

Seed Longevity in Storage is Enhanced by Controlling Water Activity

Three environmental factors are of fundamental importance in determining the longevity of stored seeds. These are water, temperature, and oxygen. The focus of this application note is water. With respect to their response to water, seeds are classified into two groups: orthodox and recalcitrant (Roberts, 1973). Orthodox seeds can be dried to low water contents without damage. Recalcitrant seeds are similar to other plant tissue in that they suffer desiccation mortality if they are allowed to dry below some critical moisture level. This application note deals mainly with orthodox seeds, though the principles described apply to both.

Measuring seed moisture

Two measures of water status are necessary to fully describe the state of water in seeds. One relates to the *amount* of water in the seed, and the other to the *energy status* of the water. The amount of water in the seed is typically expressed as the water content; the mass of water lost through a specified drying procedure divided by the wet or dry mass of the seeds. This ratio is sometimes multiplied by 100 to express the water content as a percentage. The energy status can be expressed in terms of the water activity or the water potential of the seeds. The water activity, for practical purposes, is equal to the relative humidity of air that is in moisture and temperature equilibrium with the seeds. The water potential is the potential energy per unit volume of water in the seeds. It is equal to the work required per unit volume of water, to remove an infinitesimal volume of water from the seed. Other terms applied to the water potential are the chemical potential, or partial specific Gibbs free energy of the water.

For a sample at a given temperature the water potential is uniquely related to the water activity through the equation:

$$\psi = \frac{RT}{M_w} \ln a_w \quad \text{Eqn. 1}$$

where R is the universal gas constant, T is Kelvin temperature, and M_w is the molecular mass of water.

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Water activity and water potential are measured by equilibrating a seed sample in a sealed chamber and measuring the relative humidity of the head space. The water activity is equal to the relative humidity (corrected for any temperature difference between the sensor and the sample), and the water potential is computed from eq. 1. Decagon's AquaLab Series 3 water activity meter is ideally suited for making this measurement. It equilibrates approximately 5 grams of material in a sample chamber and determines the water activity from the dew point temperature of the air in equilibrium with the sample. The sample temperature is measured using an infrared thermometer, and used to correct the readings for temperature differences. The measurement takes about five minutes.

The Isotherm

As the water content of seeds changes, so does the water activity. For a particular seed sample, with a given wetting history, there exists a unique relationship between water content and water activity called the isotherm (Roberts and Ellis, 1989). If one has the isotherm for a particular sample, it doesn't matter whether water content or water activity is measured, since the isotherm allows the other to be inferred. If no isotherm is available, then one needs to determine which of the two variables best represents the process of interest and measure that variable because the isotherm for each species is unique and there is no general relationship which will allow conversion from one to the other.

Table 1 shows data for rape (an oily seed) and wheat (a non-oily seed). As can be seen, rape has a much lower water content than barley at all of the water activities shown. The table also shows the corresponding water potentials. Clearly, isotherms differ substantially from species to species. They can also differ from cultivar to cultivar, depend on the environment in which the seed was produced, and the temperature of isotherm measurement. Extensive tables relating water activity (equilibrium relative humidity) and water content of seeds are given in Roberts (1972).

Which measure is best for predicting seed longevity?

Water content has long been used to describe the effect of moisture on seed viability, and recommendations for seed storage conditions for maximum longevity are often given in terms of water content. The relationships differ for each species, however, and must be determined for each. Roberts and Ellis (1989) have shown that a logarithmic relationship exists between longevity and seed water content, but the relationship differs for each species.

Table 1. Water activity, water potential (eq. 1), and water contents of rape (*Brassica napus*) and wheat (*Triticum vulgare*).

Water Activity	Water Potential (MPa)	Rape Water Content (g/g)	Wheat Water Content (g/g)
0.10	-314	0.031	0.060
0.20	-219	0.039	0.080
0.30	-164	0.045	0.093
0.40	-125	0.052	0.106
0.50	-94.4	0.060	0.120
0.60	-69.6	0.069	0.132
0.70	-48.6	0.080	0.147
0.80	-30.4	0.093	0.163
0.90	-14.3	0.121	0.215

Water content data are from Roberts (1972).

On the other hand, Roberts and Ellis (1989) show that the relationship between water activity and longevity is linear and similar from species to species. This is to be expected since the water activity measures the availability of the water to participate in chemical and physical processes. The use of water activity to describe seed water status therefore has enormous advantage over the use of water content. It eliminates specific testing of each seed lot and provides a general and simple (linear) relationship between viability and seed water status.

Water activity for maximum longevity

Roberts and Ellis (1989) state that the rate of loss of viability in orthodox seeds increases with increasing water potential between water potentials of -350 MPa and -14 MPa. These values correspond roughly to 0.1 and 0.9 a_w (10% and 90% rh). Below -350 MPa (0.077 a_w) there is little change in longevity with decreasing moisture. They indicate that this lower limit corresponds to seed water contents ranging from 2 to 6%. Clearly a simple and quick water activity measurement can supply the information needed to know whether seeds are at optimum moisture for storage, while substantial research is required to know what water content would be appropriate.

Complications from seed coats

Water content becomes even less useful as a measure of seed moisture when coatings are applied to seeds. Seed and coatings can have the same water activity but, vastly different water contents. The mass of the coating is often several times the mass of the enclosed seed, and the isotherm for the coating material is entirely different from that of the seed.

Water activity is the driving force for moisture migration thus, when seeds are coated it is the equilibrium water activity that best determines longevity.

For example, if at equilibrium the seed and coating have a water activity of 0.10, the water content of the seed might be 0.06 g/g, while that of the coating might be 0.02 g/g. Since the coating mass is so much larger than the seed mass, the total water content would be close to 0.02 g/g. If the specification for safe seed storage calls for a seed water content below 0.06 g/g, and the coated seed was only dried to 0.06g/g, then the water activity would be too high for safe storage. The water content measurement on the coated seed is of almost no value in determining whether or not a given seed drying operation meets that specification. On the other hand, if the specification calls for a water activity below 0.1 for safe storage, seeds and their coatings are simply dried to this water activity and stored. Water activity in the seed and the coating is the same and can be easily measured on both with no pretreatment.

Conclusion

Seed moisture status can be described in terms of water content or water activity (water potential). For historical reasons water activity is not commonly used, but has several distinct advantages for specifying conditions related to seed longevity. The most important is that it is directly and unambiguously related to longevity and critical points are similar for different species. Critical points are also similar for coated and uncoated seeds, which is certainly not the case for water content. Water activity measurements are quicker, easier, and more informative than water content measurements.

References

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