DRYING PARAMETER EFFECTS ON LENTIL SEED VIABILITY

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ABSTRACT. *Fresh Laird lentils with initial moisture contents of 16 to 20% (wet basis) were dried in a thin-layer dryer for periods up to 24 h at temperatures from 40 to 80° C and relative humidities from 5 to 70%. The germination rates of the samples were evaluated four months after drying. The seeds dried at temperatures up to 66° C had germination rates above 93%. Lentils suffered significant losses in germination when dried at temperatures between 66 and 80° C. These losses were positively correlated to air temperature, seed initial moisture content and exposure time, and negatively correlated to relative humidity. Lentils dried at 80° C lost all viability. The reductions in germination of lentils after different drying periods at 66 and 70° C were simulated using the probit viability analysis, with expressions for standard deviation of seed death time developed from dynamic drying processes.* ***Keywords.*** *Lentil seeds, Viability, Drying, Probit analysis, Simulation.*

Grain lentil (*Lens culinaris Medik*) is a high-protein pulse crop (about 28% protein, dry basis), grown mainly for direct human consumption. Canada is the second largest lentil exporting country in the world, and the Laird lentil is the most popular cultivar accounting for 75% of the total lentil production in Canada.

Lentil plants have an indeterminate growth habit so that new flowers and pods are produced continuously until plant growth ceases due to heat, drought, or early frosts (SASCC, 1987). To facilitate a more uniform maturity in the seeds, the crop is usually swathed when the earliest pods have turned light brown. After about a week of maturing and drying in the field, the swaths are threshed. While threshing at low moisture content results in severe seed breakage, tough pods at high moisture content render the operation difficult. The optimum seed moisture content for threshing is 16 to 20%*. The harvested lentils are then dried to below 14% moisture content.

High temperature facilitates the drying of the seeds and reduces the risk of field losses. However, it may also reduce seed germination. Thus, a balance has to be maintained. Canadian Seed Regulations (Anon., 1987a) specify minimum germination rates of 85 and 75% for no. 1 and no. 2 lentil seeds, respectively. To optimize the drying process, it is desirable to obtain information on the correlation between drying parameters and seed viability, and to develop a procedure for predicting germination losses during drying processes. The effect of drying temperature and initial moisture content on lentil viability was investigated by Tang et al. (1991), in which lentils were dried from 16 to 20% initial moisture contents to 13% at 12% relative humidity and a range of temperatures. The drying periods ranging from 18 to 170 min. They observed no significant germination loss in lentils when dried up to 60° C. At air temperatures of 70° C and above, the loss in germination is negatively correlated with the initial moisture content.

OBJECTIVE

The objective of the current study was to:

- Further investigate the effect of drying air temperature, relative humidity, and seed initial moisture content on lentil viability.
- Predict germination losses during drying using computer simulation.

MATERIALS AND METHODS

SAMPLE PREPARATION

Laird lentil samples of about 4 to 5 kg with an average moisture content of 16, 18, and 20% were selected from several lots of seeds obtained from an experimental field in the vicinity of Saskatoon during 1988 and 1989 harvest seasons. The seeds were hand picked, grouped according to the colour and softness of pods, and shelled. The average moisture content of each group was determined. The samples were placed in air-tight containers and stored at 4° C for three months. Prior to each drying run, a sample was brought from the storage and conditioned at room temperature of 22±2° C for 24 h.

SEED MOISTURE CONTENT

Moisture content of lentils was determined using the air-oven method as specified in ASAE Standard S352.2 (1990). The oven temperature was set at 130° C and the samples were dried for 20 h (Tang and Sokhansanj, 1991).

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* Moisture contents are reported on wet basis.

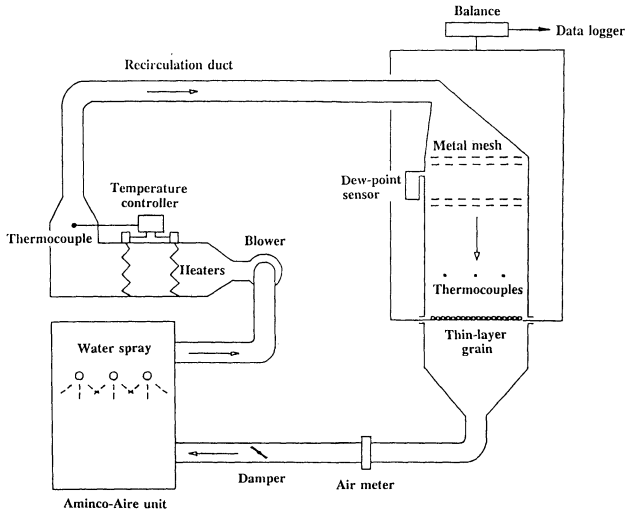

Figure 1–Schematic of the thin-layer dryer.

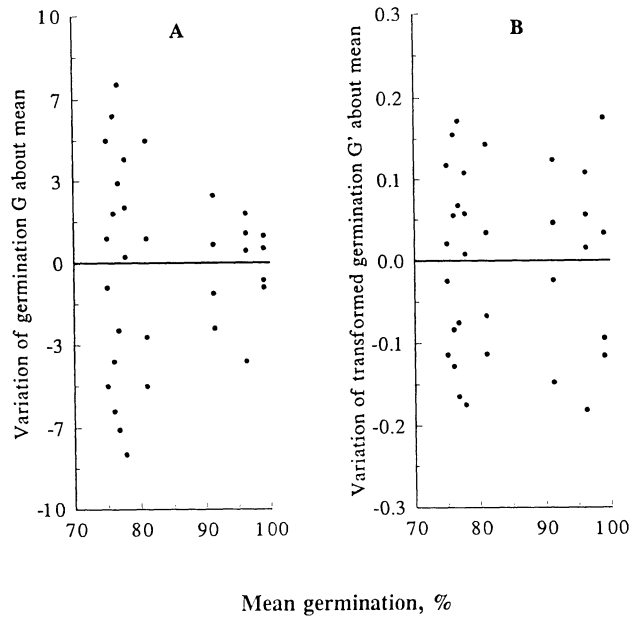

Figure 2–Variation of germinations in Laird lentils about the mean of each treatment at 70° C and 4% RH, (A) before and (B) after arcsin transformation.

Thin-Layer Drying

A laboratory thin-layer dryer was used to dry lentil samples under constant conditions. A schematic diagram of this dryer is shown in figure 1. In operation, a stream of air conditioned by an Aminco-Aire unit (Aminco-Aire Model J4s-5460a, Parameter Generation and Control, Inc., West Black Mountain, NC) was driven by a blower through an auxiliary heating unit to a drying chamber in which lentils were spread in a thin layer on a sample pan. The hot air flowed uniformly across the sample at a speed controlled by a damper. The drying air temperature measured by three type T thermocouples and the relative humidity measured by a dew-point sensor (Model Dew-10 Dew Point Transmitter, General Eastern Instruments, Woburn, MA) were continuously monitored via a computer-based data acquisition system. The air temperature in the drying chamber was controlled within 1° C and relative humidity (RH) within 2% of the desired values. According to Henderson and Pabis (1962) and Hutchinson and Otten (1983), the thin-layer drying characteristics of grains are independent of air velocity above 0.2 m/s. Thus, the air velocity in the present study was set at 0.3 m/s for all drying tests.

The experiments with lentils grown in 1988 were designed to verify the results of Tang et al. (1991). To obtain conservative information, lentil samples of 100 g each were dried for 24 h at 40, 60, and 80° C, and at relative humidities ranging from 5 to 70%.

The investigation on 1989 lentils focused on the change of seed viability with drying time. The following conditions were studied: 66° C and 4% RH, 66° C and 40% RH, 70° C and 4% RH, and 70° C and 40% RH. In the tests, thin layers seeds of 1 kg at initial moisture contents of 16, 18, and 20% were placed on a partitioned pan in the dryer so that the samples were exposed to identical drying conditions. To address the question of when injury occurred during the drying process, about 60 g of seeds was removed from each sample at an interval which increased progressively from 1 to 12 h for a total drying period of 24 h. Half of each dried sample was used for moisture content determination and another half for germination testing.

Germination Tests

Four months after drying, the germination of dried lentils was assessed in four replications of 50 seeds by the Agriculture Canada Seed Testing Laboratory in Saskatoon, following a standard test procedure (Anon., 1987b). The method involved planting the seeds in a moist mixture of vermiculite and sand, and placing them in a growth chamber set at 20° C and 100% RH. Both shoot and root systems were examined at the end of the eighth day of growth. The seedlings were classified as healthy, abnormal, and dead. The percentage of the healthy germinated seeds was recorded.

Statistical Analysis

The number of healthy seeds from a 50-seed sample can be considered as a binomial random variable with parameters (50, p), where p is the probability for healthy germination. Thus, the variance of the germination G (in percentage) in a single test is (Ross, 1987):

$$\sigma^2\left(\frac{G}{100}\right)=\frac{p(1-p)}{50} \quad (1)$$

According to the above relationship, the variance for germination increases when the value of p approaches 0.5. The non-uniform variances prevent direct application of ANOVA analysis (Hicks, 1982) on the data from the germination tests. To remedy this problem, the arcsin transformation is needed (Neter et al., 1985):

$$G' = 2\arcsin\left(\sqrt{\frac{G}{100}}\right) \quad (2)$$

where G′ varies from π to 0.

Figure 2A illustrates germination variation among four replicates as affected by the mean for 18% initial moisture lentil seeds dried at 70° C and 4% RH. The variation was small when the mean was close to 100%, and it increased when the mean approached 70%. This is in general agreement with equation 1. After data transformation using equation 2, the variations became more uniform (fig. 2B).

ANOVA analysis was performed on the transformed data from all germination tests using the PC version of Minitab Statistic Software (Anon., 1991). Significance of the treatment effect was noted at $p < 0.05$.

Probit Analysis

Probit analysis was conducted on the germination data of 1989 lentils to predict the loss of germination during drying at different air temperatures and relative humidities. The theoretical basis for this analysis is provided in the following.

The frequency of individual deaths in a seed population follows a normal distribution over time under stable storage conditions (Roberts, 1960). Therefore, the cumulative probability, p′, of dead seeds increases with storage time, t, according to the following relation:

$$p' = \frac{1}{\sigma\sqrt{2\pi}} \int_{-\infty}^{t} e^{-(t-t')^2 / 2\sigma^2} dt \qquad (3)$$

where σ is the standard deviation of the distribution of seed death time, and t′ is the mean period during which germination drops to 50%. The t' is also defined as the mean viability period by Ellis and Roberts (1980a). From equation 3, the expectation of the germination E[G], in percentage, is:

$$E[G] = 100(1 - p') \qquad (4)$$

or

$$E[G] = \frac{100}{\sigma\sqrt{2\pi}} \int_{t}^{\infty} e^{-(t-t')^2 / 2\sigma^2} dt \qquad (5)$$

Substituting the standardized normal deviate

$$X = \frac{(t' - t)}{\sigma} \qquad (6)$$

into equation 5 yields:

$$E[G] = \frac{100}{\sqrt{2\pi}} \int_{-\infty}^{X} e^{-X^2 / 2} dX \qquad (7)$$

Thus, the expectation of germination E[G] can be transformed into the standardized normal deviate X numerically via a unit normal distribution function.

Equation 6 can be re-written as:

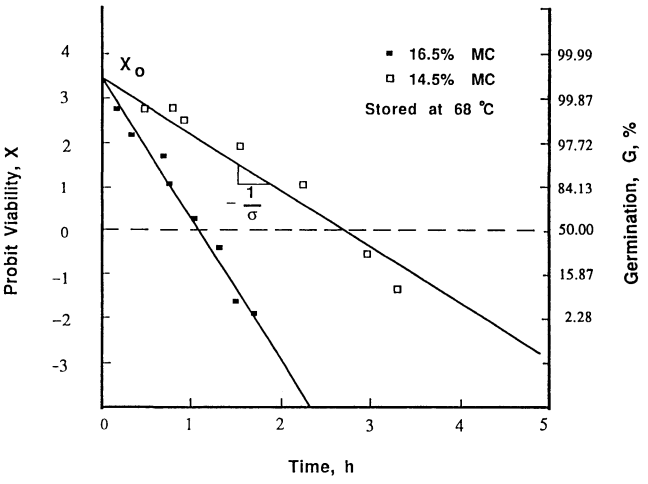

Figure 3–Decrease in germination in winter wheat with exposure time at 68° C in sealed containers (data from Nellist, 1981).

$$X = X_o - \frac{t}{\sigma} \qquad (8)$$

where X_0 is the value of X corresponding to the expectation of the germination at t = 0. The mean viability period t′ of the seeds is:

$$t' = \sigma X_o \qquad (9)$$

For stable storage conditions (constant grain temperature and moisture content), σ is a constant (Ellis and Roberts, 1980b). Thus, according to equation 8, X varies linearly with storage time with a constant slope of $-1/\sigma$. Therefore, the variation of germination of grains in a stable storage condition is characterized by two parameters, X_0 and σ, in the domain of the normalized standard deviate X, as illustrated in figure 3. The analysis in this domain is known as the probit analysis (Finney, 1952). In the probit analysis for germination, the standardized normal deviate X is defined as probit viability (Ellis and Roberts, 1980a).

The use of probit viability analysis to predict loss of seed viability in storage was pioneered by Roberts and his colleagues (Roberts, 1960, 1961, 1972). Ellis and Roberts (1980a) determined the values of σ in equation 8 for barley as a function of temperature and moisture content:

$$\ln\sigma = 26.7 - 5.896\ \ln M - 0.0921\ T - 0.000986\ T^2 \qquad (10)$$

where M is seed moisture content on a wet basis and T is temperature in ° C.

However, seed moisture content and temperature change with time during drying processes. As a result, the value of σ changes with drying time and so does the slope of the curve in figure 3. Nellist (1981) proposed an approach to account for these changes in the probit viability analysis for predicting seed viability during drying. Instead of using a constant σ, he suggested to divide the drying time into increments, Δt, and calculate σ from equation 10 with averaged temperature and moisture content in each time increment. The decrease in probit viability X in equation 8 was estimated by $\Delta t/\sigma$, and the total loss of viability was calculated by accumulating the loss in each time increment.

Table 1. Germination percentage of 1988 Laird lentils (average of four replicates of 50 seeds) as affected by temperature, relative humidity, and initial moisture content, after 24-h drying

Drying Temp. (° C)	Relative Humidity (%)	Initial Moisture Content (%)		
		16	18	20
40	5	99	99	99
	30	99	99	97
	50	100	98	98
	70	98	100	99
60	5	96	95	94
	30	99	97	97
	50	98	99	98
80	5	1	0	0
	20	0	0	0
Control		99	99	97

This approach was implemented on a personal computer in the current study.

Results and Discussion

1988 Lentils

Table 1 lists the percent germination of 1988 lentils dried at three temperatures and a range of relative humidities. The final moisture content of these samples varied from 4% when dried at 80° C and 5% RH to 14% when dried at 40° C and 70% RH.

The effect of temperature on germination is evident from the data in table 1. Germination remained high and relatively uniform at temperatures of 40 and 60° C for the relative humidity range of 5 to 70%. However, when the drying temperature increased to 80° C, lentils at three initial moisture contents lost almost all viability. These observations agree with the results of the investigation by Tang et al. (1991) in which lentil seeds suffered little germination loss at air temperature of 60° C or below; whereas seed germination dropped to 2 to 18% at 80° C.

1989 Lentils

The data in table 2 demonstrate the effect of drying time and initial moisture content on the loss of germination in 1989 lentils at two temperatures, 66 and 70° C, and two relative humidities, 4 and 40%. The correspondent moisture contents of the seeds are listed in table 3.

Samples dried at 66° C and two relative humidities for up to 24 h did not show significant loss in germination, and ANOVA analysis indicated that the effect of both initial moisture content and drying time was not significant at the 5% level.

Table 2. Germination percentages of 1989 Laird lentils as affected by temperature, relative humidity, initial moisture content, and drying time

Temp (° C)	RH (%)	Initial Moisture (%)	Drying Time (h)							
			0	1	2	3.5	5	7	12	24
66	4	16	99	97	98	100	97	99	97	97
		18	98	99	100	98	96	91	93	93
		20	97	97	96	97	95	99	94	97
	40	16	99	98	100	99	98	97	99	98
		18	98	99	98	97	99	98	97	99
		20	97	98	97	96	98	97	99	97
70	4	16	99	97	94	94	94	91	95	95
		18	98	96	91	81	77	76	78	75
		20	97	78	74	56	45	41	47	43
	40	16	99	99	98	96	97	92	94	97
		18	98	97	95	90	87	90	93	83
		20	97	89	87	76	79	72	69	68

Table 3. Variation of moisture content of 1989 Laird lentils with drying time (average of two replicates, discrepancy between the two was less than 0.3%)

Temp (° C)	RH (%)	Initial Moisture (%)	Drying Time (h)						
			1	2	3.5	5	7	12	24
66	4	16.0	12.9	11.9	10.6	9.7	8.8	7.4	5.2
		18.3	14.0	12.5	11.1	10.1	9.1	7.6	5.4
		19.7	14.3	12.9	11.6	10.5	9.6	7.7	5.5
	40	16.0	13.2	12.3	11.1	10.1	9.5	8.4	6.8
		18.3	14.1	12.7	11.5	10.4	9.8	8.7	6.9
		19.7	14.7	13.5	11.9	10.7	9.9	8.9	6.9
70	4	16.0	12.8	11.0	10.3	9.3	8.2	6.5	4.5
		18.3	13.7	12.0	10.6	9.7	8.4	6.7	4.6
		19.7	14.2	12.3	10.7	9.9	8.9	6.8	4.7
	40	16.0	13.0	11.6	10.4	9.8	8.9	7.6	6.3
		18.3	13.6	12.2	10.6	10.0	9.0	7.8	6.4
		19.7	14.4	12.8	11.1	10.5	9.2	8.0	6.3

At 70° C, the interaction of initial moisture content and drying time was significant at the 5% level. No significant germination losses were observed in 16% initial moisture content samples. Germination dropped to 90% or below in the 18% and 20% initial moisture content samples after 3.5 and 1 h of drying, respectively. After the above-mentioned periods, lentil germination continued to drop, but to a less extent and eventually levelled off. Fluctuations in germination were observed at the late stages of drying, reflecting large variation in germination data.

The effect of relative humidity on the germination of lentils dried at 70° C was also significant at the 5% level. In general, for the same drying time low relative humidity resulted in high germination losses. These observations agree with the experimental results for corn seeds (Herter and Burris, 1989a). It is possible that the high drying rates associated with low relative humidity (table 3) may induce large localized stresses within the seeds due to differential

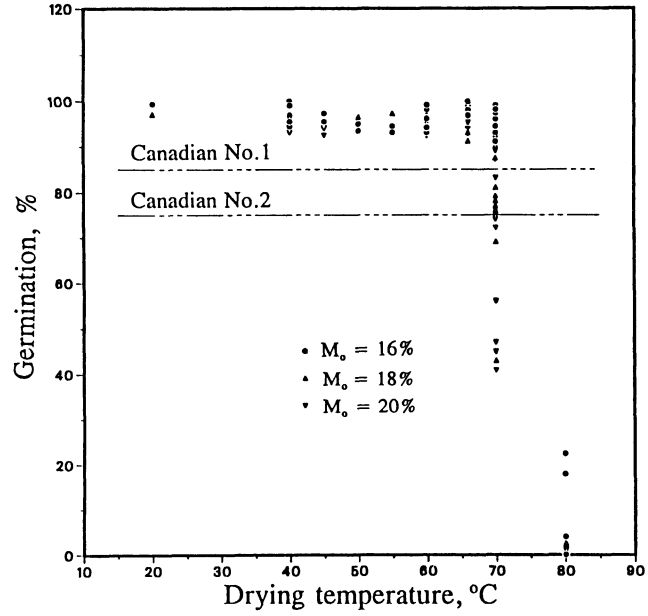

Figure 4–Effect of drying temperature on germination in Laird lentils at three initial moisture contents. The dashed lines represent minimum germination for Canadian No. 1 (> 85%) and No. 2 (> 75%) lentil seeds.

hygroscopic shrinkage. These stresses may be high enough to physically damage the germs. White et al. (1976) observed considerable cracking in soybeans dried at high temperature and low relative humidities, whereas no cracks were found in soybeans dried at relative humidities of more than 40%. Although no visible cracks were observed in lentil seeds dried at 4% relative humidity in the current study, the high drying rates might have induced sufficient mechanical stresses in the germ to damage the tissues and reduce the seed viability.

The germinations listed in tables 1 and 2 and those from Tang and Sokhansanj (1991) are summarized in figure 4. The limits for Canadian No. 1 (> 85 %) and No. 2 (> 75 %) seeds are also represented in the same diagram. The germination of lentil seeds declined sharply at temperatures above 66° C. This may have been caused through enzyme denaturation as suggested by Herter and Burris (1989b). Indeed, Lupano and Anon (1986) observed that wheat germ proteins were denatured at temperatures ranging from 69.3 to 72.3° C.

Simulation of Germination Loss in 1989 Lentils

Probit viability analysis was used to simulate seed germination loss during drying with the data of 1989 lentils. The experimental probit viabilities were obtained from germination rates via a table of unit normal distribution functions (Ross, 1987). The predictive values of probit viability were generated numerically on a personal computer in an approach similar to that suggested by Nellist (1981). The probit viability X_i at each time step t_i was calculated as:

$$X_i = X_{i-1} - \frac{(t_i - t_{i-1})}{\sigma_i} \qquad (11)$$

where i = 1 to n, $t_o = 0$, and $t_n = 24$ h. The X_o is the probit viability at the start of drying. The σ_i stands for the standard deviation of the distribution of seed death time, and its value depended upon the average moisture content between time intervals t_i and t_{i-1}. A general expression for σ as a function of seed transient moisture content M (%, wet basis) was assumed for lentils as:

$$\ln\sigma = A - B\ln(M) \qquad (12)$$

where A and B are parameters depending upon drying air temperature and relative humidity. With the experimental data of samples of 20% initial moisture content in tables 2 and 3, the values of A and B were obtained for each drying condition by minimizing the sum of squares of the residues between the probit viabilities calculated from equation 11 and the experimental probit viabilities for a given drying temperature and relative humidity:

A=17.59, B=5.896, R.M.S=0.171 at 70° C, 4%RH (13)

A=18.17, B=5.896, R.M.S=0.191 at 70° C, 40%RH (14)

A=22.20, B=5.896, R.M.S=0.0093 at 66° C, 4%RH (15)

A=23.10, B=5.896, R.M.S=0.0052 at 66° C, 40%RH (16)

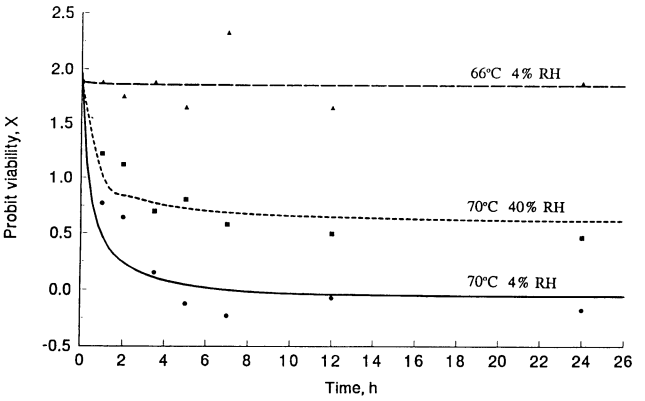

Figure 5–Probit viabilities of 20% initial moisture content samples dried at 70° C and 4% RH (●), 70° C and 40% RH (■), and 66° C and 4% RH (▲). The dots are the experimental probit viabilities and the curves represent predictive values from equations 11 and 12.

where R.M.S stands for Relative Mean Square Errors defined as:

$$\text{R.M.S.} = \sqrt{\frac{1}{N}\sum_{i=1}\left(\frac{X'_i - X_i}{X'_i}\right)^2} \qquad (17)$$

in which, X_i is the predicted value, X_i' is the experimental data and N stands for the number of data points. As shown in equations 13 through 16, the value of parameter A varied with both temperature and relative humidity, whereas parameter B remained constant.

The goodness of fit of the predicted probit viability to the experimental data for three drying conditions is illustrated in figure 5. Since the data for 66° C and 40% RH are close to those for 66° C and 4% RH, the former are not included in the diagram. In figure 5, the probit viability corresponding to the initial gemination rate of 97% (table 2) is 1.88, the probit viability corresponding to 50% germination rate is 0. It should be noted that the slope of each curve decreases with time. This resulted from increased values of σ with decreasing moisture contents during the drying process (eqs. 11 and 12), in contrast to a constant σ for a stable storage condition (fig. 3). As the moisture content decreased during drying, the ability of the seed to withstand viability loss increased.

The expected germinations corresponding to the predicted probit viabilities for samples of 20% initial moisture content are presented in figure 6 in solid curves for the two relative humidities at 70° C. The predictive values follow the general trends of germination losses with drying time.

Since parameters A and B in equation 12 depend only upon air temperature and relative humidity, the values estimated from the samples of 20% initial moisture content should also apply to the samples of 16 and 18% initial moisture contents given the same drying condition. The experimental data of lentil samples of these two initial moisture contents were used to test the prediction ability of equations 11 through 16. The results for two air conditions are presented in figure 6. In the case of 70° C and 4% RH, the curve fits the data with discrepancy of less than three percentage points for the 16% initial moisture sample, and

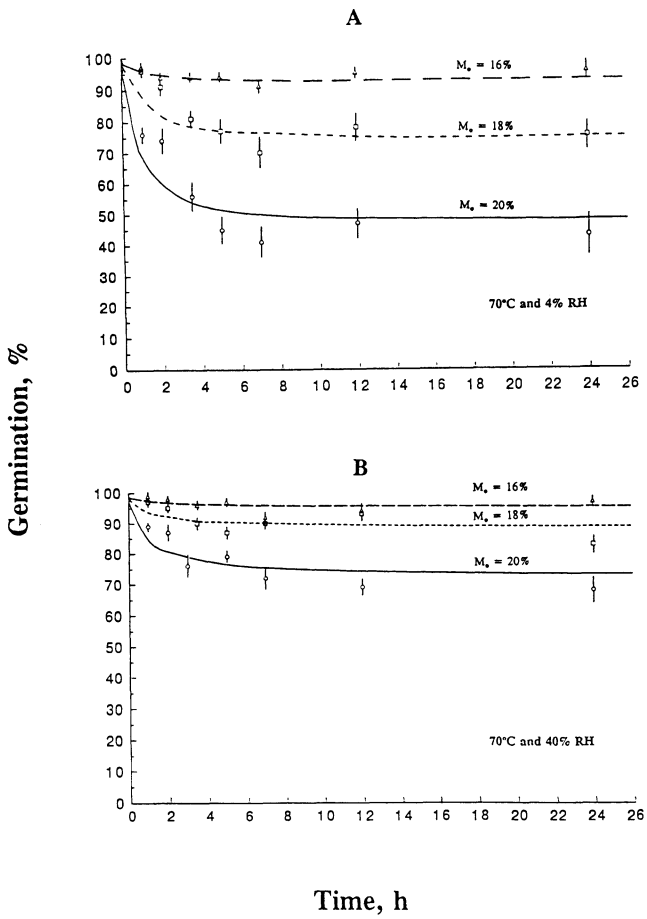

Figure 6–Germination in Laird lentils as affected by drying time at (A) 70° C and 4% RH and (B) 70°C and 40% RH. The curves stand for the predictive germination. The scattered data are from germination tests for the samples at moisture contents of 16% (△), 18% (□), and 20% (○).

less than six percentage points for the 18% initial moisture sample. The same can be said about the fit of the data from tests at 70° C and 40% RH. Considering the random nature of seed death and the order of error in germination determination (about 3%), as well as error in moisture content determination (0.3%), the prediction can be considered satisfactory. The predicted values reflect the general trend in which the drying parameters affect the germination of lentil seeds.

It may be acknowledged that probit viability analysis is a useful approach for predicting germination loss of grain seeds during dynamic drying processes. However, the idea of using the σ expression developed from steady state environmental conditions to simulate germination loss during dynamic drying conditions, as suggested by Nellist, may not be applicable, for the reason that the effect of drying rate is not considered. Instead, the expressions for standard deviation of seed death time should be developed from dynamic processes of thin-layer drying. Once this expression is developed, the probit viability analysis can be used in combination with a predictive model for the change in seed moisture content to simulate germination loss in a deep-bed dryer which is composed of a number of thin layers.

In the current study, parameters A and B in equation 11 were determined only for four drying conditions. It is desirable in future studies to develop general expressions for these parameters in terms of air temperature and relative humidity based on experimental data from a broader range of drying conditions.

Conclusions

Lentil seeds at an initial moisture content of 20% (wet basis) and lower were able to sustain a drying temperature of up to 66° C to produce no. 1 Canadian seeds. At 80° C, lentils lost almost all the viability. Between 66 and 80° C, germination loss was positively correlated to drying air temperature and seed initial moisture content, and negatively correlated to relative humidity. It also increased with drying time, with the most significant loss occurring in the first few hours of drying when the seed moisture content was relatively high. The germination loss in lentil seeds may be the result of two main causes: irreversible mechanical damage to the germ due to excessive stresses at high drying rates, and germ protein denaturation at high temperatures. Both were favored by high seed moisture contents and elevated drying air temperatures.

Computer simulation based on probit viability analysis was applicable for predicting germination loss for Laird lentil seeds in drying. However, the expression for standard deviation σ should be developed from dynamic drying processes, rather than from steady state sealed storage tests, to include the effect of drying rate.

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