Annals of Arid Zone 64(4): 507-520, 2025

Seed Storage and Germination Enhancement Methods for Six Economically Important Indigenous Trees of Ethiopia: A Review

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Received: June 10, 2025   Accepted: August 5, 2025

Abstract: Conservation and sustainable management of Ethiopia's economically important indigenous tree species are crucial for preserving biodiversity and restoring ecosystems. However, the viability and germination potential of their seeds are often hindered by dormancy, desiccation sensitivity, and improper storage techniques. These limitations in seed storage and poor germination rates present challenges for the sustainable propagation and conservation of these valuable trees. This review paper synthesizes existing knowledge on seed storage behavior, dormancy mechanisms, and germination enhancement techniques for six selected indigenous tree species in Ethiopia, namely, *Cordia africana*, *Vachellia abyssinica*, *Olea europaea ssp. africana*, *Millettia ferruginea*, *Albizia gummifera*, and *Hagenia abyssinica*. It explores the physiological and ecological factors that influence seed longevity and germination success while evaluating various pre-treatment methods such as scarification, stratification, and chemical applications. This review identifies species-specific treatments that improve germination and seed viability, helping afforestation efforts. For instance, the germination rates of *C. africana* are enhanced by soaking seeds in hot water (70 to 80°C) for 10 to 15 minutes. *V. abyssinica* can achieve up to a 98% improvement with concentrated sulfuric acid pre-treatment. The germination of *O. europaea* ssp. africana is enhanced by soaking seeds in hot water (70-80°C) for 10-15 minutes and then leaving them soaked for 12 to 24 hours. Similarly, *M. ferruginea* benefits from soaking seeds in hot water (70 to 80°C) for 10 to 15 minutes, followed by a 12 hour soak in water. *A. gummifera* also improves with hot water soaking for 10 to 15 minutes and a subsequent soak of 12 to 24 hours. Finally, *H. abyssinica* shows enhanced germination rates with the same hot water soaking method for 10 to 15 minutes, followed by a soak of 12 to 24 hours. Additionally, this manuscript assesses the effectiveness of different seed storage strategies in maintaining viability over time. By consolidating findings from diverse studies, this review paper provides critical insights for conservation practitioners, foresters, and policymakers, offering recommendations to improve seed handling practices for afforestation, reforestation, and ecological restoration initiatives. It underscores the need for

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Citation
Seid, M.A. 2025. Seed storage and germination enhancement methods for six economically important indigenous trees of Ethiopia: A review. Annals of Arid Zone 64(4): 507-520

https://doi.org/10.56093/aaz.v64i4.167739

https://epubs.icar.org.in/index.php/AAZ/article/view/167739

species-specific approaches to enhance seed viability and propagation success, ultimately contributing to afforestation and biodiversity conservation efforts in the country.

Key words: Germination enhancement, indigenous trees; seeds-treatment.

Successful forest development is highly dependent on the supply of good quality seed germplasm of the required species in sufficient quantity. However, propagation of many tree seeds is difficult due to a limited supply and availability of seed at the right time, storage difficulties, and poor germination (Mbi *et al.*, 2022). Thus, sustainable forest management in the country may rely heavily on both the retention of virgin forest areas containing the most valuable tree species and the planting and domestication of these species. In this context, most of the seed and/or seedling requirements for reforestation and rehabilitation could be met in the future, as other areas become degraded due to forest harvesting.

Ethiopia's indigenous tree species are essential for ecological balance, economic benefits, and local livelihoods (Fekadu and Yohannes, 2004; Geta *et al.*, 2014; Yibeltal, 2017; Tesfay *et al.*, 2024). For instance, indigenous trees such as *C. africana*, *V. abyssinica*, *O. europaea ssp. africana*, *M. ferruginea*, *A. gummifera*, and *H. abyssinica* are vital for Ethiopia's ecosystems and economy (Yeshiwas *et al.*, 2019; Ereso, 2023). Despite their importance, these species face propagation challenges due to seed dormancy, low viability, inadequate storage methods, and damages by insect pests (Teketay, 1996; Mng and Akinnifesi, 2007; Yirgu *et al.*, 2017; Taye *et al.*, 2022; Seid *et al.*, 2024). Therefore, understanding effective germination enhancement methods is crucial for conservation and reforestation efforts. Seed dormancies require specific treatments to enhance germination, such as scarification (e.g., mechanical, chemical, or thermal treatments to break hard seed coats), stratification (e.g., cold or warm pre-treatment to simulate natural germination conditions), hormonal Treatments (e.g., gibberellic acid (GA3) and other plant hormones to promote germination), pre-sowing treatments (e.g., soaking in water, hot water treatment), and exposure to light (dark) cycles.

Understanding the seed storage behavior is also essential for preserving genetic diversity and ensuring the availability of planting materials (González Pérez *et al.*, 2021; Kumar *et al.*, 2024). Based on storage behavior, seeds can be classified into three categories: *Orthodox, Recalcitrant,* and *Intermediate* seeds (Hong and Ellis, 1996). Orthodox seeds are seeds that tolerate drying (typically below 5%) and can be stored at low temperatures (-20°***C) for extended periods (***Pelissari *et al.*, 2013; Mayrinck *et al.*, 2016; Trusiak *et al.*, 2022). Recalcitrant seeds are seeds that are sensitive to desiccation, mostly when seed's moisture content is less than 12%, and have short storage viability (José and Davide, 2007; Lima *et al.*, 2014). Intermediate seeds are seeds with storage behavior between orthodox and recalcitrant categories (Mayrinck *et al.*, 2016). In other words, intermediate seeds lose viability at 5 to 8% moisture content if stored at -18°C for 90 days (Hong and Ellis, 1996).

Therefore, this review paper explores effective seed storage and germination enhancement methods for these species, drawing on insights from relevant research studies. Moreover, it highlights key approaches for improving seed storage and germination of these economically significant indigenous trees in Ethiopia. Overall, this review aims to synthesize existing evidence on the seed biology, dormancy, storage, and germination enhancement of six priority indigenous species in Ethiopia.

Overview of the Selected Trees

For this review, six of the most important tree species in Ethiopia have been selected for discussion: *Cordia africana Lam. (Boraginaceae), Vachellia abyssinica (Hochst. ex Benth.) P.J.H. Hurter, Olea europaea* L. subsp. africana (Mill.) P.S. Green, Millettia ferruginea (Hochst.) Baker, *Albizia gummifera* (J.F. Gmel.) C.A. Sm.*, Hagenia abyssinica* (Bruce) J.F. Gmel. The seed ecology of these species provides critical insights into their seed production, dispersal methods, dormancy types, and the factors that influence these processes (Teketay, 2005; Orwa *et al.*, 2009). The species demonstrate diverse reproductive strategies and ecological adaptations essential for their survival in the Afromontane forests of Ethiopia (Teketay, 2005; Orwa *et al.*, 2009). These tree species have been reported as the most significant in terms of ecological and economic value in Ethiopia (Yeshiwas *et al.*, 2019; Ereso,

Table 1. Summary altitude range, main uses, and IUCN conservation status of the species

Species	Occurrence altitude (m) in Ethiopia	Main uses							Conservation status (IUCN)
		T	FW	Fd (frt., gm)	Fod.	Med.	AF, Resto. and SI	Orn.	
C. africana	1,200-2,000	√	√	√	√	√	√	√	LC
V. abyssinica	1,500-2,800	√	√	√	√	√	√	√	NE
O. europaea ssp. africana	800-2,500	√	√		√	√	√	√	NE
M. ferruginea	1,000-2,500	√	√		√	√	√	√	LC
A. gummifera	1,400-2500	√	√		√	√	√	√	LC
H. abyssinica	2000-3000	√	√			√	√	√	LC

T = Timber, FW = Firewood, Fd = Food (frt. = fruits, gm = gum), Fod. = Fodder, Med. = Medicine, AF = Agroforestry, Resto. = Restoration/Rehabilitation, SI = Soil improver, Orn. = Ornamental; NE = Not Evaluated, LC = Least Concerned.

2023). For example, in many regions of Ethiopia where *Coffea arabica* is cultivated, shade trees such as *Albizia gummifera*, *Cordia africana*, and *Millettia ferruginea* are commonly used (Girma and Wolka, 2012).

However, there are limitations in geographical coverage and occurrence data for *C. africana*, *V. abyssinica*, *O. europaea ssp. africana*, *M. ferruginea*, *A. gummifera*, and *H. abyssinica*. These issues hinder ecological and conservation research and complicate the effective management of these species. The geographical distribution and occurrence data for these plants are frequently incomplete, geographically biased, and inconsistent over time, creating challenges for thorough ecological assessments and conservation planning (Klopper *et al.*, 2006; Meyer *et al.*, 2016; Oliver *et al.*, 2021). Therefore, initiatives like the Global Biodiversity Information Facility (GBIF) can promote the aggregation of diverse data types to fill gaps (Faith *et al.*, 2013). Moreover, developing comprehensive checklists and databases can facilitate better tracking and management of species (Klopper *et al.*, 2006). Furthermore, countries can work together to share data and resources, improving overall biodiversity knowledge (Oliver *et al.*, 2021). The summary of the altitude range, main uses, and conservation status of the species is presented in Table 1.

Cordia africana Lam. (Boraginaceae) is a small to medium-sized evergreen tree, reaching heights of 4 to 15 (occasionally up to 30) m. It is heavily branched with a spreading, umbrella-shaped or rounded crown (Orwa *et al.*, 2009; Seid and Gebeyehu, 2024). It is an evergreen tree native to warmer regions, and occurs at medium to low altitudes in woodland, savannah, and bush areas that are warm and moist, often along riverbanks. *C. africana* is recognized for its diverse applications and ecological importance. *It* serves multiple purposes, including providing food (fruits), fodder (leaves), fuel (firewood), timber, and medicine (Orwa *et al.*, 2009; Seid and Gebeyehu, 2024). Additionally, it offers products such as honey and services like shade (shelter), soil improvement, and ornamental uses. Its various phytoconstituents exhibit notable pharmacological properties, including antioxidant and antimicrobial activities, making it a valuable resource for both ecological and medicinal applications (Alhadi *et al.*, 2015; Nigussie *et al.*, 2021).

V. abyssinica (syn.: *Acacia abyssinica*) (Fabaceae or Leguminosae) is a large, flat-topped tree that can grow up to 20 m tall when mature. It is found throughout Africa: Angola, Eritrea, Ethiopia, Kenya, Malawi, Mozambique, Rwanda, Sudan, Tanzania, Uganda, D.R.C., and Zimbabwe (Hedberg and Edwards, 1989; Bekele-Tesemma, 2007; Orwa *et al.*, 2009; Fischer *et al.*, 2010). In Ethiopia, *V. abyssinica* thrives in wooded grasslands and along the edges of highland forests across the Dry, Moist, and Wet midland zones, as well as in the Moist and Wet highland agroclimatic zones, at altitudes ranging from 1,500 to 2,800 m. (Bekele-Tesemma, 2007; Orwa *et al.*, 2009). The species plays a significant role in forest restoration and ecological dynamics, particularly in the Ethiopian highlands (Asmelash and Getachew, 2022). It exhibits notable morphological variations influenced by environmental factors such as temperature and diurnal range, which can affect its growth and suitability for restoration projects (Seid and Gebeyehu, 2024). *V. abyssinica* contributes to nitrogen fixation, enhancing soil fertility and supporting biodiversity in degraded ecosystems (Asmelash and Getachew, 2022). It also serves as a keystone species in arid environments, maintaining high nitrogen content even under anthropogenic pressures (Vincent *et al.*, 2024).

Olea europapaea ssp. africana (Oleaceae) is a shrub or small to medium-sized tree, typically growing between 5 to 10 m tall, though it can occasionally reach heights of up to 18 m. It is widely distributed throughout its native range in southern Africa, thriving in diverse habitats, primarily near water sources like stream banks and riverine fringes. Additionally, it can be found in open woodlands, among rocks, and in mountain ravines (Orwa *et al.*, 2009). This species serves multiple purposes, providing products such as food, fodder, fuelwood, timber, and medicine, as well as contributing to services like the reforestation of degraded lands and ornamental uses. The species plays significant roles in both traditional medicine and ecological contexts. It is recognized for its medicinal properties used for treating ailments such as hypertension, diabetes, and gastrointestinal issues (Msomi and Simelane, 2017). It also possesses key compounds identified, including oleuropein, esculin, and ursolic acid, which contribute to its therapeutic effects (Msomi and Simelane, 2017). Studies show that extracts from *O. europaea* ssp. africana exhibit significant anthelmintic properties against gastrointestinal worms in dogs, supporting its traditional use (Orengo *et al.*, 2022).

Millettia ferruginea (Fabaceae or Leguminosae) is a large, shady tree that can reach heights of up to 35 m. It is endemic to Ethiopia, and thrives in upland forests, rainforests, and forest remnants throughout the country (Bekele-Tesemma, 2007). The tree serves multiple purposes, providing firewood, timber for local construction, tool handles, household utensils, shade, and fish poison derived from its ground-up seeds. *M. ferruginea* is a significant tree species in Ethiopia, recognized for its diverse applications in agriculture and medicine (Loha *et al.*, 2008; Das, 2017). It is also recognized as a potential agroforestry species, with significant genetic variation in seed and seedling traits observed across different populations (Loha *et al.*, 2008). It also serves as a valuable fodder source for livestock, and exhibits notable antimicrobial properties, particularly against various *Shigella* species (Das, 2017).

Albizia gummifera (Fabaceae or Leguminosae) is a large deciduous tree that ranges from 4.5 to 30 meters in height, with branches that ascend to form a flat top. The crown is flat, and the bark is smooth and grey. Native to East Africa, A. gummifera is common in lowland and upland rainforests, riverine forests, and in open habitats near forests (Orwa *et al.*, 2009). It is found in various agroecological zones, particularly in Ethiopia, where it is part of agroforestry practices (Abide and Birru, 2024). It occasionally serves as a pioneer species in forests and thickets. *A. gummifera* is utilized for various products, including apiculture, fuelwood, timber, gum or resin, tannin or dyestuff, and medicine. Additionally, it provides services such as erosion control, shade or shelter, nitrogen fixation, soil improvement, and ornamental use, as well as intercropping opportunities. *A. gummifera* is recognized for its ecological and medicinal significance (Nantongo *et al.*, 2009; Thuo *et al.*, 2017). The species is classified as Least Concern in terms of conservation status and is noted for its potential in agroforestry systems.

Hagenia abyssinica (Rosaceae) is commonly known as the African redwood, is a slender tree that can grow up to 20 meters tall, with a short trunk and thick branches. Its branchlets are adorned with silky brown hairs and have distinct ringed leaf scars. This species is mainly located in East Africa, found in countries such as Burundi, the Democratic Republic of Congo, Ethiopia, Kenya, Malawi, Rwanda, Sudan, Tanzania, Uganda, and Zambia (Orwa *et al.*, 2009). It typically dominates the woodland zone just above the mountain bamboo. *H. abyssinica* is a significant multipurpose tree native to the Afromontane regions of East Africa (Gérard *et al.*, 2016; Habtemariam and Woldetsadik, 2019). It predominantly thrives in high-altitude forests, particularly between 2000 and 2600 meters in the Albertine Rift, where it plays a crucial role in maintaining soil fertility and supporting biodiversity (Gérard *et al.*, 2016; Habtemariam and Woldetsadik, 2019). It is valued for its medicinal properties, ecological benefits, and various uses in local communities (Karumi, 2013; Jaiswal and Lee, 2024). Overexploitation for medicinal and commercial purposes, along with habitat loss due to agriculture and climate change, poses significant risks to its survival (Habtemariam and Woldetsadik, 2019).

Seed Storage, Germination Enhancement and Plantation Management

C. africana seeds are classified as orthodox, meaning they can be stored for extended periods under cold and dry conditions without significant loss of viability. The number of seeds (stones) per kilogram is approximately 2,500-4,500. Seed dispersal relies on frugivores (zoochory) such as birds and primates, for this process (Orwa *et al.*, 2009). The seeds of *C. africana* exhibit physical dormancy, remaining viable for at least a year; however, fresh seeds demonstrate optimal germination (Negash, 2021). *It* has also developed a light-quality sensing mechanism that inhibits germination in dense shade, which enhances seedling survival in open areas. After extraction, seeds are dried in the sun to a moisture content of 6 to 8% and can be stored for at least one year in hermetic storage at 3°C to -10°C without any loss in viability (Orwa *et al.*, 2009; Mewded *et al.*, 2019). This characteristic allows for effective seed banking (Orwa *et al.*, 2009; Mewded *et al.*, 2019). Germination enhancement techniques for *C. africana* seeds include soaking seeds in hot water (70-80°C) for 10-15 minutes (Addis, 2003; Orwa *et al.*, 2009; Mewded *et al.*, 2019), which has been shown to break dormancy and improve germination rates (Table 2). Moreover, applying gentle mechanical scarification with sandpaper can also enhance germination by breaking physical dormancy (Materechera and Materechera, 2001; Smith *et al.*, 2023).

Precipitation significantly influences the variability of seed production; with higher rainfall correlating to increased seed output (Yu *et al.*, 2024). Pruning and coppicing are the common management practices to improve seed production and tree survival of *C. africana* (Materechera and Materechera, 2001; Addis, 2003; Teklay, 2005; Orwa *et al.*, 2009; Legese *et al.*, 2019; Mewded *et al.*, 2019; Lameso and Bekele, 2020; Smith *et al.*, 2023).

V. abyssinica seeds are classified as orthodox and can be stored for up to 20 months under dry conditions at 2 to 20°C without losing viability, making them suitable for long-term conservation (Addis, 2003; Orwa *et al.*, 2009). The seed coat of *V. abyssinica* controls seed germination by acting as a barrier to the entry of water and gases, indicating the presence of physical dormancy (Negash, 2021). The number of seeds per kilogram is approximately 16,000 to 18,000 (Bekele-Tesemma, 2007). Seed dispersal relies on frugivores (zoochory) such as birds and primates, for this process (Teketay, 2005; Orwa *et al.*, 2009). Maintaining seeds at lower moisture content during storage can reduce sensitivity to temperature fluctuations and improve germination rates (O'Reilly *et al.*, 2006). Germination enhancement techniques for *V. abyssinica* seeds include mechanical scarification through sandpaper abrasion (Table 2). This method is cost-effective and improves germination rates significantly (Materechera and Materechera, 2001; Smith *et al.*, 2023). Soaking seeds in concentrated sulfuric acid for 10 to 40 minutes has been shown to break dormancy and achieve germination rates of over 98% (Materechera and Materechera, 2001; Addis, 2003). Moreover, soaking seeds in hot water (70°C) for one hour can also improve germination, though results are less consistent compared to mechanical scarification (Addis, 2003).

Precipitation significantly influences the variability of seed production; with higher rainfall correlating to increased seed output (Yu *et al.*, 2024). Regular watering, mulching, and protection from wild animals are crucial for seedling survival (Materechera and Materechera, 2001; Addis, 2003; Aerts *et al.*, 2007; Alem, 2020; Smith *et al.*, 2023; Tenkir *et al.*, 2024).

Olea europaea ssp. africana seeds are orthodox and can be stored for extended periods under cold and dry conditions (Mewded *et al.*, 2019). The endocarp of *O. europaea cana* restricts moisture and oxygen and mechanically impedes the germinating embryo's emergence from the seed coat (Negash, 2021). Removing the endocarp is crucial for successful germination. The number of seeds kg^{-1} is approximately 13,800 (Orwa *et al.*, 2009). Seed dispersal relies on frugivores (zoochory) such as birds and primates, for this process (Teketay, 2005; Orwa *et al.*, 2009). The seeds should be stored at low temperatures (-10°C) and low moisture content to maintain viability (Mewded *et al.*, 2019). Seed viability can be maintained for several years in hermetic storage at 3°C with a moisture content of 6 to 10% (Orwa *et al.*, 2009). Germination enhancement techniques including soaking seeds in hot water (70 to 80°C) for 10 to 15 minutes and leaving it soaked for 12 to 24 hours (Addis, 2003; Mewded *et al.*, 2019) has been shown to break dormancy and improve germination rates of *O. europaea ssp. africana*. Applying gentle mechanical scarification with sandpaper can also enhance germination by breaking physical dormancy (Materechera and Materechera, 2001; Smith *et al.*, 2023).

Precipitation significantly influences the variability of seed production; with higher rainfall correlating to increased seed output (Yu *et al.*, 2024). Planting in shaded areas and using nurse plants like shrubs can enhance seedling survival (Materechera and Materechera, 2001; Addis, 2003; Aerts *et al.*, 2007; Girma *et al.*, 2010; Mewded *et al.*, 2019; Alem, 2020; Dagnachew *et al.*, 2023; Smith *et al.*, 2023).

M. ferruginea seeds are classified as orthodox and can be stored for extended periods under cold and dry conditions without significant loss of viability (Mewded *et al.*, 2019). The dry pods of *M. ferruginea* have a distinctive helical shape. The uneven drying of their surfaces generates tension, which leads to explosive seed dispersal. This mechanism effectively releases physical dormancy (Negash, 2021). The number of seeds per kilogram is approximately 55,000 to 75,000 (Orwa *et al.*, 2009; Negash, 2010), and utilizes wind for seed dispersal (i.e., Anemochory), enhancing their spread across the forest (Yu *et al.*, 2024). The seeds should be stored at low temperatures (-10°C) and low moisture content to maintain germination capacity (Mewded *et al.*, 2019). Germination enhancement techniques for *M. ferruginea* seeds include soaking seeds in hot water (70 to 80°C) for 10 to 15 minutes and leaving it soaked for 12 hours (Addis, 2003; Mewded *et al.*, 2019) has been shown to break dormancy and improve germination rates (Table 2). Moreover, applying gentle mechanical scarification with sandpaper can also enhance germination by breaking physical dormancy (Materechera and Materechera, 2001; Smith *et al.*, 2023).

Precipitation significantly influences the variability of seed production; with higher rainfall correlating to increased seed output (Yu *et al.*, 2024). Pollarding and thinning are effective management practices to maintain tree health and promote regeneration (Materechera and Materechera, 2001; Addis, 2003; Teklay, 2005; Mewded *et al.*, 2019; Ereso, 2023; Smith *et al.*, 2023).

A. gummifera seeds are classified as orthodox, meaning they can be stored for extended periods under cold and dry conditions without significant loss of viability. This characteristic allows for effective seed banking (Mewded *et al.*, 2019). The fruits appear in bundles, each pod containing 8-14 **seeds.** The number of seeds kg^{-1} is approximately 10,000 to 16,000 (Orwa *et al.*, 2009). Seed dispersal mainly occurs by wind (i.e., Anemochory), with seeds remaining attached to half of the dehiscent pod. Moreover, monkeys also eat fresh pods, which may contribute to long-distance dispersal (i.e., Zoochory). Seed viability can be preserved for several years in hermetic storage at 10°C (-10°C) and low moisture content to maintain germination capacity (Orwa *et al.*, 2009; Mewded *et al.*, 2019). Germination enhancement techniques for *A. gummifera* seeds include soaking seeds in hot water (70 to 80°C) for 10 to15 minutes and leaving it soaked for 12 to 24 hours (Addis, 2003; Mewded *et al.*, 2019) has been shown to break dormancy and improve germination rates (Table 2). However, fresh seeds need no pre-treatment. Moreover, applying gentle mechanical scarification with sandpaper can also enhance germination by breaking physical dormancy (Materechera and Materechera, 2001; Smith *et al.*, 2023).

Precipitation significantly influences the variability of seed production; with higher rainfall correlating to increased seed output (Yu *et al.*, 2024). Soil preparation and organic inputs from tree foliage enhance soil fertility and germination rates (Materechera and Materechera, 2001; Addis, 2003; Mewded *et al.*, 2019; Teklay, 2005; Legese *et al.*, 2019; Alem, 2020; Dagnachew *et al.*, 2023; Smith *et al.*, 2023).

H. abyssinica seeds are classified as orthodox, meaning they can be stored for extended periods under cold and dry conditions without significant loss of viability. The specific dormancy mechanisms for *H. abyssinica* are not well understood and have not been thoroughly documented. The number of seeds per kilogram is approximately 400,000-500,000 (Orwa *et al.*, 2009), and utilizes wind for seed dispersal (i.e., Anemochory), enhancing their spread across the forest. Hermetic air-dry storage at cool temperatures is recommended to extend seed

Table 2. Summary of seed characteristics, storage behavior, pre-treatment techniques and germination outcomes of the target tree species

Species	Seed storage behavior	Seed storage methods	Pre-treatment	Germination methods	References
C. africana	Orthodox	Seeds can be stored under shade with proper ventilation to maintain viability	• Soaking hot water (70-80°C) for up to 15 minutes. • Soaking in cold water for 24-48 hours. • Mechanical scarification.	Under nursery, sowing in well-drained substrate maintaining moisture and warmth improves survival success.	Materechera and Materechera, 2001; Addis, 2003; Teklay, 2005; **Orwa** *et al.*, 2009; Legese *et al.*, 2019; Mewded *et al.*, 2019; Lameso and Bekele, 2020; Smith *et al.*, 2023
V. abyssinica	Orthodox	Seeds should be stored in a cool, dry place to maintain germination rates	• Soaking in concentrated H_2SO_4 for up to 40 minutes. • Scarification through sandpaper abrasion. • Hot water treatment for 12–24 hours.	Direct sowing with seed burial for fresh seeds Under nursery, sowing in sandy-loam soil with warmth (25–30°C).	Materechera and Materechera, 2001; Addis, 2003; Aerts *et al.*, 2007; Alem, 2020; Smith *et al.*, 2023; Tenkir *et al.*, 2024
O. europaea ssp. africana	Orthodox	Seeds benefit from cold storage at 4°C to maintain viability	• Soaking in hot water (70-80°C) for 10-15 minutes and leaving it for 12-24 hours. • Soaking in cold water for 24-48 hours; and cold stratification. • Scarification using sandpaper.	Sowing in moist soil improves success rate. Seed burial in semi-arid conditions (require 2-3 months to sprout). Removing the endocarp.	Materechera and Materechera, 2001; Addis, 2003; Aerts *et al.*, 2007; Girma *et al.*, 2010; Mewded *et al.*, 2019; Alem, 2020; Dagnachew *et al.*, 2023; Smith *et al.*, 2023
M. ferruginea	Orthodox	Seeds should be stored in a cool, dry environment to preserve viability	• Soaking in hot water (70-80°C) for 10–15 minutes and leaving it for 12 hours. • Mechanical scarification with sandpaper.	Under nursery, sowing in green manure, moist and good light medium.	Materechera and Materechera, 2001; Addis, 2003; Teklay, 2005; Mewded *et al.*, 2019; Ereso, 2023; Smith *et al.*, 2023
A. gummifera	Orthodox	Seeds can be stored at room temperature for short periods but benefit from cooler conditions for longer storage	• Hot water (70-80°C) treatment for 10-15 minutes and soaking it for 12-24 hours. • Mechanical scarification with sandpaper. • Nicking improves germination.	Under nursery, it germinates well in warm (25-30°C) and moist conditions. Germination success also improved through seed burial and soil preparation.	Materechera and Materechera, 2001; Addis, 2003; Mewded *et al.*, 2019; Teklay, 2005; Legese *et al.*, 2019; Alem, 2020; Dagnachew *et al.*, 2023; Smith *et al.*, 2023
H. abyssinica	Orthodox	Seeds should be stored in a cool, dry place to maintain viability	• Soaking in hot water (70-80°C) treatment for 10-15 minutes and soaking it for 12–24 hours. • Seed burial.	Requires cool, moist and light conditions to improve success rate	Materechera and Materechera, 2001; Addis, 2003; Mewded *et al.*, 2019; Alem, 2020; Eshete, 2004; Aerts *et al.*, 2007; Habtemariam and Woldetsadik, 2019; Smith *et al.*, 2023

viability (**Orwa** *et al.*, 2009). This characteristic allows for effective seed banking (Mewded *et al.*, 2019). The seeds should be stored at low temperatures (-0°C) and low moisture content to maintain germination capacity (Mewded *et al.*, 2019). Generally, no dormancy-breaking needed for fresh seeds which can be directly sown. But, germination enhancement techniques for *H. abyssinica* seeds include soaking seeds in hot water (70-80°C) for 10-15 minutes and leaving it soaked for 12-24 hours (Addis, 2003; Mewded *et al.*, 2019) has been shown to break dormancy and improve germination rates (Table 2). Moreover, applying gentle mechanical scarification with sandpaper can also enhance germination by breaking physical dormancy (Materechera and Materechera, 2001; Smith *et al.*, 2023).

Precipitation significantly influences the variability of seed production; with higher rainfall correlating to increased seed output (Yu *et al.*, 2024). Planting in fenced areas to protect from livestock and using litter removal to improve seedling establishment (Materechera and Materechera, 2001; Addis, 2003; Mewded *et al.*, 2019; Alem, 2020; Eshete, 2004; Aerts *et al.*, 2007; Habtemariam and Woldetsadik, 2019; Smith *et al.*, 2023)

Overall, mechanical scarification of seeds (i.e., nicking or rubbing), soaking seeds in water (hot or cold) and treatment with concentrated sulfuric acid enhance the germination rates of the target species. The germination rates vary significantly; for instance, *O. europaea* ssp. *africana* demonstrates high germination rates after storage, while *M. ferruginea* shows lower rates (Blanke, 2022). Factors such as storage duration, moisture content, and sowing (growing) substrate types and conditions directly affect the seed germination percentage (Wawrzyniak *et al.*, 2020).

Current Seed Storage Methods used in Ethiopia

Seed storage techniques for indigenous tree species vary significantly depending on their physiological characteristics, which affect seed longevity and viability. In Ethiopia, current methods focus on optimizing conditions to maintain seed viability and enhance germination, which are essential for the conservation and sustainable use of these species due to their ecological and economic importance. Common seed storage methods in Ethiopia include conventional techniques such as *dry storage*, *cold storage*, and *seed banks* (Mamo *et al.*, 2011).

Dry storage lowers seed moisture content to below 5 to 6% using desiccants like silica or activated charcoal. This method, known as ultra-dry storage, enhances seed longevity and is particularly effective for low-volume seeds, making it ideal for seed companies and banks (Nm and Gowda, 2017). *Cold storage* typically maintains seeds at -20°C, which is standard for orthodox seeds that can tolerate desiccation. For example, the Ethiopian Forestry Development (EFD) currently employs cold storage methods to preserve the seeds of various tree species. Similarly, the Ethiopian Biodiversity Institute (EBI) utilizes cold storage techniques for storing crops and tree germplasms. In contrast, *seed banks* function as repositories for genetic material, preserving seeds under controlled conditions to protect against biodiversity loss and to address challenges such as climate change and population growth (Ambrose, 2010). For instance, the Ethiopian Biodiversity Institute uses seed banks, or community seed banks, to temporarily store and distribute crop seeds to farmer groups. However, certain seeds, particularly recalcitrant types, necessitate cryopreservation techniques, including storage in liquid nitrogen, to maintain their viability (Ballesteros *et al.*, 2021).

Despite the potential of these techniques, challenges persist within Ethiopia's broader seed supply system. Issues such as the lack of provenance trials and improved seed varieties, along with the need for better legislation and infrastructure, highlight the complexities of seed conservation efforts (Bantihun *et al.*, 2024). Addressing these challenges is crucial for the effective conservation and utilization of indigenous tree species in Ethiopia.

Farmers in Ethiopia use various traditional methods to store seeds of indigenous tree species, including *C. africana*, *V. abyssinica*, *O. europaea* ssp. *africana*, *M. ferruginea*, *A. gummifera*, and *H. abyssinica*. These practices are essential for maintaining seed viability and ensuring successful future planting. To prevent mold and decay, farmers often dry the seeds to reduce moisture content. The seeds are then stored in woven baskets or clay pots, which protect them from pests and environmental factors (Teketay and Granström, 1997). While these traditional methods are effective, challenges persist, such as limited access to improved seed varieties and the need for better seed management practices to enhance agricultural productivity (Alemu, 2015).

Implications for Conservation and Afforestation Programs

This review of seed storage and germination enhancement methods holds important implications for conservation and afforestation efforts in Ethiopia. Indigenous tree species play a crucial role in maintaining biodiversity, improving ecosystem services, and supporting local livelihoods. However, their natural regeneration is often limited by factors such as seed dormancy, low germination rates, and poor seed storage viability. By implementing scientifically validated seed treatment techniques, the propagation success of these species can be improved, thereby bolstering large-scale restoration initiatives. Thus, afforestation programs should focus on species-specific seed treatments to increase germination success and seedling establishment. Furthermore, integrating ex-situ conservation strategies, such as seed banking under optimized storage conditions, can help preserve genetic diversity and support long-term reforestation efforts. Integrating traditional knowledge with scientific advancements is crucial for engaging the community for promoting the afforestation initiatives. Moreover, involving local stakeholders in seed collection, treatment, and planting can significantly enhance the sustainability of afforestation projects. Additionally, strong policy and institutional support for seed management is essential.

Countries display significant differences in their forestry and climate adaptation strategies, shaped by their distinct environmental contexts, policy frameworks, and socio-economic conditions (Keskitalo *et al.*, 2015; Ismail *et al.*, 2019; Yousefpour *et al.*, 2020). For example, Finland and Canada are developing climate-resilient seeds and forestry systems aimed at mitigating the impacts of climate change, utilizing advanced technologies such as gene editing for seed improvement. In contrast, developing countries like Ethiopia and Madagascar are often more focused on reforestation efforts to combat deforestation and land degradation, typically without the use of advanced technologies.

Stakeholder Engagement and Policy Context

In Ethiopia, the Ethiopian Forestry Development (EFD), a federal organization, is dedicated to enhancing tree seed technologies to ensure the availability of high-quality seeds. This involves research to identify suitable seed sources and improve systems for seed collection, storage, and distribution. The EFD's Plantation Research Directorate conducts studies aimed at advancing seed technologies and identifying the most suitable species for various climatic zones. This work is crucial for scaling up reforestation programs and ensuring that the right trees are planted in the appropriate locations, which is essential for successful tree planting and forest restoration across diverse ecosystems.

Additionally, the Provision of Adequate Tree Seed Portfolios (PATSPO) initiative aims to improve access to high-quality germplasm, particularly for species like *Grevillea robusta*, which can significantly enhance economic returns and environmental benefits (Pedercini and Dawson, 2022). Recommendations include using quality seedlings and matching species appropriately to their sites (Gebirehiwot, 2023). Farmers have expressed a need for diverse tree species, indicating a gap in current agroforestry practices. Furthermore, community involvement and participatory trials have shown that aligning species priorities with local knowledge can improve tree planting success (Billups, 2023). Participatory approaches, such as those utilized in the Metema frankincense forest restoration project, are vital for the effectiveness of tree seed systems. Communities are being trained in sustainable seed harvesting techniques and nursery management, equipping them with the skills necessary for forest management and contributing to restoration efforts (Tree Aid, 2024).

Future Research Directions and Recommendations

Despite advancements in seed storage and germination techniques, challenges remain: insufficient seed storage facilities and infrastructure, limited research on the dormancy mechanisms of many indigenous species, and the need to combine traditional knowledge with modern methods. Therefore, future research should focus on species-specific strategies for enhancing storage and germination, improving seed banking facilities, and providing policy support for the large-scale propagation of indigenous trees. Moreover, future studies should refine seed storage techniques to extend the viability of seeds from various indigenous species, particularly under changing climatic conditions. There is a need for more research on dormancy-breaking mechanisms tailored to the specific requirements of different species, ensuring consistent and scalable germination success. Additionally, exploring biotechnology and molecular approaches in seed science presents a promising direction for advancement in this field.

Research should also examine the ecological interactions that affect seedling survival, such as the roles of soil microbiomes and mycorrhizal associations, which can enhance growth after germination. Furthermore, investigating the genetic and physiological factors that influence seed dormancy could optimize conservation strategies. Moreover, collaboration among researchers, conservation practitioners, and policymakers is crucial for translating research findings into practical applications. Developing locally adaptable seed enhancement protocols and integrating them into national reforestation policies will help scale up restoration efforts while ensuring both ecological and socio-economic benefits (Hailu and Cheru, 2025).

Conclusions

Enhancing seed storage and germination techniques is crucial for the conservation and sustainable use of Ethiopia's indigenous trees. Effective seed storage and germination enhancement methods are critical for the conservation and sustainable use of economically important indigenous trees in Ethiopia. By understanding the specific needs of each species and applying appropriate pretreatments and storage conditions, it is possible to improve germination rates and ensure the successful propagation of these valuable trees. The species discussed in this paper (i.e., *Cordia africana*, *Vachellia abyssinica*, *Olea africana*, *Millettia ferruginea*, *Albizia gummifera*, and *Hagenia abyssinica*) have orthodox seeds and can be stored for extended periods under cold and dry conditions. Maintaining seeds at lower moisture content during storage can reduce sensitivity to temperature fluctuations and improve germination rates. Generally, soaking seeds in hot water (70 to 80°C) for 10 to 15 minutes has been shown to break dormancy and improve germination rates of the species discussed in the paper. Moreover, lighter mechanical scarification with sandpaper or boiling water can also enhance germination by breaking physical dormancy. Furthermore, soaking seeds in concentrated sulfuric acid for 10 to 40 minutes has been shown to break dormancy and achieve germination rates of the species over 98%.

References

Abide, E. and Birru, T. 2024. Distribution and Regeneration Status of Albizia gummifera and Prunus africana along Agroecology in Agroforestry: The Case of Gombora District, Southern Ethiopia. *International Journal of Forestry Research* 2024: 1-9. https://doi.org/10.1155/2024/1843379.

Addis, G. 2003. Treatments promoting germination of *Taverniera abyssinica* A. Rich. seeds. *Seed Science and Technology* 31(3): 579-586. https://doi.org/10.15258/SST.2003.31.3.07.

Aerts, R., Aerts, R., Negussie, A., Maes, W., November, E., November, E., Hermy, M. and Muys, B. 2007. Restoration of Dry Afromontane Forest Using Pioneer Shrubs as Nurse-Plants for *Olea europaea ssp. cuspidata*. *Restoration Ecology* 15(1): 129-138. https://doi.org/10.1111/J.1526-100X.2006.00197.X,

Alem, S. 2020. Seed bury vs broadcast in direct seeding: their effects on the germination of different woody plant species, in a degraded semi-arid area, Southern Ethiopia. *Journal of Degraded and Mining Lands Management* 7(2): 2041-2047. https://doi.org/10.15243/JDMLM.2020.072.2041.

Alemu, K. 2015. Seed Production and Dissemination Systems Analyses: The Case of Ethiopia. *Food Science and Quality Management* 35: 25-37. https://www.iiste.org/Journals/index.php/FSQM/article/viewFile/19173/19383.

Alhadi, E.A., Khalid, H.S., Alhassan, M.S., Ali, A.A., Babiker, S.G., Zain Alabdeen, E.M. and Kabbashi, A.S. 2015. *Antioxidant and cytotoxicity activity of Cordia africana in Sudan*. *3*(2), 29-32. http://www.netjournals.org/z_AMPR_15_011.html.

Ambrose, M. 2010. *Seed Banks and Gene Banks*. https://doi.org/10.1002/9780470015902.A0002025.PUB2.

Asmelash, F. and Getachew, E. 2022. Suitability of selected legume (Vachellia spp.) tree species for forest restoration in the Central Ethiopian highlands. *Nusantara Bioscience*, *14*(2). https://doi.org/10.13057/nusbiosci/n140210.

Ballesteros, D., Fanega-Sleziak, N. and Davies, R.M. 2021. Cryopreservation of Seeds and Seed Embryos in Orthodox-, Intermediate-, and Recalcitrant-Seeded Species. In: Wolkers, W.F., Oldenhof, H. (eds) Cryopreservation and Freeze-Drying Protocols. Methods in Molecular Biology, 2180, 663-682. Humana, New York, NY. https://doi.org/10.1007/978-1-0716-0783-1_36.

Bantihun, A., Abtew, A.A. and Mulatu, Y. 2024. Tree seed supply system in Ethiopia: modeling source and dissemination of priority species. *International Forestry Review* 26(1), 83–92. https://doi.org/10.1505/146554824838457871.

Bekele-Tesemma, A. 2007. Useful trees of Ethiopia: identification, propagation and management in 17 agroecological zones. Nairobi: RELMA in ICRAF Project, 552 p.

Billups, C. 2023. Linking farmers' tree species priority with planting niche accelerates scaling up of homestead agroforestry in semi- arid Ethiopia. https://www.doi.org/10.21203/rs.3.rs-2859126/v1.

Blanke, C.D. 2022. Advances in preservation of seed vigour during storage. *Burleigh Dodds Series in Agricultural Science* 265-292. https://doi.org/10.19103/as.2022.0105.11.

Dagnachew, S., Teketay, D., Demissew, S. and Awas, T. 2023. Evaluation of germination under different storage conditions of four endemic plant species from Ethiopia: Implications for *ex-situ* conservation in Seed Banks. *Seeds* 2(1): 45-59. https://doi.org/10.3390/seeds2010005.

Das, S. 2017. Ethanolic extract of milletia ferruginea inhibits growth of shigella species. *World Journal of Pharmacy and Pharmaceutical Sciences* 1126-1131. https://doi.org/10.20959/WJPPS20179-9974.

Ereso, T. 2023. Woody Species Conservation, Management, and Its Socioeconomic Importance of Agroforestry Practice in Ethiopia. *International Journal of Forestry Research* 2023: 1-8. https://doi.org/10.1155/2023/2623291.

Eshete, A.W. 2004. *Ethiopian Church Forests: Opportunities and Challenges for Restoration*. https://edepot.wur.nl/27911.

Faith, D P., Collen, B., Ariño, A. H., Kerr, J. and Chavan, V. 2013. *Bridging Biodiversity Data Gaps: Recommendations to Meet Users' Data Needs*. https://journals.ku.edu/index.php/jbi/article/download/4126/4203.

Fekadu, M. and Yohannes, T. 2004. Economic value of *Trichilia emetica, Delonix elata, Berchemia discolor* and *Warburgia ugandensis* in Ethiopia. https://agris.fao.org/agris-search/search.do?recordID=ET2006000046.

Fischer, E., Rembold, K., Althof, A. and Obholzer, J. 2010. Annotated checklist of the vascular plants of Kakamega forest, Western province, Kenya. *Journal of East African Natural History* 99: 129-226.

Gebirehiwot, H.T. 2023. Review on factors affecting early survival of tree /shrub seedlings and its remedy in restoration sites of Ethiopia. *Journal of Landscape Ecology* 16(1): 128-148. https://www.doi.org/10.2478/jlecol-2023-0007.

Gérard, I.M., Louis, Z., Jean De Dieu, M.M., Pancrace, P., Jean-Claude, M.M.I., Faustin, B. and Christian, A. 2016. Caractérisations Structurale, Floristique Et Biomasse Ligneuse Du Peuplement À Hagenia abyssinica Du Parc National De Kahuzi-Biega (Rift Albertin, RDC). *European Scientific Journal ESJ*, 12(15): 189. https://doi.org/10.19044/ESJ.2016.V12N15P189.

Geta, T., Nigatu, L. and Animut, G. 2014. Ecological and Socio-Economic Importance of Indigenous Multipurpose Fodder Trees in Three Districts of Wolayta Zone, Southern Ethiopia. *Journal of Biodiversity and Endangered Species* 2(4): 1-5. https://doi.org/10.4172/2332-2543.1000136.

Girma, A., Mosandl, R., El Kateb, H. and Masresha, F. 2010. Restoration of degraded secondary forest with native species: a case study in the highland of Ethiopia. *Scandinavian Journal of Forest Research* 25: 86-91. https://doi.org/10.1080/02827581.2010.485769.

Girma, Y. and Wolka, K. 2012. Effects of *Albizia gummifera*, *Millettia ferruginea* and *Cordia africana* Leaf Litter on the Germination of Coffea arabica L. Seed. *International Journal of Agricultural Research* 7(6): 315-323. https://doi.org/10.3923/ijar.2012.315.323.

González Pérez, M.Á., Cabrera-García, N. and Cayon-Fernández, I. 2021. High seed viability recorded in an endangered endemic species, *"Isoplexis isabelliana"* (Scrophulariaceae), after more than 30 years of storage in a conservation seed bank. 42(42): 21. https://doi.org/10.5209/MBOT.69341.

Habtemariam, A.A. and Woldetsadik, A.M. 2019. Current distribution, regeneration and management practice of Hagenia abyssinica in different agroforestry systems of Ethiopia: a review. *International Journal of Biodiversity and Conservation* 11(9): 266-271. https://doi.org/10.5897/IJBC2019.1294.

Hailu, K. and Cheru, U. 2025. Management and Ecological Services of Multipurpose Agroforestry Tree Species in Ethiopia. Review. *Vegetable Crops of Russia* 1: 82-87. https://doi.org/10.18619/2072-9146-2025-1-82-87.

Hedberg, I. and Edwards, S. (eds.) 1989. Flora of Ethiopia and Eritrea 3: 1-659. The National Herbarium, Addis Ababa University, Ethiopia and the Department of Systematic Botany, Uppsala.

Hong, T.D. and Ellis, R.H. 1996. *A Protocol to Determine Seed Storage Behaviour*. International Plant Genetic Resources Institute (IPGRI), Rome, 62 p (IPGRI. Technical Bulletin, 1).

Ismail, C.J., Takama, T., Budiman, I. and Knight, M. 2019. Comparative study on agriculture and forestry climate change adaptation projects in Mongolia, the Philippines, and Timor Leste. In: *Climate Change Management* (pp. 413–430). https://www.doi.org/10.1007/978-3-319-75004-0_24.

Jaiswal, V. and Lee, H. 2024. Biological Properties and Phytochemicals of Multipurpose Tree Plant Hagenia abyssinica. *Molecules, 29*(24), 5871. https://doi.org/10.3390/molecules29245871.

José, A.C. and Davide, A.C. 2007. Classificação fisiológica de sementes de cinco espécies arbóreas de mata ciliar quanto a tolerância à dessecação e ao armazenamento 1. *Revista*

Brasileira De Sementes 29(2): 171-178. https://doi.org/10.1590/S0101-31222007000200023.

Karumi, E.W. 2013. *Phytochemical, Anthelmintic And Antimicrobial Investigation of Hagenia Abyssinica (bruce) Gmelin*. http://erepository.uonbi.ac.ke/handle/11295/62684.

Keskitalo, E.C.H., Legay, M., Marchetti, M., Nocentini, S. and Spathelf, P. 2015. The role of forestry in national climate change adaptation policy: cases from Sweden, Germany, France and Italy. *International Forestry Review* 17(1): 30-42. https://www.doi.org/10.1505/146554815814725068.

Klopper, R.R., Gautier, L., Smith, G.F., Spichiger, R. and Chatelain, C. 2006. Inventory of the African flora: a world first for the forgotten continent. *South African Journal of Science* 102: 185-186.

Kumar, P., Tanveer, N., Dhiman, S., Rajput, S., Rajput, M., Rajput, Y., Pandey, N. and Kumar, P. 2024. *A Review on Seed Storage Technology: Recent Trends and Advances in Sustainable Techniques for Global Food Security*. https://doi.org/10.59983/s2024020105.

Lameso, L. and Bekele, W. 2020. Farmers Local Knowledge on Niche Selection, Management Strategies and Uses of Cordia africana Tree in Agroforestry Practices of Sidama Zone, Southern Ethiopia. *American Journal of Agriculture and Forestry* 8(6): 258. https://doi.org/10.11648/J.AJAF.20200806.14.

Legese, K.G., Gelanew, A. and Alemu, M. 2019. Soil Physical Properties Enhancement Via Native Tree Species in Northern Ethiopia. *Journal of Advances in Agriculture* 10: 1680-1691. https://doi.org/10.24297/JAA.V10I0.8203.

Lima, M. de, Jr, Hong, T.D., Arruda, Y.M.B.C., Mendes, A.M.S. and Ellis, R.H. 2014. Classification of seed storage behaviour of 67 Amazonian tree species. *Seed Science and Technology* 42(3): 363-392. https://doi.org/10.15258/SST.2014.42.3.06.

Loha, A., Tigabu, M. and Teketay, D. 2008. Variability in seed- and seedling-related traits of Millettia ferruginea, a potential agroforestry species. *New Forests* 36(1): 67-78. https://doi.org/10.1007/S11056-008-9082-Y.

Mamo, N., Nigusie, D., Tigabu, M., Teketay, D. and Fekadu, M. 2011. Longevity of *Juniperus procera* seed lots under different storage conditions: implications for ex situ conservation in seed banks. *Journal of Forestry Research 22*(3): 453-459. https://doi.org/10.1007/S11676-011-0187-3.

Materechera, E.K. and Materechera, S.A. 2001. Breaking dormancy to improve germination in seeds of Acacia erioloba. *The South African Journal of Plant and Soil* 18(4): 142-146. https://doi.org/10.1080/02571862.2001.10634420.

Mayrinck, R.C., Vaz, T.A.A. and Davide, A.C. 2016. Physiological classification of forest seeds regarding the desiccation tolerance and storage behavior. *Cerne 22*(1): 85-92. https://doi.org/10.1590/01047760201622012064.

Mbi, T.K., Ntsefong, N.G. and Lenzemo, T.E. 2022. Seed dormancy: Induction, maintenance and seed technology approaches to break dormancy. In: *Seed Biology Updates*. https://www.doi.org/10.5772/intechopen.106153.

Mewded, B., Lemessa, D., Negussie, H. and Berhanu, A. 2019. Germination pretreatment and storage behavior of Terminalia laxiflora seed. *Journal of Forestry Research* 30(4): 1337-1342. https://doi.org/10.1007/S11676-018-0717-3.

Meyer, C., Weigelt, P. and Kreft, H. 2016. Multidimensional biases, gaps and uncertainties in global plant occurrence information. *Ecology Letters* 19(8): 992-1006. https://doi.org/10.1111/ELE.12624.

Mng, S. A. and Akinnifesi, F.K. 2007. *Germination Characteristics of Tree Seeds: Spotlight on Southern African Tree Species*. http://www.worldagroforestry.org/downloads/Publications/PDFS/ja07164.pdf.

Msomi, N.Z. and Simelane, M.B.C. 2017. *Olea europaea subsp. africana (Oleaceae)*. IntechOpen. https://doi.org/10.5772/65725.

Nantongo, J.S., Okullo, J.B.L., Eilu, G., Ramonta, I.R., Odee, D.W. and Cavers, S. 2009. Structuring of genetic diversity in Albizia gummifera C.A.Sm. among some East African and Madagascan populations. *African Journal of Ecology* 48(3): 841-843. https://doi.org/10.1111/J.1365-2028.2009.01164.X.

Negash, L. 2010. *A Selection of Ethiopia's Indigenous Trees: Biology, Uses and Propagation Techniques*. Addis Ababa University Press, Addis Ababa, Ethiopia. ISBN 978-99944-52-27-9.

Negash, L. 2021. A Selection of African Native Trees: Biology, Uses, Propagation and Restoration Techniques. ISBN 978-99944-3-086-4, 621 pages, Addis Ababa, Ethiopia.

Nigussie, G., Ibrahim, F. and Neway, S. 2021. A Phytopharmacological Review on a Medicinal Plant: *Cordia africana* Lam. *Journal of Tropical Pharmacy and Chemistry* 5(3): 254-263. https://doi.org/10.25026/JTPC.V5I3.267.

Nm, S. and Gowda, B. 2017. Ultra-dry seed storage: A novel technology for enhancing seed longevity. *International Journal of Chemical Studies* 5(5): 1851-1857. http://www.chemijournal.com/archives/2017/vol5issue5/PartY/5-5-49-270.pdf.

O'Reilly, C., Doody, P., MacLennan, L. and Fennessy, J. 2006. *Reaping What You Sow - Seeds and Plant Quality*. 11-20. https://www.cabdirect.org/cabdirect/abstract/20073000461.

Oliver, R.Y., Meyer, C., Meyer, C., Ranipeta, A., Winner, K. and Jetz, W. 2021. Global and national trends, gaps, and opportunities in documenting and monitoring species distributions. *PLOS Biology* 19(8). https://doi.org/10.1371/JOURNAL.PBIO.3001336.

Orengo, K.O., Mbaria, J.M., Ndichu, M., Jafred, K. and Okumu, M.O. 2022. Preliminary phytochemical composition and *in vitro* anthelmintic activity of aqueous and ethanol extracts of olea africana against mixed gastrointestinal worms in dogs. *Evidence-Based Complementary and Alternative Medicine* 2022: 1-8. https://doi.org/10.1155/2022/5224527.

Orwa, C., Mutua, A., Kindt, R., Jamnadass, R. and Anthony, S. 2009. Agroforestree database: A tree reference and selection guide version 4.0. World Agroforestry Centre, Kenya. https://www.worldagroforestry.org/output/agroforestree-database

Pedercini, F. and Dawson, I.K. 2022. *Cost Benefit Analysis for Grevillea Robusta in Ethiopia: Linking Establishment of a Breeding Seedling Orchard to the Economic Returns of Quality Plantings*. https://www.doi.org/10.17528/cifor-icraf/008579.

Pelissari, F., Silva, C.J. and Vieira, C.V. 2013. Classification for Tolerance and the Storage to Desiccation Seed *Cassia fistula* L. *Scientific Electronic Archives* 2: 1-5. https://doi.org/10.36560/20201315.

Seid, M.A. and Gebeyehu, M.N. 2024. Morphological variations between provenances of *Vachellia abyssinica* Hochst. ex Benth. and *Cordia africana* Lam. from different seed sources in Ethiopia. *Annals of Arid Zone* 63(4): 171-183. https://doi.org/10.56093/aaz.v63i4.151127.

Seid, M. A., Wondimu, T., Degu, A. and Assefa, A. 2024. Seed Germination Enhancement of *Ziziphus spina-christi* (L.) Willd. and *Ziziphus mucronata* Willd. (Rhamnaceae) Using Different Pre-sowing Treatments in Ethiopia. *Annals of Arid Zone* 63(4): 159-169. https://doi.org/10.56093/aaz.v63i4.154240.

Smith, T.P., Wilson, S.B., Marble, S.C. and Xu, J.-J. 2023. Propagation for commercial production of sweet acacia (Vachellia farnesiana): A native plant with ornamental potential. *Native Plants Journal* 23(3): 337-348. https://doi.org/10.3368/npj.23.3.337.

Taye, S., Negeyo, D. and Kelil, S. 2022. Soil seed bank study and propagation methods of selected gums and resin producing tree species in Wachile District of Borana Zone. *Agriculture, Forestry and Fisheries* 11(1): 21. https://doi.org/10.11648/j.aff.20221101.14.

Teketay, D. 1996. *Seed Ecology and Regeneration in Dry Afromontane Forests of Ethiopia*. https://agris.fao.org/agris-search/search.do?recordID=SE9611954.

Teketay, D. 2005. Seed and regeneration ecology in dry Afromontane forests of Ethiopia: I. Seed production - population structures. *Tropical Ecology* 46(1): 29-44.

Teketay, D. and Granström, A. 1997. Seed viability of Afromontane tree species in forest soils. *Journal of Tropical Ecology* 13(1): 81-95. https://doi.org/10.1017/S0266467400010270.

Teklay, T. 2005. *Organic Inputs from Agroforestry Trees on Farms for Improving Soil Quality and Crop Productivity in Ethiopia*. https://pub.epsilon.slu.se/988/1/Thesis-Final-_TT.pdf.

Tenkir, E., Bekele, T., Demissew, S. and Aynekulu, E. 2024. Site Suitability, Early Survival, and Growth Performance of Five Indigenous Tree Species to Integrate in Urban Green Space of Addis Ababa, Ethiopia. *Arboriculture and Urban Forestry* (AUF) 50(2): 169-184. https://doi.org/10.48044/jauf.2024.003.

Tesfay, A., Tewolde-Berhan, S., Birhane, E., Rannestad, M.M., Gebretsadik, A., Hailemichael, G., Haile, M. and Gebrekirstos, A. 2024. Edible Indigenous Fruit Trees and Shrubs in Tigray, Ethiopia. *Trees, Forests and People* 100525. https://doi.org/10.1016/j.tfp.2024.100525.

Thuo, B.M., Thoithi, G.N., Maingi, N., Ndwigah, S.N., Gitari, R.N., Githinji, R.W. and Otieno, R. 2017. *In vitro* anthelmintic activity of Albizia gummifera, Crotalaria axillaris, Manilkara discolor, Teclea trichocarpa and Zanthoxylum usambarense using sheep nematodes. *The African Journal of Pharmacology and Therapeutics* 6(1). http://journals.uonbi.ac.ke/ajpt/article/view/1552.

Tree Aid 2024. An update from our Future Forest project in Ethiopia. Brunswick Court, Brunswick Square, Bristol, BS2 8PE. https://www.treeaid.org/blogs-updates/future-forest-project-update/.

Trusiak, M., Plitta-Michalak, B.P. and Michalak, M. 2022. Choosing the Right Path for the Successful Storage of Seeds. *Plants* 12(1): 72. https://doi.org/10.3390/plants12010072.

Vincent, B., Bourillon, J., Gotty, K., Boukcim, H., Selosse, M.-A., Cambou, A., Damasio, C., Voisin, M., Boivin, S., Figura, T., Nespoulous, J., Galiana, A., Maurice, K. and Ducousso, M. 2024. Ecological aspects and relationships of the emblematic Vachellia spp. exposed to anthropic pressures and parasitism in natural hyper-arid ecosystems: ethnobotanical elements, morphology, and biological nitrogen fixation. *Planta* 259. https://doi.org/10.1007/s00425-024-04407-0.

Wawrzyniak, M.K., Michalak, M. and Chmielarz, P. 2020. *Effect of different conditions of storage on seed viability and seedling growth of six wild fruit woody plants. Figshare dataset*. https://doi.org/10.6084/m9.figshare.9080513.

Yeshiwas, Y., Tadele, E. and Tiruneh, W. 2019. The dynamics of medicinal plants utilization practice nexus its health and economic role in Ethiopia: A review paper. *International Journal of Biodiversity and Conservation* 11(1): 31-47. https://doi.org/10.5897/IJBC2018.1201.

Yibeltal, T. 2017. Contingent Valuations of Indigenous Timber Tree Resources: The Case of Cheha District, Gurage Zone, Ethiopia. *Journal of Economics and Sustainable Development*, *8*(21): 93-101. https://www.iiste.org/Journals/index.php/JEDS/article/download/39771/40888.

Yirgu, A., Manjur, B., Haile, A., Girmay, T., Getnet, D., Gezahgne, A. and Guilbert, E. 2017. Leaf defoliators associated with Cordia africana Lam. in Ethiopia. *African Entomology 25*(1): 108-112. https://doi.org/10.4001/003.025.0108.

Yousefpour, R., Nakamura, N. and Matsumura, N. 2020. Forest management approaches for climate change mitigation and adaptation: A comparison between Germany and japan. *Journal of Sustainable Forestry* 39(6): 635-653. https://www.doi.org/10.1080/10549811.2020.1771376.

Yu, F., Zhang, M., Yang, Y., Wang, Y. and Yi, X. 2024. Seed size and dispersal mode select mast seeding in perennial plants. *Integrative Zoology*. https://doi.org/10.1111/1749-4877.12874.

Printed in December 2025