Hawaiʻi Seed Bank Partnership: Best Management Practices—Seed Drying June 2025

Purpose

The Hawaiʻi Seed Bank Partnership (HSBP) presents the following best management practices for drying seed to obtain optimal storage conditions in a seed bank.

HSBP Seed Drying Recommendations

- For long-term storage (10+ years), at both 5°C and -18°C, seeds should be dried at **20% Relative Humidity (RH) at ~20°C**
- Aim to achieve these RH targets with a **tolerance of ± 3%**
- This protocol, for plants native to Hawaiʻi, assumes the species is **not desiccation-sensitive or extremely short-lived**. Refer to the Seed Bank User's Guide to find this information for your species.
- This **unified protocol** simplifies procedures, improves seed longevity, and mitigates risks posed by under-drying. Each seed is unique, and **species-specific protocols** that differ from these may improve longevity for certain taxa in storage.

Advancements in Seed Storage Research

The longevity of orthodox seeds is significantly increased by desiccation (drying) and cooling. Early observations by Ewart (1908) first highlighted the varying storage durations among species. Building on this, Harrington (1960) developed "thumb rules," which posited that seed lifespan doubles for every 5.6°C decrease in storage temperature or 1% decrease in seed moisture content. Crucially, these rules apply independently, and their effects on longevity are multiplicative. Seven years later, James (1967) introduced the "James rule," also known as the "100 rule," stating that the sum of temperature in degrees Fahrenheit and relative humidity (%RH) should not exceed 100 for optimal seed storage (or 60 if using degrees Celsius). While much more has been discovered about seed conservation since then, these foundational rules continue to provide valuable baselines for storing orthodox and temperature-sensitive seeds.

Understanding the Relationship Between Seed Moisture and Longevity

Significant progress in understanding the relationship between seed moisture content and longevity emerged over the subsequent decades. One of the most impactful developments was the introduction of viability equations (Ellis & Roberts, 1980), which mathematically describe the decline of seed viability as a function of moisture and temperature. These equations are comprehensively explored on the online seed information database, https://ser-sid.org. Although other models have been developed (e.g., Walters, 1998), readily available online viability tools and step-by-step guides (e.g., Wolkis et al., 2025) are not yet widely available. While these models have undergone extensive testing for some orthodox species, their predictive accuracy for the storage longevity of Hawaiʻi's flora largely remains to be determined.

Evolving Drying Protocols and Best Practices

Research at local, national, and international levels has consistently refined the protocols for preparing seeds for storage. In 2004, the Society for Ecological Restoration International and the Center for Plant Conservation (CPC) published drying protocols in *Ex Situ Plant Conservation: Supporting Species Survival in the Wild* (Guerrant et al., 2004). This publication suggested drying seeds at 25°C (approximately ambient temperature) to 33% RH for storage at 5°C and 46% RH for storage at -18°C. The Hawaiʻi Seed Bank Partnership adopted this protocol, incorporating it into the Hawaiʻi World Conservation Congress (WCC) 2016 Conservation Handbook. Since then, the CPC has continued to publish and maintain a revised and comprehensive set of Best Practices to support species survival, offering guidelines that enhance conservation management strategies to prevent plant extinction.

Best Practices from the Food and Agriculture Organization of the United Nation's Genebank Standards for Agriculture (FAO, 2014) and the Royal Botanic Gardens, Kew Millennium Seed Bank Project Seed Conservation Standards (MSB, 2015), provide guidelines for seed storage, including recommendations that the drying RH may be lower than initially suggested to achieve optimum 20% RH in storage. These guidelines extend to maintaining living collections, monitoring wild populations, tissue culture techniques, and cryopreservation, serving as an invaluable resource for all plant conservation practitioners.

The Hawaiʻi Seed Bank Partnership has also made significant advancements in understanding seed storage behavior within Hawaiʻi's flora. In 2019, Chau et al. conducted research to determine optimal seed storage conditions and recommend re-collection intervals (RCI) to maximize the viability of stored seeds. By analyzing over 20 years of real-time seed storage viability data, they assessed freeze sensitivity and calculated RCIs at 70% of the highest germination (P70). This crucial research guides restoration practices in Hawaiʻi and informs global seed conservation efforts, particularly in tropical and subtropical regions. The study revealed that the majority of the 295 species tested were orthodox, with most exhibiting re-collection intervals greater than 10 years. Notably, four families and four genera contained species that were temperature-sensitive at -18°C and, therefore, should not be stored at this temperature.

Research continues at institutions worldwide, both local and global, to guide best practices for seed storage. These best practices will continue to evolve as our understanding improves. For more resources on seed behavior, please see the Center for Plant Conservation's (CPC) Best Practices for Seed Banking, SER Seed Informational Database, FAO Genebank standards, practical guides to the genebank standards, RBG Kew Millenium Seed Bank Technical Sheets, Standards, Videos, and manuals, and the literature referenced below.

Contemporary Research: Lyon Arboretum Seed Conservation Lab

At the Lyon Arboretum Seed Conservation Lab (LASCL), approximately 80 temperature-sensitive and 75 orthodox taxa were dried and stored in ultra-dry conditions of ~10% RH at 5°C and -18°C, respectively. For comparison, seeds from the same accessions were dried under CPC standards (~30-40% RH at ~20°C). After drying, both sets of seeds were then hermetically sealed and stored at -18°C or 5°C. We recently analyzed 25 years of germination data from the LASCL database, comparing tests from the same time, substrate, and dormancy pre-treatment conditions to control for variability. The analyses at -18°C and 5°C were conducted separately due to the influence of temperature on seed longevity. We applied a linear mixed-effects model (LMM) to estimate the effect of RH on germination, treating RH and storage duration as fixed effects, and germination rate (%) as the response variable. The effects of individual taxa were included as a random effect to account for species-specific variation in germination rate.

For seed collections of both temperature-sensitive and orthodox storage behavior, storage time had a significantly negative effect on germination rates. As expected, germination decreased with increasing storage time. However, there was no significant difference in germination response between the ultra-dry and traditional drying treatments. Although we did not measure moisture content directly, ultra-dry storage, also called low moisture content storage, is a technique for decreasing seed moisture content below 5-6% (Ashok et al., 2017).

Despite finding no significant difference among desiccation treatments, our results suggest that drying seeds below CPC's recommended RH values (~10%) can maintain (not deleterious to) longevity in species that exhibit orthodox and temperature-sensitive seed storage behavior. Alternatively, any potential adverse effects of ultra-drying may be masked by viability decline resulting from under-drying via CPC's methods. BlueMaestro sensor data indicate that CPC drying protocols (~30-40% RH at ambient temperature) do not achieve the target ~20% eRH in storage, whereas lowering the initial drying environment (i.e., ~20% RH at 20°C) consistently results in ~20% eRH once stored.

Discussion: Updated HSBP Seed Drying Best Management Practices

Based on research conducted by the HSBP (see Contemporary Results from the Lyon Arboretum Seed Conservation Lab), the updated drying protocol aims for a Relative Humidity below previously-recommended levels but above ultra-dry conditions. This protocol aligns with international standards and is achievable across a variety of seed storage facilities statewide, providing conservative, long-term storage conditions for native species with orthodox and temperature-sensitive storage behavior. The updated protocol is:

For long-term storage (10+ years), at both 5°C and -18°C, seeds should be dried at 20% Relative Humidity (RH) at ~20°C.

Practitioners should feel comfortable achieving RH targets within ±3 % while drying seeds. This unified approach simplifies protocols, improves seed longevity, and mitigates risks posed by under-drying. However, for facilities with fewer resources or those focusing on short- to mid-term storage, the previously recommended ~30-40% RH at room temperature for cold storage remains a viable option. Drying seeds at temperatures lower than the storage temperature is not cost-effective and is therefore strongly discouraged. Tailoring drying strategies to specific capacity and storage objectives will ultimately strengthen seed conservation efforts.

This protocol aims to optimize seed longevity for both long-term (>10 years) and short-term (<10 years) collections in a conventional freezer (-18°C), and a refrigerator (5°C) for seeds of orthodox and -18C-sensitive (for storage not at –18°C) taxa. The protocol assumes the species is not desiccation-sensitive or extremely short-lived. Please refer to the Seed Bank User's Guide to find this information for your species. If conditions are unknown, please contact Nate Kingsley at the University of Hawai'i Lyon Arboretum's Seed Conservation Laboratory (nkingsle@hawaii.edu) and Kim Shay at Laukahi (coordinator@laukahi.org).

For more information on drying methods, please refer to the following documents on seed banking protocols:

- Seed drying
- Relative humidity using salts
- Silica gel drying
- Determination and control of seed moisture
- Module VI Drying Seeds in CPC's Applied Conservation Course
- Low-cost monitors of seed moisture status
- Equilibrating seeds to specific moisture levels

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