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유채종자의 건조조건에 따른 발아특성

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The Effects of Drying Conditions on the Germination Properties of Rapeseed

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Abstract

This study was performed to determine the effect of drying conditions on the germination properties of rapeseed after seeds were dried under different drying conditions: 40℃, 50℃, or 60℃ in combination with 30%, 45%, or 60% relative humidity. As analytic results, drying conditions had significant effects (*P-value* < 0.001) and drying temperature was considered as the main factor on the germination properties of rapeseed. When drying temperature increased or relative humidity decreased, the vigor rate and germination rate decreased, the median germination time increased. The maximum values of vigor rate and germination rate were 90% and 95.44%, and their minimum values were 60.17 and 75%, respectively. To ensure the standard germination rate of 85%. The appropriate drying zone was determined and the drying temperature should be less than 51.0℃, 54.5℃ and 58.7℃ at 30%, 45% and 60% RH, respectively. The values for median germination time varied from 2 to 4 days. The predicted models of germination rate, vigor rate, and median germination time were determined.

Keywords : Rapeseed, Drying condition, Germination rate, Vigor rate, Median germination time

1. INTRODUCTION

Rapeseed (*Brassica napus* L.) should be harvested at full maturity in order to guarantee marketing quality of seeds. Harvesting too early is one of the causes of poor seed quality, whereas harvesting too late may result in reducing seed yield. For most crops, maximum seed germination is reached when seeds are physiologically mature (Tekrony, 2003). Seed physiological maturity was reached at approximately 42 days after pod formation, and the maximum germination was attained at harvest maturity about 7 days past physiological maturity (Elias and Copeland, 2001). This may be explained by enzymatic changes that occur within the seed after physiological maturity (Berti and Johnson, 2008).

Rapeseed must be dried after harvest so as to reach a final moisture content of 8% (d.b.) which is ideal for safe storage. The drying process has been a frequent cause of seed injury. Once the free moisture has been removed, further exposure to heat raises the seed temperature to a level with loss of quality could happen. Drying is therefore a critical step in the post harvest process. During the drying process, air temperature and relative humidity are two major factors that influence the germination characteristics of the seed.

The germinability of the seed is considered as the first and foremost factor for assessing its viability. There are many studies published on the germination rates of various seeds, but there are only a few of studies that have been performed on rapeseed. However, these studies were not

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performed to determine the effect of drying conditions on the germination properties of rapeseed. Sadowska et al. (1996) used the values of oil-point parameters and the degree of elasticity of bulk rapeseed for the evaluation of drying temperature. Marshall et al. (2000) assayed germination conditions of rapeseed at temperatures of 4℃, 10℃, and 19℃ to test the temperature effect on the germination rate as well as the presence or absence of dormancy at low temperatures. Christian et al. (2004) determined the effect of moisture stress and polymer coats on unfrozen canola seed germination at two different temperatures. Sathya et al. (2006) determined the safe storage period for rapeseed (as determined by three traits: germination rate, moisture content, and visible mold growth) under various moisture and temperature conditions.

Identifying the effects of different drying conditions on the germination characteristics of rapeseed is necessary to establish the optimal protocol for ensuring seed quality, facilitating improved seedling vigor, and providing additional information on potential crop establishment. The objective of this study was to investigate the effects of different drying conditions on the germination properties of rapeseed, namely germination rate, vigor rate, and median germination time.

2. MATERIALS AND METHODS

A. Apparatus and experimental procedures

Samples of freshly harvested rapeseed were used in the drying test. Thin layer drying technique (ASAE Standards, 2004) was used to ensure that the stream of drying air approaching the sample was as uniform as possible on all seeds of the sample. A laboratory thin layer dryer (Han et al., 2006) equipped with temperature and humidity controls (air-conditioning equipment model MTH4100, Sanyo, UK; with a range of operation from temperature of 20-70℃ (±0.1℃)) and relative humidity of 30-98% (±1%) was used in the drying tests. Nine drying conditions combine three drying air temperature levels (40℃, 50℃, and 60℃) and three relative humidity levels (30, 45, and 60%) with three replications. The moisture content of the samples was determined using the drying oven method: 10 g in a drying oven at 130℃ for 4 hours (ASAE Standards, 2004). The drying process was stopped when the moisture content of the sample 8% (d.b.).

Germination properties of rapeseed were determined from samples that were dried under the different conditions. After thin layer drying tests were completed, samples were sealed in double-layer polyethylene bags and allowed to reach ambient conditions. The samples were then tested for germinal quality under controlled conditions. The germination tests were conducted according to protocols described for the standard germination test (Association of Official Seed Analysis, 1993).

Groups of 100 seeds used for germination tests were laid over filter papers (Whatman No. 2) and humidified with distilled water inside a 150 mm diameter transparent petri dish with a cover to prevent desiccation of the filter papers. Afterwards, the petri dishes were placed in a non-illuminated germinator (model HK-B1025, with an accuracy of ±0.1℃) to maintain the temperature at 25℃ for seven days (Henryk et al., 1999; Guner, 2007). Previous tests had shown that germination was the same whether the seeds were kept in the dark or exposed to normal fluorescent laboratory lighting (Marshall et al., 2000). Three replications for each drying result were performed.

Seeds were considered germinated when the radicle emerged from the seed surface and grew to a length greater than 1 mm (Marian et al., 2000; Christian et al., 2004; Larsen and Andreasen, 2004). The germination rates of the samples were enumerated every 24 hours and germinated seeds were removed. The results from the count five days after the beginning of the test were used as a vigor indicator. Final germination percentage was calculated as the cumulative number of germinated seeds in each experimental unit at termination of the experiment on the seventh day.

B. Germination and vigor model

Median germination time was used to characterize germination. Median germination time (MGT) is the time at which 50% of seeds have germinated (of those that would have germinated by the conclusion of the experiment) (Christian et al., 2005). However, median germination time alone is not an adequate descriptor of germination characteristics, as two treatments may have the same median germination time yet the seeds may germinate at different rates. Germination rate (G) and vigor rate (V) were therefore used to further describe the germination characteristics for each treatment. Germination rate is the total percent germination obtained by dividing the number of seeds germinated by the total number of seeds within each experimental unit.

$$G = \frac{\sum n}{N} \quad (1)$$

where: n: number of seeds germinated on each day.
N: the total number of seeds within each experimental unit.

$$V = \frac{\sum m}{N} \quad (2)$$

where: m: number of seeds germinated after five days from the beginning of the test.

To estimate the vigor and germination of the seeds as a function of temperature and relative humidity, the following statistical model was fitted to the experimental data (Cody et al., 1997; Duc et al., 2008):

$$V_{ij} = a_0 + a_1 \times T_i + a_2 \times RH_j + a_3 \times T_i^2 + a_4 \times RH_j^2 + a_5 \times (T \times RH)_{ij} + E_{ij} \quad (3)$$

$$G_{ij} = b_0 + b_1 \times T_i + b_2 \times RH_j + b_3 \times T_i^2 + b_4 \times RH_j^2 + b_5 \times (T \times RH)_{ij} + E_{ij} \quad (4)$$

where: V_{ij} and G_{ij}: the values of vigor and germination (%) at the i^{th} temperature and j^{th} relative humidity; ($i = 1,\cdots, 3$; $j = 1,\cdots, 3$).

a_0, a_1, a_2, a_3, a_4, a_5, b_0, b_1, b_2, b_3, b_4, b_5: the regression constants.

T_i : the effect of the i^{th} drying temperature (℃).
RH_j : the effect of j^{th} relative humidity (decimal).
E_{ij} : the random error.

Median germination time in days was calculated with the following equation (Larsen and Andreasen, 2004):

$$MGT = \frac{\sum (D \times n)}{\sum n} \quad (5)$$

where: n: number of seeds germinated on day D.
D: number of days counted from the beginning of the germination test.

C. Statistical analysis

All of variables were analyzed by a stepwise multiple regression method, using the Statistical Analysis System (SAS) program. The measured and predicted values were compared and statistically analyzed for determining the fitness of the models. The coefficient of determination (R^2), the root mean square error (RMSE) and Chi-square (χ^2) were used to evaluate the models. The high values of R^2 and low values of RMSE and χ^2 were considered as the criteria for goodness of fit. Pareto analysis was performed to determine the main effect factor on germination properties.

3. RESULTS AND DISCUSSION

The cumulative germination rate over time following different combinations of drying conditions is shown in Fig. 1. It is easy to recognize that the germination rate decreased as the drying temperature was increased and the relative humidity was decreased. This may be explained by an effect of temperature causing physiological changes that can reduce germination rate. The data from the counts at the fifth day were used as vigor values, and the counts at the seventh day were used as germination values. The initial germination rate and vigor rate of rapeseed before drying is 97.33% and 96.67%, respectively.

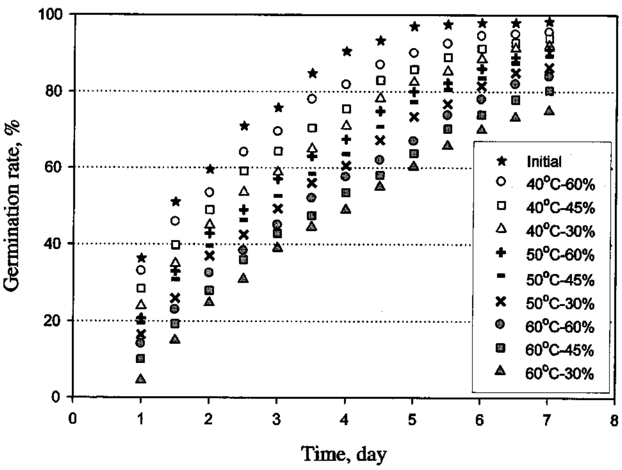


Fig. 1 Cumulative germination rate over time under different drying conditions.

The mean values of vigor rate, germination rate, and median germination time for rapeseed and coefficients of variation (CV) for measured parameters are calculated (Table

Table 1 Mean and coefficients of variations for the germination characteristics of rapeseed under different drying conditions

Drying conditions		Vigor rate		Germination rate		MGT	
Temp. (℃)	RH (%)	Mean (%)	CV[a] (%)	Mean (%)	CV[a] (%)	Mean (day)	CV[a] (%)
40	30	82.44	1.06	92.00	1.30	2.82	2.53
	45	85.78	1.47	94.00	1.33	2.60	2.68
	60	90.00	0.74	95.44	1.65	2.37	2.32
50	30	73.56	0.95	86.22	1.47	3.12	1.96
	45	76.78	0.74	88.78	1.33	3.04	2.57
	60	80.00	1.13	91.00	1.28	2.89	2.24
60	30	60.22	0.75	75.00	0.86	3.47	2.29
	45	63.78	0.96	80.22	1.37	3.38	2.48
	60	67.00	0.77	84.00	1.18	3.28	2.33

[a]CV = (standard deviation/mean) × 100 (%)

1). In the range of the experimental conditions tested, the maximum values of vigor rate and germination rate were 90% and 95.44% and the minimum values were 60.22 and 75.0%, respectively. The median germination time increased as drying temperature increased and relative humidity decreased. The value for the median germination time varied from 2 to 4 days. The maximum variation of vigor rate, germination rate and median germination time were less than 1.5, 1.7, and 2.7%. On the average, the variation of vigor rate, germination rate and median germination time were 0.95, 1.31, and 2.38%, respectively.

These results showed the effect of the drying temperature, relative humidity, and interaction of temperature and relative humidity on germination characteristics (i.e. the germination characteristics of rapeseed as a function of drying temperature and relative humidity). Using statistical analysis this correlation becomes clearer.

Statistical analysis showed that the germination properties of rapeseed were significantly affected by the drying conditions over the entire range of data (*P-value* < 0.001). Therefore, the behavior of vigor and germination as a function of temperature and relative humidity were described by fitting Equation (3) and (4) with high R^2, low RMSE and low χ^2 as Equation (6) and (7).

Vigor model:

$$V = 75.75 + 0.746667 \times T + 23 \times RH - 0.0186667 \times T^2 \quad (6)$$

$$(R^2 = 0.999;\ RMSE = 0.00232;\ \chi^2 = 0.00583)$$

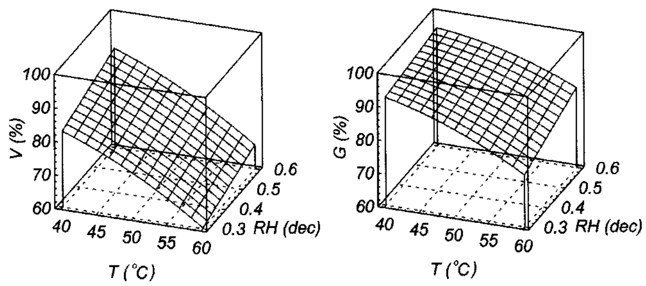
Germination model:

$$G = 88.3917 + 0.784167 \times T - 26.7222 \times RH - 0.019 \times T^2$$

$$+ 0.916667 \times T \times RH \quad (7)$$

$$(R^2 = 0.996;\ RMSE = 0.00352;\ \chi^2 = 0.01324)$$

The response surfaces for predicting the vigor rate and germination rate of rapeseeds are shown in Fig. 2. These figures indicate that the best temperature and relative humidity combination, which gives the maximum vigor rate and germination rate, are 40℃ and 60%, at which vigor rate and germination rate was 90% and 95.44%, respectively.



(a) vigor rate (b) germination rate versus drying conditions

Fig. 2 Surface of response for predicting.

To determine the most important factor among a set of factors (temperature, relative humidity, interaction of temperature and relative humidity) that has the most dominant effect on vigor rate and germination rate, Pareto analysis was performed. The Pareto chart, representing a Pareto analysis, is a frequency histogram in which the length of each bar on the chart is proportional to the value of its associated estimated effects. The values of the factors being plotted are arranged in a descending order. The results of these analyses are shown in Fig. 3. It indicates that temperature has a greater effect than the other factors on both vigor rate and germination rate of rapeseed. The interaction of T×RH, T^2 and RH^2 can be ignored for vigor and germination models, respectively.

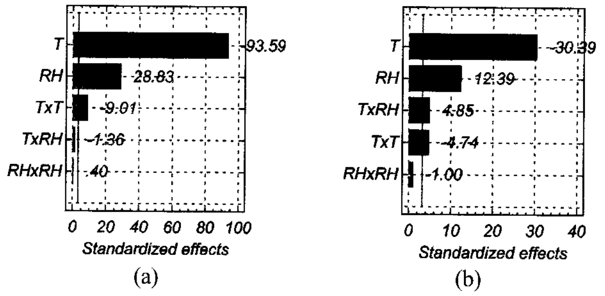


Fig. 3 Standardized Pareto chart for (a) vigor rate, and (b) germination rate.

The measured data obtained were fitted with the models. Fig. 4 shows the comparison of the measured and predicted germination rates at nine different combinations of drying conditions. Based on the germination experimental data and the values from the predicted model, three pairs of regression curves for the measured and predicted data were plotted. The curves show the best agreement between the measured and predicted values. Similar result was also obtained with vigor rate.

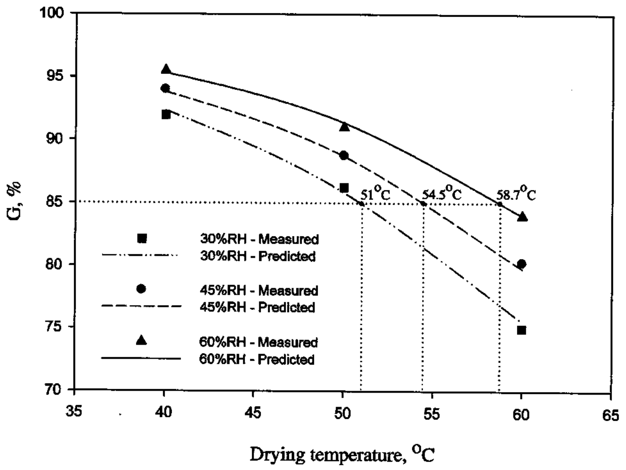


Fig. 4 Comparison of the measured and predicted germination rates at different drying conditions.

The slope of curves showed the relative humidity more significantly affected germination rate as the drying temperature increased, namely the difference in germination rate among relative humidities from 30% to 60% are maximum at a drying temperature of 60℃. The drying temperature less affected the germination rate when the relative humidity was increased. Namely when drying temperature increased from 40℃ to 60℃, at 30% RH the loss of germination was 17%, at 45% and 60% RH the loss of germination down to 13.8% and 11.5%, respectively. To ensure the minimum germination rate of rapeseeds, That is 85% (Smith, 2002), the drying temperature should be less than 51℃, 54.5℃ and 58.7℃ at 30%, 45% and 60% RH, respectively (Fig. 4). Based on this standard germination rate, the appropriate drying conditions were determined by the relationship between drying temperature (℃) and relative humidity (decimal). The drying temperature for ensuring the standard germination rate of rapeseeds (T_{85},℃) can be expressed as Equation (8). The appropriate drying zone was shown in Fig. 5.

$$T_{85} \leq T = 46.1 + 11.667 \times RH + 15.556 \times RH^2 \quad (8)$$

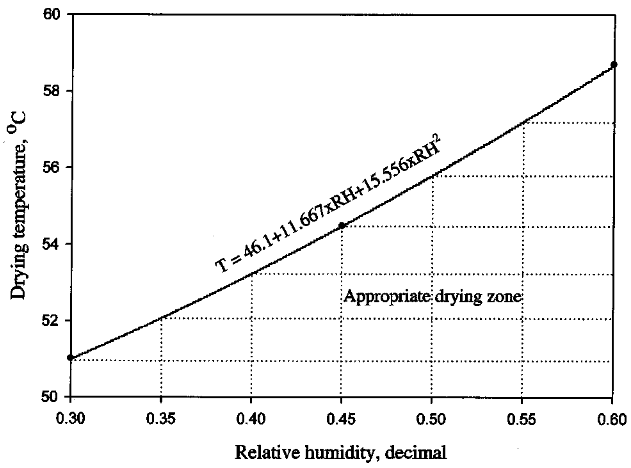


Fig. 5 Appropriate drying conditions for ensuring standard germination rate of 85%.

The fitness of germination and vigor models, plotted as the predicted values versus the measured values, is presented in Fig. 6, where the data points have a close correlation with the perfect fit line (measured values = predicted values). This result affirmed the good agreement of the model with the experimental data.

From the data of the median germination time presented in Table 1, we used statistical analysis to determine the median germination time model, as in Equation (9). The response surfaces for predicting the median germination time of rapeseeds are shown in Fig. 7.

$$MGT = 1.16167 + 0.0728333 \times T - 3.12222 \times RH - 0.000533 \times T^2 + 0.043333 \times T \times RH \quad (9)$$

($R^2 = 0.995$; RMSE = 0.00024; $\chi^2 = 0.00167$)

Median germination time was also significantly effected by drying temperature, relative humidity, and the interaction of temperature and relative humidity (*P-value* < 0.05).

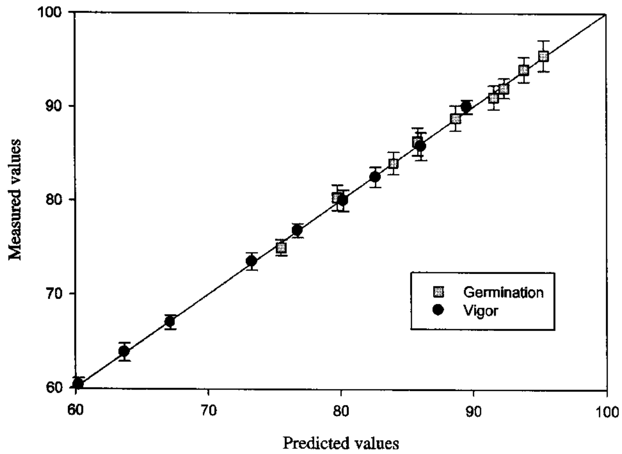


Fig. 6 Measured values versus predicted values of the germination and vigor models.

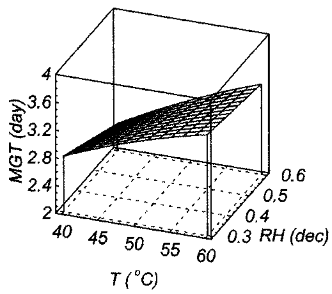


Fig. 7 Surface of response for predicting the median germination time versus drying conditions.

4. CONCLUSIONS

The effects of air drying temperature and relative humidity on the germination properties of rapeseed were investigated experimentally. The analytic results indicated that both drying air temperature and relative humidity affected significantly the germination characteristics of rapeseed. The germination and vigor rate decreased when the drying air temperature increased or relative humidity decreased, but the effect of drying air temperature increase was dominant. The median germination time increased when the drying temperature increased or relative humidity decreased. The appropriate drying conditions for ensuring the standard germination rate of rapeseed were determined. The regression models depicting germination properties were found with high accuracy and reliability. These models are completely suitable for the prediction of the germination properties of rapeseed after drying.

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