Hindawi Publishing Corporation
International Journal of Biodiversity
Volume 2015, Article ID 323128, 8 pages
http://dx.doi.org/10.1155/2015/323128

Research Article

Germination Ecology of *Arundinaria alpina* (K. Schum.) and *Oxytenanthera abyssinica* (A. Rich.) Munro Seeds: Indigenous Bamboo Species in Ethiopia

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Received 11 July 2015; Accepted 15 September 2015

Academic Editor: Alexandre Sebbenn

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Highland bamboo (*Arundinaria alpina*) and lowland bamboo (*Oxytenanthera abyssinica*) are indigenous to Ethiopia and endemic to Africa. Seeds of *A. alpina* were collected from Dawa Wereda (District), while *O. abyssinica* seeds were collected from Pawe and Sherkole Weredas. In this study, seed presowing treatments, effects of dry heat, moist heat, and light/dark treatments on the germination of seeds were tested. The averages were of 59,416 and 8,393 seeds contained within 1 kg of *A. alpina* and *O. abyssinica* seeds within 86 and 91% pure seeds, respectively. From 1 kg of pure seeds 37,301 and 7,168 seedlings are raised in the laboratory in their respective orders. The result revealed that control seeds of *A. alpina* and *O. abyssinica* showed the best germination of 73 and 98%. Germination of both dry and moist heat treatments of *O. abyssinica* seeds was significantly improved at 60 and 80°C. Unlike *A. alpina* seeds, seeds of *O. abyssinica* had better germination for light treatment compared to dark. For effective large scale plantation and raising of *A. alpina* and *O. abyssinica* seedlings from its seeds for laboratory, control seeds supply to necessary light source (for *O. abyssinica* seeds) is recommended.

1. Introduction

There are two indigenous species of bamboo in Ethiopia: the highland bamboo (*Arundinaria alpina* (K. Schum.)) and lowland bamboo (*Oxytenanthera abyssinica* (A. Rich.) Munro) [1, 2]. These species are indigenous to Ethiopia and endemic to Africa [2]. The species of bamboo are classified under the member of grass family known as *Poaceae* [1]. *Arundinaria alpina* is commonly known by various local names including QERKEHA in Amharic; LEMEN in Afan Oromo; ARKAY in Tigrinya; SHIKATO/SHINATO in Kefinya; and WEYSHA in Welaytinya/Gamonya [1, 3]. It is a hollow clump forming bamboo growing up to a height of 15 m and a diameter of 12 cm from a stout branching rhizome [1]. *Arundinaria alpina* is found in montane forest often on volcanic soils and forming extensive pure stands. In addition, *A. alpina* occurs with *Podocarpus* in upland rainforest and with *Juniperus* in drier forest frequently planted along roads and in villages. It is widely distributed in Cameroon Mountain, Zaire (Kivu), Rwanda, Burundi, Sudan (Imatong mountains), the east African mountains, and Malawi. In Ethiopia *A. alpina* is found in Gojam, Shewa, Kefa, Gamo Gofa, Sidamo, and Bale Regions at the altitudes ranging from 2,200 to 4,000 m above sea level [1].

Similarly, *O. abyssinica* is commonly known by various local names in different areas with respect to their languages. Accordingly, it is known as SHIMEL in Amharic; ARKAY in Tigrinya; and SHIMALA in Welaytinya or Afan Oromo [1, 4, 5]. *Oxytenanthera abyssinica* is a solid woody clump forming bamboo growing up to a height of 3–13 m and a diameter of 5–10 cm [1]. It is widely distributed in eastern and southern Africa mainly Ethiopia, Malawi, Zimbabwe, and Zambia [5, 6], while in western Africa, it is located in some parts of Ghana and Senegal. The species is widely distributed in lowland regions of western and northwestern parts of Ethiopia [6] in Tigray, Gonder, Gojam, and Welega Regions [1]. *Oxytenanthera abyssinica* is found in Savanna woodland, favoring river valleys, often forming extensive stands at

the altitudes ranging from 1,200 to 1,800 m above sea level [1]. Its annual rainfall is ranging from about 700 to 1,000 mm, which is concentrated over a period of three to four months with the mean annual temperature of above 30°C [5]. The species is easily adaptable to poor soils and provided as a buffer zone for desert areas [5].

Bamboo resources in Ethiopia have a considerable potential to socioeconomic development of the local people; mitigation and adaptation of global climatic change through carbon sequestration; biodiversity conservation and wider ecological adaptation [1, 7–9]. However, little or almost no significant research and development attention are given to bamboo resources. Currently, the bamboo resources of Ethiopia are underutilized and have been neglected by development practitioners. For instance, their importance and use are limited to hut construction, fencing, production of handicrafts (basketry, mats, and decorative items), furniture, and other household utensils [1, 3–5, 8]. Due to this reason, there is indiscriminate resource depletion by various human activities and mass flowering and subsequent death of bamboo resources [2, 3, 5, 8, 10]. This, in turn, influences the sustainable use and management of the species and its genetic resource conservation. Furthermore, poor seed storage characteristics and hence low viability as well as limited availability of seeds and flowering at longer intervals are the practical problems in bamboo large-scale propagation using seeds [3, 5, 11]. Various sources reported that the species produces seeds, which is difficult to get, collect, and process. Lack of easy access to seeds and seedlings are in general associated with seed handling and storage problems, which further limit the use of the species in bamboo improvement, expansion, and conservation programmes. Therefore, to fill this research gap it is imperative to find appropriate *ex situ* conservation methods of bamboo genetic bases on the long- and short-term bases. Genetic improvement and large scale plantation of bamboo seedlings are largely dependent upon quality and quantity of seeds. Seed quality, in turn, comprises both the physiological viability and vigour of the seeds and their genetic quality. The ability to produce vigorous and healthy seedlings in the field, which are well adapted to the field, is an essential complement to genetic improvement. Secondly, planted seedlings are intended to provide the necessary product or service due to its high viability and vigour of seeds [12]. Hence, studying the germination ecology (effect of presowing seed treatments, light, and seed storage time) of seeds helps to select rapidly and vigorously germinating seeds under favourable environmental conditions that are capable of producing vigorous seedlings in the field. Therefore, the present study aimed at investigating germination ecology of *A. alpina* and *O. abyssinica* seeds for proper *ex situ* conservation of its genetic base.

2. Materials and Methods

2.1. Seed Collection, Handling, and Processing. Seeds of *A. alpina* were collected from Dawa Wereda (District), Guji Zone, Oromia Regional State, Ethiopia, whereas *O. abyssinica* seeds were collected from Pawe especial Wereda, Metekel Zone and Sherkole Wereda, Assosa Zone of Benishangul-Gumuz Regional State, Ethiopia. To ensure maximum genetic diversity, seeds were collected from selected clumps of bamboo stands at a distance of at least 100 m apart between them [13]. The collected fresh seeds were put into perforated plastic bags and safely transported to Central Ethiopia Environment and Forest Research Center (CEE-FRC), Ethiopian Environment and Forest Research Institute (EEFRI). Seeds which had been attacked by insects or decayed were excluded, extracted, and cleaned in CEE-FRC seed processing room following the procedures by FAO [12]. Finally, the seeds were placed in perforated plastic bags and stored in cold room at +5°C until the experiment was started as also partially applied by C. C. Baskin and J. M. Baskin [14]. This enables us to maintain the viability of seeds and prevent from insect attack by reducing seed moisture [12, 15]. Moreover, the rate of physiological changes of many seeds becomes slow down by storing them at low temperatures [14]. Various germination tests were started shortly after the collection of seeds, that is, within a week [14].

2.2. Determination of Purity Analysis and Moisture Content of Seeds. Moisture content and purity analysis of *A. alpina* and *O. abyssinica* seeds were determined in the laboratory following the methods by FAO [12]. To determine moisture content, two samples of 5 gm seeds each were drawn from the total seed lot of each species before the determination of purity analysis. Samples were weighed and dried in an oven for 17 hours at 103°C. Finally, samples were placed in a desiccator, cooled for 30 minutes, and then reweighed. The wet weight or fresh weight basis of moisture content was calculated as

$$\text{Moisture content } \% = \frac{\text{Original weight} - \text{Oven dry weight}}{\text{Original weight}} \times 100. \quad (1)$$

Similarly, two samples of 35 gm seeds each were drawn from the total seed lot of each species containing all the impurities and weighed. Following this, the pure seed was removed and reweighed separately. The percentage of pure seed was determined as follows:

$$\text{Purity } \% = \frac{\text{Weight of pure seed}}{\text{Total weight of original sample}} \times 100. \quad (2)$$

2.3. Determination of Seed Size and Weight of A. alpina and O. abyssinica Seeds. Seed weight of *A. alpina* and *O. abyssinica* was determined following FAO [12]. Accordingly, 8 replicates of 100 pure seeds each were randomly drawn from the total seed lot and expressed as weight of whole seeds. Hence, the 1000 pure seed weight was converted to number of pure seeds per kg:

$$\text{Number of seeds per kg} = \frac{1000 \times 1000}{\text{weight in g of 1000 seeds}}. \quad (3)$$

To measure the seed size of *A. alpina* and *O. abyssinica* seeds, 100 seeds in 4 replicates of 25 seeds each were randomly drawn from the total seed lot of each species. Following this,

the seed length and seed width were measured in millimeters (mm) using seed caliper [16].

Finally, the number of seedlings raised per kg of seeds in the laboratory also was calculated as follows:

$$\text{Number of seedlings raised per kg of seeds} = \text{Number of seeds per kg} \times \text{percentage germination} \times \text{percentage purity}. \quad (4)$$

2.4. Presowing Seed Treatments. Effect of presowing seed treatments on the germination of *A. alpina* and *O. abyssinica* species was assessed by conducting different presowing seed treatments. Accordingly, whether pretreatment improves seed germination or not, *A. alpina* seeds were subjected to six treatments, which was decided by the first author based on the past experience on various seed tests (T1–T6): nicking the seeds at the opposite side of embryo or bottom part (T1); soaking the seeds in cold water (19°C) for 6 hrs (T2); soaking the seeds in cold water (19°C) for 12 hrs (T3); soaking the seeds in cold water (19°C) for 24 hrs (T4); seeds immersed in hot/boiling water (100°C) for 1 minutes (T5); and control seeds (seeds without treatment or intact seeds) (T6).

Similarly, *O. abyssinica* seeds treated to five treatments (T1–T5): nicking the seeds at the top part where the embryo located (T1); nicking the seeds at the opposite side of embryo or bottom part (T2); soaking the seeds in cold water (19°C) for 24 hrs (T3); the seeds immersed in hot/boiling water (100°C) for 5 minutes (T4); and control seeds (seeds without treatment or intact seeds) (T5). To investigate the effect of nicking on germination of seeds, a small portion of the seed coat was carefully removed at the side or opposite of the hilum using the sharp edge of a Scissor until a small hole was remained. This allows imbibitions of water and oxygen by braking seed coat dormancy for some species [12, 17]. Great care was taken to avoid/not to damage seed embryo and the emerging radical as well.

2.5. Dry Heat Treatment. In this test, *O. abyssinica* seeds were treated with dry heat (seeds placed in glass bottle without water) in preheated dry oven at a range of different temperatures (60, 80, and 100°C) and duration (15, 30, and 60 minutes) for each range. The test had also a control (without heat treatment). This was applied following the method by Martin et al. [18], Teketay [19, 20], C. C. Baskin and J. M. Baskin [14], and Bahru et al. [17].

2.6. Moist Heat Treatment. Seeds of *O. abyssinica* were treated with moist heat in preheated dry oven at a range of different temperatures (60, 80, and 100°C) and duration (15, 30, and 60 minutes) for each range following the method by Bahru et al. [17]. Moist heat treatment is similar to dry heat but the only difference is in moist heat seeds which were placed in glass bottle containing water and treated in dry oven. The test had also a control (without heat treatment).

2.7. Light/Dark Treatment. Effect of light or darkness on the germination of *A. alpina* and *O. abyssinica* seeds was tested by sowing seeds in light and under dark condition. Based on this, for both treatments control seeds were sowed and enclosed in Petri-dishes on moist filter paper. For dark treatment, Petri-dishes were immediately wrapped with aluminum foil to avoid exposure of seeds to light. For light treatment, Petri-dishes were exposed to light from florescent tubes, which are provided for the laboratory room. Finally, the Petri-dishes of both treatments were placed on a table at room temperature (21/22°C). This was applied following the methods by Teketay [19, 20], C. C. Baskin and J. M. Baskin [14], and Bahru et al. [17].

2.8. Effect of Storage Time on Germination Capacity. To assess effect of storage time of *A. alpina* seeds on seed germination, seeds were stored for 0, 180, 300, and 360 days at room temperature (21/22°C) in cold room and the seed germination tests were carried out following the methods by Bahru et al. [21].

2.9. Daily Germination Assessment of Seeds. All germination tests were conducted in such a way that all treatments had 100 seeds in 4 replicates of 25 seeds each. The filter paper was kept moist with distilled water as much as possible throughout the entire experimental period. In order to moisten the filter paper, water was added until the paper was saturated. Following this, the Petri-dish was holding on its side to allow excess water drained from the filter paper [14]. Seeds were inspected everyday starting from the 2nd day after sowing except those seeds incubated in the dark. All germinated seeds were counted and discarded daily in order to avoid the double counting of seeds. A seed was considered as germinated when the radicle was penetrated out from the seed coat and clearly appeared visually. The daily germination count was continued until no more seeds had been germinated, that is, 28 germination days. This method was applied following C. C. Baskin and J. M. Baskin [14] and Bahru et al. [17, 21].

Statistical Data Analysis. Germination percentage data were first arcsine transformed before statistical analysis to fulfill the normality assumption [14, 22]. Germination capacity (GC) and coefficient of rate of germination (CRG) or coefficient of velocity were determined following the method adopted by Hartmann and Kester [15] and Mamo et al. [16]. Germination capacity is the proportion of total number of germinated seeds to that of sown seeds and expressed as in percentage. Coefficient of rate of germination also is calculated and expressed in percentage as follows:

$$\text{CRG} = \left[\frac{\Sigma n}{\Sigma (t \times n)}\right] \times 100, \quad (5)$$

where n is the number of seeds completing germination on day t and t is the time in days starting from day 0, the day of sowing.

Mean daily germination or daily germination speed (DGS) was calculated as the cumulative germination percentage at the end of the test divided by the number of days from sowing to the end of the test.

Germination energy (GE) was measured based on the energy period lasting until daily germination falls to less than

Table 1: Determination of purity analysis, moisture content, seed weight, and seed characterisation of *A. alpina* and *O. abyssinica* species.

BS	BP	PP	MC	SK	GP	SW	SL	SW
A. alpina	Dawa	86%	6.9–8%	59,416	73	17	0.59 ± 0.09	0.17 ± 0.05
O. abyssinica	Pawe	78%	4–7%	8,393	98	119	1.60 ± 0.18	0.30 ± 0.06
	Sherkole	91%	4–6.9%	8,121	97	123	1.60 ± 0.18	0.30 ± 0.06

BS: bamboo species, GP: germination percentage, MC: moisture content, SW: 1000 seed weight (g), BP: provenance (locality), PP: purity percentage, SL: seed length (mm), SK: seeds per kg, and SW: seed width (mm).

25% of the peak germination so as to include germinable seeds. It was measured following the method applied by FAO [12]:

$$\mathrm{GE} = \left(\frac{\Sigma \mathrm{DGT}}{n}\right) \times 100, \quad (6)$$

where GE is germination energy, DGT is daily germination total, ΣDGT is the total obtained by adding DGT figure obtained from the daily counts, and n is total number of sowed seeds.

Germination value (GV) is expressed as total germination at the end of the test period with germination energy or speed of germination. It was calculated following the method adopted by FAO [12]:

$$\mathrm{GV} = \left(\frac{\Sigma \mathrm{DGS}}{N}\right) \times \left(\frac{\mathrm{GP}}{10}\right), \quad (7)$$

where GV is germination value, GP is germination percent at the end of the test, DGS is daily germination speed, ΣDGS is the total obtained by adding every DGS figure obtained from the daily counts, and N is the number of daily counts, starting from the date of first germination.

Data were analysed and evaluated by using descriptive statistics such as percentages, tables, graphs, and figures. In addition, the generalized linear model (GLM) was employed for the analysis of dry heat and moist heat data using SPSS Version 20.0 Computer Software Programme, whereas all the remaining data were determined by one-way analysis of variance (ANOVA) test at 95% or 99.9% confidence interval to test the statistical significance difference. Multiple comparison of Least Significance Difference (LSD) was also applied to show significance difference among the treatments.

3. Results and Discussion

3.1. Determination of Purity Analysis and Moisture Content. Purity analysis of *A. alpina* seeds indicated that its percentage was 86% (Table 1). Similarly, purity analysis of *O. abyssinica* seeds indicated that Sherkole provenance (91%) had better purity analysis than Pawe provenance (78%). Hence, the seeds are said to be pure seeds. Purity analysis of a given seed sample is the first test to be conducted so as to identify mature, pure, and germinating seeds for subsequent tests [12]. FAO [12] explained that moisture content has an impact on longevity of seeds in storage. Therefore, it is very important to check the amount of moisture in a given sample during storage.

On the other hand, the percentage moisture content from the average of the two samples of *A. alpina* and *O. abyssinica* seeds was found to be 6.9–8% and 4–6.9%, respectively, for storage in cold room at room temperature (21/22°C). Hartmann and Kester [15] reported that the most important storage conditions that maintain seed viability are low moisture content and low storage temperature. Hence, for seeds not adversely affected by low moisture conditions, each 1% decrease in seed moisture (between 5 and 14% range) doubles the lifespan of the seed [15]. This is because various storage problems arise with increasing seed moisture including insect and fungal attack, stimulating germination and heating effect. Overall, in desiccation tolerant seeds, 4 to 6% moisture content is favourable for prolonged seed storage [15].

3.2. Determination of Seed Weight and Size of A. alpina and O. abyssinica Seeds. The overall seed weight test after purity analysis indicated that there were 59,416 seeds contained within one kilogram (kg) of pure *A. alpina* seeds (Table 1). This, in turn, has a mean thousand seed weight of 17 g. Therefore, from one kg of pure *A. alpina* seeds 37,301 seedlings are raised in the laboratory. Similarly, there were 8,393 and 8,121 seeds contained within 1 kg of pure *O. abyssinica* seeds in Pawe and Sherkole provenances, respectively. This, in turn, has a mean thousand seed weight of 119–123 g. The results showed significant variation in seed weight from the two seed sources. Therefore, from 1 kg of pure *O. abyssinica* seeds 6,416 and 7,168 seedlings are raised in the laboratory in their respective orders.

On the other hand, *A. alpina* seed size reported that there were no significant differences ($F_{(0.05)}$ = 0.556 and 0.813, df = 3, and P = 0.646 and 0.490) among the replications of seed length and width, respectively. The mean values were 0.59 ± 0.09 mm and 0.17 ± 0.05 mm, in their respective orders. The lowest and maximum seed length were 0.40 and 0.80 mm, respectively. The lowest and maximum seed width were also 0.1 and 0.2 mm, respectively. Likewise, *O. abyssinica* seeds revealed no significant differences ($F_{(0.05)}$ = 0.000, df = 1, and P = 1.000) between provenances in both seed length and width, respectively. Their mean values were 1.60 ± 0.18 mm and 0.31 ± 0.06 mm, in their respective orders. The lowest and maximum seed length were 1.2 and 1.9 mm, respectively. In turn, the lowest and maximum seed width were 0.2 and 0.4 mm, respectively. Overall, FAO [12] and Ghosh and Singh [23] reported that heavy and larger seeds weigh more per seed than smaller seeds and hence contain more food reserves. Consequently, they are more likely to have higher germination percentage (Table 1) by providing more energy and produce initially more vigorous seedlings [12, 23]. Therefore, seed size and weight are important characters for selection of well-adapted and highly productive seed sources

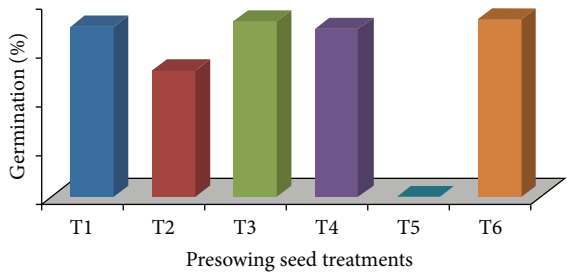


Figure 1: Presowing seed treatments of *A. alpina* seeds.

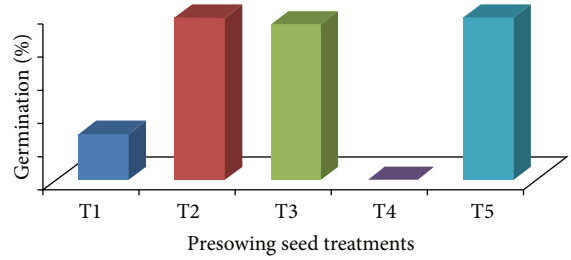


Figure 2: Presowing seed treatments of *O. abyssinica* seeds.

for silvicultural practices. As a result, this improves seedling productivity and reducing nursery cost through selection of quality seeds [12, 23].

3.3. Presowing Seed Treatment. Germination of *A. alpina* seeds recorded at the end of the experiment ranged between 0 and 73% (Figure 1). Treatment 6 (T6) showed the best germination, which accounted 73%. This was followed by T3 (72%) and T1 (70%). On the other hand, T5 had the least germination (0%). A decreased germination in hot or boiling water treatment is an indication of possibly damaged seed embryos [14].

Likewise, germination of *O. abyssinica* seeds among the different seed treatments ranged between 0 and 98% at 4–7% of moisture content stored in cold room (+5°C) (Figure 2). Treatment 5 (T5) as well as T2 had the best germination (98% each treatment), followed by T3 (94%). For these treatments, germination was fastest, uniform, and completed within the 6th and 7th days after sowing. But, from the practical aspect sowing control seeds (T5) is more useful to save human power, time, and resource. This is due to the fact that treating seeds (e.g., acid or mechanical scarification using file, scalpel, and knife) is a very time-consuming and labour intensive method of making seeds permeable to water [14]. On the contrary, T4 scored 0% germination. Germination variation between T1 (28%) and T2 (98%) might indicated that nicking the seeds at the side of embryo damages the seed embryo and hence falls to germinate, whereas nicking the seeds at the opposite side of embryo improves seed germination. The statistical test for *A. alpina* and *O. abyssinica* seeds also showed that there was a highly statistical significant difference ($F_{(0.001)} = 45.725$ and 240.562, df = 5 and 4, and $P = 0.000$) among treatments, respectively. Overall, the research output for *A. alpina* and *O. abyssinica* seeds indicated that seeds do not require seed treatment for seed germination.

3.4. Germination Rate, Germination Energy, and Germination Value of Seeds. Germination data reported that out of the total 100 *A. alpina* and *O. abyssinica* sowed seeds in the laboratory, the germination capacity was 73 and 98%, respectively. Their coefficients of rate of germination were 10.7 and 20.9%, in their respective order. Coefficient of rate of germination is a measure of vigour of seed, and hence germination percentage. Thus, low germination rate means low germination percentage and low vigour of seed. This, in turn, has strong impact on viable seedling production and seedling growth rate as well as morphological appearance [15].

Germination of *A. alpina* seeds was started on the 7th day and completed on the 17th day. All germinated seeds were recorded within the energy period of 17 days. No germinated seeds were recorded all in all after 17 days of sowing. However, out of the total 28 days of germination period (4 weeks), the germination time was almost uniform within the 1st and 3rd weeks among all the treatments (T1–T6). Germination of *O. abyssinica* seeds, in turn, was completed from the 4th to the 9th day, which lasted for 5 days.

The mean daily germination or daily germination speed of *A. alpina* and *O. abyssinica* seeds was 4.29 and 10.89%, respectively. During the entire 28 energy period of the test, their respective peak value (maximum mean daily germination) 6.63 and 18.2% reached at the 8th and 5th day, in their respective order. *Oxytenanthera abyssinica* seeds had higher germination energy (98%) than *A. alpina* (72%) within 9 days of energy period. As a result, the percentage of total germinated seeds within the energy period, that is, 16 and 9 days was 98.6% (*A. alpina*) and 100% (*O. abyssinica*). FAO [12] defined germination energy as the number of germinated seeds in a given sample within a given period, that is, energy period under optimum conditions. It is a measure of the speed of germination and hence the vigour of the seed and the seedlings it produces. Seeds which germinate rapidly and vigorously under favourable conditions of the laboratory are likely to be capable of producing vigorous seedlings, whereas weak or delayed germination is often fatal. Therefore, seeds with shorter germination period have greater germination energy [12]. In line with this, *O. abyssinica* seeds (85.95) had higher germination value than *A. alpina* (19.86). This suggests an indication of better seed quality and high vigour of *O. abyssinica* seeds. This, in turn, contributes to better survival rate and well-adapted seedlings in the field [12, 23].

3.5. Effect of Storage Time on A. alpina Seeds Germination Capacity. Germination of *A. alpina* seeds was 73, 59, 66, and 30% for 0, 180, 300, and 360 days storage, respectively (Figure 3). Freshly collected seeds (0 storage days) had the highest germination, while seeds stored after 360 days had the least. The statistical test similarly reported highly significant differences ($F_{(0.001)} = 29.443$, df = 3, and $P = 0.000$) among the treatments of different storage times. The total mean value was 51.06 ± 11.69%. This indicated that storage time had a negative impact on seed germination. Similar earlier

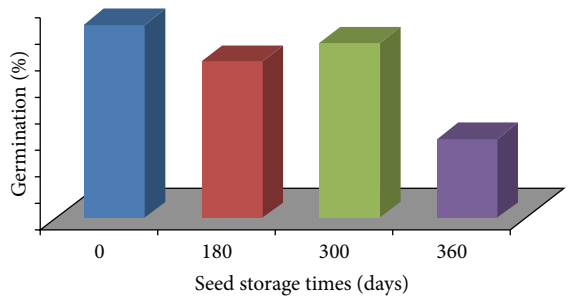


Figure 3: Effect of different storage times on *A. alpina* seeds germination capacity.

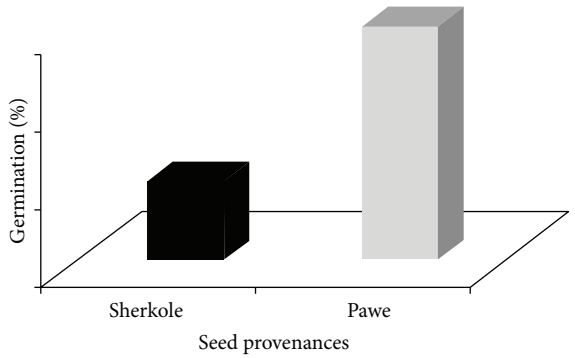


Figure 4: Effect of provenances on *O. abyssinica* seed germination.

finding was reported by Ayana et al. [24]. As the seed storage time increased, there is a gradual decrease in seed viability and/or an increase in seed dormancy in some bamboo species [14]. This showed that seed viability and vigour become gradually declined with increase in storage times. Similar finding was reported by Teketay [25]. Thus, seed storage time has a significant impact on seed germination. However, to conclude the storage behavior of *A. alpina* seeds, the seeds should be further stored at +5°C or lower temperature in cold room and the germination test will be carried out. On the other hand, the orthodox seed storage behavior of *O. abyssinica* seeds was reported by Bahru et al. [21].

3.6. Effect of Provenances on O. abyssinica Seed Germination. The results of *O. abyssinica* seeds germination in the laboratory indicated that Pawe provenance (98%) had slightly higher germination percentage than Sherkole provenance (97%) (Figure 4). However, both provenances had the potential in producing viable seeds. The statistical test also showed that there was no significant difference ($F_{(0.05)}$ = 0.053, df = 1, and P = 0.826) between the provenances. The total mean value was 83.62 ± 7.01%. Therefore, seeds from both provenances will be recommended for raising seedlings in the laboratory and transplanting to the nursery.

3.7. Dry Heat Treatment. The experimental result on *O. abyssinica* seeds showed that there was a highly statistical significant difference ($F_{(0.05)}$ = 4.515 and 6.623, P = 0.018 and 0.004) among temperature and duration treatments on

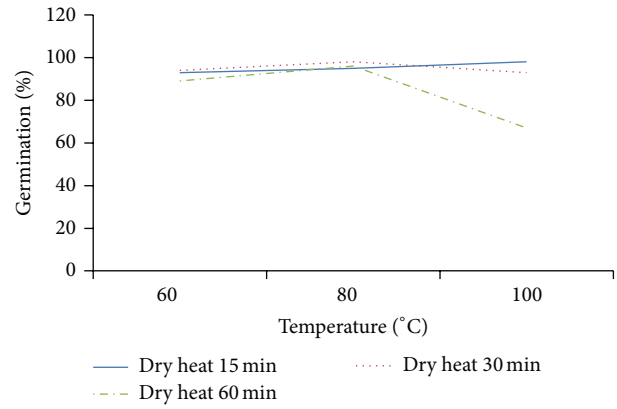


Figure 5: Effect of dry heat treatment on *O. abyssinica* seed germination.

seed germination, respectively. The highest dry heat treatment mean value was 85.89 ± 8.22% at 100°C for 15 minutes. This was followed by 84.23 ± 6.66% at 80°C for 30 minutes and the control experiment, whereas the least dry heat mean value of 55.25 ± 8.17% was recorded at 100°C for 60 minutes. Except seeds treated at 100°C for 60 minutes, the rest had significantly higher and uniform germination (93–98%). This figure was partially reported by earlier studies of Teketay [20]. Overall, the germination percentage of *O. abyssinica* seeds was steeply increased from 60 to 80°C and declined to 100°C with increasing time (Figure 5). C. C. Baskin and J. M. Baskin [14] reported that dry heat at temperatures of 60–100°C causes seeds of many species to become permeable to water. This revealed that appropriate dry heat treatments trigger the germination of *O. abyssinica* seeds. Therefore, heat generated from forest fire in dryland areas acts as one of the factors stimulating seed germination. This is because dry heat caused seed coats of some species to develop cracks and permeable to water thereby promoting the germination of seeds [14, 18]. According to Martin et al. [18] and C. C. Baskin and J. M. Baskin [14] dry heat treatment is the most effective method in breaking physical dormancy in seeds of a number of species. As the temperature increases, there is a decrease in the length of time to break seed dormancy in most species. For instance, only a few minutes of exposure to temperatures of ≥100°C are required to break physical dormancy [14]. This result was also similarly reported by earlier studies of Teketay [19, 20] and Eshete et al. [26]. In the same way, heat generated from forest fire in dryland areas causes the regeneration of various plant species. This is because it acts as one of the factors stimulating seed germination by breaking the physical dormancy of seeds buried in the soil [14, 18]. Furthermore, dry heat treatment significantly increased germination more than moist heat in *O. abyssinica* seeds. But, this result totally disagrees with earlier studies of Martin et al. [18] and Teketay [19, 20].

3.8. Moist Heat Treatment. In moist heat treatments, the highest germination percentage was recorded (98%) at 60°C for 30 minutes and the least germination (0%) was at 100°C for 60 minutes. According to Martin et al. [18] moist heat exposure for 4 min in the range of 90°C–110°C appears to

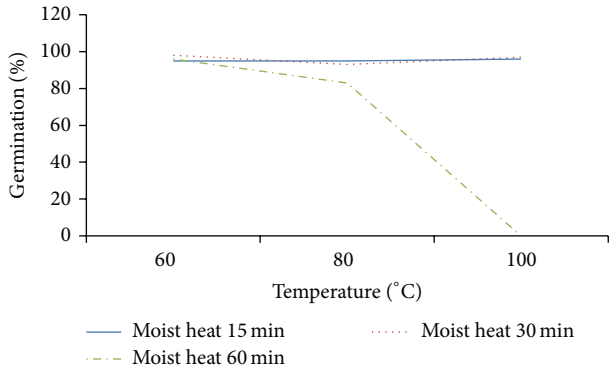


Figure 6: Effect of moist heat treatment on *O. abyssinica* seed germination.

be lethal to all seed tested. The statistical test using GLM indicated a highly significant difference ($F_{(0.01)}$ = 6.446 and 10.478, P = 0.004 and 0.000) among temperature and duration treatments, respectively. The highest moist heat treatment mean value was 84.23 ± 6.66% at 60°C for 30 minutes and for control. Except seeds treated at 100°C for 60 minutes, the rest had significantly higher and uniform germination (83–98%). But, exposure of seeds to 100°C for 60 minutes was lethal (0% germination), suggesting that they are highly sensitive to very high temperature. These seeds were highly infected by seed borne pathogens three to seven days after sowing and decomposed eventually. Seed borne pathogens either reduce germination capability of seeds or cause the failure of germination through weakening or death of embryos [27]. In general, the germination percentage of *O. abyssinica* seeds was increased from 60 to 80°C but declined to 100°C with increasing time (Figure 6). This showed that appropriate moist heat treatments break seed dormancy and trigger the germination of *O. abyssinica* seeds. Therefore, moisture generated from forest fire in dryland areas serves as a favourable environmental condition to break seed dormancy and stimulate seed germination as also reported by Martin et al. [18], Teketay [19, 20], and C. C. Baskin and J. M. Baskin [14].

3.9. Light or Dark Treatment. Effect of light or darkness on germination of *A. alpina* seeds indicated that the dark treatment showed a significantly higher germination percentage (72%) than the light treatment (59%). The result suggests that there are seeds of some species insensitive to light and hence capable of germinating in darkness even buried in the soil [14]. This is because light can prevent the germination of negatively photoblastic (light inhibited) seeds [14]. Consequently, light is not a limiting factor for the germination of these seeds [25]. On the contrary, light treatment of *O. abyssinica* seeds had slightly higher germination percentage (98%) than the dark treatment (97%). Teketay [20] reported that although reasonably high germination can be recorded from dark treated seed, light is necessary to get nearly complete germination. Hence, nondormant seeds of some species do not germinate in darkness or in the absence of light at any temperature. This means they have an absolute light requirement for seed germination [14]. The statistical test of one-way ANOVA showed that there was a significant difference ($F_{(0.05)}$ = 8.620, df = 1, and P = 0.026) between light and dark treatments for *A. alpina* seeds, but no significant difference ($F_{(0.05)}$ = 0.053, df = 1, and P = 0.826) for *O. abyssinica* seeds. Their total mean values were 54.18 ± 5.52% and 83.62 ± 7.01% for *A. alpina* and *O. abyssinica* seeds, respectively. This clearly showed that light is significant for the complete or high germination of *O. abyssinica* seeds as also reported in earlier study by Teketay [19, 25].

4. Conclusion and Recommendation

Overall, the present study for *A. alpina* and *O. abyssinica* seeds indicated that seeds do not require appropriate presowing seed treatments. Control seeds had the best germination, that is, 73 and 98% for *A. alpina* and *O. abyssinica* seeds, respectively. Effect of provenance on *O. abyssinica* seed germination further revealed that Pawe provenance (98%) had slightly higher germination than Sherkole provenance (97%). However, both provenances had the potential in producing viable seeds, which indicates their potential as a seed source. There are 59,416 and 8,393 seeds contained within 1 kg of *A. alpina* and *O. abyssinica* seeds within 86 and 91% pure seeds, respectively. Hence, from 1 kg of pure seeds 37,301 and 7,168 seedlings are raised in the laboratory in their respective orders. Germination of both dry and moist heat treatments of *O. abyssinica* seeds was significantly improved at 60 and 80°C but declined gradually to 100°C with time. Unlike *A. alpina* seeds, seeds of *O. abyssinica* had better germination for light treatment compared to dark. Effect of light or darkness on germination of *A. alpina* seeds indicated that the dark treatment showed a significantly higher germination (72%) than the light treatment (59%). On the contrary, light treatment of *O. abyssinica* seeds had slightly higher germination (98%) than the dark treatment (97%). In general, for the large scale raising and plantation of *A. alpina* and *O. abyssinica* seedlings from its seeds in the laboratory, untreated/control seeds supply to necessary light source (for *O. abyssinica* seeds) should be recommended.

Conflict of Interests

The authors declare that there is no conflict of interests regarding the publication of this paper.

Acknowledgments

The authors are grateful to CEE-FRC/EEFRI, for the financial support and provision of necessary logistic facilities for the entire work. Sincere thanks also go to Assosa and Pawe Agricultural Research Centers as well as Mr. Tesfaye Hunde for collecting and provision of seeds. They are also greatly indebted to seed processing room, tree seed laboratory, nursery, and cold room staffs for their invaluable contribution during the experiment as well as others which directly or indirectly offered their support.

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