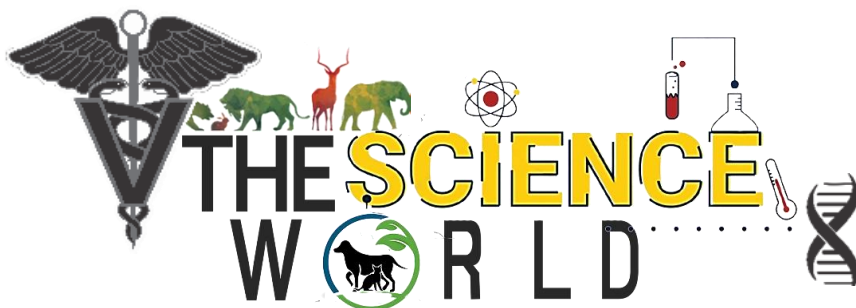




A Monthly e Magazine

ISSN:2583-2212

Popular article

July, 2026 Vol.6(7), 1922-1925

Seed Storage Technologies

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doi.org/10.5281/ScienceWorld.21337609

Introduction

Seeds are living packages of the future each one carrying the genetic blueprint of a plant, suspended in a state of low metabolic activity until conditions favor germination. This dormancy is not passive; it is a finely regulated biological state that can be extended for years, decades, or even centuries if the seed is stored correctly. As agriculture faces mounting pressure from climate change, shrinking biodiversity, and the need to safeguard crop genetic resources, seed storage has evolved from a simple farmer's practice into a rigorous applied science combining physiology, biophysics, and engineering.

The Physiology Behind Longevity

Most crop seeds fall into one of two broad physiological categories: orthodox and recalcitrant. Orthodox seeds found in cereals, legumes, and many vegetables can be dried to very low moisture content without injury, and their longevity increases predictably as moisture and temperature are reduced. Recalcitrant seeds, typical of many tropical trees and some fruit crops, cannot tolerate desiccation below a relatively high moisture threshold and lose viability quickly regardless of temperature, making them far harder to store long-term. Between these extremes lie intermediate types, which tolerate partial drying but remain sensitive to freezing.

The scientific basis for predicting orthodox seed longevity was formalized by Roberts, whose seed viability equation expressed the logarithm of the mean viability period as a function that decreases with the logarithm of moisture content and decreases linearly with temperature, within a defined moisture range over which the relationship holds. This



relationship, later refined by Ellis and Roberts into the widely used "viability equations," remains the theoretical backbone of modern genebank storage protocols: within the valid moisture range, every reduction in moisture content or temperature extends storage life, but the relationship is not open-ended below a species-specific lower moisture limit the log-linear relationship breaks down, and further drying yields no additional benefit and may even cause desiccation-related injury in some species.

At the cellular level, deterioration during storage is driven by the accumulation of oxidative damage, lipid peroxidation in membranes, and slow degradation of nucleic acids and proteins. Water acts as both a reactant and a plasticizer; reducing its availability slows these degenerative reactions by limiting molecular mobility within the cytoplasm, which behaves as an amorphous, glass-like solid at very low moisture levels. Maintaining seeds in this "glassy state" is central to modern long-term storage strategy, since it dramatically slows the diffusion-dependent chemical reactions responsible for aging.

Storage Methods in Practice

Traditional seed storage relied on ambient conditions clay pots, granaries, or simply dried seed kept in cool, shaded rooms and remains widespread among smallholder farmers globally. While inexpensive, these methods offer poor control over humidity and temperature and are vulnerable to insect and rodent damage, resulting in significant viability losses within one or two seasons for many species.

Modern genebanks instead rely on controlled environmental storage, categorized broadly by duration of intended use. Short and medium-term "active collections," used for regeneration, characterization, and distribution, are typically held at around 0 to 10 degrees Celsius, with seeds dried to a moisture content appropriate for the species, allowing viable storage for years to a couple of decades. Long-term "base collections," meant to conserve genetic diversity for the future, are stored at minus 18 degrees Celsius or below, after drying seeds to moisture content equilibrium with approximately 15 percent relative humidity air at 5 to 20 degrees Celsius the internationally recommended standard for orthodox species conditions under which many species can remain viable for decades to centuries. For species or genetic materials that cannot be conserved as dry seed including recalcitrant seeds, vegetatively propagated crops, and elite breeding lines cryopreservation in liquid nitrogen at around minus 196 degrees Celsius offers a further option, effectively halting biochemical activity altogether, though it requires specialized cryoprotection protocols to prevent ice-crystal damage to tissues.



Packaging complements these environmental controls. Moisture-proof containers such as heat-sealed aluminum foil laminate pouches or airtight glass and metal containers with desiccants prevent seeds from re-absorbing atmospheric moisture, which would otherwise negate the benefits of drying. Periodic viability monitoring through germination testing is essential, since even well-stored accessions require regeneration once germination percentage falls below an agreed threshold, ensuring that genetic material is refreshed before it is lost.

Storage Type	Temperature	Seed Moisture Content	Approximate Longevity	Typical Use
Traditional/ambient	Room temperature (variable)	Variable, often >10%	Months to 1–2 years	On-farm seed saving
Short-term (active collection)	0–10 °C	Species-appropriate, dried below field level	Years to ~20 years	Regeneration, breeding, distribution
Long-term (base collection)	≤ –18 °C	Equilibrated with ~15% relative humidity at 5–20 °C (roughly 3–7% for most orthodox species)	Decades to centuries	Long-term genetic conservation
Cryopreservation	–196 °C (liquid nitrogen)	Species-specific cryoprotection protocol required	Potentially indefinite	Recalcitrant seeds, elite lines, vegetative tissues

Global Efforts and Future Directions

These principles underpin some of the most consequential conservation infrastructure in the world today. National and international genebanks, coordinated through frameworks associated with the Food and Agriculture Organization and the global network of institutions safeguarding plant genetic resources, apply these storage standards to preserve crop diversity against genetic erosion. The Svalbard Global Seed Vault, built into permafrost on a Norwegian



archipelago, exemplifies this approach at its most secure scale, serving as a backup repository for duplicate seed samples from genebanks worldwide, insulated against both technological failure and geopolitical disruption.

Looking forward, research continues to refine our understanding of the biophysical limits of seed aging, improve rapid and non-destructive viability assessment methods, and extend cryopreservation techniques to a wider range of recalcitrant and vegetatively propagated species that remain difficult to conserve by conventional drying and freezing. As pressures on global crop diversity intensify, the science of seed storage quiet and unglamorous as it may seem stands as one of humanity's most practical insurance policies against an uncertain agricultural future.

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