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THE POTENTIAL OF SELECTED SEED PRE-TREATMENT METHODS TO INITIATE AND SPEED UP GERMINATION, AND SEEDLING VIGOUR OF *ADANSONIA DIGITATA* L. (BAOBAB)

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ABSTRACT

Seed dormancy influences the regeneration of plants worldwide. Several methods have been reported to break seed dormancy in different plants, but we cannot generalise the methods because the dormancy types differ among and between species. Adansonia digitata L. (Baobab) seeds do not germinate readily under natural conditions. In baobabs, seed dormancy is caused by the hard seed coat (testa) and pulp. The tree is very useful apart from being deforested in many regions of the world. This study therefore aimed to explore the effectiveness of different seed pre-treatment methods on breaking seed dormancy in baobab. Specifically, the study intended to provide knowledge on the germination percentage of baobab seeds under different pre-treatment methods and resultant vigour of the seedlings. Experimentation involved Randomized Complete Block Design using six blocks with six treatments (hot water, cold water, smoke, acid, dry heat and water at room temperature). Standard methods were used to determine germination percentage, germination speed and seedling vigour of baobab under the aforementioned seed pre-treatment methods. The differences in germination percentage, germination speed and seedling vigour in all methods were significant ($p < 0.05$). The best methods for enhancing germination of baobab seeds and vigour of seedlings are hot water, acid (H_2SO_4) and dry heat. On the other hand, the best methods for enhancing germination speed are cold water and the control. Therefore we recommend the use of hot water and acid (sulfuric acid 98%) in preparation of nurseries for planting baobab seeds.

Keywords: Baobabs; dormancy; germination; pre-treatment; seeds

INTRODUCTION

The usefulness of forests and forest products continues to attract the world population. The African baobab and its related species belong to the family Bombacaceae and genus *Adansonia* and are among the most widely used trees. The African baobab (*Adansonia digitata*) occurs naturally in many countries of the sub-Saharan Africa. In Tanzania baobabs are found in Dodoma, Iringa, Lindi, Morogoro, Singida, Tabora, Manyara, Kilimanjaro, Simiyu and Shinyanga regions (Coates-Palgrave, 1983). The importance of baobabs cannot be overemphasised; for example, the plant is useful in environmental sustainability through the sequestration of carbon, and also as a source of feeds, medicines, ornaments, clothing, countless non-wood forest products and spices (Rahul *et al*., 2015; Lisao *et al*., 2017; Asogwa *et al*., 2021; Fischer *et al*., 2020; Mganga and Yusuph, 2022). The pulp of baobab is rich in vitamin C, the leaves are rich in calcium while, the whole seed and kernels are mainly composed of lipids (Chadare, 2010; Muthai *et al*., 2017). The increasing demand for baobab products is reported in almost every part of the world (Darr *et al*., 2020). However, deaths of baobab plants are heard in many regions as well (Patrut *et al*., 2019).

In Benin, Mali and Senegal excessive utilisation of the leaves was reported to lower the density of baobabs (Buchmann *et al*., 2010). In Zimbabwe and Tanzania destruction of baobabs was mainly caused by elephants through uprooting the plants, also drought conditions and fires that altogether ended up lowering their populations (Barnes, 2008; Ndoro, 2013; Venter and Witkowski 2013; Msalilwa *et al*., 2020). Furthermore, in Tanzania it was estimated that 3% of the baobabs were annually killed by elephants and in 30 – 170 years to come the baobabs will disappear if measures are not taken (Barnes, 2008). Additionally, more baobab fruits though with fewer seeds were recorded in disturbed areas than in undisturbed areas (Razafimahefa *et al*., 2022).

It follows therefore that baobab is among the African indigenous trees requiring domestication (Gebauer *et al*., 2016), to enhance their conservation. The call for domestication of baobab was first made by Michel Adanson in whose honour the plant was scientifically named *Adansonia digitata* (Rahul *et al*., 2015). This can be achieved through establishing nurseries and subsequently planting baobabs particularly in geographically feasible areas. However, *A. digitata* is a plant species which hardly regenerates under natural conditions (Danthu *et al*., 1995; Falemara *et al*., 2014). This is because baobab seeds may remain underground even if supplied with water particularly if there is no appropriate pre-treatment method(s) done (Gebauer *et al*., 2002; Southampton Centre for Underutilised Crops (SCUC), 2006). The main restricting factor in germination of baobabs like many other plants is mechanical seed dormancy (Egbadzor, 2020). Seed dormancy is an inherent property that governs environmental conditions in which case, the seed is able to germinate (Finch-Savage and Leubner-Metzger, 2006). There are several reasons associated with seed dormancy, such as (i) immaturity of seeds in harvested fruits; (ii) low permeability of seed coat to water and/or oxygen; (iii) seed coat hindrance to embryo growth; (iv) presence of metabolic inhibitors in the embryo; and (v) interactions of the aforementioned factors (Baskin *et al*., 2000; Kozlowski, 2002).

Therefore, by considering the hard seed coat of baobabs, suitable pre-treatment methods for breaking mechanical and physical dormancy are those with potential for allowing water and oxygen entry (Gebauer *et al*., 2002; Egbadzor, 2020). These initiatives reportedly require hot water and acids to break the physical dormancy of baobab seeds (Egbadzor, 2020). However, the seed pre-treatment methods cannot be generalised since the methods are variable among species, within a species and among seed sources of the same species (Danthu *et al*., 1995; Falemara *et al*., 2014). Thus, in this study seed pre-treatment methods that mimic heat and smoke of wildfires, wild animal acid digestion of baobab seeds, and cold and hot temperatures that are common in baobab environments were used (Mabberley, 2008; Flematti *et al*., 2011; Nelson *et al*., 2012; Egbadzor, 2020). It was hypothesised that different baobab seed pre-treatment methods result in variations in germination percentages and seedling vigour.

This study therefore aimed to assess the effects of hot water, cold water, smoke, acid and dry heat on breaking seed dormancy of *Adansonia digitata* L. (Baobab) for germination and seedling performance in an arid area of the Dodoma District. Baobab seeds soaked in water at room temperature served as control.

MATERIAL AND METHODS

Description of the study area

This study was conducted at the University of Dodoma which is found in the Dodoma District. Dodoma District is one of the seven districts of the Dodoma Region in Tanzania. The University of Dodoma is located along latitude 6°10’23''S and longitude 35°44’31’’E (Figure 1).

The region has a semi-arid climate with the lowest temperature of 13ºC which is experienced in July and the highest of 30.6ºC in November; this gives an annual mean temperature of 29ºC (Kayombo *et al.*, 2020; Gayo, 2021). Also, the region receives a modest amount of rainfall which ranges between 550 and 600 mm per year; the rainy season usually starts from December to April (Gayo, 2021). In Dodoma, the soil texture comprises of coarse sand, loamy and clays, characterised by hard sub-soils (Msanya *et al*., 2018). According to the National Census of 2022 Dodoma Region had a population of 3,085,625 people (United Republic of Tanzania (URT), 2022).

In Dodoma District the predominant vegetation is mainly wooded land, notable by two important genera in the drier forests which are *Acacia* and *Brachystegia* (Timberlake *et al*., 2013; Kyalangalilwa *et al*., 2013). Dodoma is among the Tanzanian regions with abundant baobabs (Ministry of Transport, 2016), thus geographically appropriate for baobab afforestation and reforestation programs. This is recommended based on reports on deforestation of baobabs in that area (Msalilwa *et al*., 2020; BirdLife International, 2022).

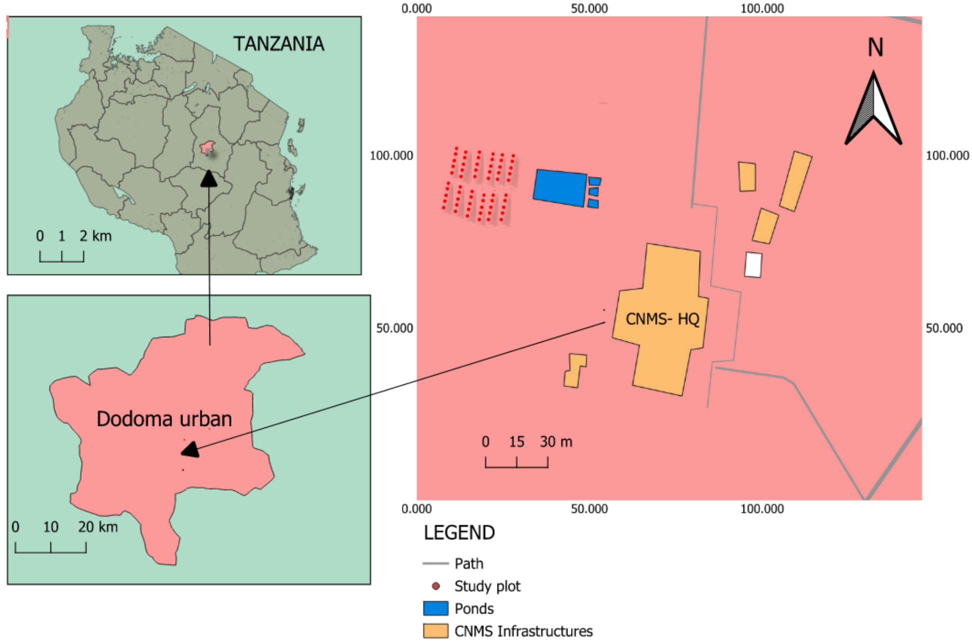

Figure 1: Location of the University of Dodoma (College of Natural and Mathematical Sciences (CNMS))

Source: Field work

Research design

The experimental design used a Randomized Complete Block Design (RCBD) with six treatments (hot water, cold water, smoke, acid, dry heat and water at room temperature) and five blocks. The design involved twelve plots of 10 m^2 each which were prepared for germination of baobab seeds at the College of Natural and Mathematical Sciences of the University of Dodoma. In each plot, five subplots of 2 m^2 each were established for replication. From a village near the University of Dodoma (Michese) several mature baobab trees (*A. digitata*) were located, from which several fruits were collected. About one thousand two hundred (1200) seeds were isolated from fruit pulps and powdery substances were physically removed. Viability test was done by floatation method, and then the settled seeds air dried and kept for two days before experimentation. The baobab seeds were treated differently based on the nature of the methods and duration of treatment (long time or short time).

Pre-treatment of baobab seeds with smoke was done by using an aqueous solution of smoke (Drewes *et al.*, 1995). The procedure involved collection of plant litter and burning it in a bee smoker. The smoke was then bubbled through a clear tube into a container (water bottle) containing a litre ofwater. The bubbling of smoke into the water bottle (containing water) continued until a yellow colouration was seen; which indicated the presence of smoke's water soluble compounds. Eighteen baobab seeds were soaked in smoke water separately for 24 and 48 hours (for imbibitions).

Dry heat pre-treatment was done by embedding 36 baobab seeds in wet sand then 18 of them were put in an oven at

150ºC and the other 18 seeds at 100ºC each for 40 minutes, the temperatures and duration of exposure were representatives of wildfire intensities as recommended by Kempe *et al*. (2018).

Cold water pre-treatment was done by soaking 18 baobab seeds in water at a temperature of 20ºC for 24 and other 18 seeds for 72 hours (Johansson, 1999). Hot water pre-treatment was done by immersing 36 baobab seeds in hot water at 100ºC for five minutes (Southampton Centre for Underutilised Crops, 2006), then separately soaking 18 seeds in water at room temperature for 24 and 48 hours.

Acid pre-treatment of baobab seeds was done by separately soaking 18 seeds in concentrated sulphuric acid (98%) for six hours and other 18 seeds for 12 hours (Niang *et al*., 2015). Then, 18 baobab seeds were separately soaked in water at room temperature for 24 and other 18 seeds for 72 hours.

After all pre-treatments the baobab seeds were ready for sowing in the prepared plots. Prior to baobab seed germination trials, sand was added to soils for improvement of aeration as recommended by Niang *et al*. (2015), also animal manure was added for soil nourishment. After all pre-treatments eighteen (18) baobab seeds as recommended by Salami *et al*. (2021) were sown in each sub-plot at a spacing of 30 × 40 cm. The experiment was laid in RCBD. Germination was monitored daily and seeds were watered as needed.

Data collection

In this study emergence of the cotyledonary leaves out of soil was considered as germination (Chichaghare *et al*., 2020). In each baobab seed, pre-treatment and daily germination count was done until no further change in the counts (Chichaghare *et al*., 2020).

Data processing and analysis

Germination percentage was computed using the following formula (Chichaghare *et al*., 2020):

$$\text{Germination Percentage (\%)} = \frac{\text{Number of germinated seeds}}{\text{Number of Total seeds}} \times 100\% \quad \textbf{eqn 1}$$

Then, germination energy was determined as the peak of germination percentage (Chichaghare *et al*., 2020).

The seedling vigour index was calculated by adopting the method recommended by Abdul-Baki and Anderson (1973) as follows:

$$\text{Vigour index} = \text{Germination\%} \times \text{Total seedling length (cm)} \quad \textbf{eqn 2}$$

The germination speed of baobab seeds under different pre-treatment methods was determined by the number of days to 50% of seeds germinated (Niang *et al*., 2015).

Data on germination percentage, seedling vigour and germination speed of baobabs under pre-treatment of acid, hot water, cold water, smoke, dry heat and control were subjected to one-way ANOVA because they were parametric (Gomez and Gomez, 1984), with 5% level of significance. Multiple groups of treatments were compared using the Tukey-Kramer test.

RESULTS

Germination percentage of baobab seeds at the University of Dodoma

The results in Figure 2 show the germination percentage of baobab seeds under different treatments. The mean germination percentage of baobab seeds (%) with ranges in brackets for short time pre-treatment with smoke, hot water, dry heat, sulfuric acid, cold water and control was 54.55 ± 3 (52.5 – 56), 86.3 ± 4 (85 – 88), 61.85 ± 2.2 (60 – 63.8), 81.55 ± 3 (80 – 84.3), 67.3 ± 2.5 (65.75 – 68.75) and 43.7 ± 2.2 (42 – 45.25), respectively (Figure 2). The trend of decreasing germination percentage of baobab seeds for a short time was: hot water > acid (sulfuric acid) > cold water > dry heat (100ºC) > smoke > control. The results of one way ANOVA indicated that the differences in germination percentages of baobab seeds pre-treated with smoke, hot water, dry heat, sulfuric acid, cold water and control are significant ($p < 0.05$). Tukey-Kramer test showed that all groups differed in germination percentage ($p < 0.05$).

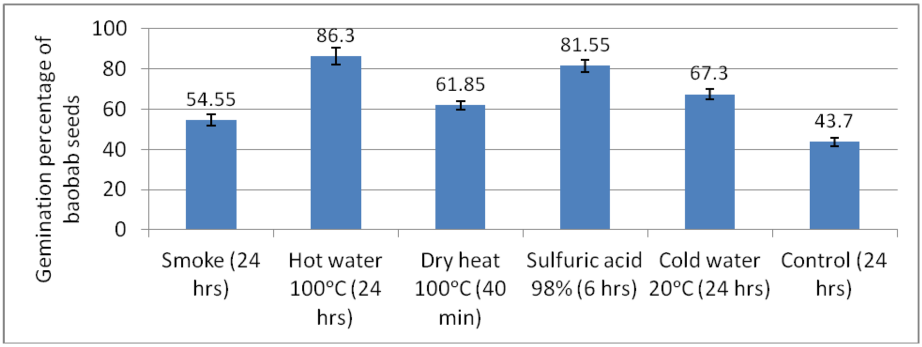

Figure 2: Germination percenatge of baobab seeds pre-treated for a short time

Additionally, the results in Figure 3 show that the mean germination percentages of baobab seeds (%) with ranges in brackets for long time pre-treatment with smoke, hot water, dry heat, sulfuric acid, cold water and control were 55.6 ± 2.7 (54.75 – 57), 62.5 ± 3.3 (61.75 – 63.25), 73.8 ± 4.2 (72 – 76), 96.6 ± 5 (90 – 100), 55.5 ± 2.7 (54 – 57) and 47.6 ± 2 (45 – 45.25), respectively (Figure 3). The increasing trend in germination percentages of baobab seeds for long time pre-treatment was: acid (sulfuric acid) > dry heat (150ºC) > hot water > smoke > cold water > control.

The results on One Way ANOVA revealed that the germination percentages of baobab seeds pre-treated with smoke, hot water, dry heat, sulfuric acid, cold water and control were significantly different ($p < 0.05$). TheTukey-Kramer test shows that all groups differ in germination percentages ($F = 171.88$, $p < 0.05$), except between smoke and cold water pre-treatment ($p > 0.05$).

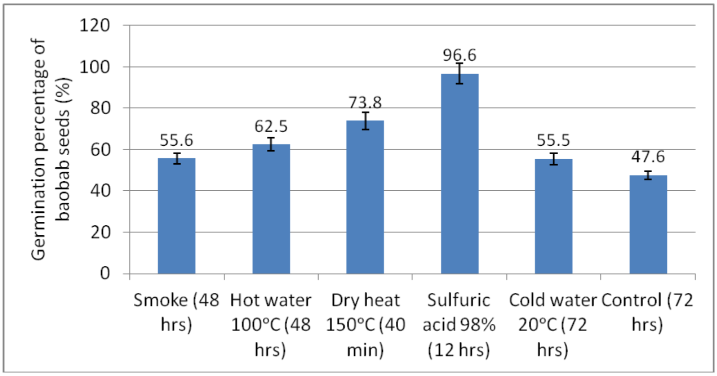

Figure 3: Germination percentage of baobab seeds pre-treated for a long time

The results of t-test showed that germination percentages of baobab seeds were significantly different between hot water pre-treatments that lasted for 24 and 48 hours, dry heat of 100ºC and 150ºC, sulfuric acid for 6 and 12 hours and cold water for 24 and 72 hours (t = 35.381, DF = 8, $p < 0.05$; t = 11.803, DF = 8, $p < 0.05$; t = 7.349, DF = 8, $p < 0.05$; t = 14.823, DF = 8, 0.05), respectively. On the other hand, germination percentages of baobab seeds in smoke and control were not significantly different between pre-treatments that lasted for 24 and 48 h, and 24 and 72 hours (t = 1.342, DF = 8, $p > 0.05$ and t = 1.509, DF = 8, $p > 0.05$), respectively.

Germination speed of baobab seeds

The results in Figure 4 show the germination speed of baobab seeds (in days) under pre-treatments of smoke, hot water, dry heat, sulfuric acid, cold water and control for short time basis with ranges in brackets was 11 ± 0.32 (10 – 12), 8 ± 0.31 (7 – 9), 8 ± 0.31 (7 – 9), 8.2 ± 0.36 (7 – 9), 13 ± 0.31 (12 – 14) and 12 ± 0.32 (11 – 13), respectively. The order of increasing the germination speed of baobab seeds was: cold water > control > smoke > acid (sulfuric acid) > similar for hot water and dry heat (100ºC). The results of One Way Analysis of Variance (ANOVA) revealed that the germination speed of baobab seeds pre-treated with smoke, hot water, dry heat, sulfuric acid, cold water and control is significantly different ($p < 0.05$).

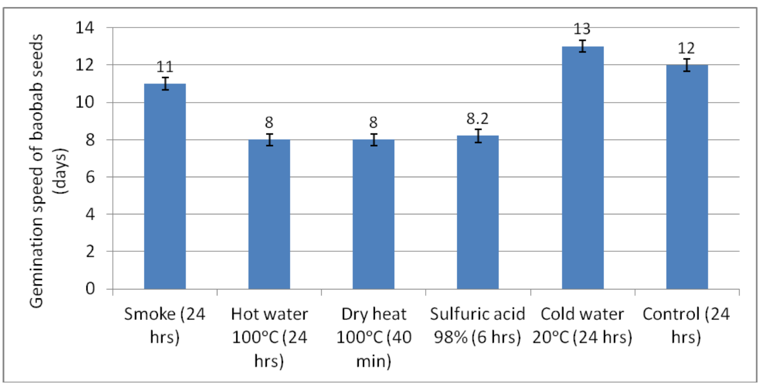

Figure 4: Germination speed of baobabs after seed pre-treament for a short time

The results in Figure 5 show the germination speed of baobab seeds (days) under pre-treatments of smoke, hot water, dry heat, sulfuric acid, cold water and control for long time basis with ranges in brackets was 11 ± 0.3 (10 – 12), 8 ± 0.32 (7 – 9), 9.8 ± 0.36 (9 – 11), 8.2 ± 0.58 (7 – 10), 12 ± 0.32 (11 – 13) and 12 ± 0.31 (11 – 13), respectively. The order of increasing germination speed of baobab seeds was: similar for cold water and control > smoke > dry heat (150ºC) > acid (sulfuric acid) > hot water. The results of One Way Analysis of Variance (ANOVA) revealed that the germination speed of baobab seeds pre-treated with smoke, hot water, dry heat, sulfuric acid, cold water and control was significantly different ($p < 0.05$).

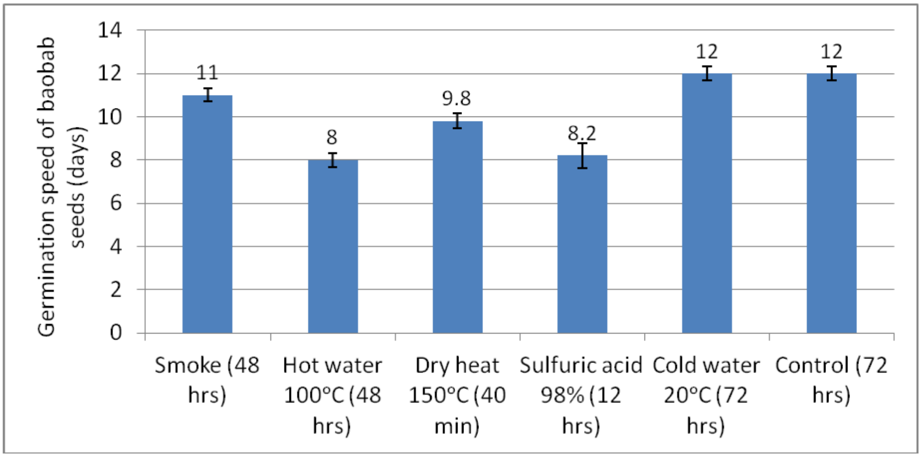

Figure 5: Germination speed of baobabs after seed pre-treatment for a long time

Seedling vigour index of baobabs

The results in Figure 6 show the seedling vigour index (SVI) of baobabs under different seed pre-treatments for a short time basis. The mean seedling vigour of baobab (% cm) with ranges in brackets for short time pre-treatment with smoke, hot water, dry heat, sulfuric acid, cold water and control was 309.4 ± 18.3 (288.8 – 324), 676.9 ± 25.1 (663 – 693), 383.8 ± 15 (375 – 390), 691.9 ± 30 (672 – 707.7), 296.7 ± 14.4 (284.9 – 305.3) and 255.04 ± 9.8 (243.6 – 271.5), respectively (Figure 6).

The trend of increasing seedling vigour of baobabs for a short time was: acid (sulfuric acid) > hot water > dry heat (100ºC) > smoke > cold water > control. The results of One Way Analysis of Variance (ANOVA) revealed that the seedling vigour index of baobab seeds pre-treated with smoke, hot water, dry heat, sulfuric acid, cold water and control was significantly different ($p < 0.05$). The Tukey-Kramer test showed that all groups had different seedling vigour ($p < 0.05$), except for smoke against cold water as well as hot water against acid (sulfuric acid) ($p > 0.05$).

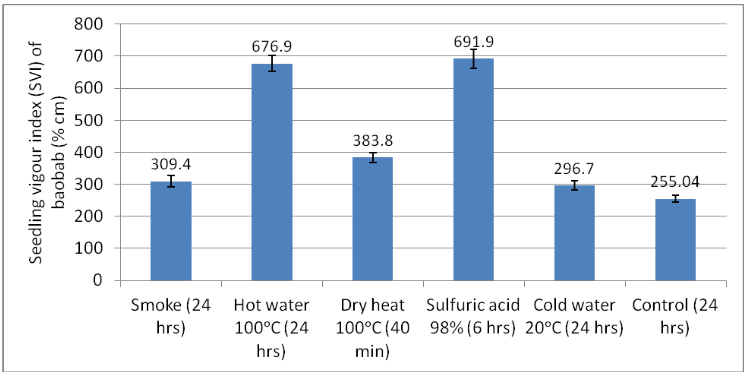

Figure 6: Seedling vigour index of baobabs after seed pre-treament for a short time

On the other hand, the results in Figure 7 show the seedling vigour index (SVI) of baobabs under different seed pre-treatments for a short time basis. The mean seedling vigour of baobab (% cm) with ranges in brackets for long time pre-treatment with smoke, hot water, dry heat, sulfuric acid, cold water and control was 320.1 ± 20.1 (317.3 – 324.9), 418.9 ± 22 (409.5 – 426.1), 398.98 ± 17.8 (379.6 – 425.6), 763.5 ± 31 (720 – 810), 283.5 ± 14.4 (268.3 – 296.4) and 221.2 ± 11.9 (192 – 247.5), respectively (Figure 7). The trend of increasing seedling vigour of baobabs for a long time was: acid (sulfuric acid) > hot water > dry heat (150ºC) > smoke > cold water > control. The results of One Way Analysis of Variance (ANOVA) revealed that the seedling vigour index of baobabs seeds pre-treated with smoke, hot water, dry heat, sulfuric acid, cold water and control is significantly different ($p < 0.05$). TheTukey-Kramer test showed that all groups had different seedling vigour ($p < 0.05$), except for smoke against cold water as well as dry heat (150ºC) for 40 minutes against hot water (100ºC) for 48 hours ($p > 0.05$).

Moreover, t-test revealed that the differences in seedling vigour index between short time and long time baobab seed pre-treatments were not significant ($t = 0.308$, $DF = 10$ and $p > 0.05$).

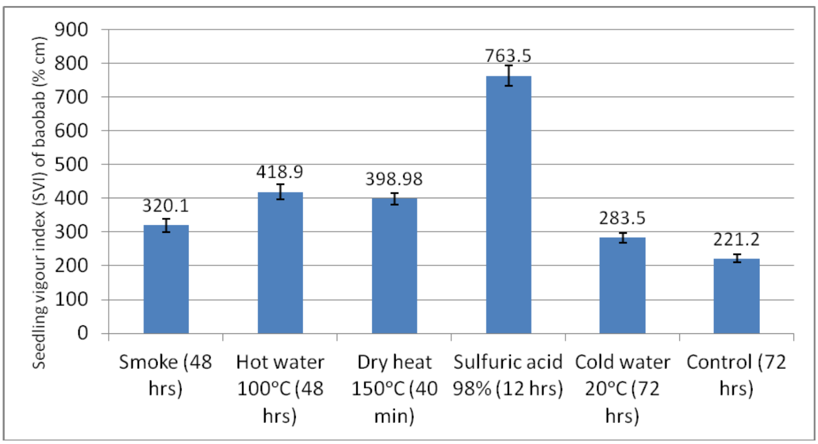

Figure 7: Seedling vigour index of baobabs after seed pre-treament for a long time

DISCUSSION

Hot water seed pre-treatment ranked the first in enhancing germination of baobab particularly for a duration of 24 hours. This suggests that hot water is capable of weakening the hard seed coat (testa) of the baobab seed and subsequently removing it. This allows entry of air and water which mobilize the food reserve for nourishing the embryo. Water is the main factor controlling seed germination by enabling enzymatic reactions and mobilisation of storage reserves such as lipids, carbohydrates and proteins (Szczerba *et al*., 2021). Following imbibition, oxygen enters the mitochondria of an embryo breaking down glucose to carbon dioxide for the generation of energy in the form of ATP; this energy is used for growth, repair and transport in the germinating seeds (Kuznetsov and Hasenstein, 2003; Budko *et al*., 2013; Corbineau, 2022). Additionally, water entry and swelling of seeds are reported to wash out tannin which hinders the germination of *A. digitata* (Lautenschläger *et al*., 2020). The finding of this study is in agreement with Esenowo *et al*. (1991) and Abubakar *et al*. (2022), though the pre-treatments were done at different durations. On the contrary, hot water seed pre-treatment which was done for a longer time (48 hours) ranked third after acid and dry heat (150ºC) methods, such difference was significant. This demonstrates that prolonged soaking of baobab seeds resulted in excessive swelling of the seeds which limited mobilisation and breakdown of food reserve in the seeds. Excessive imbibition was observed to cause seed necrosis (Danthu *et al*., 1995). Additionally, imbibition temperature has been reported to negatively affect the vigour of seedlings though it was species-specific (Booth and Bai, 1995). The finding of this study conforms with El-Bably and Rashed (2018) and Salami *et al*. (2021) who observed better germination of baobab seeds when using acid (98.5% and 95% H_2SO_4) than hot water in Egypt and Nigeria, respectively. Similarly, in Nigeria, Bashir *et al*. (2021) reported prolonged pre-treatment of baobab seeds in hot water to lower germination percentage. In Kondoa (Tanzania) hot water pre-treatment of baobab seeds ended up killing many seeds (Johansson, 1999). This added on the argument that suitable seed pre-treatment methods cannot be generalised for seeds collected from the same plant species (Falemara *et al*., 2014).

Furthermore, the study revealed that pre-treatment of baobab seeds with acid (H_2SO_4) ranked first in effecting germination but for long time (12 hours), contrary to the duration of 6 hours. This suggests that prolonged soaking of baobab seeds in the acid was sufficient in rupturing the seed coat. Disruption of seed coat is physiologically important for initiation of germination because of letting water and air in. Sulfuric acid is known to accelerate physiological and biochemical processes through enhancement of water absorption, availability of dissolved sugar and α-amylase activity for starch degradation (Wang *et al*., 2012). This finding is in agreement with the study conducted in Senegal by Danthu *et al*. (1995) though that one took much more time than one, by Wickens and Lowe (2008), in Nigeria by Falemara *et al*. (2013), Bashir *et al*. (2021) and, Egbadzor (2020) in Ghana. However, the finding of this study contradicts that of Amusa (2011) who argued on the destruction of seeds by acids. Despite the good germination of baobab seeds using acid for the named time, germination speed (time to 50% germination of total seeds sown) was not so high. However, the germination speed under acid pre-treatment of baobab seeds is in agreement with Falemara *et al*. (2013) in Nigeria.

Dry heat pre-treatment of baobab seeds enhanced germination at 150ºC when compared with 100ºC. This suggests that when dry heat is applied to break seed dormancy in baobabs the temperature should be high enough. Dry heat is useful in burning/ diminishing the hard seed coat so that water and oxygen can enter the seed enabling physiological and metabolic processes needed for germination. Dry heat treatment at 150ºC also resulted in high germination speed and seedling vigour. The results of this study are in agreement with Gashaw and Michelsen (2002) who reported on seeds from savannah that tolerated a temperature of 200ºC. On the contrary, the findings of this study contradict with Lautenschläger *et al*. (2020) who recorded no germination in *A. digitata* at 150ºC in Angola.

Cold pre-treatment of baobab seeds ranked third after hot water and acid in contributing to germination. Cold seed pre-treatment and control performed better in enhancing the speed of germination (time to 50% germination) for durations of 24 and 72 hours, though the two did not perform quite well for the case of germination percentage. These results suggest the contribution of water during the early development of seeds. These results are in agreement with Assogbadjo *et al*. (2011) who observed the best germination time of baobab seeds (11 days only) in non-treated seeds in Benin. Also, Johansson (1999) reported about three days cold pre-treatment of *A. digitata* as sufficient in enhancing germination. Likewise, in China, Cheng *et al*. (2022) reported that cold pre-treatment of seeds lowered the germination time by enhancing early seed emergence. It appears that 50% of seeds in these two groups germinated earlier, but later on, the progress was not so effective when compared to hot water, dry heat, smoke and acid treatments as depicted by the findings on germination percentage. On the other hand, this finding is in conformity with Falemara *et al*. (2013), but contrary to Abubakar *et al*. (2022) who noted the least baobab seedling emergence after cold water pre-treatment. The discrepancy could be associated with the limited time for cold water seed pre-treatment in that study; it lasted for 8 hours, while in this study it was separately done for 24 and 72 hours.

On the other hand, similar germination speed (time taken to 50% of seeds germinated) was observed for hot water (24 hrs.) and dry heat (100ºC). This is indicative of similarity in the two sets due to the involvement of heat i.e. dry and wet heat used in breaking seed dormancy in baobab seeds through burning and softening the hard seed coat, respectively. The action of wet and dry heat probably was not so effective when compared to cold water and control (water at room temperature) in enhancing imbibition for early attaining 50% of the baobab seeds germinated. Heat is important for removing hard seed coat of baobab through burning and lowering the levels of tannin which hinders germination (Morrison *et al*., 1998; Kassegn *et al*., 2018; Gashaw and Michelsen, 2022).

In terms of seedling vigour, baobabs that were pre-treated with hot water and then separately soaked for 24 and 48 hours, both ranked second after two sets of acid (H_2SO_4) pre-treated for 6 and 12 hours, respectively. These findings suggest the effectiveness of acid pre-treated baobab seeds over hot water in enhancing seedling growth and development. Furthermore, the results are indicative of different growth rates of root and shoot apices of baobab seedlings after pre-treatment with hot water and acid. Hot water pre-treated seeds probably contributed to more water entry and resultant swelling of seeds as opposed to acid pre-treatment in which there was no comparable swelling. About 68% of total baobab water tends to be stored in taproots with only a limited amount found in the shoots; this is reported to cause succulence in the roots of growing plants (Van den Bilcke *et al*., 2013). It is likely that the limited amount of water in the shoots developed after the water pre-treatment of seeds experienced low metabolic reactions when compared to the acid pre-treated sets. The result of this study is in agreement with El-bably and Rashed (2018) who reported on high seedling vigour of baobabs pre-treated with hot water and acid (H_2SO_4) in Egypt. On the contrary, the finding of this study on prolonged pre-treatment of baobab seeds with hot water and limited seedling vigour contradicts Bashir *et al*. (2021); who observed an increase in the seedling vigour. The discrepancy could be explained by the nature of the experimental site; that study was conducted in screenhouse while ours was done in an open field. Screenhouse is known to enhance the growth and yield of crops/plants as opposed to open fields (Romero-Gámez *et al*., 2012).

Smoke pre-treatment of baobab seeds moderately affected germination, speed of germination and vigour of the seedlings. The possible reasons are; firstly chemical substances in smoke were not satisfactorily captured to break seed dormancy. Secondly, water which was used in this study was not the right solvent for dissolving suitable compounds in smoke during bubbling for experimentation. Karrikin and cyanohydrin are among the products of cellulose degradation during the formation of smoke (Keeley and Pausas, 2018; Khatoon *et al*., 2020). This result conforms with Keley and Fotheringham (1998) but contradicts Dayamba *et al*. (2008) who found high seed germination using smoke pre-treatment. The discrepancy could be caused by the use of aerosol smoke in that study contrary to aqueous smoke which was used in this study.

CONCLUSIONS AND RECOMMENDATIONS

This study revealed that application of hot water at 100ºC for 5 minutes then soaked for 24 hrs, acid (H_2SO_4 98%) both for 6 and 12 hrs and, dry heat (150ºC) for 40 minutes is capable of enhancing germination of baobab seeds thereby breaking the dormancy. These pre-treatments were proved to promote the vigour of baobab seedlings as well. These methods are thus suitable for enhanced planting of baobabs and resultant high yield. On the other hand, the use of cold water and water at room temperature (control) is the best for enhancing the speed of germination of baobab seeds, but beyond the time of 50% germination of seeds, the efficacy of breaking dormancy slowed down. Thus the two methods are not recommended. Nevertheless, seed size, age and environmental factors could influence germination percentage, speed and vigour of baobabs; however, these factors were not covered in this study. Studies on agronomic preferences of baobab seeds under different edaphic characteristics are recommended. Also, we advise governments to campaign on the domestication of baobabs particularly in friendly environments for conservation purposes.

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Declaration of competing interest

There are no competing interests to declare.

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