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The Miracle of Seeds

To hold a seed in the palm of the hand is to hold a small future that is impossible to predict. Is the seed alive or is it dead? Will it germinate if it is given water, or is it dormant? The seed could be in any of these conditions and the internal mechanisms that determine which actually pertains is one of the great biological enigmas remaining to be unravelled by today's plant scientists. Another question: does each seed have a defined lifespan?

Dormancy of Seeds

Consider life spans first. Certain seeds that are kept dry in bottles on the laboratory bench stay alive less well than those buried in the soil. This is true of charlock and the wild oat. In soil however, seed moisture contents can rise to 40 per cent or more so permitting metabolic activity, but because many weed seeds possess a block to growth, they remain there, dormant, for long periods and do not germinate until the developmental block is eliminated.

In one study of wild oats stored dry at 6-9ºC, 10 per cent germinated at harvest, 28 per cent after 18 days, 57 per cent after 66 days and 80 per cent after 4-5 years. Dormancy, whether the seed is imbibed or not, was lost after in 5 years. After that, viability declines and records say that by 25 years, only 4 per cent of the seed could still germinate.

This is not the response of another one time weed, the red poppy. These seeds too possess a developmental block to germination, but this is not lost by time – instead it is lost when seeds are exposed to light. This is why the shell-disturbed fields of Flanders blossomed so profusely and why we still see poppies flowering on roadside earthworks.

So either slowly with time or immediately with light, dormancy is broken through the removal of a restraint to cell growth and cell division. With either dry or imbibed wild oat seed, germination inhibitors are progressively degraded; with the poppy it is the conversion of a pigment (phytochrome) to a light-activated form that then unlocks the processes of embryo cell division. But unlike wild oat, poppy seeds must be imbibed for this to happen.

Moisture Content

Serious danger can arise, however, if seed is neither dry nor fully imbibed. Most crop seeds survive best at 5-10 per cent moisture content. Above this value, and up to about 25 or 30 per cent, life spans are progressively reduced. In a clover experiment, seeds held at 6 per cent moisture content retained viability for 3 years, but kept at 16 per cent, viability was reduced within 3 months.

So returning to our initial question, we can say that unlike other mammals there is no limit to the lifespan of a seed; longevity depends upon the conditions in which it is kept and moisture content has a powerful influence on how long that lifetime shall be. It helps to keep most seed cool. If the moisture content is low, no ice crystal will form and seeds can be kept at -20°C for many years (as in a Seed Bank) and almost indefinitely if held in liquid nitrogen at -196°C.

Specialised Shutdown Programme

A long-ago evolutionary adaptation of temperate plants to the seed forming habitat was the ability of embryo cells to dehydrate without drying. This was and still is, a remarkable event in cell physiology.

Few living things can survive a 10 per cent water loss without harm but maturing seeds of nearly all non-tropical plants can reduce their moisture content by as much as 90 per cent in a few days through a specialised shutdown programme of their life processes. First, the nucleus in each cell stops dividing and the DNA becomes condensed into a highly stable and protected molecular conformation. At the same time, metabolic activity and respiratory events are reduced to undetectable levels, so without wetting the seed again, it is impossible to tell if the seed is still alive. Hence, those who discovered the ancient seeds in the tomb of Tutankhamen could not be sure if they would germinate, so some were sent to the University of Reading, who after proper tests pronounced them long dead. But because a Frenchman, visiting the tomb at the time, was sold so-called “mummy wheat”, no doubt collected from the banks of the Nile that very day, the myth arose that tomb seeds could still germinate because our traveller successfully grew his modern purchase.

Repair of DNA

So what are the changes that take place in a stored seed and how do even small increases in moisture content lead to loss of quality and viability when that seed is sown? Degenerative changes are many. Oxidative reactions cause cell membranes to become leaky and free radicals can alter the molecular state of proteins and other cell components, but the most serious damage to arise is the slow fragmentation of DNA in the nucleus of every embryo cell. In dry stored seed, most enzymes remain stable, becoming active again within minutes of the embryo receiving water. Providing the enzymes that carry out DNA repair are not degraded during storage, then repair of DNA is one of the very first events of germination. Subsequently other cell restoration follows, but not by a repair process. Instead, new molecules are synthesized from the coding sequences of the newly repaired nuclear DNA. DNA is the only biological molecule that is actually repaired – all others are replaced. However, if the DNA repair enzymes lose their activity in storage, then no DNA repair and no replacement of other molecules is possible on imbibition of water, and the embryo will die.

Storage of Seed

So why is storage of seed so important?

Below about 10 per cent moisture content there is no free water present in the seed and little movement of molecules. At 14-16 per cent moisture content molecular mobility is greater and certain new enzymic events can take place. Nucleuses can cleave DNA into particular sized segments called nucleosomes, and these, unlike the random sized breaks that occur in the dry, cannot be re-assembled. Nucleosome accumulation is part of the irreversible death programme that many plant and animal cells undergo as part of the ageing process.

Only when the moisture content of an embryo reaches 25 per cent or more, is there sufficient free water for the energy-requiring metabolic repair of random DNA breaks or the synthesis of new cell molecules. So, if held for any length of time above 10 per cent but below around 25 per cent moisture content, DNA fragmentation to irreparable nucleosomes and other molecular damage will accumulate.

Effect of Drought after Sowing

When cell division stops at seed maturity, an embryo becomes desiccation tolerant and remains so until cell division restarts at germination. The earliest cell divisions (these take place in the root tip) may not occur until several days after a seed is fully hydrated, but once they start, the embryo ceases to be desiccation tolerant and a lack of water can then lead to embryo death. Graminaceous seed have a better chance of survival in an early drought because the embryo has several root tips which emerge at different times, but seeds like clover with only one root tip are very vulnerable.

Desiccation Tolerance

What happens to seeds that are alive but dormant?

Surprisingly, studies of wild oat have shown that dormant and non-dormant seeds behave in a quite similar way in the dry state and when first supplied with water. Both repair their nuclear DNA; both re-synthesize all the essential components of the live cell, but embryos of dormant seeds fail to undergo cell division. So although they can reinstate full metabolic function, they are unable to grow. This

means that dormant seeds never lose the state of desiccation tolerance, and can therefore be hydrated and re-hydrated many times without harm, as happens frequently in the soil. Only when the cell division block is lifted – and we still do not fully understand how this block operates – only then will the dormant embryo start to grow and, of course, in doing so, it loses its drought resistant status.

One practice of the modern seed industry takes advantage of the desiccation tolerant period of early germination, when DNA is repaired and metabolic activity is restored. Methods called “priming” or “advancement” are used in which seed is held for a few days at a moisture content (25 to 35 per cent) that permits the early events of germination but below one that will allow cell division. Embryos are then still desiccation tolerant so seed can be dried back safely. They can then be treated with fungicides and pelleted for easy sowing, giving faster and safer field emergence. Even low quality, slow germinating seeds are improved by such treatments.

Clearly we cannot visually predict a seed’s performance, nor by looking at that same seed at a later date will we learn if the germination potential has changed. It is however of great importance to the seed industry and to the farmer that quality guarantees can be given for seeds the merchant sells and the farmers buy. Much depends upon how well seeds are stored between harvest and sowing.

Present crop seeds, whether they be for grain, for grassland or for vegetables, have been selected by plant breeders for best performance and yield, so essentially they are initially all good seed. New genetic lines of rice and wheat led to the post Second World War Green Revolution. But even the best seeds have to be stored. Professor Hampton in New Zealand gives a good example for clover. Seed lots that have high germination potential when tested soon after harvest show big differences in their performance after a period of storage.

The GM Debate

There is much debate on the value or advantages of genetically manipulative (GM) seed and the dangers and environmental damages that such using can bring. One area of plant molecular biology in which it is not necessary to transfer genes is being directed to the problems of storing seed.

Specific sequences in DNA molecules are commonly used in forensic work for identifying humans, animals and plants. Such precise DNA fingerprinting can also be used to seek plants with good seed storage attributes. It is being done in rice in the following way.

Representative seeds of a range of high yielding lines with high germination rates are tested for maintaining their high germination potential following storage. The nuclear DNA profiles of the best and the poorest rice lines are then analysed and unique fragments of DNA that accompany good or poor storage qualities are isolated and sequenced. These sequences are markers for good or poor storage are then used to screen and select amongst the DNA profiles of other lines of rice for those that will store best. The unique sequences can also be used for screening local lines or wild populations for the highly desirable attribute of good storage. This approach premises to place the very best producing varieties of seeds on a genetically proven basis for best storage survival, so adding further level of guarantee to both the seed industry and to the farmer. It is using molecular biology in a way that cannot endanger other species, wild life or the environment.

So when you next hold a seed in the palm of your hand, marvel at this tiny biological miracle for survival.

Table. 1 Post-storage germination of clover seeds of initial similar high quality				
	Seed lot			
	1	**2**	**3**	**4**

Initial germination %	90	90	90	90
Germination % after 12 months in similar storage	71	90	66	89
From Y.R. Wang and J.G. Hompton, Plant Varieties and Seeds 4, 61-66, 1991)				

by Professor Daphne J Osbourne of the Oxford Research Unit, The Open University, Foxcombe Hall, Boars Hill, Oxford, OX1 5HR who has been working for many years with seeds and has been described as having an addiction to seeds dating from her close involvement in the study of embryos. This work has included investigations into cell ageing, dessication tolerance, dormancy and the controls that initiate cell cycling. She can truly be said to be an expert in this field.

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