



Prediction of Seed Viability Through Viability Nomograph

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Seed viability constants and the seed viability equation, developed by Roberts and refined by Ellis and Roberts, provide the theoretical foundation for predicting how long orthodox seeds remain viable under defined storage conditions. The seed viability nomograph is the graphical expression of this equation: a chart that allows a practitioner to read off the expected loss of viability for a seed lot directly from its moisture content and storage temperature, without solving the underlying logarithmic equation by hand. This article reviews the biological basis of seed ageing, traces the historical development of the viability equation, explains the mathematical structure and species-specific constants that underlie the nomograph, describes how the nomograph is constructed and used, and discusses its applications in gene bank management, seed testing, and agronomy. The review closes with a discussion of the tool's practical value, its assumptions, and its limitations, particularly for recalcitrant and intermediate seed types to which the model does not directly apply.

Key words: seed viability, seed longevity, Ellis–Roberts equation, seed viability nomograph, moisture content, storage temperature, seed storage

Introduction

Seed viability, the capacity of a seed to germinate and produce a normal seedling, declines progressively from the moment a seed reaches physiological maturity. The rate of this decline is not fixed; it depends heavily on the moisture content of the seed and the temperature at which it is stored, as well as on the genetic constitution of the species itself. Understanding and predicting this rate of decline is central to seed science, plant breeding, agricultural seed supply, and the long-term conservation of plant genetic resources in gene banks. Because the relationship between storage environment and loss of viability is quantitative and reasonably consistent within a species, it became possible in the second half of the twentieth century to describe seed survival mathematically. The resulting seed viability equation allows the probit of percentage viability to be predicted from three variables: initial seed quality, moisture content, and temperature. The seed viability nomograph translates this equation into a set of graduated scales and curves so that the prediction can be read visually, without computation, making the model accessible to seed technologists, gene bank curators, and extension workers in the field.

The Concept of Seed Viability and Longevity

Seed longevity refers to the length of time a seed lot can be stored while retaining an acceptable level of germination. Within a population of seeds stored under uniform conditions, viability does not fall abruptly from 100% to 0%; instead, individual seeds die at different times, producing a characteristic sigmoid survival curve when germination percentage is plotted against storage period. Roberts (1972, 1973) demonstrated that this sigmoid curve becomes a

straight line when germination percentage is transformed to probits (the inverse of the cumulative normal distribution) and plotted against storage time. This linearization is the empirical foundation on which the viability equation, and therefore the nomograph, is built. Two environmental variables dominate the rate at which the probit line declines: the moisture content of the seed and the storage temperature. Within the range typical of orthodox seed storage, viability loss approximately doubles for each 1% increase in seed moisture content and for each 5–6°C rise in temperature, a relationship first generalized as “The Rule of Thumb” by Harrington (1972) and later placed on a rigorous quantitative footing by Roberts and Ellis.

The Seed Viability Equation

The improved seed viability equation of Ellis and Roberts (1980) is written as:

$$v = Ki - \frac{p}{10^{(KE - CW \cdot \log_{10} m - CH \cdot t - CQ \cdot t^2)}}$$

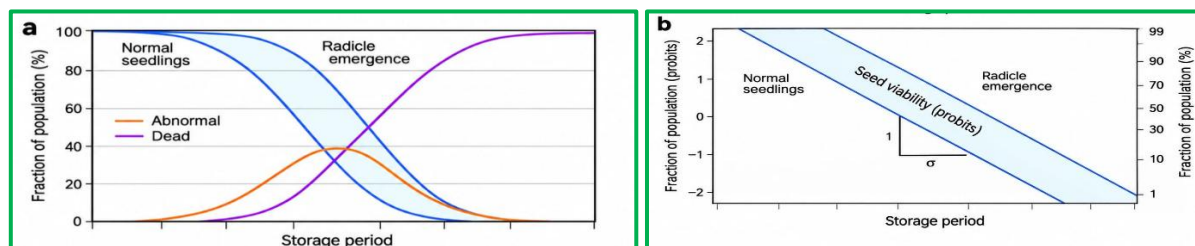
where the terms are defined as follows:

- v - probit percentage viability remaining after the storage period.
- Ki - initial seed viability, expressed as a probit, at the start of the storage period.
- p - the period of storage, in days.
- m - seed moisture content, expressed as a percentage of fresh weight.
- t - storage temperature, in degrees Celsius.
- KE , CW , CH , CQ - species-specific constants that describe, respectively, the general longevity of the species and its sensitivity to moisture, temperature, and the curvature of the temperature response.

The denominator of the equation, $10^{(KE - CW \log m - CH t - CQ t^2)}$, is the standard deviation of the frequency distribution of seed deaths in storage (σ), commonly called the “time constant.” A larger σ indicates a seed lot that loses viability more slowly; a smaller σ indicates faster ageing. Because σ depends exponentially on moisture content and temperature, small changes in either variable produce large changes in predicted storage life, which is precisely why the relationship is easier to interpret graphically than numerically.

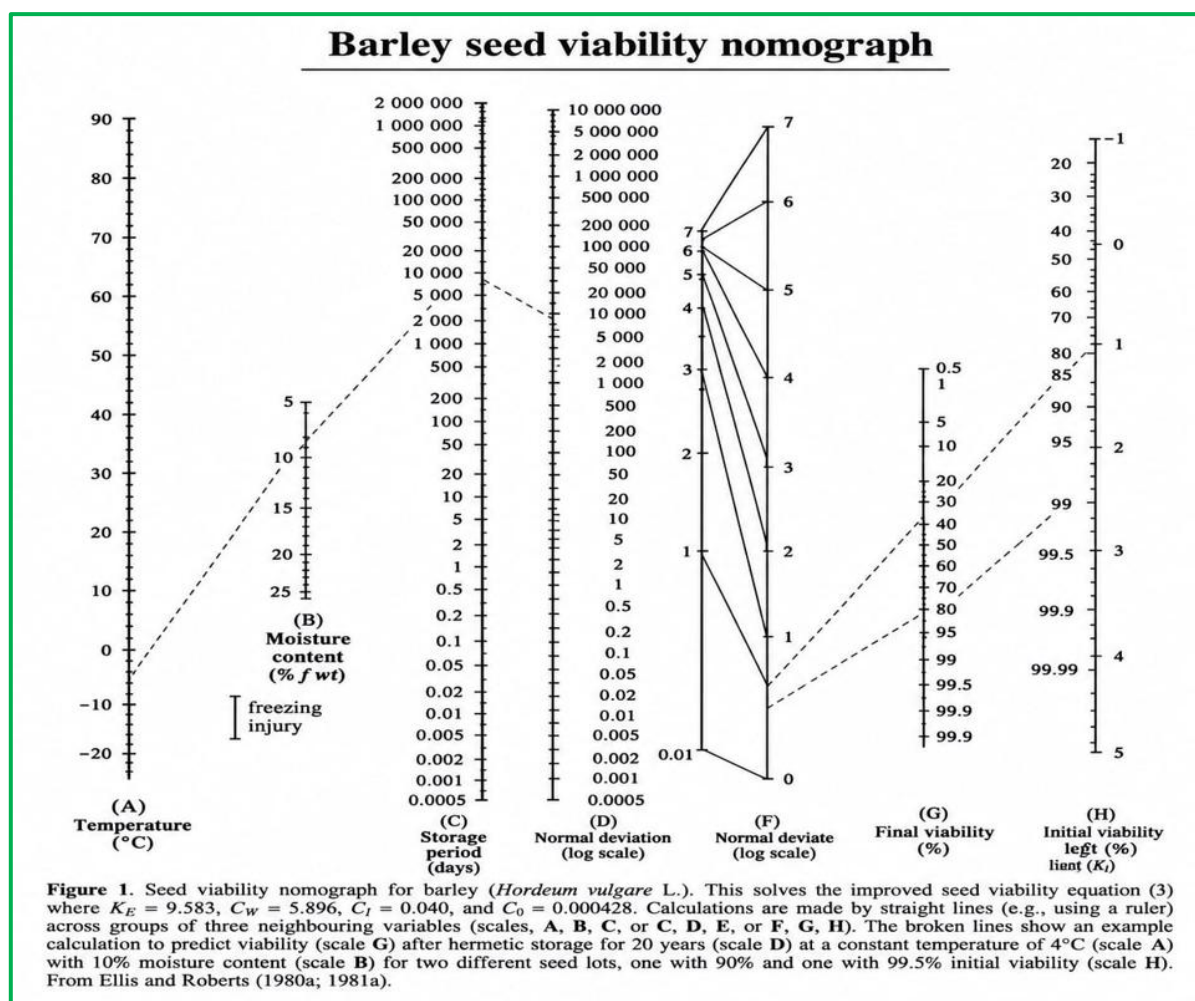
Construction and Use of the Nomograph

A nomograph (or nomogram) is a graphical calculating device consisting of several graduated scales arranged so that a straight line, or a set of connected line segments, drawn through known values on some scales intersects an unknown value on another scale. The seed viability nomograph applies this principle to the Ellis–Roberts equation by constructing coordinated scales for moisture content, temperature, storage period, and probit viability, with the species-specific constants KE , CW , CH , and CQ built into the spacing and curvature of the scales.



The graph illustrates the decline in seed viability during storage. Initially, most seeds are viable and produce normal seedlings, so the percentage of normal seedlings and successful radicle emergence is high. As the storage period increases, seeds undergo ageing due to processes such as membrane deterioration, loss of enzyme activity, oxidative damage and depletion of stored food reserves. Consequently, fewer seeds are able to germinate normally, while the proportion of abnormal seedlings initially increases because deteriorating seeds can still germinate but cannot develop normally. With further storage, deterioration becomes severe, causing more seeds to become dead, so both normal and abnormal seedlings decline. Graph (b) represents this loss of viability in probit units; seed viability decreases approximately linearly with storage time, and the right-hand scale shows the corresponding percentage of viable seeds.

Structure of the Chart



This is a seed viability nomograph for barley (*Hordeum vulgare* L.), developed from the seed viability equation. It is a graphical tool used to predict how much viability a seed lot will retain after storage when the temperature, seed moisture content, storage period and initial viability are known. The basic principle is that seed viability decreases as storage conditions become more severe. Higher temperature, higher moisture content, and longer storage duration generally increase the rate of seed deterioration. Therefore, the seed loses viability faster under warm and moist conditions, whereas cool, dry and properly controlled storage slows deterioration. The nomograph uses several scales because the seed viability equation involves these factors together. Instead of doing the mathematical calculation, we can simply use a straight ruler/line to connect the appropriate values on the scales. The intersection with the later scales gives the predicted final viability.

Example shown in the figure

The example assumes:

Temperature = 4°C → select 4 on scale A

Moisture content = 10% → select 10 on scale B

Storage = 20 years → convert to approximately 7,300 days and use scale C

Two seed lots are considered:

Initial viability 90%

Initial viability 99.5% → scale H

By drawing the required straight lines through these values and transferring the readings across the intermediate scales D–F, the final viability can be read from scale G. Thus, the nomograph demonstrates that two seed lots stored under exactly the same conditions can have different final viabilities because their initial viabilities are different.

Reading the Nomograph

To use the chart, the practitioner locates the moisture content of the seed lot on the horizontal axis, moves vertically to the isotherm corresponding to the intended storage temperature, and reads across to the σ value. This value of σ is then combined with the initial viability (K_i) using the linear probit relationship to estimate germination at any future storage period, or, working in the opposite direction, to estimate the storage period after which germination will fall to a specified threshold, such as the 85% viability standard commonly used for gene bank regeneration triggers. Because the isotherms are approximately straight when moisture content is plotted logarithmically, and because σ itself spans several orders of magnitude across the practical range of moisture and temperature, seed viability nomographs are almost always constructed with one or both axes on a logarithmic scale. This design choice compresses an otherwise unwieldy exponential relationship into a chart that can be read with useful precision by eye.

Species-Specific Viability Constants

Because KE, CW, CH, and CQ differ substantially between species, a nomograph constructed for one crop cannot be applied to another without first re-deriving the constants from controlled experimental ageing data, usually generated by storing seed lots at several combinations of elevated moisture content and temperature and monitoring the decline in germination over time. Representative published constants for several widely studied species are summarized below.

Table 1. Representative Ellis-Roberts viability constants for selected crop species (values compiled from published seed storage literature; constants vary slightly between cultivars and experimental sources).

Species	KE	CW	CH	CQ ($\times 10^{-4}$)
Lettuce (<i>Lactuca sativa</i>)	9.671	5.897	0.2755	3.68
Barley (<i>Hordeum vulgare</i>)	9.523	5.817	0.2769	3.85
Groundnut (<i>Arachis hypogaea</i>)	5.646	3.947	0.3608	6.02
Soybean (<i>Glycine max</i>)	7.581	4.673	0.3286	4.90
Rice (<i>Oryza sativa</i>)	9.469	5.723	0.2660	3.32
Onion (<i>Allium cepa</i>)	5.884	4.129	0.3624	6.63

Species with a high KE value and low CW and CH values, such as many cereals, tend to be comparatively long-lived in storage and relatively tolerant of moderate fluctuations in moisture and temperature. Species with low KE and high CW and CH values, such as groundnut and onion, lose viability far more rapidly under the same storage conditions, and their nomographs show isotherms that converge much more steeply as moisture content rises.

Advantages

- Provides a rapid, calculation-free estimate of storage life directly from routinely measured variables (moisture content and temperature).
- Grounded in a well-validated statistical model (the probit-linear decline of viability) rather than an arbitrary rule of thumb.
- Readily adaptable to any orthodox species once the four constants have been determined experimentally.
- Widely adopted in genebank operating procedures, giving it broad institutional familiarity and comparability across collections.

Limitations

- The model applies to orthodox seeds, which tolerate desiccation and low-temperature storage; it does not describe the storage behaviour of recalcitrant seeds (which cannot be dried without losing viability) or intermediate seeds, which follow different physiological rules.

- Accuracy depends entirely on the quality of the experimental data used to derive the species-specific constants; constants derived from one seed source, cultivar, or maturity stage may not transfer precisely to another.
- The equation assumes a constant storage environment; fluctuating temperature or moisture, or damage from mechanical handling, pests, or pathogens, is not captured by the model and can cause actual viability loss to diverge from the prediction.
- At very low moisture contents, some species deviate from the simple logarithmic relationship, requiring modified or segmented versions of the equation.

Conclusion

The seed viability nomograph is a practical, graphical distillation of the Ellis–Roberts seed viability equation, one of the more durable quantitative models in seed biology. By encoding species-specific sensitivity to moisture and temperature into a small set of constants and a readable chart, it converts a nonlinear statistical relationship into a tool that can be used at the bench or in the field without specialized computation. Its central role in gene bank regeneration scheduling and seed quality management reflects both the robustness of the underlying probit model of seed ageing and the enduring practical value of expressing quantitative biology in graphical form. Continued refinement of species-specific constants, and extension of predictive frameworks to recalcitrant and intermediate seeds, remain active areas of seed conservation research.

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