = C to N ratio*

Table 3. Average temperatures obtained during the tests

Shelter treatments	Average temperatures measured (°C)
Aér_S	25.71 ± 1.41 c
Aér_G	34.70 ± 3.91 b
Fer_S	25.73 ± 1.36 c
Fer_G	35.24 ± 4.51 b
Flu_S	25.72 ± 1.36 c
Flu_G	34.96 ± 4.26 b
ManA_S	26.12 ± 1.45 c
ManA_G	36.26 ± 4.84 a
ManB_S	25.63 ± 1.46 c
ManB_G	38.63 ± 5.31 a
S_S	25.86 ± 1.42 c
S_G	37.05 ± 5.50 a
T°C_A	25.15 ± 1.23 c
T°C_G	37.72 ± 5.41 a
F_{cal}	89.83**
P_{cal}	.00
P_{theor}	≤.01

*Pcal = Pcalculated; Ptheor = Ptheoretical ; ** = highly significant*
Are_S = Arenosol under greenhouse, Are_S = Arenosol under shade, Fer_G = Ferralsol under greenhouse,Fer_S = Ferralsol under shade, Flu_G= Fluvisol under greenhouse, Flu_S= Fluvisol under shade, ManA_G = Organic manure at 3 months of degradation under greenhouse, ManA_S = Organic manure at 3 months of degradation under shade, ManB_G= Organic manure at 6 months of degradation under glass, ManB_G = Organic manure at 6 months of degradation under glass, S_G = Sawdust under glass, Sc_S= Sawdust under shade

3.3 Final Germination Percentage (FGP)

The results on the final germination percentage (FGP) of shea seeds in substrates under shade and greenhouse are shown in Table 4 and Fig. 6. Thus, a highly significant difference is recorded in these different levels (Fcal = 326.33 **, Pcal < .001). In general, considering each treatment category, i.e. each substrate (soil and biowaste), the tests installed in the greenhouse recorded a high germination rate compared to those installed in the shaded environment. At the bio-waste level, with the exception of the sawdust (FGPS_S = 42.55% and FGPS_G = 64.18%) and the ManB_G treatment (FGP = 52.3%), the germination rates recorded are lower (2.95 to 19.95%) than those obtained at the level of the treatments having as semi-bed the different soils

(24.87 to 51.97%). The lowest final germination rate was obtained in the substrate ManA_S (FGP = 2.95%) while the highest was recorded in the substrate S_G (FGP= 64.18%).

3.4 Germination Average Time (GAT)

The Kruskal-Wallis test applied to the data collected indicates a significant difference (χ^2_{obs} = 29.39 *, Pcal =.02) between values of mean germination time (GAT). It varies from 45 to 66 days in soils and sawdust. The highest values were obtained at the FuB_S treatments (GAT = 75 days); ManA_G (GAT = 87 days) and ManA_S (GAT = 87 days). The ManB_G treatment recorded an average germination time of 39 days corresponding to the lowest value (Table 4).

3.5 Speed (CVG), Uniformity (CVT) and Synchronicity (Ē), of Germination

The averages of shea seed germination rate did not differ from one treatment to another and from one shelter to another (Fcal = 1.68ns, Pcal = .13). The values recorded are essentially the same statistically. CVG values range from 1.50 to 2.51%. At the level of the uniformity of germination, the coefficients of variation of the germination time (CVt) evaluated at the level of each treatment comprise a significant difference (χ2obs =29.40*, P =.02). The ManB_G treatment registers the highest coefficient (20.56%), whereas the one that is relatively weakest is observed at the level of Fer_S treatments (CVt = 10.61%). There is therefore no uniformity and therefore a variation of the germination time between the seeds of Shea in this study.

The parameter Ē recorded at the level of the set of treatments has no significant difference. The set of values obtained is greater than 0. The synchronic thus evaluated at the level of this experiment reflects the fact that the number of seed that germinates over time is not periodic. However, the value obtained at the level of the treatments ManA_S and ManA_G (Ē = 0.03 bit) is close to 0 (Table 4).

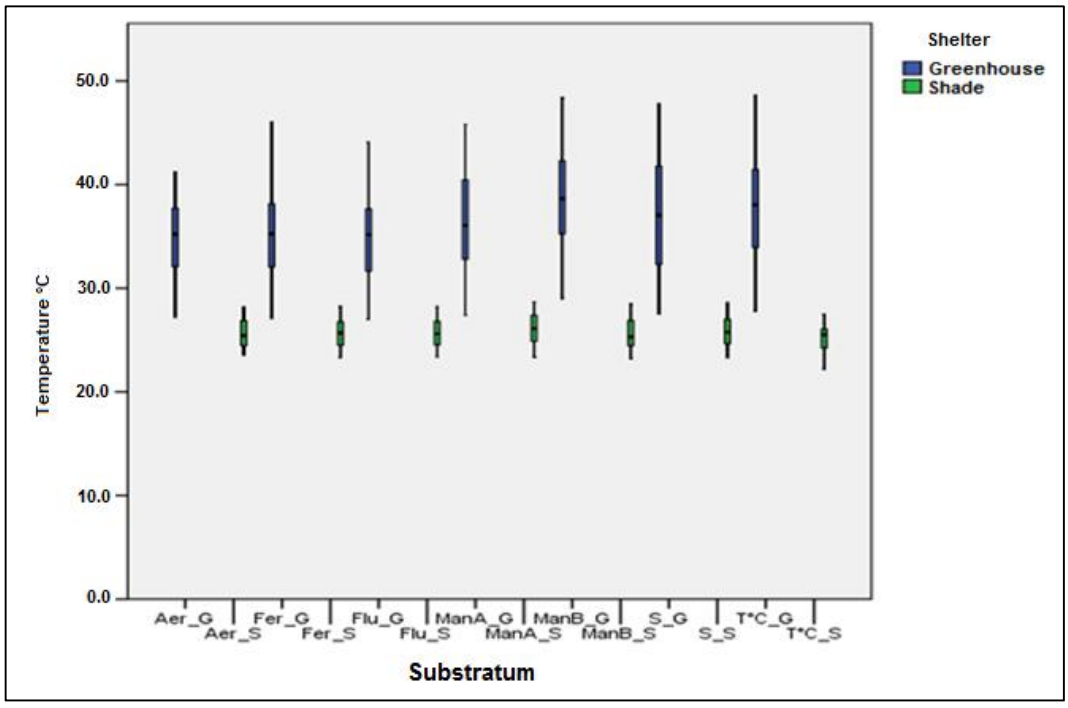

Fig. 5. Average temperatures measured in substratum under shade and greenhouse

Are_G = Arenosol under greenhouse, Are_S = Arenosol under shade, Fer_G = Ferralsol under greenhouse, Fer_S = Ferralsol under shade, Flu_G = Fluvisol under greenhouse, Flu_S = Fluvisol under shade, ManA_G = Organic manure at 3 months of degradation under greenhouse, ManA_S = Organic manure at 3 months of degradation under shade, ManB_G = Organic manure at 6 months of degradation under glass, ManB_G = Organic manure at 6 months of degradation under glass, S_G = Sawdust under glass, S_S = Sawdust under shade

Table 4. Germination parameters evaluated at each treatment level

Shelter treatment		Germination parameters evaluated (SI unit)					
		L (days)	**FGP (%)**	**MGT(days)**	**CVG (%)**	**CVt (%)**	**Ē (bit)**
Treatment	Aer_S	43±3 c	42.79±0.94 bc	62±4 c	1.6±0.05 a	11.3±0.51 c	0.3±0.01 a
	Aer_G	34±2 c	51.97±1.24 b	49±3 c	2.01±0.5 a	14.28±0.50 ab	0.36±0.01 a
	Fer_S	43±3 b	35.96±0.61 bc	66±4 c	1.5±0.5 a	10.61±0.51 c	0.11±0.01 a
	Fer_G	35±2 c	50.06±0.19 b	53±3 c	1.96±0.07 a	13.2±0.50 bc	0.12±0.19 a
	Flu_S	35±2 c	24.87±1.09 c	60±4 c	1.55±0.51 a	11.66±0.50 c	0.1±0.01 a
	Flu_G	35±2 c	30.89±0.45 bc	50±3 c	2±0.03 a	14±0.50 ab	0.1±0.01 a
	ManA_S	81±7 a	2.95±0.83 d	87±8 a	1.38±0.54 a	8.04±0.50 b	0.03±0.01 a
	ManA_G	52±4 b	19.95±0.75 c	87±8 a	1.38±0.54 a	8.04±0.50 b	0.03±0.01 a
	ManB_S	72±5 b	6.01±1.15 d	75±6 b	1.44±0.54 a	9.33±0.50 b	0.05±0.01 a
	ManB_G	28±1 d	52.3±1b	39±2 d	2.51±0.51 a	20.56±0.50 a	0.12±0.02 a
	S_S	40±4 c	42.55±0.9	57±4 c	1.58±0.52 a	12.28±0.50 ab	0.11±0.01 a
	S_G	38±3 c	64.18±1.45 a	45±3 c	1.64±0.56 a	15.52±0.50 ab	0.11±0.03 a
Associated statistical tests		F_{cal} = 5.7* P_{cal} = .04 $_{Ptheor}$ ≤.05	F_{cal} = 326.33** P_{cal} = .00 $_{Ptheor}$ ≤ .01	χ^2_{obs} = 29.39* P_{cal} = .02 $_{Ptheor}$ ≤ .05	F_{cal} = 1.68 ns P_{cal} = .13 $_{Ptheor}$ ≥.05	χ^2_{obs} = 29.40* P_{cal} = .02 $_{Ptheor}$ ≤ .05	F_{cal} = 1.31 ns; P_{cal} =.27 $_{Ptheor}$ ≥ .05

*Pcal = Pcalculated; Ptheor =Ptheoretical; ** = highly significant*

Are_G = Arenosol under greenhouse. Are_S = Arenosol under shade, Fer_G= Ferralsol under greenhouse, Fer_S= Ferralsol under shade, Flu_G = Fluvisol under greenhouse, Flu_S= Fluvisol under shade, ManA_G = Organic manure at 3 months of degradation under greenhouse, ManA_S = Organic manure at 3 months of degradation under shade, ManB_G = Organic manure at 6 months of degradation under greenhouse, ManB_G = Organic manure at 6 months of degradation under glass, S_G = Sawdust under greenhouse, S_S = Sawdust under greenhouse. L = Latency FGP=final germination percentage, MGT = germination time, CGV= Coefficient of germination velocity, UG = Uniformity of germination, Ē = Synchronous germination

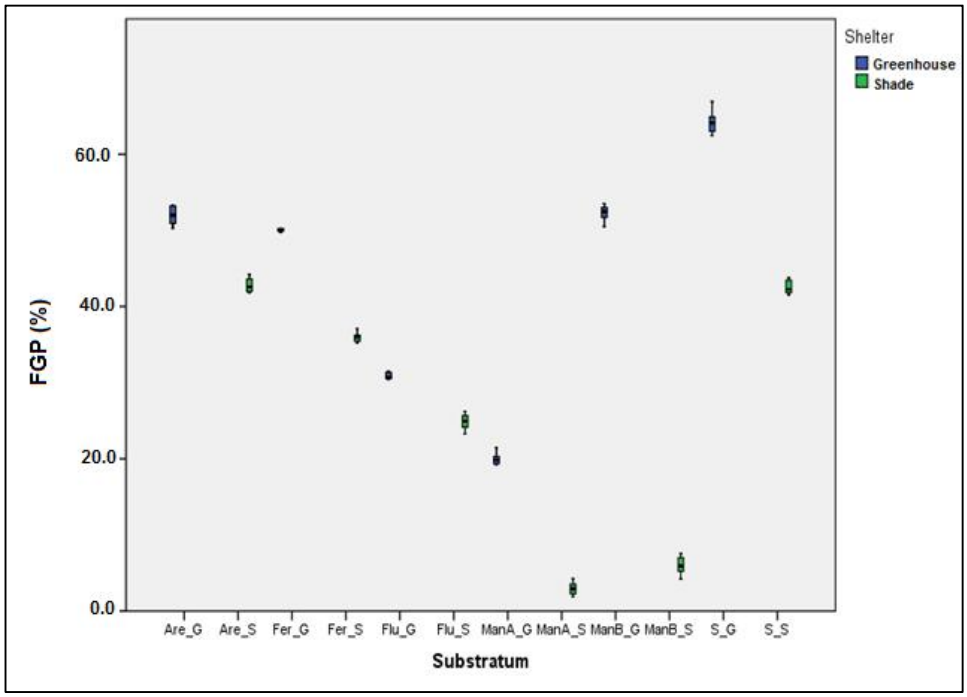

Fig. 6. Final germination rate obtained at each treatment

Are_G = Arenosol under greenhouse, Are_G = Arenosol under shade, Fer_G = Ferralsol under greenhouse, Fer_S = Ferralsol under shade, Flu_G = Fluvisol under greenhouse, Flu_S = Fluvisol under shade, ManU_G = Organic manure at 3 months of degradation under greenhouse, ManU_S = Organic manure at 3 months of degradation under shade, ManU_G = Organic manure at 6 months of degradation under glass, ManU_G = Organic manure at 6 months of degradation under glass, S_G = Sawdust under glass, S_S = Sawdust under shade

4. DISCUSSION

Plant production and the establishment of good agricultural crops depend heavily on seed germination, which is a crucial step in the life cycle of higher plants. This study has shown that the temperatures recorded are of the order of 25.15 to 25.86ºC in the substrates installed under the shade compared to those found in treatments under the greenhouse (34.7 to 38.63ºC). The highest temperature, 38.63ºC was obtained at the level of the organic manure at 6 months of degradation (ManB_G) installed under the greenhouse. The latency recorded under the greenhouse varies from 28 to 52 days against 40 to 81 days for treatments installed under the shade.

It is lower at ManB_G (28 days) and longer at ManA_S (81 days). Thus, to have a quick germination, it is necessary to sow the seeds of the shea under a greenhouse which mobilizes a good amount of heat. In general, considering each category of treatment, i.e. each substrate (soils and biowaste) taken twice by category, the tests installed in the greenhouse recorded a high germination rate compared to those installed under shade. At the bio-waste level, with the exception of the sawdust (FGPS_S=42.55% and FGPS_G=64.18%) and the ManB_G treatment (FGP=52.3%), the germination rates recorded are lower (2.95 to 19.95%) than those obtained at the level of the treatments having as semi-bed the different soils (24.87 to 51.97%). The lowest final germination rate was obtained in the substrate ManA_S (FGP=2.95%) while the highest was recorded in the substrate S_G (FGP = 64.18%) installed under the greenhouse.

The shelters used and the temperatures recorded significantly influenced the lag time and seed germination of shea tree in this study. Our results are in agreement with those previously obtained that showed that germination is a quantitative trait, ie a phenotypic characteristic governed by several genes interacting with some environmental factors such as water, oxygen, temperature and light [12]. Although the success of germination strongly depends on seed quality (physical, physiological and health qualities),

environmental factors contribute to the activation of hormones and enzymes essential for germination [13]. In addition, light intensities significantly affect seed germination [14]. For example, seed germination of *Euphorbia heterophylla* is very poor in the dark, whereas that of *Acacia raddiana* is indifferent to light [14].

Indeed, any variation of the incubation temperature can affect in addition to some enzyme activities, some essential processes for the control of germination such as membrane permeability and extensibility of the wall [15].

The work done in eastern Côte d'Ivoire showed that moderate light intensity positively influenced the timing and germination rate of *Entandrophragma angolense* (Meliaceae) [16]. The author emphasizes that phytochromes located in seeds sometimes need a moderate intensity of light to facilitate the exit of radicules. In general, the treatments installed under the greenhouse showed a germination rate relatively higher than those installed under the shade. The high amount of heat could influence the final germination rate of shea seeds. However, these results do not agree with those indicated that for oilseeds such as *Polycarpon butyracea*, the action of heat appears to be detrimental to germination because of their high oil content [17].

Compared with other treatments, the high final germination rate at S_G (FGR = 64.18%) installed in the greenhouse could be due to the moisture content in interaction with the amount of heat. Indeed, the sawdust let easily water spray compared to other treatments.

The moisture content of seed beds plays an important role in seed germination. So, previously studies showed that the type of substrate used could have a significant effect on the seed germination rate of Shea tree [18,19]. The relatively high final germination rate at the ManB_G treatment (FGR = 52.3%) would be due to the amount of heat associated with the C / N ratio (12.46) that characterizes the decomposition of the material indicates as well as its good mineralization thus promoting good microbial activity. The great richness in organic and inorganic substance of the substrate could influence these results as previously reported that indicated the intervention of soil microorganisms is sometimes necessary for the germination of species especially those whose fruits are indehiscent as in the case of *Prosopis africana* [20].

5. CONCLUSION

The present study is a contribution to know the effects of substrates and shelter type on the evolution of seed germination rate of shea seeds in nurseries in Northern Côte d'Ivoire. Considering each category of treatment, the seeds have a better ability to germinate in a greenhouse than under a shelter covered with straw. Thus, at the bio-waste level, with the exception of the sawdust (FGPS_S=42.55% and FGPS_G=64.18%) and the ManB_G treatment (FGR = 52.3%), the germination rates recorded are lower (2.95 to 19.95%) than those obtained at the level of the treatments having as semi-bed the different soils (24.87 to 51.97%). The lowest final germination rate was obtained in the substrate ManA_S (FGP=2.95%) while the highest was recorded in the substrate S_G (FGP =64.18%). The latency recorded under the greenhouse varies from 28 to 52 days against 40 to 81 days for treatments installed under the shade. The average Germination Time (AGT) varies from 45 to 66 days in soils and sawdust. The highest values were obtained in FuB_S treatments (AGT=75 days), ManA_S (AGT = 87 days) and ManA_G (AGT=87 days). The ManB_G treatment recorded an average germination time of 39 days corresponding to the lowest value. While the success of germination strongly depends on the quality of seeds (physical, physiological and health qualities), environmental factors (temperature, humidity, *etc.*) interacting with the richness of organic and inorganic substances in certain substrates have strongly influenced the quality of seeds germination rate of different treatments.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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