Seed Science Research

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Editorial

Cite this article: Hilhorst H (2020). Editorial to the Special Issue on Seed Longevity and Conservation. *Seed Science Research* **30**, 73–74. https://doi.org/10.1017/S096025852000029X

First published online: 25 August 2020

CAMBRIDGE UNIVERSITY PRESS

Editorial to the Special Issue on Seed Longevity and Conservation

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This Special Issue on Seed Longevity and Conservation is a follow-up on the ISSS-sponsored meeting on this topic in Fort Collins, USA, in 2018. This important meeting was organized by Professor Christina Walters who is also the Guest-Editor for this issue of Seed Science Research. Not only did she do a fantastic job in organizing that meeting but also in collecting several papers on the subject which are now making up this Special Issue.

The collection starts off with an overview of the conference by Hugh Pritchard which highlights the pivotal importance of long-term seed storage for both crop improvement and preservation of biodiversity. Going through all the contributions at the meeting, it becomes clear that the topic is highly diverse and covers a wide array of disciplines, including ecology, (eco) physiology, biophysics, biochemistry, (molecular) genetics, as well as various technological aspects of seed quality assessment. The overview also makes clear that seeds are by far the most important way to preserve genetic resources for the long term and considerably more research is required to increase the reliability of long-term storage of an enormous diversity of species.

The following regular contributions reflect the wide diversity in research approaches. The first is a Review by Ballesteros et al. addressing some very fundamental biophysical aspects of longevity. Central to this is the association between the rate of auto-oxidative processes occurring in the dry cells and impacting on the heterogeneous nature longevity in diverse seed types. This rate of oxidation may be affected by several cell constituents including chlorophyll and lipids.

A second Review Paper by Umarani et al. discusses the release of volatile components by dry seeds as a result of the multitude of oxidative processes, contributing to seed deterioration (ageing). As the deterioration progresses, so does the volatile spectrum, providing a basis for seed quality assessment during dry storage. This, of course, is only possible with quite advanced machinery, but its validation on a number of seed systems over recent years is establishing this non-destructive seed viability assay as a valuable tool in longevity studies.

One important 'victim' of oxidative processes in ageing seeds during dry storage is DNA. It has long been known that DNA integrity is compromised during storage and that higher temperature and humidity may accelerate this process. Comparing non-aged and aged *Mentha aquatica* seeds, Mira et al. show that random amplified polymorphic DNA profiles of aged seeds do not differ much from the non-aged but a remarkable difference was found when comparing seedlings. More specifically, they found that the differences were most prominent in methylation-sensitive amplification polymorphisms, affecting epigenetic regulation. These findings are also promising for the development of markers of nucleic acid stability during ageing and reinforce the importance of assessing germination performance beyond radicle emergence.

Similarly to DNA, RNA is very sensitive to oxidation during dry storage of seeds. Walters et al. compared RNA integrity and viability of soybean seeds stored at 5, −18 or −176°C. Their aim was to further investigate the validity of accelerated ageing conditions in relation to seed longevity. Their work makes clear that accelerated ageing conditions must reflect the 'structural context of solidified cytoplasm'. Under conditions of elevated temperature (but low moisture), this seemed to be the case and RNA integrity, as an indicator of oxidative damage, co-correlated with seed viability but at higher moisture levels, they were uncoupled. This work should be an eye-opener for those of us who are involved in seed testing, using accelerated ageing protocols.

Seed longevity is a complex trait which depends *inter alia* on genetic background, maternal effects during seed development, seed handling and storage environment. As a rule of thumb, higher initial seed quality results in better longevity. The influence of seed mass on longevity is still a matter of debate. Genna et al. present a study on *Rudbeckia mollis* seeds to address this issue. They compared longevity and viability in a number of seed mass classes at constant and fluctuating conditions. They found that the heavier seeds seemed to have an all over disadvantage over smaller seeds in terms of p_{50}, the time for viability to fall to 50% during storage. Intra-specific variation of seed longevity may have implications for subsequent phases of the plant's life cycle and, hence, on restoration projects. Underlying questions about adaptation strategies and sibling competition are evident.

Seeds may employ a vast array of antioxidants to counteract oxidative attack. A well-known anti-oxidant is the lipid-soluble Vitamin E, a likely protector of cellular membranes. Lee et al. used a collection of 185 Aus rice varieties to test the hypothesis if certain types of Vit E correlate with seed longevity at the genetic level. Genome-wide association mapping, combined with Vit E assays revealed associations of three genetic markers with the Vit E type δ-tocopherol and Ki, the initial seed viability before storage, whereas two other markers were associated with δ-tocopherol and p_{50}. This is highly suggestive of a genetic basis of natural, intra-specific, variation in seed longevity.

Dormancy is a seed trait that is known to interact with seed longevity in several ways. Long-term dry storage may break dormancy (afterripening) but may also induce secondary dormancy. This interferes with seed viability assessments and the requirement for certain methods to break dormancy. Seglias et al. studied this interaction at a seed banking storage temperature of −20°C in six restoration-priority species in the southwestern United States. They concluded that short-term seed banking conditions did not have an appreciable effect on final germination or germination rate of these species. Only the one species which also possessed a physical component of dormancy next to the physiological showed significant differences in all germination parameters. The study also makes clear that longevity studies on a much wider variety of species are important, not only to further unravel the variation in longevity but also to create better protocols for long-term seed storage.

This was exactly one of the objectives of a study by Davies et al. They screened a collection of 22 UK native woody species for potential longevity, using accelerated ageing, in order to further optimize their conservation in a seed bank. They found that there is no direct relationship between potential longevity and species, genus or family. Of the 22 species, *Fraxinus excelsior* and *Ulmus glabra* were classified as short-lived and extra attention to seed banking for these two species seems to be necessary. Other species still performed well, even after >20 years under seed banking conditions. This study again underlines the necessity of seed longevity research at the species level and likely also at the intra-specific (e.g. ecotypes) level.

Recalcitrant seeds form a category of seeds which are extremely short-lived. Often of tropical origin, these seeds (largely) lack desiccation tolerance. This means that storage is only possible at non-critical moisture content. This allows metabolic activity which will deplete the reserves of the seed very quickly. In addition, high-moisture storage is conducive to growth of micro-organisms. Apart from *in situ* storage for the long term, *ex situ* storage is the most applied method, for example, for seeds to survive an unfavourable period before planting. Pereira et al. studied seeds of *Inga vera*, a native to the riparian forests of Southeast Brazil and of great importance to reforestation projects. The critical moisture content of this species is 28% which precludes long-term storage, the more so because the seeds are also very sensitive to temperatures <5°C. They tested storage of seeds in osmotic solutions to inhibit metabolic activity at moderately low temperature of 10°C. Under such conditions, these polyembryonic seeds could be kept for more than 200 days with germination maintained at 90% and development of one normal seedling per seed. Although not suitable for seed banking, this allows storage of the seeds until the next wet season.

Taken together, this collection of excellent papers on seed longevity highlights the fascinating biology of dry systems and how it is influenced by the environment and genetics of the species. It also emphasizes the urgency of seed longevity studies on a much wider array of species for seed banking purposes, but also for agriculture and recuperation of degraded areas. It again makes clear how important seeds are to addressing many societal challenges, including adapting to climate change, protecting against biodiversity loss, accelerating landscape recovery and supporting sustainable development.

With this, I want to thank all the authors for their excellent contributions and Chris Walters as a Guest-Editor for bringing these together. With presenting this Special Issue, I hope that more researchers in this field will consider Seed Science Research as their primary outlet.