Seed Longevity Chart and Modeling to Predict Viability of Corn Seed During Open Storage

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The accelerated aging test has been used to estimate seed vigor and deterioration during storage (Delouche and Baskin, 1973). However, this test does not account for the effect of seed moisture and temperatures during storage. For this reason, seed viability equations which incorporate the effects of storage temperatures and seed moisture have been developed for many species (Roberts, 1960, 1973). The improved model of seed deterioration is relatively accurate at constant temperatures and seed moisture content. However, most seed crops stored in warehouses are not normally exposed to constant environmental variables. Lately, Tekrony et al. (1993) proposed a model using Ellis and Roberts' (1980) equation to predict changes in soybean seed deterioration in an open warehouse. This predictive model, although offers potential for predicting seed deterioration under warehouse storage condition, it has the disadvantage of recording and applying monthly the climatic data on the equation. A fast, simple and accurate prediction of seed viability under changing environmental conditions would be of a great value to seed producers. The objectives of this study were: a) to test the simplified viability equation for corn seed lot and, b) to determine the storage condition (σ) in order to construct a seed longevity chart for predicting changes in germination of corn during warehouse storage.

The basic viability equations

Three factors are of fundamental importance in controlling seed deterioration - water, temperature and initial quality. The relationship between moisture content, temperature and mean viability period is described by the following equation:

$$\log p = K_v - C_1 m - C_2 t, \qquad (1)$$

where *m* is the moisture content (per cent), *t* is the temperature (º C), and K_v, C_1 and C_2 are constants. Thus, to predict the percentage viability of a seed lot after any period of storage the four viability constants need to be determined.

Improved basic viability equations

As seed survival curves conform to negative cumulative normal distributions [Equation (1)], each curve may be quantified by the mean viability period, *p*, measured in days and the standard deviation of the distribution of deaths in time, σ. Ellis et al. (1991) have shown that, within a species, the constant values C_1 and C_2 are not affected by either the genotype and or the seed quality. If these constants and σ are independent of genotype and seed quality, then the value of K_i must also be independent of these factors (Ellis and Roberts, 1980).

Following these arguments, Ellis and Roberts (1980) proposed an improved viability equation:

$$v = Ki - p/10^{K_L - C_1 m - C_2 t} \qquad (2)$$

where

$$\log \sigma = K_L - C_1 m - C_2 t, \qquad (3)$$

This equation relates probit percentage viability, *v* at any time *p*, to any combination of moisture content, *m* and temperature, *t*. Three of the constants K_L, C_1 e C_2 are specific to the species, but independent of genotype and initial seed quality. Extreme storage conditions place limits on the applicability of the improved equations. For these reasons, they conclude that the following equation describe the relationship between seed longevity in barley and the storage environment over a wide range of conditions:

$$\log \sigma = K_E - C_1 \log m - C_H t - C_Q t^2 \quad (4)$$

For application to normal storage conditions, the improved viability equation (2) is appropriate, but for a wider range of storage conditions the following equation, is recommended:

$$v = Ki - p/10^{K_E - C_1 \log m - C_H t - C_Q t2} \quad (5)$$

Simplification of seed viability equation

It follows from equation (1) and (2) that seed survival curves (percentage viability plotted against time) are cumulative normal distributions of negative slope, which become straight lines if the percentage values are transformed to probit. In such plots the slope of the curves is given by $1/\sigma$ (Finney, 1971), thus Andreoli (2004) proposed a new simplified model as it follows:

$$V_t = V_i - (tg\beta).p \quad (6)$$

where the slope $tg\beta$ from equation (6) is a direct measure of the slope ($1/\sigma$) of the seed survival curves, therefore $tg\beta$ is the seed deterioration rate of under any specific storage environment expressed by the angular coefficient of the survival curve, which corresponds to $10^{K_E - C_1 \log m - C_H t - C_Q t2}$ of Ellis and Roberts' (1980) equation. Neither does genotype nor seed quality affect the slope ($tg\beta$) of the simplified viability equation (6); it is only the intercept, V_i, of the survival line which is affected by such factors (Ellis and Roberts, 1980).

Material and methods

Storage treatment

Five seed lots of corn double hybrid BRS201 were stored in an open warehouse at Embrapa Milho e Sorgo, Sete Lagoas, the State of Minas Gerais. Each seed lot was conditioned, dividing into three replications and sub-dividing into 2-kg sub-samples, which were placed in multi-wall paper bags (20-kg capacity), normally, used by seed companies. The multi-wall paper bags in each replication were stacked on a pallet at the experimental site in the warehouse. The pallets were placed in the center of the warehouse on 4 July 1998.

Sampling

An initial seed sample was taken before seeds were stored (time = 0) and samples were taken at 30, 60, 90, 120, 180 240 and 360 days. After sampling, the multiwall paper bags were placed back on the storage pallets at the same location in the stack. Maximum and minimum air temperatures and relative humidity (RH) near the pallets were recorded on a daily basis.

Seed quality tests

The initial seed moisture (fresh weight basis) of all samples was determined by drying a 20 g sample at 105 ºC for 24 hours. Standard germination was examined following the procedures described in the rules for seed testing (BRASIL, 1992) using eight replicates of 50 seeds per sample. The accelerated aging test (AA) was conducted following the procedures outlined by Krzyzanowski et al. (1991). The percentage germination observed in the germination test and in the AA test data were transformed in probit scale (Finney, 1971).

Storage index (σ)

The storage index (σ) for corn seeds stored in an open warehouse, in Sete Lagoas, State of Minas Gerais, was calculated for all five seed lots as the time taken, in days, for the germination to fall to a certain germination value in the accelerated aging test.

Statistical analysis

Analysis of variance (ANOVA), the regression analysis and R^2 determination for all five seed lots was made by MSTAT (Michigan State University, East Leasing, Michigan) software and it was used to compare the mean differences of the variables.

Results and discussion

Viability Equation

The initial germination, the accelerated aging germination, the predicted germination after 180 days, and the slopes of the survival lines are shown in the Table 1. There was a high correlation between the actual and the predicted values. The value of $tg\beta$ for five seed lots was calculated from the storage experiment and the viability curves were plotted (Figure 1). The regression analysis and the slope of the lines as a deterioration rate ($tg\beta$) of each seed lot are in Table 1. The value of the $tg\beta$ varied from $8.0147.10^{-4}$ (R^2 = 0.98) for lot 02 to $2.0031.10^{-3}$ (R^2 = 0.97) for lot 06. The equation accurately predicted the viability for all seed lots of corn under open warehouse at Sete Lagoas conditions. Another advantage of this model is that relative humidity is more directly related to water activity, thus it is more relevant to discuss changes in the physiological status of seeds in thermodynamic terms than by seed moisture (Vertucci and Roos, 1990, 1993; Vertucci *et al*. 1994). It is important to note also that Ellis and Roberts' equation predicts seed viability of the species and the simplified model estimates the seed deterioration rate of seed lots.

Based on the data of germination and aging test of the five seed lots, the storage index (σ) was calculated specifically for Sete Lagoas conditions. The storage index value is unique for each species and environmental condition (temperature and relative humidity of the warehouse), but independent of the initial quality of the seed and the genotypes (Andreoli, 2004; Ellis et al. 1991). The estimates of σ for corn seed lot provided by probit analysis are shown in Figure 1. The storage index value of 120 days was determined for all five seed lots stored in an open warehouse in Sete Lagoas, State of Minas Gerais (Figure 1). This σ value corresponded to the time taken, in days, for germination of all five seed lots to fall during storage to the same germination value in the accelerated aging test at 42º C and 100% R.H. The seed deterioration values change depending upon the environmental conditions of the warehouse, so under unfavorable storage condition (high temperatures and RH), the storage index value (σ) tends to be lower and vice-versa.

Seed Longevity Chart

Based upon the data of this trial a seed longevity chart was built up (Figure 2). It illustrates the relationship between initial germination, seed deterioration rate and storage conditions over time. This trial attempted to design a model in which seeds, exposed to actual temperatures and RH in an open warehouse, could be predicted by plotting the storage index value (σ), the initial germination and the aging test in a longevity chart as shown in the Figure 2.

To use the chart, the value of *Vi* (initial probit germination) at time zero should be placed on the left of vertical axis scale and the value of the AA test on the right axis. The storage index line at 120 days should be drawn perpendicular to the axis line X (*p*). A ruler is now placed on the AA scale and moved toward left till find the σ value (120 days). Finally, by connecting these two points, a straight line can be drawn and the viability of a seed lot over a period of time might be predicted (Figure 2). The chart can be used by any seed producer once the value of storage index (σ) *in situ* is determined for each species. For instance, a seed producer determines the storage index for corn as 120 days at his warehouse and wishes to predict the viability loss of the seed lots during storage. For testing the model, seed lots of corn harvested in 1999, with initial germination and aging test of 98.0 and 96.4 percent, were transformed to probit scale that correspond to 2.0537 and 1.7991, respectively. After plotting the initial germination (2.0537) on left axis and the aging test value (96.4% = probit 1.7991) on right axis of the chart on Figure 2 and move the later horizontally left until find the perpendicular line (storage index). By connecting these two points, a straight line can be drawn and the viability of this seed lot can be predicted over time. For validation of the seed longevity chart, two corn seed lots were stored in Sete Lagoas, MG. As shown in the Figure 2, the seed lot SET01, with initial germination of 98.0 per cent, falls to 95.4 and 91.0 percent after 180 and 360 days, respectively, stored at that particular condition. Whilst in the same period, at these conditions the viability of another seed lot SET03 with 96.2 % germination initially and AA test of 93.2 % fall to 91.0 and 81.6 per cent, respectively (Figure 2). Crossing the data of Table 1 and Figure 2, we can note that the observed and predicted values are closely related (mean R^2>0.97), confirming the predictive model of the simplified equation proposed by Andreoli (2004). Furthermore, the seed longevity chart also takes into account variations in vigor among seed lots. Let us consider two seed lots with initial germination (time = 0 days) of 95 per cent, and vigor of 90 and 86 percent. Placing the probit values in the chart (Figure 2), the germination of these two seed lots fall to 86.5 and 77.5 percent after 180 days of storage (data no plotted). This means that the seed longevity chart is a good tool to monitor seed lots even before storage and low vigor seed lots could be discarded before packing, saving labor, money, and space in the seed warehouse.

This viability chart is simple, reliable and it can be applied with confidence to any particular seed lot. Moreover, it is not needed to estimate the constants of the viability equation (Ellis and Robersts, 1980) for each seed lot and the climatic data of the warehouse do not need to be recorded as described by Tekrony et al. (1993). Yet, it takes into account variations in seed quality before and during storage resulting from environmental factors.

The data suggest that the application of the seed viability chart for short storage conditions seems to be promising for seed growers. This seed deterioration predictive model is the first attempt that has incorporated the effects of initial quality and deterioration rate(temperature and relative humidity of the storage) into a seed longevity chart in an open storage.

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TABLE 1. Performance of initial germination, accelerated aging germination, predicted probit germination after 180 days and the slope (*tgβ*) of five corn seed lots stored in an open warehouse in Sete Lagoas, State of Minas Gerais. Seeds were initially stored on July 04, 1998.

Seed Lot	Germination (%)	Aging Test (%)	Probit Germination after 180 days, (%)	Slope (*tgβ*) of the survival curves[$]	R^2
Lot 02	92	89.6	1.2462 (89.2)	$-8.0147.10^{-4}$	0.98
Lot 03	93	90.8	1.2948 (90,2)	$-1.3056.10^{-3}$	0.97
Lot 04	95	92.8	1.4159 (92.0)	$-1.4972.10^{-3}$	0.98
Lot 06	98	96.2	1.6931 (95.4)	$-2.0031.10^{-3}$	0.97
Lot 07	96	93.0	1.5703 (94,2)	$-1.5029.10^{-3}$	0.99

[$] The slope of the survival curves (seed deterioration rate = *tgβ*) was calculated by the model $Vt = Vi - tg\beta.p$, where Vt is the probit germination at the time p, Vi is the probit germination at time = 0.

FIGURE 1. The value of storage index (σ) of five seed lots of maize seeds stored in Sete Lagoas, State of Minas Gerais in an open warehouse. The index value of σ =120 days, for these seed lots, corresponds to the time taken in days for the germination of corn seeds to reach a similar value observed in the accelerated aging test. Bar denotes $LSD_{0.05}$

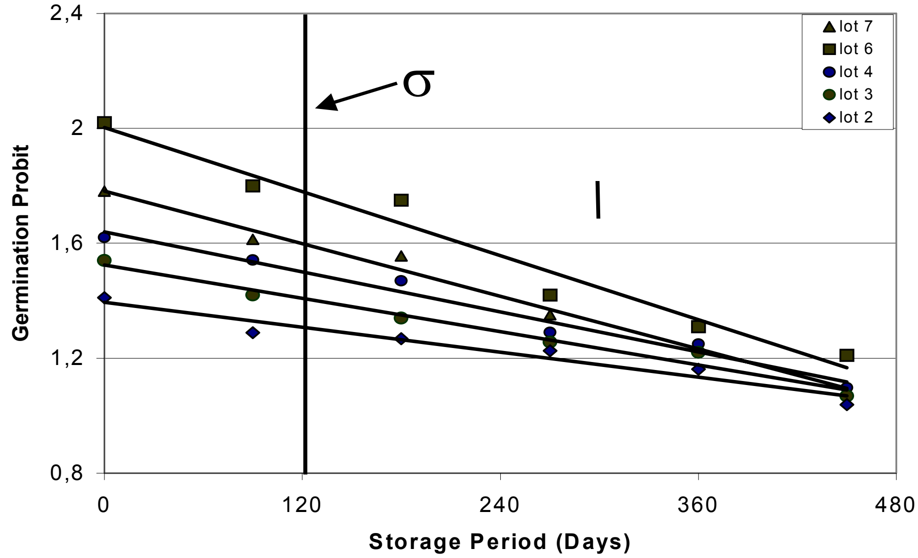

FIGURE 2. Seed longevity chart to predict and monitor corn seed lots during storage. For predicting the viability of corn seed lots, the initial probit germination (time = 0) is placed on left axis Y and the accelerated aging germination are placed on the right axis. The storage line perpendicular line to the axis X (p) at 120 days is drawn in the chart. The AA value is, then, moved toward left till find the line of the storage index (σ = 120 days). By connecting these two points, a straight line can be drawn and the viability of seed lots over a period of time might be predicted. The numbers in parenthesis at time = 0 day are the initial germination, at 120 days are the AA germination and the predicted values after 180 and 360 days for seed lot SET01 and lot SET03 stored in Sete Lagoas, in 1999.