

# Effect of Desiccation and Storage Environment on Longevity of *Ehretia Cymosa* Thonn. Seeds.

Peter Murithi Angaine (✉ [pangaine@gmail.com](mailto:pangaine@gmail.com))

Kenya Forestry Research Institute <https://orcid.org/0000-0002-6477-8802>

Stephen Muriithi Ndungú

Kenya Forestry Research Institute

Alice Adongo Onyango

Kenya Forestry Research Institute

Jesse Omondi Owino

Kenya Forestry Research Institute

---

## Research

**Keywords:** Ehretia cymosa seeds, moisture content, storage temperature, storage duration and germination

**Posted Date:** August 4th, 2020

**DOI:** <https://doi.org/10.21203/rs.3.rs-43618/v1>

**License:**  This work is licensed under a Creative Commons Attribution 4.0 International License. [Read Full License](#)

---

## Abstract

**Background:** Globally, forestry faces challenges in the availability of seeds due to limited knowledge on seed handling of various species. Forestry seeds are constantly being reviewed and classified as either recalcitrant, intermediate, or orthodox based on their storage behavior. It is essential to understand the tree seed storage behavior to maintain seed viability and thus minimize seed losses. There is scanty literature combining factors of seed moisture content (6%, 9%, 12%, 15%, and 20%), seed storage temperature (20°C, 5°C and -20°C), seed storage duration (1, 4, 9 and 12 months), and germination in different sites with varying environmental variables. *Ehretia cymosa* is important in the Afromontane forestry landscape as a medicinal, rehabilitation, and conservation species. This study conducted desiccation and storage studies and their influence on the viability of *E. cymosa* seeds. The study sought to determine the optimum conditions for the storage of *Ehretia cymosa* that maintains viability.

**Results:** This study observed that *E. cymosa* dried to seed moisture content of 6%, stored for 12 months at 20°C and sown in the laboratory had the highest germination performance ( $27.6 \pm 3.18\%$ ) ( $p < 0.05$ ).

**Conclusion:** This confirms that *E. cymosa* seeds exhibit orthodox storage behavior. The authors recommend longer storage studies (>12 months) to determine the actual longevity of the seeds of this species. The significance of these results would be useful for foresters and farmers that would need to use this species for various purposes.

## Background

Trees seeds have in previous studies been classified as either orthodox, intermediate, or recalcitrant based on the moisture content level at storage (Bonner, 1990; Hong & Ellis, 1996). Orthodox seeds tolerate desiccation to a low moisture content of between 2–5% (Dardengo et al., 2019). Intermediate category of seeds have been observed from other studies that they can be dried to certain levels, but not as low as orthodox species, and often observed to fail to survive sub-zero temperatures (Ellis et al., 1990; Wyse & Dickie, 2017). Seeds that are not tolerant and cannot survive dehydration are categorized as recalcitrant (De Vitis et al., 2020; Wyse & Dickie, 2017). Variability in seed recalcitrance and desiccation tolerance has previously been studied in two ways: desiccation sensitivity and post-harvest behavior (Berjak & Pammenter, 1997; Costa et al., 2016; Gold & Hay, 2008). There are challenges in clearly defining the seeds' storage behaviors of critical species leading to seed losses impacting seed availability (Hong & Ellis, 1996; Ndungú & Kimiti, 2017; Sivakumar et al., 2006; Thomsen, 2000).

There is scanty information on *Ehretia cymosa* Thonn. seed storage behavior. This species of the family *Boraginaceae* is distributed in parts of West Africa, Eastern Africa, and Northern Madagascar (Mbuvi et al., 2019; Miller & Porter Morgan, 2011; Ogundajo & Ashafa, 2017; Reshad, 2019). Past studies have focused on the medicinal values and distribution of *E. cymosa*, thereby highlighting a gap in seed collection and handling. There is scanty information focusing on desiccation tolerance and germination responses of *E. cymosa* (Ellis et al., 1990; ELLIS et al., 2007).

*Ehretia cymosa* has a crucial space in Kenyan communities for medicinal, conservation, and a species useful for rehabilitation of degraded areas (Bussmann & Lange, 2000; Ogundajo & Ashafa, 2017; Reshad et al., 2020). In order for the species to be utilized, there is an expectation for the availability of seed, but this has been a challenge exacerbating the demand (Albrecht, 1993; Bussmann & Lange, 2000). These shortages can be associated with the limited information on its handling.

This study sought to assess the effect of desiccation and storage environment on the longevity of *Ehretia cymosa* seeds. The specific objectives were: i) to assess the effect of varying seed moisture content on germination *E. cymosa* seeds, ii) to determine the effect of storage temperature and seed moisture content on germination of *E. cymosa* seeds, iii) to determine the effect of seed moisture content and storage duration on germination of *E. cymosa* seed, and iv) to determine the effect of seed, storage temperature, storage period and site on germination of *Ehretia cymosa* seeds. The findings from these objectives would guide organizations that collect, store, and distribute such seeds in a manner that maintains their quality.

## Methods

The study was conducted between June 2009 and July 2010 at Kenya Forestry Seed Centre in Muguga, which is a Programme of the Kenya Forestry Research Institute (KEFRI). The seeds were collected from the Thogoto forest in the month of June 2009, which is the peak seeding season for the species (Bussmann & Lange, 2000). Thogoto forest is situated within Kiambu county at Latitude - 1.275495S Longitude 36.667082E and altitude 2,020 masl

Seeds were collected from 5 randomly selected trees that had mature fruits. Mature fruits for *E.cymosa* turn colour from green to orange-red (Thomsen, 2000). Three kilograms of mature *E.cymosa* fruits were collected from each of the identified trees. The collected fruits were carried in cotton bags from the field and transported to the laboratory at the Kenya Forestry Seed Centre, Muguga, for processing.

Fruits were taken from the bag and seeds extracted by squeezing the fruits by hand to remove the seeds, followed by surface drying the seeds with a dry towel (Hong & Ellis, 1996). A sample weighing 5 g seeds was then subjected to moisture content test using an infrared moisture analyzer (Himmel-Changzhou scientific instrument). The moisture content (MC) value obtained was assigned as the initial moisture content (control) for this experiment (Hong et al., 1996; Hong & Ellis, 1996; Thomsen, 2000) Schmidt 2000). Seeds from the rest of the fruits were extracted by de-pulping (gently rubbing with hand to remove the fresh pulp). Seeds were cleaned further in running water to remove the excess mucilage and dried by gently rubbing with a towel to remove the excess water on the seed surface (Hong and Ellis.1996). One sub-sample of 2,000 seeds was randomly drawn from the extracted seeds to act as control with five other subsamples of 6,000 seeds each extracted for the five MC levels (Ellis & Hong, 2007; Thomsen, 2000)

This desiccation procedure involved the packing of five lots (MC: 20%, 15%, 12%, 9%, and 6%) of the seed samples in porous cloth bags (Table 1). These cloth bags were then put on blue silica gel and covered in a desiccator. During desiccation each bag was checked hourly by weighing and calculating using Eq. 1: where  $Wt_s$  is seed weight at desired MC,  $Wt_i$  is the initial weight of seed,  $MC_i$  is the initial Moisture content, and  $MC_t$  is the targeted Moisture content (Hong & Ellis, 1996; Thomsen, 2000).

$$Wt_s = \frac{Wt_i * (100 - MC_t)}{(100 - MC_i)}$$

Equation 1

From each bag, the seeds were further split into three groups (of 2,000/group) for storage temperatures: minus 20°C, 5°C, and 20°C (Sivakumar et al., 2006). Each storage temperature group for each MC was further split into five storage period groups (400/group) for storage periods: 1, 2, 4, 9, and 12 months (Table 1). The seeds in each storage period group were packed in 75 airtight aluminum foil sachets for storage (25 @ minus 20°C, 25 @ 5°C and 25 @ 20°C).

Germination testing was conducted in both laboratory (Lab) and transparent glasshouse (G.H.) conditions. Each of the storage period groups after the expiry of the storage duration was split into two groups for the different germination sites: Lab and GH. the seeds in each site for each storage period group, for each storage temperature group and for each MC level, were finally divided into four replicates of 50 seeds each.

The seeds extracted earlier for the control were subjected to germination in 4 replicates of 50 seeds per replicate in both Lab and G.H. Seeds used for the control were germinated immediately when the targeted MC was attained.

During germination, all the seeds were placed in Petri dishes containing 1% Agar-agar solution and incubated in the germination chamber set at alternating temperatures 20°C and 30°C in 12 hours intervals (Ellis et al., 1990; ISTA, 2015). A seed was considered to have germinated when the radicle protruded (citation). In the glasshouse (mean rH 53.8% and mean temperature 27.3°C) and seeds of *E.cymosa* were sown in germination boxes containing river sand that was sterilized by pouring a mixture of 450 ml, 3.5% concentration. Sodium Hypochlorite solution in 20 litres of water.

Germinated seeds were counted three times per week on Mondays, Wednesdays, and Friday by counting all seeds that had germinated cumulatively for 30 days or until there was no further germination taking place within three consecutive counts, whichever came first.

The experiment had four treatments; Desiccation (MC) with 5-factor levels (20%, 15%, 12%, 9%, and 6%); Storage temperature with three levels (Minus 20°C, +5°C, and +20°C), five storage levels (1, 2, 4, 9 and 12 months) and site with two levels, Laboratory (Lab) and Glasshouse (G.H.) (Table 1) with four replicates of 50 seeds per replicate (200 seeds for each of the 150 treatment level) totaling to 30,000 seeds.

Table 1  
Experimental design

Treatment	Levels				
Desiccation MC	6%	9%	12%	15%	20%
Storage temperature	Minus 20°C	+ 5°C	+ 20°C		
Storage period (months)	1	2	4	9	12
Site	Laboratory (Lab)		Greenhouse (G.H.)		

## Data analysis

The data were tabulated in a data-sheet in M.S. excel and analysed for: effects of varying seed moisture content on germination, combined effects of storage temperature and seed moisture content on germination, combined effects of seed moisture content and storage duration on germination, and combined effects of seed storage temperature, storage period and experimental sites on germination of *Ehretia cymosa* seeds. This analysis was done with RStudio Version 1.2.1335. Post hoc analysis (Tukey's HSD) was used to determine the difference in means (95% CI) in the ANOVA with factors desiccation MC, storage temperature, storage period, and experimental site differences compared.

## Results

This study observed the mean germination was highest when *E.cymosa* seeds were dried to SMC 9% ( $18.0 \pm 0.77\%$ ) (Fig. 1a). This performance was not significantly different from SMC 6% ( $P > 0.05$ ) but differed from the rest ( $P < 0.05$ ), and the least performing was SMC 20% ( $7.8 \pm 0.74\%$ ) (Fig. 1a). Mean germination of *E.cymosa* seeds under laboratory conditions outperformed the greenhouse condition, with 9% in the laboratory having the highest mean germination ( $20.0 \pm 1.07\%$ ) (Fig. 1b).

The highest mean germination percentage was observed from *E. cymosa* seeds dried to SMC 6% and stored in a 20 °C environment ( $21.1 \pm 1.45\%$ ) (Fig. 2a). Seeds stored at 20 °C performed the best in germination for moisture content 6%, 9%, and 12% (Fig. 2a). Seeds stored at 5 °C performed highest in MC 15% and 20% (Fig. 2a). Generally, the mean germination of seeds stored at 5 °C and 20 °C in the laboratory performed better than in the greenhouse (Fig. 2b). It was also observed that in the laboratory seeds stored at 20 °C performing better in MC 6%, 9%, and 12% while seeds stored in 5 °C environment performed better in 15% and 20% (Fig. 2b). The mean germination of seeds in the greenhouse gave the highest results on seeds that were immediately sown at SMC 21% ( $20.5 \pm 1.19\%$ ).

The highest mean germination was observed from seeds with SMC 9% stored for 12 months ( $24.4 \pm 1.79\%$ ) ( $p < 0.05$ ) (Fig. 3a). Similar observations were seen in SMC 6% and 12% for SMC 15% and 20%, where the storage duration of 1 month resulted in the best germination (Fig. 3a). Germination performance was highest under laboratory conditions; more so, the storage period of 12 months performed the best for SMC 6%, 9%, and 12%. Seeds stored for one month performed the best for the remaining SMC (15% and 20%) in laboratory conditions (Fig. 3b).

The analysis for germination performance *E.cymosa* showed that seeds dried to SMC 6%, stored at 20 °C for 12 months, and germinated in laboratory conditions (20–30 °C) had the best germination performance ( $27.6 \pm 3.18\%$ ) ( $p < 0.05$ ), which was not significantly different from drying at 9% SMC ( $p > 0.05$ ) (Fig. 4).

## Discussion

Other studies focusing on the effect of moisture content on germination have shown lower SMC to be advantageous in the maintenance of seed viability (Balouchi et al., 2017; De Vitis et al., 2020). Lower seed moisture content in seed storage was shown to be beneficial by reducing lipid peroxidation of cell membranes and enhancing the activity of antioxidant enzymes after imbibition, thereby slowing the decline in viability (Li et al., 2020; Zhi-Hong et al., 2011). This study also agreed with other studies that lower SMC for orthodox seeds encourages germination performance.

Past studies on other species have shown that temperature and SMC affect seed viability of stored orthodox seeds as germination increases with a decrease in seed SMC and a decrease in storage temperature (Dardengo et al., 2019; Reed, 2005). This study's observation on the effect of storage temperature and SMC disagrees with past studies as for *E.cymosa* had better germination for lower SMCs and higher storage temperatures. The present study, however, shows that for *E.cymosa*, the germinability increases with a decrease in MC and an increase in storage temperature under laboratory conditions.

Previous studies on other species have shown that seeds with less moisture stored for longer periods resulted in higher mean germination (Rajjou & Debeaujon, 2008; Walters et al., 2005). This study on *E.cymosa* seeds shows that there is no deterioration with longer storage duration (12 months). There are studies that have shown there are environmental effects that prevent seed deterioration in longer storage durations at higher temperatures (Kalsa et al., 2011; Qaderi et al., 2005).

Few studies have focused on germination behavior under a combination of factors; seed MC, storage temperature, and duration, though on other species (Berjak & Pammenter, 1997; Dussert et al., 2018; Ellis & Hong, 2007; Schmidt, 2000). This study looked at a combination of SMC, storage temperature, storage duration, and germination site conditions (temperature and relative humidity). The key factor of comparison was the two sites (greenhouse and laboratory conditions). The trends seen in the results section are similar to studies on other species focusing on low moisture content (< 10%) and longer storage periods (12 months) (De Vitis et al., 2020; Ellis et al., 1990; Li et al., 2020). The differences observed in this study came from storage and germination temperature that were higher compared to other studies for other species (Reed, 2005; Sivakumar et al., 2006).

## Conclusion

This study observes that *E.cymosa* seeds had the highest germination when seeds were dried to 6% MC, stored at 20<sup>0</sup>C for 12 months, and germinated in the laboratory (relative humidity 70% and temperature range 20-30°C). This confirms that *E.cymosa* seeds exhibit orthodox storage behavior. The authors recommend longer storage studies (> 12months) to determine the actual longevity of the seeds of this species.

## Declarations

### Ethics approval and consent to participate

Not applicable

### Consent for publication

Not applicable.

### Availability of data and material

The data sets used and analyzed during the current study are available from the corresponding author on reasonable request.

### Competing interests

The authors declare that they have no competing interests.

### Funding

The Government of Kenya, through Kenya Forestry Research Institute, provided facilitation for the data collection and experimentation.

### Authors' contributions

PMA SMN- Conceived, designed, and performed the experiments.

JOO -Analyzed the data

PMA SMN AAO JOO - Contributed to the writing of the manuscript

All authors read and approved the final manuscript.

### Acknowledgments

The authors wish to acknowledge the Kenya Forestry Research Institute and the staff of the Kenya Forestry Seed Centre laboratory for the support accorded throughout the process of this study.

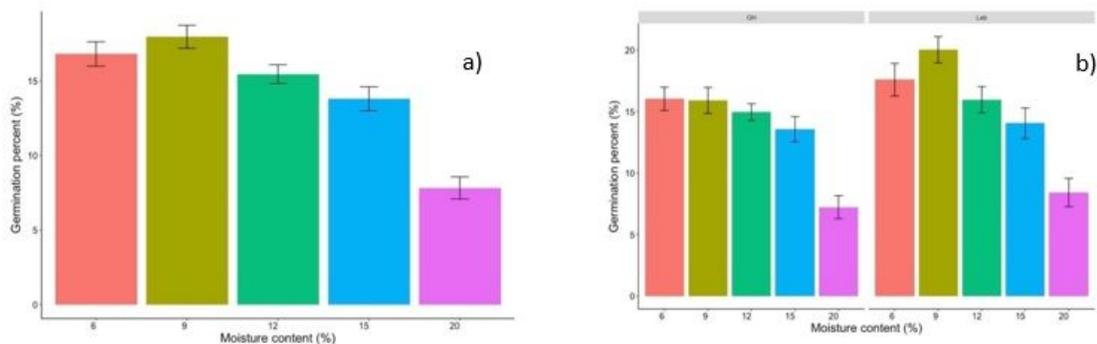
## References

1. Albrecht, J. (1993). *Tree seed handbook of Kenya. Nairobi, Kenya: GTZ Forestry Seed Centre Muguga* (W. Omondi, J. O. Maua, & F. N. Gachathi (eds.); 2nd ed.). Kenya Forestry Research Institute. <https://www.worldcat.org/title/tree-seed-handbook-of-kenya/oclc/38979878>

2. Balouchi, H., Baladi, S., Moradi, A., & Dehnavi, M. M. (2017). The influence of temperature and moisture content on seed longevity of two genotypes of *Linum usitatissimum*. *Seed Science and Technology*, *45*(1), 130–138. <https://doi.org/10.15258/sst.2017.45.1.08>
3. Berjak, P., & Pammenter, N. W. (1997). Progress in the Understanding and Manipulation of Desiccation-Sensitive (Recalcitrant) Seeds. In R. H. Ellis, M. Black, A. J. Murdoch, & T. D. Hong (Eds.), *Basic and Applied Aspects of Seed Biology* (pp. 689–703). Kluwer Academic Publishers. [https://doi.org/10.1007/978-94-011-5716-2\\_76](https://doi.org/10.1007/978-94-011-5716-2_76)
4. Bonner, F. T. (1990). Storage of seeds: Potential and limitations for germplasm conservation. *Forest Ecology and Management*, *35*, 35–43.
5. Bussmann, R. W., & Lange, S. (2000). Germination of Important East African Mountain Forest Trees. *Journal of East African Natural History*, *89*(1), 101–111. [https://doi.org/10.2982/0012-8317\(2000\)89\[101:goieam\]2.0.co;2](https://doi.org/10.2982/0012-8317(2000)89[101:goieam]2.0.co;2)
6. Costa, M. C. D., Faria, J. M. R., José, A. C., Ligterink, W., & Hilhorst, H. W. M. (2016). Desiccation tolerance and longevity of germinated *Sesbania virgata* (Cav.) Pers. seeds. *Journal of Seed Science*, *38*(1), 50–56. <https://doi.org/10.1590/2317-1545v38n1155510>
7. Dardengo, A. O., Vieira, H. D., Deminicis, B. B., Berbert, P. A., & Oliveira, M. T. R. de. (2019). *Jatropha curcas* seed tolerance to desiccation and storage at low temperatures. *Scientia Agraria Paranaensis*, 396. <https://doi.org/10.18188/sap.v18i4.22682>
8. De Vitis, M., Hay, F. R., Dickie, J. B., Trivedi, C., Choi, J., & Fiegenger, R. (2020). Seed storage: maintaining seed viability and vigor for restoration use. *Restoration Ecology*, rec.13174. <https://doi.org/10.1111/rec.13174>
9. Dussert, S., Serret, J., Bastos-Siqueira, A., Morcillo, F., Déchamp, E., Rofidal, V., Lashermes, P., Etienne, H., & Joët, T. (2018). Integrative analysis of the late maturation programme and desiccation tolerance mechanisms in intermediate coffee seeds. *Journal of Experimental Botany*, *69*(7), 1583–1597. <https://doi.org/10.1093/jxb/erx492>
10. Ellis, R. H., & Hong, T. D. (2007). Seed longevity - Moisture content relationships in hermetic and open storage. *Seed Science and Technology*, *35*(2), 423–431. <https://doi.org/10.15258/sst.2007.35.2.17>
11. Ellis, R. H., Hong, T. D., & Roberts, E. H. (1990). An intermediate category of seed storage behaviour? *Journal of Experimental Botany*, *41*(9), 1167–1174. <https://doi.org/10.1093/jxb/41.9.1167>
12. ELLIS, R. H., MAI-HONG, T., HONG, T. D., TAN, T. T., XUAN-CHUONG, N. D., HUNG, L. Q., NGOC-TAM, B., & LE-TAM, V. T. (2007). Comparative analysis by protocol and key of seed storage behaviour of sixty Vietnamese tree species. *Seed Science and Technology*, *1993*, 460–476.
13. Gold, K., & Hay, F. (2008). Identifying desiccation- sensitive seeds. *Millennium Seed Bank Project, Kew, Technical Information Sheet-10, 4*. <http://brahmsonline.kew.org/Content/Projects/msbp/resources/Training/10-Desiccation-tolerance.pdf>
14. Hong, T. D., & Ellis, R. H. (1996). A protocol to determine seed storage behaviour. In *IPGRI Technical Bulletin No. 1* (No. 1). [https://books.google.co.ke/books?hl=en&lr=&id=g9QJrGkv7NAC&oi=fnd&pg=PA7&dq=protocol+to+determine+seed+storage+behaviour&ots=FKWmqqmI3y&sig=c\\_7ZXuM-yRFH7veGU3aaGzGsh5A&redir\\_esc=y#v=onepage&q=protocol to determine seed storage behaviour&f=false](https://books.google.co.ke/books?hl=en&lr=&id=g9QJrGkv7NAC&oi=fnd&pg=PA7&dq=protocol+to+determine+seed+storage+behaviour&ots=FKWmqqmI3y&sig=c_7ZXuM-yRFH7veGU3aaGzGsh5A&redir_esc=y#v=onepage&q=protocol%20to%20determine%20seed%20storage%20behaviour&f=false)
15. Hong, T. D., Linington, S., & Ellis, R. H. (1996). Seed Storage Behaviour: a Compendium. Handbooks for Genebanks No. 4. In *Ecology and Classification of North American Freshwater Invertebrates* (Vol. 26, Issue 1). <https://doi.org/10.1007/s10661-016-5178-6>
16. ISTA. (2015). International rules for seed testing 2015. In *The International Seed Testing Association (ISTA) Zürichstr. 50, 8303 Bassersdorf, Schweiz Zürichstr.: Vol. 12. ISTA* (Issues 12. ISTA (1993) International rules for seed testing. Zurich, Switzerland.). ISTA. <https://doi.org/10.15258/istarules.2015.F>
17. Kalsa, K. K., Tomer, R. P. S., & Abebie, B. (2011). Effects of storage duration and hydro-priming on seed germination and vigour of Common vetch. *Journal of Science and Development*, *1*(1), 65–73.
18. Li, X. Z., Simpson, W. R., Song, M. L., Bao, G. S., Niu, X. L., Zhang, Z. H., Xu, H. F., Liu, X., Li, Y. L., & Li, C. J. (2020). Effects of seed moisture content and Epichloe endophyte on germination and physiology of *Achnatherum inebrians*. *South African Journal of Botany*, *000*, 1–8. <https://doi.org/10.1016/j.sajb.2020.03.022>
19. Mbuvi, M. T. E., Kungu, J. B., Gachathi, F. N., Wekesa, C., Leley, N., & Muthini, J. M. (2019). Annotated checklist of plant species of Loita Forest (Entim e Naimina Enkiyio Forest or the forest of the lost child), Narok County, Kenya. *Int. J. Adv. Res. Biol. Sci*, *6*(2), 163–168. <https://doi.org/http://dx.doi.org/10.22192/ijarbs.2019.06.02.XXX>
20. Miller, J. S., & Porter Morgan, H. A. (2011). Assessing the effectiveness of Madagascars changing protected areas system: A case study of threatened Boraginales. *Oryx*, *45*(2), 201–209. <https://doi.org/10.1017/S0030605310000803>
21. Ndungú, S. M., & Kimiti, J. M. (2017). Effect of Moisture Content and Temperature on Viability and Longevity of *Cordia Sinensis* Lam . Seeds. *Journal of Resources Development and Management*, *28*, 14–19. <https://iiste.org/Journals/index.php/JRDM/article/viewFile/35222/36225>
22. Ogundajo, A., & Ashafa, A. (2017). Phytochemical compositions and In vitro assessments of antioxidant and antidiabetic potentials of fractions from *Ehretia cymosa* Thonn. *Pharmacognosy Magazine*, *13*(51), 470. [https://doi.org/10.4103/pm.pm\\_118\\_17](https://doi.org/10.4103/pm.pm_118_17)

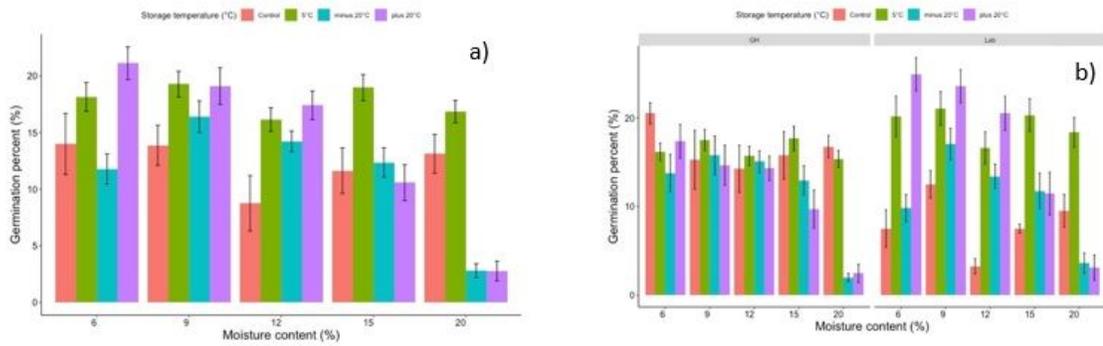
23. Qaderi, M. M., Presti, A., & Cavers, P. B. (2005). Dry storage effects on germinability of Scotch thistle (*Onopordum acanthium*) cypselas. *Acta Oecologica*, 27(2), 67–74. <https://doi.org/10.1016/j.actao.2004.09.004>
24. Rajjou, L., & Debeaujon, I. (2008). Seed longevity: Survival and maintenance of high germination ability of dry seeds. *Comptes Rendus - Biologies*, 331(10), 796–805. <https://doi.org/10.1016/j.crv.2008.07.021>
25. Reed, S. M. (2005). Effect of Storage Temperature and Seed Moisture on Germination of Stored Flowering Dogwood Seed. *Horticultural Research Institute*, 23(1), 29–32.
26. Reshad, M. (2019). Woody Species Richness and Diversity at Ades Dry Afromontane Forest of South-Eastern Ethiopia. *American Journal of Agriculture and Forestry*, 7(2), 44. <https://doi.org/10.11648/j.ajaf.20190702.12>
27. Reshad, M., Muhammed, M., & Beyene, A. (2020). Distribution and Importance Value Index of Woody Species Under Different Successional Stages at Jello-Muktar Dry Afromontane Forest, South-eastern Ethiopia. *American Journal of Agriculture and Forestry*, 8(1), 1–8. <https://doi.org/10.11648/j.ajaf.20200801.11>
28. Schmidt, L. H. (2000). Guide to the handling of tropical and subtropical forest seed: Chapter 12 - Genetic Implications of Seed Handling. *Danida Forest Seed Centre*, 2000, 1–12. <http://citeseerx.ist.psu.edu/viewdoc/download?doi=10.1.1.706.5441&rep=rep1&type=pdf>
29. Sivakumar, V., Anandalakshmi, R., Warriar, R. R., Tigabu, M., Odén, P. C., Vijayachandran, S. N., Geetha, S., & Singh, B. G. (2006). Effects of pre-sowing treatments, desiccation and storage conditions on germination of *Strychnos nux-vomica* seeds, a valuable medicinal plant. *New Forests*, 32(2), 121–131. <https://doi.org/10.1007/s11056-005-5038-7>
30. Thomsen, K. (2000). *Handling of Desiccation and Temperature Sensitive Tree Seeds* (No. 56; Issue 56, p. 34). Danida Forest Seed Centre.
31. Walters, C., Wheeler, L. M., & Grotenhuis, J. M. (2005). The longevity of seeds stored in a genebank: species characteristics. *Seed Science Research*, 15(1), 1–20. <https://doi.org/10.1079/ssr2004195>
32. Wyse, S. V., & Dickie, J. B. (2017). Predicting the global incidence of seed desiccation sensitivity. *Journal of Ecology*, 105(4), 1082–1093. <https://doi.org/10.1111/1365-2745.12725>
33. Zhi-Hong, C., Zan, W., Xu-Jiang, Y., Xiang-Fang, L., & Hong-Wen, G. (2011). Physiological and biochemical responses of ultra-dry storage of *Elymus dahuricus* seeds. *African Journal of Biotechnology*, 10(66), 14862–14867. <https://doi.org/10.5897/AJB11.1555>

## Figures



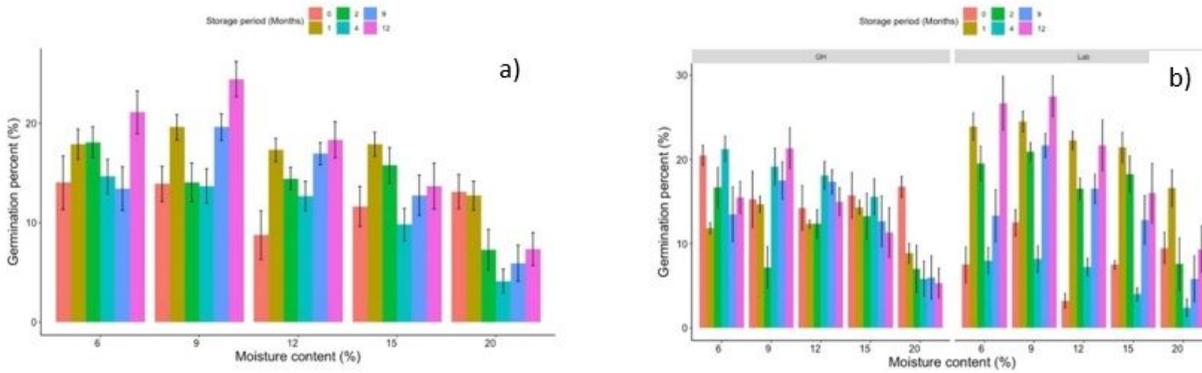
**Figure 1**

The effect of varying seed moisture content on mean germination of *E. cymosa* in both laboratory and greenhouse conditions (a and b) from each of the moisture content categories (6%, 9%, 12%, 15%, and 20%)



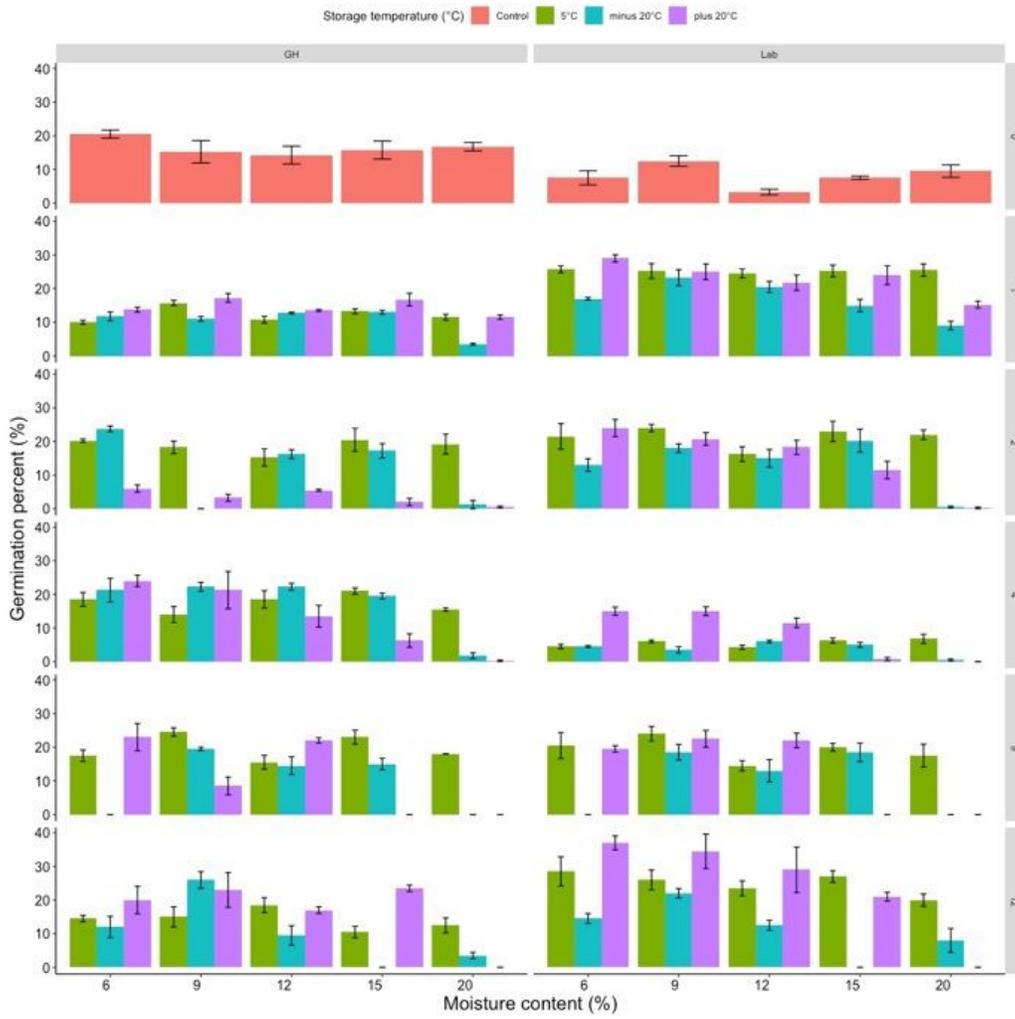
**Figure 2**

Germination performance of *E. cymosa* seeds stored in different temperatures (control, 5°C, 20°C and minus 20°C) after being dried to different moisture content (6%, 9%, 12%, 15%, and 20%).



**Figure 3**

Effects of seed moisture content (6%, 9%, 12%, 15% and 20%) and storage duration (0, 1, 2, 4, 9 and 12 months) on germination of *E. cymosa* seeds.



**Figure 4**

Combined effects of seed Moisture Content (6%, 9%, 12%, 15%, and 20%), storage temperature (5C, 20C and -20C), storage period (0, 1, 2, 4, 9,12 months) and site (laboratory and greenhouse) on germination of *Ehretia cymosa* seeds.