Journal of Stored Products Research 59 (2014) 328–337

Contents lists available at ScienceDirect

Journal of Stored Products Research

journal homepage: www.elsevier.com/locate/jspr

# Quality changes in high and low oil content canola during storage: Part II – Mathematical models to predict germination

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A R T I C L E I N F O

*Article history:*
Available online 3 July 2014

*Keywords:*
Canola
Rapeseed
Storage
Germination
Mathematical model

A B S T R A C T

Novel mathematical models to predict germination of canola (including rapeseed) stored under laboratory and field conditions were developed with certain assumptions. The models were developed based on the data collected under laboratory condition (constant temperatures). The hypothesis of the developed models was that germination of stored canola was influenced by temperature, moisture content, storage time, and airtightness. The effect of these factors on germination of stored canola was the product of effective storage time and interactive effect of temperature, moisture content, storage time, and airtightness. Data collected under both laboratory and filed conditions were used to calibrate and verify the developed models. The prediction accuracy of the models associated with field conditions (except canola seeds with 14% moisture content stored inside silo bags) was higher than that under laboratory conditions. The developed models could visually or mathematically predict germination of canola or rapeseed stored under any condition. The developed models explained more than 96% variation of observed germination of the canola or rapeseed seeds with ≤10% moisture content stored inside a flat bottom bin or commercial silo bags.



## 1. Introduction

In the first part of this study (Sun et al., 2014), different cultivars of canola with different oil contents were stored under constant temperatures, and germination, free fatty acid values (FAV), visible and invisible mold were determined every 2 or 4 wk during a 20 wk storage period. Storage guidelines were developed based on 20% loss in initial germination. This guideline could be visually used to determine safe storage time of canola seeds which could contain up to 50% oil. Safe storage guidelines for other grain crops were also developed using this method (Mills and Sinha, 1980; Schroth et al., 1998; Sathya et al., 2008, 2009).

Regression equations for safe storage time of different crops based on the time of 5% or 20% loss in initial germination or visible mold appearance (whichever occurred first) were developed by different researchers (Fraser and Muir, 1981; White et al., 1982a,b). Sanderson et al. (1989) compared the storage times predicted with measured times for several near-ambient drying conditions of wheat and found deterioration was not excessive when the predicted storage times were reached. There is no other study to verify these equations and guidelines under other storage conditions. This verification is important because stored grain is exposed to fluctuating temperatures and moisture contents (Jian et al., 2009). Grain is produced and stored worldwide and the initial moisture content and temperature inside storage bins are different. During storage, both temperature and moisture content will change due to ambient temperature change, moisture migration, and respiration of mold, insects and canola itself when the grain is wet (Mills and Sinha, 1980; Sinha and Wallace, 1977). There is no model available to predict germination loss under fluctuating temperature and moisture conditions. It is also not known whether grain can be safely stored longer under fluctuating conditions than under constant temperature and/or moisture content conditions.

The developed regression equations or guidelines can only be used to predict the safe storage time for 5% (White et al., 1982a,b) or 20% (Fraser and Muir, 1981; Sathya et al., 2008, 2009) initial germination losses. A mathematical model to predict germinations under different storage conditions for different storage times is required because germination loss is related to mold infection, carbon dioxide production, dry mass loss, grain deterioration and grade loss (Steele et al., 1969; White et al., 1982a,b; Jian et al., 2014, Sun et al., 2014). Therefore, germination loss predicted by

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http://dx.doi.org/10.1016/j.jspr.2014.05.007

mathematical equations can be used to predict dry mass loss, grain deterioration and grade loss. The developed mathematical equations could also be used to find the effect of different combinations of fluctuating temperatures and moisture contents on grain deterioration.

The objective of this study was to develop mathematical models to predict canola germination under various storage conditions for different storage times. The developed models were calibrated, verified and validated by using data collected under both laboratory and field storage conditions.

## 2. Materials and methods

### 2.1. Model development

Seed germination, moisture content, and temperature data of the Nex4 105 (45.4 ± 0.35% oil content, referred to as H-N) and 5525 Clearfield (42.4 ± 0.07% oil content, referred to as L-C) canola, which were collected in Part I (Sun et al., 2014), were used to develop the models to predict germination of canola under both laboratory and field conditions. To develop the model, the following assumptions were made:

1. Newly harvested canola with 100% maturity had ≥98% initial germination.
2. About eight years would be required for the canola seeds with 8% moisture content (MC) stored at 10 °C to decrease its germination from initial 98% to 0% (Verma et al., 2003).
3. Canola temperature, moisture content and the interaction between these two factors had linear or non-linear additive effects on the decrease of germination.
4. The effect of temperature, moisture content and their interaction on seed germination could be arbitrarily divided into 0–7 scale. The scale values increased with the increase of temperature or moisture content or both.

Canola with 8% MC at 10 °C had scale value 1. When scale value was 0, the canola with 0% MC would be stored at −273.15 °C forever without any loss of germination (if seed could not be shattered at absolute zero). Scale value 7 indicated that 22.5% MC canola with 100% initial germination at 43 °C would have zero germination in 2 d (White et al., 1982a; Sun et al., 2014). The combinations of moisture contents and temperatures corresponding to scale values 0.5, 1–6 were assumed as 2% MC at 4 °C, 4% MC at 17 °C or 8% at 10 °C, 6% MC at 30 °C or 12% MC at 20 °C, 8% MC at 37 °C, 12% MC at 37 °C, 14% MC at 45 °C, and 18% MC at 37 °C, respectively. These assumed scale values associated with combinations of temperatures and moisture contents could be calculated by Eq. (1).

$$S_{T-M} = \frac{7}{\left(1+\left(\frac{M-22.6}{13.6}\right)^2\right)\left(1+\left(\frac{T-43.1}{22.1}\right)^2\right)} \quad T<43.1\ ^\circ\text{C and } M<22.6\%$$
$$S_{T-M} = 7 \quad T \ge 43.1\ ^\circ\text{C and } M>22.6\% \tag{1}$$

where, $S_{T-M}$ = scale value of the combinations of temperatures and moisture contents (numerical number from 0 to 7), $M$ = grain moisture content (%), and $T$ = grain temperature (°C). Eq. (1) was obtained through regression ($R^2 = 0.99$) using the assumed scale values and the associated combinations of temperatures and moisture contents.

These calculated scales at each combination of temperature and moisture content were regressed with the time that the canola at this combination had 5% germination (referred to as GT5%). The GT5% was found by using the measured data of the H-N and L-C at different combinations of temperatures and moisture contents. If the measured data were not available (e.g., the germination of 8% MC H-N at 10 °C in 20 wk had ≥96% germination), GT5% was calculated by using the regression equations found in Part I (Sun et al., 2014). The same procedure was conducted to find the time for the 50 and 95% germination of H-N and L-C (referred to as GT50% and GT95%, respectively). All the regression equations for the GT5%, GT50% and GT95% followed an exponential decay equation (Eq. (2), Table 1). The times for other percentages of germination were tested and also followed this exponential decay equation, but are not reported in this article for the reason of a concise presentation.

$$\text{GT5\%, GT50\% or GT95\%} = Ae^{-BS_{T-M}} \tag{2}$$

where, $A$ and $B$ are constants (Table 1). Eqs. (1) and (2) were supported by the fact that the relationship among GT5% (or GT95%), temperature and moisture content followed a parabolic equation with all $R^2 > 0.85$ (Fig. 1, Table 2). Times to GT5%, GT50% and GT95% could separate the canola storage condition into three zones (non-spoil, spoil, and complete spoil zones) and sub-zones (Fig. 2). Germination was ≤5%, >5% and <95%, and ≥95% inside the complete spoil, spoil, and non-spoil zones, respectively (Fig. 2).

Based on the concept of the zones, canola germination in a storage period under any storage condition could be calculated using daily average temperature and moisture content.

$$\begin{aligned} &G = G_i - 100\sum_{i=1}^{i=\theta}\tau_i\left(\theta_{eT}+\theta_{eM}-\theta_{fl}-\theta_{\text{air}}\right)\\ &G = 0 \quad \text{if } G<0\\ &G = 100 \quad \text{if } G>100 \end{aligned} \tag{3}$$

$$\tau_i = e^{C+DS_{T-M}} \tag{4}$$

$$\begin{aligned} &\theta_{eT} = ie^{E+DS_{T-M}} \quad \text{if } \theta_{eT} \le 2\\ &\theta_{eT} = 2 \quad \text{if } \theta_{eT} > 2 \end{aligned} \tag{5}$$

$$\begin{aligned} &\theta_{eM} = -0.0728 + \frac{1.114}{1+e^{\frac{M-10.6966}{1.0135}}} \quad \text{MC} > 8\%\\ &\theta_{eM} = 0 \quad \text{MC} \le 8\% \end{aligned} \tag{6}$$

where, $G$ = germination (%), $G_i$ = initial germination at the start of the storage period (%), $\tau_i$ = effect of the combination of the average daily temperature and daily moisture content in day $i$ on seed germination, $C = -9.79 \pm 0.16$ for canola with high oil content (such