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Germination Responses of *Terminalia superba* Engl. and Diels Seeds on the 2-Way Grant's Thermogradient Plate

[1]Joseph M. Asomaning, [2]Moctar Sacande and [3]Nana S. Olympio

[1]Forestry Research Institute, Ghana University, P.O. Box 63, Kumasi, Ghana
[2]Department of Seed Conservation, Royal Botanic Gardens, Kew, Wakehurst Place, Ardingly, West Sussex RH17 6TN, United Kingdom
[3]Department of Horticulture, Faculty of Agriculture, Kwame Nkrumah University of Science and Technology, Kumasi, Ghana

Corresponding Author: Joseph M. Asomaning, Forestry Research Institute, Ghana University, P.O. Box 63, Kumasi, Ghana

ABSTRACT

The goal of the study was to take a more comprehensive look at germination responses of the species to a broad range of alternating or constant temperatures on the thermogradient plate. *Terminalia superba* seeds were placed in Petri dishes containing a gel of 1% agar for germination over a period of 30 consecutive days. Petri dishes were arranged 8×8 units on the 2-way Grant's thermogradient plate (a bi-directional incubator). The instrument allows for germination testing of seeds over a wide range of single temperature and alternating temperature regimes over a time continuum, given 64 temperature combinations (regimes) (5 to 40°C). Conditions were 40/40°C (day/night temperature) on the high end of the plate and 5/5 °C (day/night temperature) on the cool end. Dried out agar in petri dishes located at the hot end of the plate were replaced periodically. Two temperature gradients ranging from 5 to 40°C were used. The first gradient, progressing from left to right on the thermogradient plate in dark, was alternated every 12 h with the second progressing from front to back of the thermogradient plate with light. The study was repeated two times. Twenty seeds were used in each replication. The various temperature combinations had significant effect on final germination percentage, mean germination time, time for first germination and rate of germination. Alternating temperatures improved overall germination. The best germination at a constant temperature was at 35/35°C (88%). The best temperature combinations for seed germination at alternating temperatures were 35/40°C (100%); 35/15°C(95%); 40/25°C(95%); 20/40°C (92.5%) and 40/30°C (92.5%).

Key words: *Terminalia superba*, germination responses, thermogradient plate, single temperatures, alternating temparetures, amplitude, germination curves

INTRODUCTION

Terminalia superba Engl. and Diels is geographically distributed in tropical Africa (Richter and Dallwitz, 2009). In West-Central Africa, it occurs in Cameroon, Equatorial Guinea, Gabon and Zaire; in West Tropical Africa it is found in Benin, Cote D'Ivoire, Ghana, Guinea, Guinea-Bissau, Liberia, Nigeria and Sierra Leone. The species belongs to the family Combretaceae. The fibre of *T. superba* has potential importance in paper making, offering the capability of producing a relatively wide range of pulps. The wood may be used in the manufacture of cellulose, panelling and also as particle boards. It is widely known and used, particularly in Belgium, Germany and Switzerland ICRAF (2004). Used in plywood manufacture, furniture, joinery, for plinths, mouldings, general fittings and door faces and, after suitable treatment, for external joinery (Groulez and Wood, 1985).

Terminalia superba is becoming progressively impoverished by heavy exploitation (FAO, 1984). (N'Sosso, 1990) noted that the species is declining in Congo following 60 years of exploitation and would benefit from trade controls.

A more comprehensive look at it germination responses to a broad range of alternating or constant temperatures is vital for its ex-situ conservation and it use in afforestation and reforestation pragrammes.

Temperature influences both the percentage of germination and rate of germination of seeds; it is one of the most critical factors affecting seed germination (Smith *et al*., 2002). There is usually an optimal temperature below and above which germination is delayed or prevented (Rawat, 2005). Each species requires a range of temperatures for seed germination and seedling establishment (Bradbeer, 1988). For most tropical tree seeds, room temperature of 25 to 30°C in the tropics will be quite suitable for maximum germination (Smith *et al*., 2002).

Alternating temperatures are preferred to constant temperatures because they can overcome shallow seed dormancy and enhance uniform germination (ISTA, 1996). Although natural fluctuations between day and night temperatures are less in the lowland moist tropical forests than in other forest types, alternating temperatures may still affect germination of tropical species (FAO, 1985). The FAO (1985) prescribed an alternating temperature of 30/20°C for most tree seed germination. The Grant thermogradient plate is a bi-directional incubator (Manger, 1999). The instrument allows for germination testing of seeds over a wide range of single temperature and alternating temperature regimes over a time continuum (Tarasoff *et al*., 2005). Within a predetermined range this device simultaneously provides all possible alternating and constant temperature combinations (Larsen *et al*., 1973).

The present study was conducted to ascertain optimum germination requirements as well as all possible alternating and constant temperature combinations for the germination of the species.

MATERIALS AND METHODS

Seed materials: Seeds of *Terminalia superba* were harvested at full maturity from forests in the Gambia No 1 (In the Brong Ahafo Region) of Ghana in October 2005. Seeds were spread on wheat sacks and cleaned of twigs, bark, foliage and other impurities (Turnbull, 1975). They were then shade- dried for 3 days and packed into cotton bags. Samples were immediately sent by air to the Seed Conservation Department of the Royal Botanic Gardens, Kew, in the United Kingdom where the experiment was conducted.

Seed moisture content and Equilibrium Relative Humidity (ERH) determination: In order to establish the moisture status of the seed samples on receipt at the laboratory, the ERH or water activity (aw) of the seeds and its moisture contents were determined. The eRH of the seed samples was measured using a Rotronic AW-14P water activity measuring station (Rotronic Instruments, UK, Horley) set up with a DMS 100H humidity sensor. The essence of this experiment was to measure the relative humidity of air above the seed samples. These are indications of how dried seed samples were when they were first received at the laboratory which could inform post-harvest handling of the seeds (MSBP, 2005).

Seed moisture contents of the species was determined on whole seeds, five replicates of 10 seeds each was weighed before and after drying at 103°C for 17 h (ISTA, 1999). The moisture content was then calculated using the formula:

$$(IW-FW)/IW\times 100$$

where, IW = initial weight and FW = final weight.

Terminalia superba seeds were dried in silica gel by mixing them on a 1:1 ratio overnight to reduce its moisture content to 6.2% after which seed sample was sealed in aluminium foil laminate bags and held at 15°C until use two weeks later (Table 1).

Germination of seeds on the 2-way Grant's thermogradient plate: Seeds of *T. superba* were germinated on a gel of 1% water-agar in 90 mm (9 cm) plastic petri dishes. Each petri dish contained approximately 40 mL of agar as recommended by (Manger, 1999). Petri dishes were arranged 8×8 units on the thermogradient plate given 64 temperature combinations (regimes) (5 to 40°C). Conditions were 40/40°C (day/night temperature) on the high end of the plate and 5/5°C on the cool end. Dried out agar in Petri dishes located at the hot end of the plate were replaced periodically. Two temperature gradients ranging from 5 to 40°C were used. The first gradient, progressing from left to right on the thermogradient plate in dark, was alternated every 12 h with the second progressing from front to back of the thermogradient plate with light. Seeds were subjected to 8 constant and 56 alternating temperature regimes as shown by Fig. 1.

Table 1: Equilibrium relative humidity (%) and seed moisture content (%) of *Terminalia superba* seed samples measured on receipt at the laboratory and after desiccation in silica gel overnight

ERH (%) of seed samples upon receipt in the United Kingdom	61.50
ERH (%) of seed sample after desiccation in silica gel overnight	34.10
Moisture content (%) of seed samples upon receipt in the United Kingdom	13.80
Moisture content (%) of seed sample after desiccation in silica gel overnight	6.20

H1(40/5)	H2(40/10)	H3(40/15)	H4(40/20)	H5(40/25)	H6(40/30)	H7(40/35)	H8(40/40
G1(35/5)	G2(35/10)	G3(35/15)	G4(35/20)	G5(35/25)	G6(35/30)	G7(35/35)	G8(35/40)
F1(30/5)	F2(30/10)	F3(30/15)	F4(30/20)	F5(30/25)	F6(30/30)	F7(30/35)	F8(30/40)
E1(25/5)	E2(25/10)	E3(25/15)	E4(25/20)	E5(25/25)	E6(25/30)	E7(25/35)	E8(25/40)
D1(20/5)	D2(20/10)	D3(20/15)	D4(20/20)	D5(20/25)	D6(20/30)	D7(20/35)	D8(20/40)
C1(15/5)	C2(15/10)	C3(15/15)	C4(15/20)	C5(15/25)	C6(15/30)	C7(15/35)	C8(15/40)
B1(10/5)	B2(10/10)	B3(10/15)	B4(10/20)	B5(10/25)	B6(10/30)	B7(10/35)	B8(10/40)
A1(5/5)	A2(5/10)	A3(5/15)	A4(5/20)	A5(5/25)	A6(5/30)	A7(5/35)	A8(5/40)

Fig. 1: Layout of the arrangement of treatments on the thermogradient plate. The letters A1 to H8 represent the petri dishes (treatments) and the figures in parentheses are the 64 temperature combinations in °C experienced by each treatment during the experimental period. The zero amplitude diagonal gives a gradient of constant temperatures

The study was repeated two times. Twenty seeds were used in each replication. Normal seedlings were scored and removed as soon as radical was 1 cm long and the plumule was visible and the location and time of removal were recorded as done by (Larsen *et al.*, 1973).

The germination percentage, the weighted mean germination time, germination rate and the time for first germination which are important aspects of the germination process, informing the dynamics of the process (Bewley and Black, 1994; Silveira *et al.*, 2005) were measured.

The germination percentages at 30 days after imbibing were calculated from the total number of seeds germinated at each temperature divided by the total number of seeds used for each species.

The Mean Germination Time (MGT) or average time to germination (Atg in days) was calculated as:

$$MGT (Atg) = S (t.n)/Sn$$

(Yang *et al.*, 2003), where t is time in days, starting from the day of sowing and n is the number of seeds completing germination on day time (t). The time for first germination, were all calculated as functions of the rate of germination (Bannister, 1990). Germination rate was calculated as the reciprocal of the mean germination time after (Mattews and Hosseini, 2006).

Results were subjected to Analyses of Variance to determine main effects and interaction effects using GensStat Release 4.21 (Rothamsted Experimental Station, United Kingdom). Map showing germination percentages was developed using SigmaPlot 8.0 software.

RESULTS

Equilibrium Relative Humidity (ERH%) and Moisture Contents (MC%) of *Terminalia superba* seed samples when they were received fresh at the laboratory and after desiccation in equal weight of silica gel overnight are presented in Table 1, equilibrium relative humidity values of 61.5% and moisture content of 13.8%, respectively were recorded for seeds on receipt at the laboratory in the United Kingdom. Drying the seeds in silica gel overnight lowered the ERH to 34.1% and seed moisture content to 6.2%.

Germination occurred at forty out of the sixty four temperature combinations made possible by the thermogradient plate (Table 2).

Germination percentages of the species was significantly ($p<0.001$) influenced by the various temperature combinations at which seeds were placed for germination on the thermogradient plate. The highest germination percentages were recorded at alternating temperature combinations: 35/40°C (100%); 35/15°C (95%) and 40/25°C (95%). The germination percentage of 92.5% recorded at the alternating temperature combinations: 20/40°C and 40/30°C were significantly lower than ($p<0.001$) the 100% germination recorded at the temperature combinations of 35/40°C but statistically equal to 95% germination registered at 35/15 and 40/25°C. The 85% germination recorded at the alternating temperatures: 25/30, 30/40 and 35/25°C were statistically equal to the 90% germination registered at alternating temperatures: 15/35, 15/40 and 20/35°C but significantly lower than ($p<0.001$) the 92.5% recorded at 20/40 and 40/30°C. Very low germination percentages (<10%) were recorded at the alternating temperatures: 5/30, 10/30, 20/25, 25/20 and 30/10°C. These germination percentages were significantly lower than germinations recorded at the other alternating temperatures on the thermogradient plate. No germination occurred at areas with low alternating temperatures and low constant temperatures on the thermogradient plate such as 5/10; 5/15, 5/20, 5/25 and 5/5°C. Areas with one very low alternating temperature and the other high (but the higher alternating temperature being <35°C) also recorded zero or very low germinations (Fig. 2).

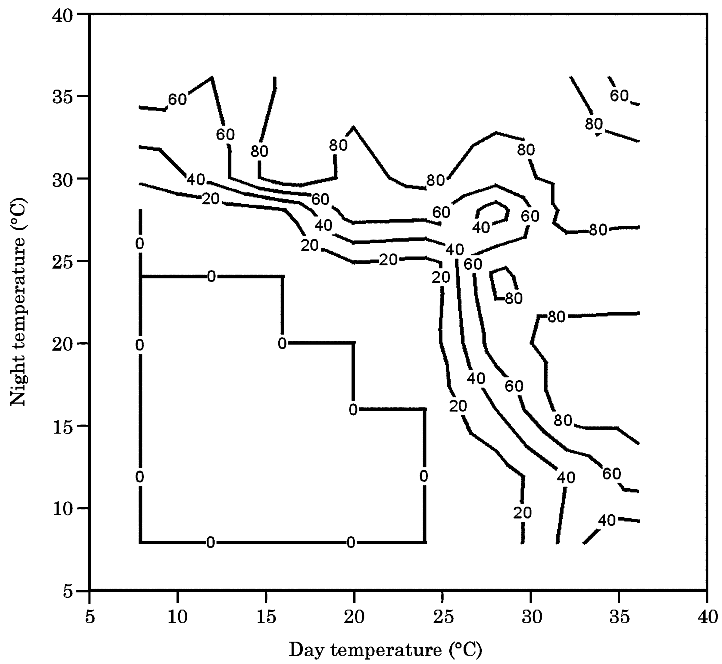

Fig. 2: A map showing final germination percentages of *Terminalia superba* seeds on the thermogradient plate. Percentage germination values are shown on the isopleths

Table 2: Germination percentages of *Terminalia superba* seeds incubated at different temperature combinations on the 2-way thermogradient plate

Temp. (°C)	Germination (%)	Temp (°C)	Germination (%)	Temp. (°C)	Germination (%)	Temp. (°C)	Germination (%)
5/30	5.0	20/30	70.0	30/25	70.0	35/35	87.5
5/35	45.0	20/35	90.0	30/30	30.0	35/40	100.0
5/40	25.0	20/40	92.5	30/35	87.5	40/5	75.0
10/30	7.5	25/20	5.0	30/40	85.0	40/10	60.0
10/35	40.0	25/30	85.0	35/5	25.0	40/15	82.5
10/40	70.0	25/35	65.0	35/10	47.5	40/20	85.0
15/30	40.0	25/40	65.0	35/15	95.0	40/25	95.0
15/35	90.0	30/10	5.0	35/20	75.0	40/30	92.0
15/40	90.0	30/15	17.5	35/25	85.0	40/35	80.5
20/25	5.0	30/20	72.5	35/30	70.0	40/40	45.0

SED = 3.062, replication = 2, d.f = 40, cv = 5.0%

Results presented in Table 3 showed that there were significant differences ($p<0.001$) between Mean Germination Times (MGTs) recorded at the various temperature combinations used in the germination study on the thermogradient plate. The shortest MGT recorded were 12.6 days at temperatures 40/30°C (92.5%); 15.4 days at 30/40°C (85.0%); 15.6 days at 30/35°C (87.5%); 16.4 days at 25/40°C (65.0%) and 17.4 days at 35/40°C (100%). These MGT were however significantly different from each other ($p< 0.001$). The longest MGT were 32.2 days at 5/40°C (25%); 32.0 days at 20/25°C (5.0%); 32.0 days at 25/20 (5.0%); 30.0 days at 30/30°C (30%); 31.7 days at 35/5°C (25.0%); 30.8 days at 35/10°C (47.5%); 29.4 days at 40/5°C (75.0%) and 30.4 days at 20/30°C (70.0%). The following temperature combinations among others recorded high

Table 3: Mean germination time (days) of *Terminalia superba* seeds incubated at different temperature combinations on the 2-way thermogradient plate

Temp. (°C)	Mean germination time (Days)	Temp. (°C)	Mean germination time (Days)	Temp. (°C)	Mean germination time (Days)	Temp. (°C)	Mean germination time (Days)
5/30	24.0	20/30	30.4	30/25	26.0	35/35	24.4
5/35	28.7	20/35	21.0	30/30	30.0	35/40	17.4
5/40	32.2	20/40	21.4	30/35	15.6	40/5	29.4
10/30	25.0	25/20	32.0	30/40	15.4	40/10	27.4
10/35	25.5	25/30	25.3	35/5	31.7	40/15	24.8
10/40	28.6	25/35	20.0	35/10	30.8	45/20	19.8
15/30	20.6	25/35	20.0	35/15	21.2	40/25	18.3
15/35	24.6	30/10	24.0	35/20	21.8	40/30	12.6
15/40	28.4	30/15	25.2	35/25	18.2	40/30	18.1
20/25	32.0	30/20	27.3	35/30	17.5	40/40	27.1

SED = 0.4617, replication = 2 d.f = 40, cv = 1.9%

Table 4: Germination rate of *Terminalia superba* seeds incubated at different temperature combinations on the 2-way thermogradient plate

Temp. (°C)	Germination rate	Temp.(°C)	Germination rate	Temp. (°C)	Germination rate	Temp. (°C)	Germination rate
5/30	0.0416	20/30	0.0333	30/25	0.0384	35/35	0.0411
5/35	0.0344	20/35	0.0477	30/30	0.0335	35/40	0.0575
5/40	0.0307	20/40	0.0474	30/35	0.0644	40/5	0.0399
30/10	0.0418	25/20	0.0312	30/40	0.0650	40/10	0.0365
35/10	0.0348	25/30	0.0395	35/5	0.0316	40/15	0.0403
40/10	0.0347	25/35	0.0495	35/10	0.0325	45/20	0.0505
15/30	0.0483	25/40	0.0609	35/15	0.0472	40/25	0.0547
15/35	0.0407	30/10	0.0418	35/20	0.0459	40/30	0.0794
20/30	0.0354	30/15	0.0398	35/25	0.0549	40/35	0.0549
20/35	0.0315	30/20	0.0367	35/30	0.0571	40/40	0.0369

SED = 0.0008286, replication = 2, d.f = 40, cv = 1.9%

germination percentages with significantly lower MGT compared with the temperature combinations which recorded the longest MGT. These include: 20/35°C (90.0%) with 21.0 days; 20/40°C (92.5%) with 21.4 days; 35/15°C (95.0%) with 21.2 days; 35/40°C (100%) with 17.4 days.

Placing the seeds at the various temperature combinations significantly affected seed rate of germination ($p<0.001$). The fastest rate of germination of *T. superba* was 0.0794 recorded at the temperature combination 40/30°C .This was significantly higher ($p<0.001$) than rate of germination recorded at the other temperature combinations. The rate of germination of 0.0650 and 0.0644 recorded at 30/40°C and 30/35°C, respectively were also significantly higher than rate of germination recorded at the rest of the germination temperature combinations.

The time for first germination expresses the time of germination of the fastest seeds (Silveira *et al*., 2005). This was significantly ($p<0.001$) affected by the temperature combinations at which seeds were placed for germination on the thermogradient plate (Table 5). The earliest time for first germination was 7.5 days recorded at 40/30°C. This was significantly ($p<0.001$) faster than first time germination recorded for any of the rest of temperature combinations on the

Table 5: Time to 1st germination (days) of *Terminalia superba* seeds incubated at different temperature combinations on the 2-way thermogradient plate

Temp. (°C)	Time to 1st germination (Days)	Temp. (°C)	Time to 1st germination (Days)	Temp. (°C)	Time to 1st germination (Days)	Temp. (°C)	Time to Ist germination (Days)
5/30	25.0	20/30	26.0	30/25	21.0	35/35	15.0
5/35	25.0	20/35	14.0	30/30	24.5	35/40	13.0
5/40	32.0	20/40	15.0	30/35	13.0	40/5	24.0
10/30	23.5	25/20	33.0	30/40	13.0	40/10	22.0
10/35	23.0	25/30	18.0	35/5	29.0	40/15	16.0
10/40	24.0	25/35	15.0	35/10	24.0	40/20	14.0
15/30	24.5	15/40	13.0	35/15	16.0	40/25	14.0
15/35	19.0	30/10	25.0	35/20	19.0	40/30	7.5
15/40	22.0	30/15	21.0	35/25	15.0	40/35	15.0
20/25	32.0	30/20	21.0	35/30	16.0	40/40	13.0

SED = 0.982, Replications = 2 d.f = 40, c.v. = 3.5%

thermogradient plate. Time for first germination of 13 days recorded at 25/40, 30/35, 30/40, 35/40, 40/40°C and 14 days recorded at 20/35, 40/20 and 40/25°C as well as 15 and 16 days at 20/40, 25/35, 35/25, 35/35, 40/35, 35/15, 35/30 and 40/15°C are also significantly faster than first time germination of 18 days and beyond recorded at other temperature combinations. The longest time to first germination of 32 and 33 days were recorded at 5/40, 20/25 and 25/20°C.

At the alternating temperature of 20/35°C, the germination percentage increased until the 6th day (the largest germinability was observed during this period), remaining constant till the 10th day. It then increased again till the 12th day and remained constant till the 19th day, increased again till the 21st day remaining constant afterwards. At 15/40°C, the germination percentage increased till the 21st day remaining constant afterwards. At 15/35°C, germination percentage increased till the 8th day, remained constant till the 10th day and increased until the 21st day (the largest germinability was observed during this period), remaining constant afterwards (Fig. 3a).

When seeds were placed at 30/35°C, the germination percentage increased until the 11th day (this period gave the highest germinability), after which it remained constant. At the alternating temperature of 20/40°C, germination percentage increased until the 10th day, remaining constant until the 11th day and presented a continuous germination until the 18th day during which the largest germinability was recorded. After this period germination percentage remained constant. At 25/30°C germination percentage increased until the 10th day, remained constant until the 13th day and gave a continuous germination until the 22nd day (this period gave the highest germinability), after which it remained constant (Fig. 3b).

Seeds incubated at 30/40°C gave increased germination until the 13th day registering the largest germinability during this period, remaining constant till the 18th after which it increased in germination again. At 35/15°C, there was increased germination percentage until the 21st day, remaining constant afterwards. Increased germination percentage was recorded at 35/25°C until the 13th day remaining constant afterwards. The largest germinability was recorded during the first 13 days (Fig. 3c).

Seeds of *Terminalia superba* placed at the alternating temperature of 35/40°C registered increased germination percentages reaching the maximum of 100% on the 14th day. At a constant temperature of 35/35°C, germination percentage increased until the 10th day after which it

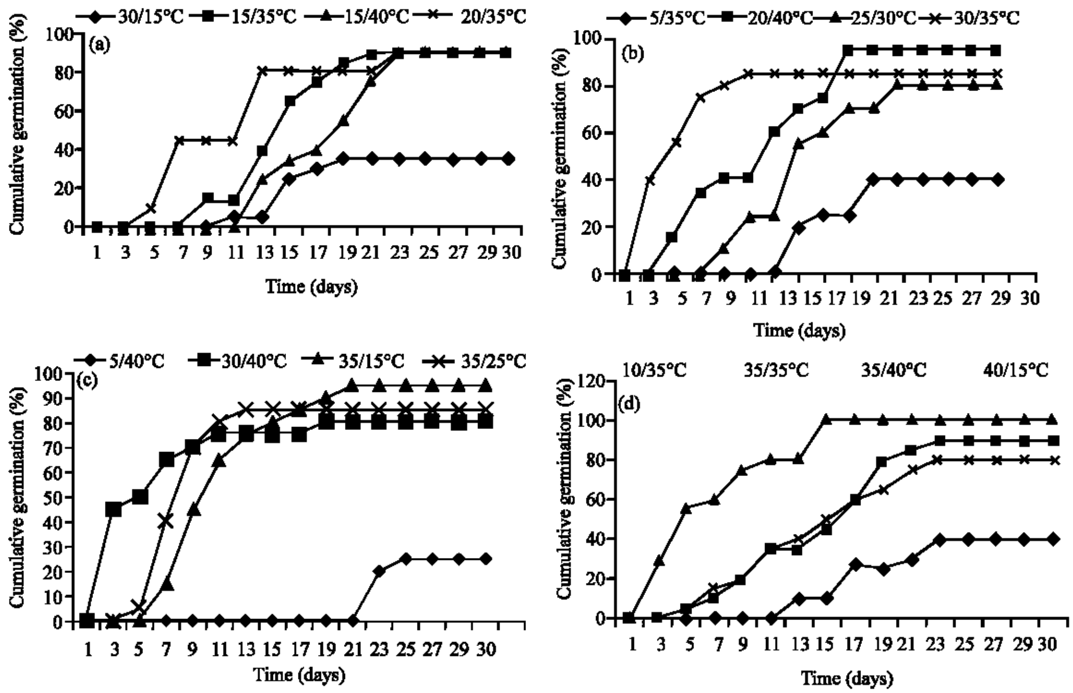

Fig. 3a-d: Cumulative germination curves of *T. superba* at some selected temperature regimes on the Thermogradient plate

remained constant till the 13th day. Germination further increased until the 23rd day (this period observed the largest germinability). At the alternating temperature of 40/15°C, germination percentage increased continuously until the 22nd day after which it remained constant (Fig. 3d).

Seed of the species placed at the alternating temperature of 40/25°C recorded increased germination percentage for the first 2 days. Germination percentage remained constant until the 5th day after which it increased until the 14th day, observing the largest germinability during this period. Germination percentage remained constant afterwards. At 40/20°C, germination percentage increased until the 21st day. Germinability was largest during this period and germination percentage remained constant after this period (Figure not shown).

DISCUSSION

The Equilibrium Relative Humidity (ERH) of 61.5% and moisture content of 13.8%, respectively recorded for seeds on receipt at the laboratory in the United Kingdom indicated that the seed sample could be placed in the "damp" seed status and that they required immediate drying to reduce the risk of fungi attack as stated by the MSBP (2005). Drying the seeds in silica gel overnight lowered the eRH to 34.1% with seed moisture content of 6.2% and this placed them in the "dry" seed status (MSBP, 2005) and making them safe from fungi attack before the germination experiment three weeks later.

The observation that germination of *Terminalia superba* occurred at forty out of the sixty four temperature combinations made possible by the thermogradient plate is an indication that the species has the ability to germinate in a large range of alternating and constant temperature combinations. The relatively high temperature combinations which supported high final germination percentages in the species (Table 2 and Fig. 2) has reiterated the fact that the species is a typical tropical plant requiring a relatively higher alternating or constant temperatures for optimum germination. According to (Tompsett and Kemp, 1996), germination at temperatures between 25-35°C or even higher (Smith *et al.*, 2002) is typical for many tropical species. This is probably explained by the fact that in the natural environment, dispersed seeds are likely to experience soil temperatures of 36°C or more (Daws *et al.*, 2002).

It is clear from the study that higher alternating temperatures stimulated germination of seeds compared with constant temperature germination. No seed germinated at constant temperatures of 20/20, 25/25°C and even at 30/30°C a low percentage germination of 30% was recorded. On the other hand significantly higher percentage germinations were observed at alternating temperatures such as 20/30, 30/20, 25/30 and 30/25°C (Table 2). In general, germination was highly influenced by the components of the alternating temperature regime. The result was in agreement with (FAO, 1985), who prescribed an alternating temperature of 30/20°C for most tree seed germination. The (ISTA, 1996) also reported that alternating temperatures are preferred to constant temperatures because they can overcome shallow seed dormancy and enhance uniform germination.

In general, germination was highly influenced by "reversed" alternating temperature regimes. "Reversed" temperature regimes pairs such as {5/40 and 40/5°C }; {10/40 and 40/10°C}; {15/30 and 30/15°C}; {20/35 and 35/20°C}; {25/35 and 35/25°C} as well as {25/40 and 40/25°C} among others had significantly different germination percentages, mean germination and time to first germination (Table 2-4). In the majority of cases rather than in all cases, "reversed" temperature regimes with low daytime temperatures followed by high nighttime temperatures recorded higher final seed germination percentages than in situations with high daytime temperatures followed by low nighttime temperatures. These observations illustrated that seed germination in *T. superba* was stimulated by lower daytime temperatures followed by warmer nighttime temperatures. Asomaning (2009) reported of a similar situation with *Terminalia ivorensis* in another thermogradient experiment.

In general, germination of *T. superba* in the present study was highly influenced by the components of the alternating temperature regimes as reported in the case of *Orobanche* species by Kebreab and Murdoch (1999). The effect of difference between daily maximum and minimum temperatures known as amplitude which is a very important characteristic of alternating temperatures was observed to have influenced seed germination. Generally amplitude of change between day and night temperatures of between 5-30°C resulted in germination percentages above 60%. Asomaning (2009) observed that amplitude of change between day and night temperatures of between 5-20°C resulted in very high germination percentages in *Terminalia ivorensis*. In the present study, where the mean of the upper temperature and that of the lower temperature of the alternating temperature regimes was ≤22.5°C such as {5/30; 5/35; 5/40; 10/30; 10/35; 15/30; 20/25; 5/30; 5/35; 30/10; 35/10; 30/15; and 25/20°C} germination percentages recorded was<50%. On the other hand where the mean of the upper temperature and that of the lower temperature of the alternating temperature regimes was ≥25.0°C such as {10/40; 15/35; 15/40; 20/35; 20/40; 25/30; 30/35;30/40 and 35/40°C} germination percentages recorded was 65% and above. These observations clearly suggest that the mean of the upper temperature and the lower temperature of the alternating temperature regime is critical for the germination of the species. It also point to the fact that the species is classically tropical in origin (Dupuy and Mille, 1993), which requires minimum temperatures of 25°C and above for maximum germination (Smith *et al.*, 2002).

The observation from the study that temperature combinations which recorded the highest final germination percentages achieved this with minimum mean germination time compared with temperature combinations which recorded low final germination percentages (Table 2 and 3) is in agreement with the findings of Kochankov *et al.* (1998) who reported that in *Echinacea purpurea* (L.), the highest germination percentage was recorded for seeds with the shortest meam germination time. Silveira *et al.* (2005) also reported of a similar observation in *Calliandra fasciculata* (Benth.) Mean germination time is an indication of the spread of germination of a seed lot. Low mean germination time is an indication of seed rapid germination and uniform seedling (Silveira *et al.*, 2005).

The results of the present study indicated that seeds placed at temperatures 40/30, 30/40 and 30/35°C on the thermogradient plate can be said to have germinated with more vigour compared to seeds placed at other temperatures. According to Mattews and Hosseini (2006), the reciprocal of the mean germination time known as rate of germination can be used as an assessment of vigour. The lowest rate of germination and for that matter seed that germinated with the least vigour were recorded at the temperature combinations: 5/40, 20/25, 25/20, 35/5, 35/10 and 20/30°C (Table 4).

The steepness of the cumulative germination percentage curves of *Terminalia superba* seeds incubated at the different temperature regimes showed differences in increases in germination percentages over time, periods of largest seed germinability, continuity in seed germination and periods at which germination remained constant and maximum germination had been attained (Fig. 3a to d). The steepness of the curves revealed how fast or otherwise the biological relevant parameters namely: the final germination percentage, the mean germination time, rate of germination and time to first germination which informed the dynamics of the germination measured in this study were attained at these incubation temperatures. Thus germination curves generated at temperatures {35/40; 35/15; 40/25; 20/40; 40/30; 30/35; 35/25; 35/35°C} among others where significantly higher germination percentages were recorded with shorter mean germination time had steeper curves, faster increases in germination over time and showed continuity in seed germination compared to temperatures regimes where low germination percentages were observed. These observations were in agreement with what was reported by Silveira and Fernandes (2006) on *Mimosa foliolosa* seeds. In general, the cumulative germination of *T. superba* at all the temperatures over time appeared as S-Shaped curves (Fig. 3a-d) resembling typical cumulative germination of a population of seeds over time as reported by Palazzo and Brar (1997), Shafii and Price (2001).

CONCLUSION

The results obtained in this study put forward the following main conclusions:

- Warmer alternating temperatures stimulated the germination of *Terminalia superba* seeds The best temperature combinations for seed germination at alternating temperatures were 35/40°C(100%); 35/15°C(95%); 40/25°C(95%) 20/40°C and 40/30°C (92.5%)
- The best constant temperature for germination of *Terminalia superba* seeds is 35/35°C
- In general, germination of *T. superba* in the present study was highly influenced by the components of the alternating temperature regimes

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