

HIGH GERMINABILITY CAN FACILITATE RECOVERY OF *ADELIA VASEYI* (EUPHORBIACEAE), AN IMPERILED TAMAULIPAN THORNSCRUB SHRUB

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ABSTRACT

While critical to maintaining dryland biodiversity and drought resilience, reforestation has been limited in subtropical dry forests because of knowledge gaps in seed biology that must be filled to upscale seedling production and ensure recovery of imperiled endemic plants. We characterized seed germination, dormancy, and storage needs for *Adelia vaseyi*, a threatened endemic shrub commonly included in planting mixes to restore Tamaulipan thornscrub, an imperiled subtropical forest spanning South Texas and Northeastern Mexico. We found *A. vaseyi* seeds have high germinability (82.0%) and a short mean germination time (3.04 ± 0.08 days). *A. delia vaseyi* seed does not appear to have physical or other dormancies and may have orthodox behavior maintaining their viability with a moisture content of 6.7%, which is adequate for long-term storage. Our results indicate that *A. vaseyi* can be readily propagated in nurseries and seed banked for future recovery actions. Conversely, its high germinability and lack of dormancy hint there are no inherent constraints to germination, suggesting that natural seedling recruitment may instead limit population growth in the wild. Therefore, reforestation with nursery-grown seedlings of *A. vaseyi* may be necessary to support recovery of this threatened shrub.

KEY WORDS: germination; threatened plant; restoration; species recovery; Texas

RESUMEN

Aunque fundamental para mantener la biodiversidad de las zonas áridas y su resiliencia a la sequía, la reforestación bosques secos subtropicales ha sido limitada debido a carencias en el conocimiento de la biología de las semillas. Dichas carencias limitan la producción de plántulas a mayor escala que podría garantizar la recuperación de plantas endémicas y en peligro. Caracterizamos la germinación, la dormancia, y requerimientos de almacenamiento de semillas de *Adelia vaseyi*, un arbusto endémico amenazado que se incluye con frecuencia en plantaciones para restaurar el matorral espinoso Tamaulipeco, un bosque subtropical en peligro que se extiende en el sur de Texas y el noreste de México. Encontramos que las semillas de *A. vaseyi* tienen una alta germinación (82.0 %) y un tiempo medio de germinación corto (3.04 ± 0.08 días). Las semillas de *A. vaseyi* no parecen tener dormancia física ni de otro tipo y pueden tener un comportamiento propio de semillas ortodoxas, ya que que mantienen su viabilidad con un contenido de humedad del 6.7 %, adecuado para el almacenamiento a largo plazo. Nuestros resultados indican que *A. vaseyi* puede propagarse fácilmente en viveros y almacenarse en bancos de semillas para futuras acciones de recuperación. Por el contrario, su alta germinación y ausencia de dormancia sugieren que existen pocas limitaciones inherentes a la germinación, lo que apunta al reclutamiento natural de plántulas como limitante al crecimiento poblacional en estado silvestre. Por lo tanto, la reforestación con *A. vaseyi* parece ser necesaria para la recuperación de poblaciones de este arbusto amenazado.

INTRODUCTION

Reforestation is a growing approach to address dryland deforestation. Globally, dryland forests were decimated by rapidly expanding farms and cities over the past century (Bastin et al. 2017; Rivas et al. 2025). Recently, conservation efforts have intensified in these habitats, particularly as the ongoing United Nations Decade on Ecosystem Restoration (2021–2030) is calling to halt degradation and restore ecosystems.

Reforestation of degraded drylands is viewed as critical to improve drought resilience and protect biodiversity (Tuinenburg et al. 2022; Rayden et al. 2023). Dryland forests, particularly those in subtropical and tropical regions, are frequently noted as biodiversity hotspots, harboring high species diversity including endemic species (Miles et al. 2006; Buchadas et al. 2023). Restoring these habitats frequently involves planting a wide variety of trees in large numbers as an attempt to rebuild some of the original forest composition, structure, and function lost to deforestation (Bastin et al. 2017; Holl 2020). Reforestation can involve direct seeding or planting seedlings, but frequently, these efforts are limited by the lack of available seeds or the production of sufficient seedlings required to restore large areas of degraded drylands (Holl & Brancalion 2020).

Expanding reforestation efforts in drylands will require increasing the available number of seeds and seedlings, but this is complicated by knowledge gaps in seed biology of many dryland species (Luera 2021). Generally, dryland species are understudied, which means there are few published protocols or natural history studies that document seed germination, dormancy, and storage requirements for many species of interest to reforestation (Ohse 2023). These knowledge gaps are most prominent in subtropical and tropical dryland forests (Cazzolla Gatti et al. 2022), where reforestation needs are the most acute to preserve water resources and biodiversity (Buchadas et al. 2023). The Tamaulipan thornscrub encompasses dryland subtropical forests that span from South Texas to Northeastern Mexico and are home to a variety of trees and shrubs with phylogenetic links to those of central Mexico's tropical forests (Brush 2005). Since the 1980s, there has been extensive reforestation of thornscrub along the Rio Grande between Texas and Mexico involving around forty species, but the number of acres successfully restored has been limited due to various factors, including access to seedlings representative of old growth thornscrub (Ewing & Best 2004). This is especially problematic for endemic species, such as *Adelia vaseyi* (J.M. Coult.) Pax & K. Hoff., or Vasey's wild lime, that are imperiled due to declining populations range-wide and have little natural history data to support seedling propagation (Texas Parks and Wildlife 2025; NatureServe 2025). Large scale propagation of this species has been flagged as problematic by contract seedling growers who frequently report low germination (pers. comm.).

In this study, we characterized the seed biology of *Adelia vaseyi*, a dioecious shrub typically found in small populations scattered throughout Tamaulipan thornscrub in South Texas and along the US-Mexico border in Northeastern Mexico (Richardson & King 2011). Recently, *A. vaseyi* was listed as imperiled in Texas because its remaining natural populations are declining, which places the species at moderate risk for extinction (NatureServe 2025). Reintroducing and augmenting existing populations of *A. vaseyi* through reforestation can preclude extinction while supporting the high diversity of woody species characteristic of Tamaulipan thornscrub. We collected *A. vaseyi* seeds from thornscrub remnants in the Rio Grande Valley in South Texas and characterized its germination process, verified possible dormancy, and inferred the ability to store seeds after desiccation, a necessity for recovery efforts. The objectives included to contribute knowledge that inform how well this species can be propagated at a larger scale from wild seed, and if any seed treatment is needed to improve propagation outcome and support seedling production.

MATERIALS AND METHODS

Seed Collection

We obtained *Adelia vaseyi* seeds from multiple individuals (8–10) in various thornscrub remnants in Cameron County, Texas. We collected fruits when they reached morphological maturity (i.e., full seed size with endosperm and well-formed embryo; Fig. 1) but prior to dehiscence. To extract seeds, fruit capsules were exposed to 30°C in a convection oven for six to seven days in a closed container to prevent seeds being lost due to ballistochory. The extracted seeds were pooled and air dried for 14 more days at room temperature (23°C).

Germination tests

We determined germinability, weighted germination time, mean germination rate, coefficient of variation of germination time, and germination synchrony for *Adelia vaseyi* seeds, following the approach of (Ranal et al. 2009). These parameters of the germination process can define the suitability of *A. vaseyi* seedlings to be



FIG. 1. Close view of *Adelia vaseyi* fruit and seed. Fully developed embryo and endosperm visible in bottom-left view. Note thin seed coat allowing water imbibition.

efficiently produced in nurseries. This data also provides insights into early life history traits for the species. We initiated germination trials by soaking 250 seeds in continuously aerated deionized (DI) water for 24 hours (Larson 1968; Basra et al. 2005), after which we soaked seeds in a 0.6% NaOCl solution for 2 minutes followed by rinsing with DI water three times (Gilbert et al. 2023). We placed 50 seeds in five replicate petri dishes lined with paper towels, which we continuously kept moist with DI water over the duration of the tests. Seeds were incubated at 27°C with a 12-hour photoperiod (Milberg 1996). We recorded the number of germinants per plate daily and terminated tests after 10 days passed without further germination. Seeds were considered germinated if they had a 2 mm long radicle (Basra et al. 2005; Musara et al. 2015). At the end of the trial, we verified the viability of ungerminated seeds by cutting seeds longitudinally and immersing them in a 2,3,5 - triphenyl-2H-tetrazolium chloride solution (1%) for four hours at 40°C (Souza et al. 2010; Paiva et al. 2017). Any embryos that stained pink were scored as live while unstained embryos were scored dead.

We determined germinability as the percentage of germinants per plate at the end of the trial. Weighted mean germination time is the mean time from the start of a germination test to the time when seeds germinated in a plate. We observed germination time for each seed in each plate. Total germinated seeds count was used to calculate it (Ranal & Santana 2006). The mean germination rate is the reciprocal of the weighted germination time, which we also calculated for each plate. The coefficient of variation is the standard deviation of germination time divided by the mean germination time for each plate, and it indicates uniformity of the germination process. The synchrony of germination measures the degree of germination overlapping over time (Ranal & Santana 2006), which we determined for each plate. This is a critical parameter for nursery propagation because it allows for smoother nursery operations. Ideally, seeds should germinate simultaneously, resulting in a more uniform crop of seedlings that arrive at the prescribed planting size around the same time.

Imbibition tests for dormancy

We verified if *Adelia vaseyi* seeds have physical dormancy by assessing their ability to readily absorb water. We distributed 100 *A. vaseyi* among five plates with a coordinate grid drawn at the base and lined with paper towels. We weighed each dry seed individually and placed it within a grid location on a plate. We then placed a DI-soaked paper towel for 48 hours at room temperature over all seeds on a given plate. We then weighed each seed individually to determine how much water each seed absorbed (Larson 1968). We estimated the percentage of water absorbed by dividing the wet weight by the dry weight of each seed.

Seed moisture content analysis

From the seed lot used in germination testing, we weighed 100 air-dried seeds and placed them in a drying oven at 103°C for 17 hours (ISTA 2023). After oven drying, we cooled seeds to room temperature in a silica bead desiccator for 30 minutes and then recorded dry weights for each seed (Miao et al. 2014). We calculated moisture content by dividing dry weight after oven drying by its air-dried weight before oven drying.

RESULTS

Germination tests

Adelia vaseyi seeds can be classified as orthodox; they remain viable and germinated abundantly after desiccation (air drying) to low moisture content (6.67%). Germinability was high at $82.0 \pm 7.3\%$, occurring between 2 and 7 days, with maximum cumulative germination attained after about 4 days (Fig. 2). The mean weighted germination time was short at only 3.04 ± 0.08 days with some germination happening at 2 and 4 days (Fig. 3). The mean germination rate was $0.33 \pm 0.01 \text{ day}^{-1}$. The coefficient of variation of the germination time was $3.41 \pm 0.08\%$, indicating a relatively uniform process. Synchrony of germination was 0.56 ± 0.04 which is considered moderate (a value of one means germination of all seeds occurred at same time, zero when all seeds germinated at different times). Seeds that did not germinate during the trial were found to be not viable as confirmed by the tetrazolium test.

Water imbibition test and desiccation tolerance

Results from the imbibition test indicate that *Adelia vaseyi* seeds absorb water well, with a mean increase in

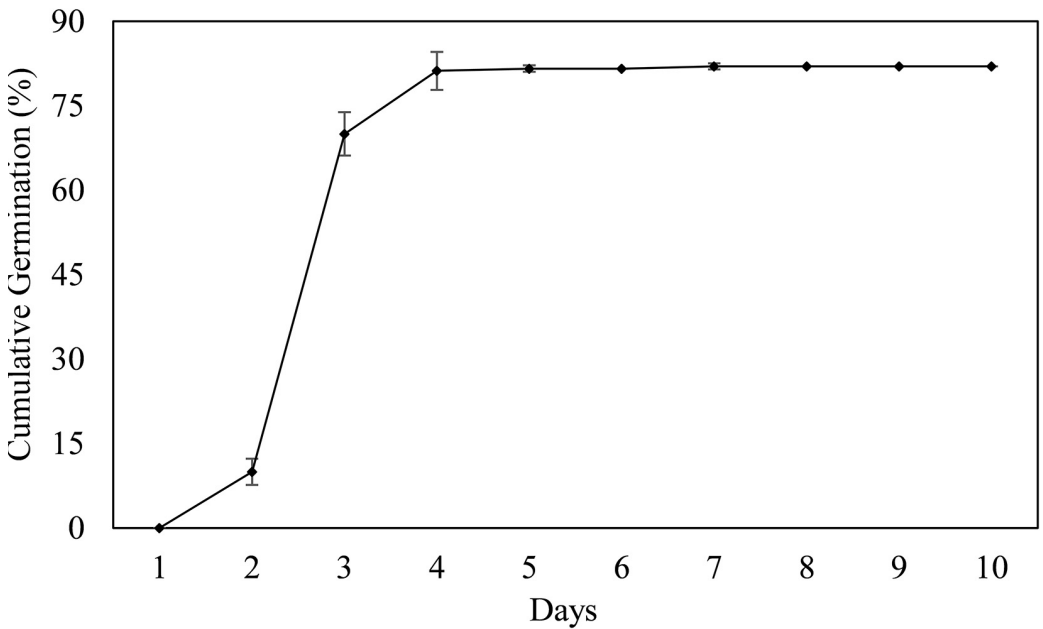


FIG. 2. Cumulative germination of *Adelia vaseyi* seeds during the germination trial. Values represent means and error bars represent standard deviation of five replicate plates. Each plate had 50 seeds.

weight of 42.9% after 48 hours. This suggests that seeds do not present physical dormancy and would not benefit from seed coat scarification to enhance germination. Air dried seeds reached a low moisture content (6.67%) and were stored for a few weeks before the germination test, suggesting that *A. vaseyi* may be stored in the same conditions as other orthodox seeds.

DISCUSSION

This study showed high germinability, short germination times, and little variation in germination traits of *Adelia vaseyi* seeds which suggest that this species can be readily propagated from seed for species recovery or reforestation of Tamaulipan thornscrub. This contrasts with other thornscrub species, such as *Cordia boissieri* and *Zanthoxylum fagara*, that coexist with *A. vaseyi* in old growth thornscrub remnants but have low germinability, 40% and <1% respectively (Luera 2021) with high variability (personal observations). In addition to high germinability, *A. vaseyi* seeds have a short germination time of two to four days and fair synchrony, suggesting the potential to grow seedlings under nursery conditions at large scales required for reforestation. This would augment restoring forest diversity and establish new populations of *A. vaseyi* within its historic range. *Adelia vaseyi*'s germination time is comparable to other thornscrub species (personal observations), and more generally, dryland flora, which germinate within a few days (Fenner & Thompson 2005). We observed little variation in germination time and a low coefficient of variation, suggesting there is high uniformity in germination for *A. vaseyi* seeds. Several thornscrub species, including frequently planted trees like *Ebenopsis ebano*, show high variation in germination traits (Luera 2021) in the absence of seeds coat treatments (personal observation), which complicates nursery management, sometimes resulting in insufficient numbers of seedlings available for reforestation projects. Regional contract seedling growers have reported low germinability of *A. vaseyi* seeds observed as seedling emergence, which is not in alignment with our results (personal communications). We collected fully developed fruits prior to dehiscence. Due to ballistochory occurring in this species, it is possible that growers sometimes collect fruits not yet fully developed in

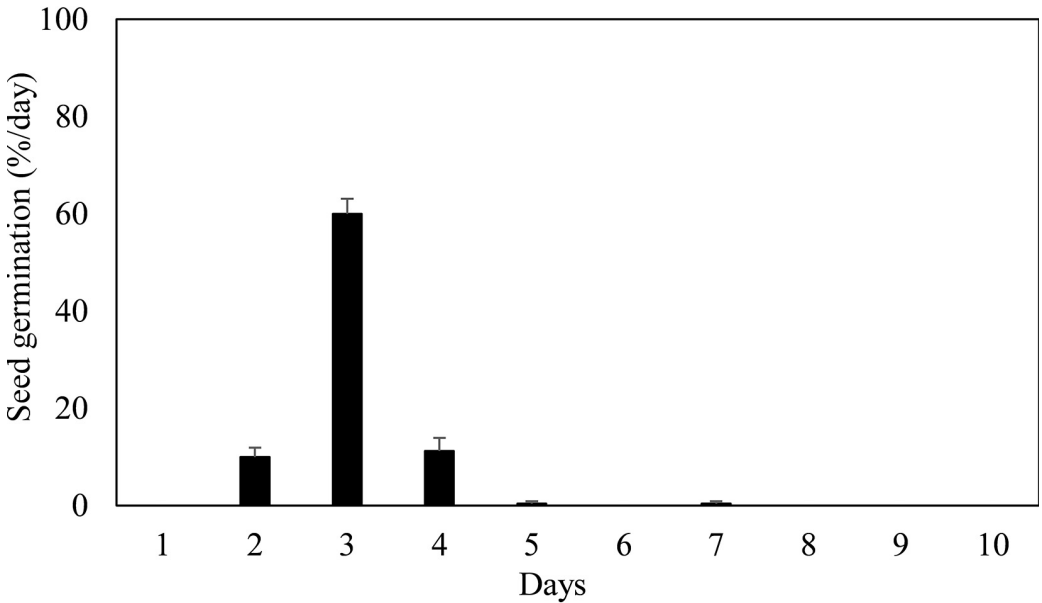


FIG. 3. Germination per day of *Adelia vaseyi* seeds. Values represent means and error bars represent standard deviation of five replicate plates. Each plate had 50 seeds. Most seeds germinated after three days.

an effort to avoid seed loss due to explosive dehiscence of fruits. Storage conditions and duration can affect seed viability and might also partially explain this discrepancy.

High germinability observed in *Adelia vaseyi* also suggests that there are few barriers to germination in natural populations, but seedling recruitment and survival may limit population growth. While laboratory conditions cannot capture conditions in wild populations, our study used seeds pooled from various populations, suggesting there are few generalized constraints to germination. It might be assumed that *A. vaseyi*'s high germinability is common across its species range, which is geographically restricted to Tamaulipan thornscrub near coastal areas (Richardson & King 2011). Survey data suggests steep population declines in *A. vaseyi* in South Texas, leading to its recent listing as vulnerable to extinction and as a species of conservation concern in Texas (NatureServe 2025). These declines may be aggravated by poor seedling recruitment and survival, which has been documented for similar species (Shriver et al. 2021). Herbivory, drought, and competition from non-native grasses have been implicated in poor seedling outcomes in thornscrub restoration efforts, but reforestation utilizing shelter tubes can attenuate these pressures (Alexander et al. 2016).

Given that there is little apparent intraspecific variation in germination time, it was expected that *Adelia vaseyi* would demonstrate higher germination synchrony, but we observed moderate synchrony. This may not be a practical difficulty for growers since all germination occurred within 7 days, the large majority in 2 to 4 days. This moderate synchrony may be advantageous for *A. vaseyi* because it does not appear to have any dormancy as observed from imbibition testing in this study. Lower synchrony produces flexibility in when *A. vaseyi* can germinate, increasing the chance of seedling survival despite unpredictable rain events (Dos Santos et al. 2023; Londoño-Lemos et al. 2024). The absence of dormancy and some level of within-season germination asynchrony hints that annual seedling recruitment may limit population growth, making reforestation a critical activity for the recovery of this species.

Adelia vaseyi appears to have orthodox seed behavior given that seed moisture content was below 10% in the seeds we tested, yet germinability was high. Assessment of long-term effects of conventional seed banking storage conditions on seed viability is necessary to better characterize seed storage behavior. Assuming *A.*

vaseyi has orthodox seeds, conventional seed banking for this species would be a safe strategy to preserve its remaining germplasm from natural populations as well as seed storage for nursery propagation (Center for Plant Conservation 2019).

Our study demonstrates seeds from *Adelia vaseyi* have high germinability, have no dormancy requirements, and can be dried for conventional seed storage—qualities that make this species amenable to nursery propagation and seed banking. Conversely, its lower germination synchrony and lack of dormancy elevate the importance of planting seedlings grown ex-situ from seeds for species recovery as these data suggests seedling recruitment and survival, not germination, may be limiting natural population growth.

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