Safe storage guidelines for canola as the seeds slowly dry

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Sathya, G., D.S. Jayas and N.D.G. 2009. **Safe storage guidelines for canola as the seeds slowly dry**. Canadian Biosystems Engineering/Le génie des biosystèmes au Canada **51**: 3.29–3.38. Safe storage guidelines based on canola seed moisture content and storage temperature are needed to know how long seed can be held in storage without deterioration. Canola samples with 7.5, 10.0, 12.5 and 15.0% initial moisture content (m.c.) (wet basis) were stored at 10, 20, 30 and 40°C for 16 wk. The seeds retained initial moisture levels at 10°C, while, at 20, 30, and 40°C, the seeds dried during the several weeks of this study. Seed germination, moisture content, appearance of visible mould, free fatty acid value (FAV) and invisible microflora were monitored at regular intervals. Germination of the 7.5 and 10.0% moisture content samples stored at 10 and 20°C remained above 80% throughout the study, whereas that of the other samples dropped over time with higher initial moisture contents and with higher storage temperature. The samples stored at 30 and 40°C lost moisture more rapidly than at 20°C. Visible mould appeared in all the 15.0% moisture content samples and in all the samples stored at 40°C in the early stages of storage. The FAV increased with increasing moisture content, temperature and storage time. Safe storage guidelines were developed for canola with respect to initial moisture content and storage temperature using the measured quality parameters. Canola with $<10.0\%$ moisture content stored at <20°C will not deteriorate for at least 15 wk, whereas the 12.5 and 15.0% moisture content seeds stored at >25°C need to be dried within a week to avoid spoilage. **Keywords:** canola, moisture content, temperature, safe storage guidelines.

Des lignes directrices sur l'entreposage sécuritaire du colza basées sur la teneur en eau et la température des graines sont nécessaires pour déterminer combien de temps les graines peuvent être entreposées sans qu'il y ait détérioration. Des échantillons de colza à des teneurs en eau initiales de 7,5, 10,0, 12,5 et 15,0% (base humide) ont été entreposés à 10, 20, 30 et 40°C durant 16 semaines. Les graines ont maintenu leur teneur en eau initiale lorsqu'entreposées à une température de 10°C. Des températures d'entreposage de 20, 30 et 40°C ont toutefois résulté en un assèchement des grains. La germination des graines, la teneur en eau, l'apparence de moisissures visibles, la teneur en acides gras libres (FAV) et la microflore invisible ont été évaluées périodiquement durant l'entreposage. La germination des échantillons ayant une teneur en eau initiale de 7,5 et 10,0% et entreposés à 10 et 20°C est demeurée au-dessus de 80% durant toute l'étude tandis que celle des autres échantillons ayant des teneurs en eau initiales et des températures d'entreposage plus élevées a diminué. Les échantillons entreposés à 30 et 40°C ont perdu leur humidité plus rapidement que qu'à 20°C. Des moisissures visibles sont apparues dans tous les échantillons à 15% de teneur en eau initiale de même que dans tous les échantillons entreposés à 40°C et ce tôt durant la période d'entreposage. Le FAV a augmenté avec une augmentation de la teneur en eau, de la température et du temps d'entreposage. Des lignes directrices d'entreposage sécuritaire ont été développées pour le colza en tenant compte de la teneur en eau initiale et de la température d'entreposage et en utilisant les paramètres de qualité mesurés. Le colza ayant une teneur en eau inférieure à 10,0% et entreposé à une température dépassant 20°C ne se détériorera pas sur une période d'au moins 15 semaines, toutefois les graines ayant une teneur en eau de 12,5 et 15,0% et entreposées à des températures supérieures à 25°C doivent être séchées à l'intérieur d'un délai d'une semaine pour éviter les pertes. **Mots clés:** colza, teneur en eau, température, lignes directrices d'entreposage.

INTRODUCTION

Most grains in Canada are planted in April or May and harvested in the autumn (August–September). Rain during harvest sometimes causes the crop to be harvested at high moisture levels that are not suitable for safe storage and in some years farmers may not have a chance to harvest the grain before snow fall, which leads to extensive spoilage. In 2002, the rainy weather conditions during harvest delayed the harvest of canola in western Canada and the harvest could not be completed until 2003 (DeClercq and Daun 2003). Moreover, even the grains with safe initial moisture contents deteriorate during storage if the storage conditions are poor.

Canola (*Brassica napus* L.) is the second largest oilseed crop in the world next to soybean, and it accounts for 13% of the world's oilseed supply (Raymer 2002). In Canada, the average annual canola production is 6.9 Mt (million tonnes), which is 12% of the nation's principal grain production (CWB 2005). Swathing of canola is carried out when the average seed moisture is 35–40%. Under good weather conditions, the canola seeds can lose 1–2% moisture every day. Threshing the swathed crop is carried out at approximately 12% moisture content or slightly higher (Mills 2001). Freshly harvested canola maintains a high rate of respiration up to 6 wk before becoming physiologically quiescent. This high respiration process is called sweating of canola, which is considered to be an unstable condition and needs careful monitoring. According to the Canadian Grain Commission the standard moisture content for canola oil extraction is 8.5%. Furthermore, for safe and prolonged storage, the canola seeds have

to be dried below 8% moisture content (Mills 1989; Anonymous 2005) and hence it is essential to dry the threshed canola both for oil production and safe storage. Safe storage guidelines are necessary to know how long the grain will remain safe at given moisture and temperature conditions so that drying and cooling of the bulk grain can be done in a timely manner. The choice of conditioning systems (heated air; near-ambient air) and the airflow rate of fans also depend on the available time.

Water content and temperature of the stored grain are the primary physical factors that influence the deterioration of stored grain. High moisture content of the stored canola seed is the first and most important factor that speeds up the deterioration, followed by high temperature (White 1995; Jayas and White 2003). When the storage temperature and moisture exceed particular levels, microflora and mites will multiply and the grain will spoil quickly (Sinha 1973; Wallace et al. 1983).

Safe storage guidelines with respect to biochemical and microbial measure are available for wheat (Wallace et al. 1983), rapeseed (Mills and Sinha 1980), canola meal (White and Jayas 1989) and flax seed (White and Jayas 1991). Because only limited data are available on the postharvest deterioration of canola, the objective of this work was to monitor the quality changes of canola under different moisture and temperature conditions during storage and to develop safe storage guidelines.

MATERIALS and METHODS

Sample preparation and storage conditions

Canola seeds, grown in 2004, were obtained from Agriculture and Agri-Food Canada, Winnipeg, and reconditioned to 7.5, 10.0, 12.5 and 15.0% m.c., wet mass basis. Even though 10% moisture content canola seeds are assigned straight grade, 8% moisture content is considered necessary for prolonged storage (Anonymous 2005) and therefore the 7.5–15.0% m.c. range was chosen for this study. The samples were stored at -5^{o}C until used for the study to prevent seed deterioration.

Four environmental chambers (E15 and C1010, CONVIRON, Controlled Environments Limited, Winnipeg, MB) were used to maintain 10, 20, 30 and 40°C and the RH inside the chambers was maintained at 50 ± 5%. The 10–40°C range was based on the possible temperatures the grain would be at during and after harvest. The average daily temperature of the Canadian prairies is around 25°C during normal harvesting periods (Muir and Jayas 2001) and the canola seeds in the swath can be about 5° above the ambient temperature (Prasad et al. 1978). At 30°C deterioration occurs rapidly.

Equilibrium relative humidity of the 7.5, 10.0, 12.5 and 15.0% m.c. samples (60, 75, 85 and 90% RH, respectively) were maintained using potassium hydroxide (KOH) solutions at specific gravities of 1.285, 1.211, 1.147 and 1.108, respectively (Solomon 1951).

Experimental setup

About 400 mL of KOH solution were placed in a sealed plastic container with perforations on the outer surface above the solution level, and placed inside a plastic pail (5.5 L capacity). Two kilograms of conditioned canola samples in a mesh bag were placed over the KOH-filled container inside the pail, which had a lid on the top (Fig. 1). Three replications (separate containers) were conducted at each temperature and moisture combination. The canola in the mesh bag was mixed thoroughly and samples were taken weekly for 16 weeks for quality analysis. No quality measurements were carried out once the germination of a sample dropped to 0%.

Grain quality assessment

Germination was measured every week by placing 25 seeds on a Whatman no. 3 filter paper in a 90 mm Petri dish saturated with 5.5 mL of distilled water. The dishes were incubated at 22 ± 1°C for 7 days and the number of germinated seeds was counted (Wallace and Sinha 1962).

Moisture content of the samples was measured every week by drying approximately 10 g of sample in a hot air oven at 130°C for 4 h (ASAE 2003) and expressed as percentage wet mass basis.

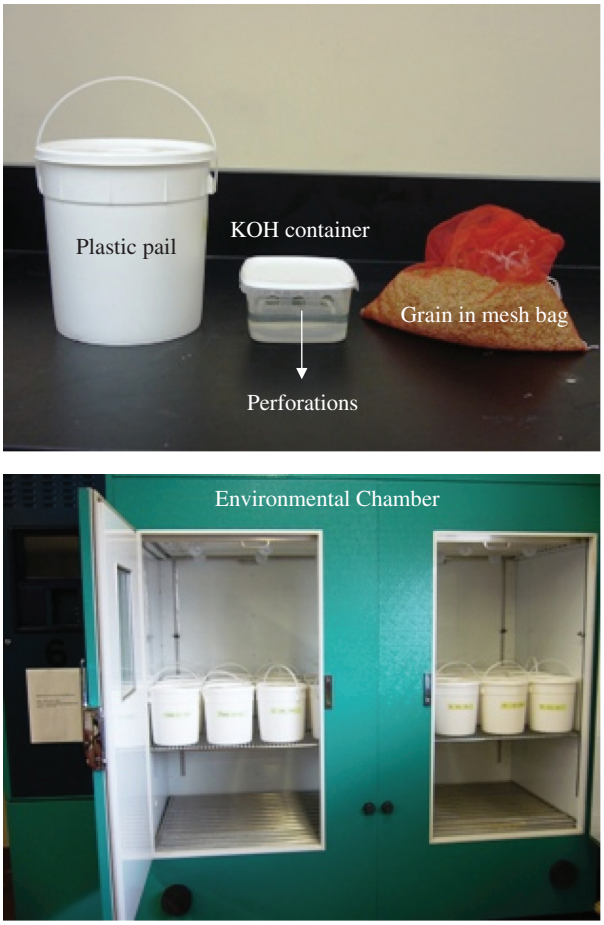

Fig. 1. Canola sample in a mesh bag which was placed on a perforated support in a pail containing KOH solution which maintained a specified relative humidity within the pail which was placed in a growth chamber at maintained storage temperature.

Appearance of visible mould was monitored every week by visually inspecting the samples. Invisible microflora species were identified at 4 week intervals by placing 25 seeds on a Whatman no. 3 filter paper in a 90 mm diameter Petri dish saturated with 5.5 mL of 7.5% aqueous sodium chloride (NaCl) solution. The plates were incubated at 25°C for 7 days and the microfloral species were identified using a dissection microscope (Mills et al. 1978).

Free fatty acid values, unlike the weekly analysis for the other variables were measured at 2 week intervals using Goldfisch fat extractors and KOH titration (Schroth et al. 1998).

Statistical analysis

Effects of moisture content, temperature and storage period on germination and FAV were analyzed using analysis of variance (ANOVA) using a three factorial design model (4 moisture contents $\times$ 4 temperatures $\times$ 16 weeks). Changes in the germination and FAV over storage period were analyzed using least significant difference (LSD) means of comparison with 95% confidence interval.

RESULTS and DISCUSSION

Germination

Changes in germination of canola with respect to time are given in Tables 1–4. Initially, the samples had 96% germination. At 10°C, germination of all the samples remained above 70% throughout the study, even at 15% moisture content and germination of the 7.5 and 10.0% moisture samples remained above 80%. At 20°C, only the 7.5% moisture samples had more than 80% germination throughout the 16 week storage period; other moisture samples decreased in germination with time. At 30 and 40°C, all the samples decreased in germination over time and none of them had above 80% germination by the end. The canola seeds with 7.5% moisture content can be kept at 10, 20 and even at 30°C without considerable loss in seed viability, whereas the high moisture seeds have to be dried immediately to prevent loss in seed viability. Germination of the samples was significantly affected by moisture content, temperature and storage period ($\alpha = 0.05$). Germination decreased with increasing moisture content and temperature. This confirms the results of Christensen and Kaufmann (1969), who reported that with higher moisture content, most types of grains become more sensitive to injury or death by fungi at high storage temperature. The same trend was observed by Wallace and Sinha (1962), who reported that germination had a positive correlation with field fungi (newly harvested seed); and a negative correlation with temperature and storage fungi (after prolonged storage).

Moisture content

Potassium hydroxide solutions of different specific gravities were used to maintain the equilibrium relative humidity of the grain samples, which it did at 10°C, but at 20, 30, 40°C the seed gradually dried from all initial moisture contents (Fig. 2).

Table 1. Germination ($n = 3$) of canola stored at 10°C for different storage periods.

Initial MC (%)	Storage period (wk)															
	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
7.50	96.0^{a}*	94.67^{a}	92.00^{ab}	88.00^{bcd}	88.00^{bcd}	86.67^{cde}	88.00^{bcd}	92.00^{ab}	92.00^{ab}	89.33^{bc}	80.00^{f}	85.33^{cde}	86.67^{cde}	84.00^{def}	82.67^{ef}	86.67^{cde}	88.00^{bcd}
	±0.00**	±2.31	±0.00	±0.00	±4.00	±6.11	±0.00	±4.00	±4.00	±2.31	±0.00	±2.31	±2.31	±4.00	±4.62	±2.31	±0.00
10.0	96.0^{a}	88.00^{b}	82.67^{bcd}	76.00^{de}	76.00^{de}	74.67^{e}	78.67^{cde}	84.00^{bc}	85.33^{bc}	82.6^{bcd}	78.67^{cde}	82.67^{bcd}	78.67^{cde}	81.33^{bcde}	85.33^{bc}	81.33^{bcde}	80.00^{bc}
	±0.00	±0.00	±6.11	±4.00	±6.93	±2.31	±2.31	±4.00	±6.11	±6.11	±2.31	±6.11	±2.31	±2.31	±4.62	±2.31	±0.00
12.5	96.0^{a}	85.33^{bc}	82.67^{bcd}	78.67^{cde}	73.33^{e}	80.00^{cde}	77.33^{de}	88.00^{b}	73.33^{e}	78.67^{cde}	77.33^{de}	85.33^{bc}	77.33^{de}	77.33^{de}	76.00^{de}	77.33^{de}	76.00^{de}
	±0.00	±2.31	±2.31	±4.62	±6.11	±4.00	±4.62	±4.00	±10.07	±2.31	±6.11	±4.62	±2.31	±2.31	±0.00	±2.31	±0.00
15.0	96.0^{a}	84.00^{b}	80.00^{bcd}	78.67^{bcde}	65.33^{f}	74.67^{de}	74.67^{de}	77.33^{bcde}	72.00^{ef}	74.67^{de}	82.67^{bc}	82.67^{bc}	72.00^{ef}	73.33^{de}	76.00^{cde}	74.67^{de}	72.00^{ef}
	±0.00	±4.00	±4.00	±4.62	±10.07	±4.62	±4.62	±4.62	±6.93	±2.31	±2.31	±2.31	±0.00	±2.31	±0.00	±4.62	±4.00

*Values with same superscripts in a row are not significantly different by least significant difference (LSD) comparison of means.
**Standard deviation.

Table 2. Germination ($n = 3$) of canola stored at 20°C for different storage periods.

Initial MC (%)	Storage period (wk) 0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
7.50	96.0^{a}*	90.67^{ab}	85.33^{bcde}	84.00^{cdef}	85.33^{bcde}	85.33^{bcde}	86.67^{bcde}	88.00^{bc}	86.67^{bcd}	84.00^{cdef}	80.00^{efg}	82.67^{cdefg}	77.67^{g}	80.00^{efg}	81.33^{defg}	78.67^{fg}	80.00^{efg}
	±0.00**	±2.31	±2.31	±0.00	±2.31	±6.11	±6.11	±0.00	±2.31	±4.00	±4.00	±2.31	±2.89	±4.00	±6.11	±2.31	±0.00
10.0	96.0^{a}	84.00^{bc}	78.67^{cd}	81.33^{bcd}	74.67^{d}	80.00^{bcd}	81.33^{bcd}	76.00^{d}	86.67^{b}	84.00^{bc}	77.33^{cd}	78.67^{cd}	74.67^{d}	76.00^{d}	80.00^{bcd}	78.67^{cd}	78.67^{cd}
	±.00	±4.00	±6.11	±6.11	±4.62	±4.00	±6.11	±4.00	±2.31	±4.00	±4.62	±4.62	±2.31	±4.00	±0.00	±2.31	±2.31
12.5	96.0^{a}	82.67^{b}	78.67^{bcd}	74.67^{bcde}	72.00^{de}	73.33^{cde}	78.67^{bcd}	76.00^{bcde}	81.33^{bc}	77.33^{bcde}	78.67^{bcd}	77.33^{bcde}	74.67^{bcde}	74.67^{bcde}	72.00^{de}	69.33^{e}	69.33^{e}
	±0.00	±2.31	±6.11	±10.07	±6.93	±6.11	±2.31	±4.00	±2.31	±2.31	±6.11	±6.11	±4.62	±6.11	±8.00	±6.11	±2.31
15.0	96.0^{a}	76.00^{bc}	77.33^{b}	61.33^{fg}	72.00^{bcdef}	73.33^{bcde}	74.67^{bcd}	73.33^{bcde}	73.33^{bcde}	69.33^{bcdefg}	66.67^{bcdefg}	72.00^{bcdef}	64.00^{defg}	65.33^{cdefg}	66.67^{bcdefg}	62.67^{efg}	60.00^{g}
	±0.00	±4.00	±2.31	±2.31	±4.00	±6.11	±6.11	±8.33	±11.55	±2.31	±16.17	±8.00	±4.00	±2.31	±2.31	±6.11	±4.00

*Values with same superscripts in a row are not significantly different by least significant difference (LSD) comparison of means.
**Standard deviation.

Table 3. Germination ($n = 3$) of canola stored at 30°C for different storage periods.

Initial MC (%)	Storage period (wk) 0	1	2	3	4	5	6†	7	8	9	10	11	12	13	14	15	16
7.50	96.0^{a}*	85.33^{b}	81.33^{bc}	81.33^{bc}	81.33^{bc}	74.67^{de}	77.33^{cde}	81.33^{bc}	78.67^{cd}	72.00^{e}	78.67^{cd}	81.33^{bc}	76.00^{cde}	77.33^{cde}	78.67^{cd}	78.67^{cd}	78.67^{cd}
	±0.00**	±4.62	±4.62	±2.31	±4.62	±4.62	±2.31	±2.31	±6.11	±6.93	±2.31	±2.31	±4.00	±2.31	±2.31	±2.31	±2.31
10.0	96.0^{a}	78.67^{b}	76.00^{bc}	74.67^{bcd}	72.00^{bcde}	68.00^{cde}	72.00^{bcde}	72.00^{bcde}	66.67^{cde}	64.00^{e}	64.00^{e}	70.67^{bcde}	69.33^{bcde}	68.00^{cde}	72.00^{bcde}	66.67^{cde}	65.33^{de}
	±0.00	±2.31	±4.00	±6.11	±4.00	±8.00	±4.00	±4.00	±12.86	±4.00	±8.00	±8.33	±4.62	±8.00	±4.00	±4.62	±2.31
12.5	96.0^{a}	77.33^{bc}	78.67^{b}	64.00^{de}	68.00^{bcd}	57.33^{de}	60.00^{de}	66.6^{cd}	68.00^{bcd}	64.00^{de}	60.00^{de}	62.67^{de}	66.67^{cd}	57.33^{de}	54.6^{e}	60.00^{de}	57.33^{de}
	±0.00	±4.62	±2.31	±6.93	±6.93	±4.62	±4.00	±2.31	±14.42	±4.00	±4.00	±12.22	±9.24	±6.11	±10.07	±4.00	±2.31
15.0	96.0^{a}	74.67^{b}	76.00^{b}	62.67^{bc}	54.67^{cd}	38.67^{efg}	45.33^{def}	38.67^{efg}	46.67^{de}	34.67^{efg}	33.33^{efg}	28.00^{g}	40.00^{efg}	32.00^{fg}	32.00^{fg}	34.67^{efg}	29.33^{g}
	±0.00	±2.31	±4.00	±11.55	±4.62	±15.14	±6.11	±12.22	±8.33	±12.86	±12.86	±10.58	±4.00	±4.00	±10.58	±2.31	±2.31

*Values with same superscripts in a row are not significantly different by least significant difference (LSD) comparison of means.
**Standard deviation.
†All samples dry by 6 weeks.

Table 4. Germination ($n = 3$) of canola stored at 40°C for different storage periods.

Initial MC (%)	Storage period (wk)															
	0	1	2†	3	4	5	6	7	8	9	10	11	12	13	14	15	16
7.50	96.0^{a*} ±0.00**	85.33^{ab} ±2.31	70.67^{cd} ±6.11	73.33^{cd} ±2.31	73.33^{cd} ±6.11	78.67^{bc} ±2.31	74.67^{bc-d} ±9.24	73.33^{cd} ±6.11	74.67^{bcd} ±4.62	64.00^{d} ±6.93	68.00^{cd} ±13.86	70.67^{cd} ±6.11	45.33^{fg} ±10.07	41.33^{g} ±6.11	49.33^{fg} ±6.11	50.67^{ef} ±6.11	46.67^{ef} ±2.31
10.0	96.0^{a} ±0.00	72.00^{b} ±4.00	62.67^{b} ±12.22	41.33^{ede} ±10.07	36.00^{de} ±10.58	44.00^{ed} ±10.58	41.33^{ede} ±6.11	46.67^{e} ±11.55	42.67^{ede} ±12.86	30.67^{fg} ±4.62	36.00^{ede} ±4.00	33.33^{ede} ±18.48	38.67^{ede} ±2.31	34.67^{ede} ±2.31	29.33^{g} ±4.62	29.33^{g} ±6.11	13.33^{g} ±2.31
12.5	96.0^{a} ±0.00	69.33^{b} ±6.11	46.67^{e} ±4.62	29.33^{fg} ±4.62	5.33^{g} ±6.11	2.67^{g} ±2.31	4.00^{g} ±0.00	0.00^{g} ±0.00	–	–	–	–	–	–	–	–	–
15.0	96.0^{a} ±0.00	68.00^{b} ±6.93	29.33^{g} ±4.62	12.00^{fg} ±4.00	0.00^{g} ±0.00	–	–	–	–	–	–	–	–	–	–	–	–

*Values with same superscripts in a row are not significantly different by least significant difference (LSD) comparison of means.
**Standard deviation.
†All samples dry by 2 weeks.

At 40°C, the 7.5 and 10.0% moisture samples decreased to 3.2 and 2.6%, respectively, by the end of the study. The rate of decrease in moisture content increased with increasing initial moisture content and storage temperature. The seeds gradually dried over the first 4 weeks, which simulated near ambient aeration at 30 and 40°C, but deterioration still was advanced.

Microflora

Sorger-Domenigg et al. (1955) indicated that, if the stored grain is damp, a combination of tests needs to be done to determine the level of spoilage; these include changes in germinability, free fatty acid levels and percentage of the number of seeds affected by mould. As fungi cause deterioration in stored grain quality, it is important to quantify the presence of fungi, which will give some indication of the magnitude of deterioration that has occurred. Many studies have tried several methods of quantifying fungi. A common and simple method is to place a representative sample of seeds on a filter paper saturated with 7.5% sodium chloride (NaCl) and count the percentage of kernels infected after 7 days (Wallace and Sinha 1962; Sinha 1983).

Table 5 shows the time of first appearance of visible mould and respective germination of the samples. Visible mould appeared in all the 15.0% moisture content samples regardless of the storage temperature and in all the samples stored at 40°C irrespective of the moisture content.

Initially, all the samples had a high number of seeds infected with *Penicillium* spp. and *Aspergillus* spp. *Penicillium* spp. were the predominant species in all the samples. At 10°C, *A. glaucus* was present in the low moisture samples, but there was no *A. ochraceus* Wilhelm in any of the samples. A few seeds in the high moisture samples had *Fusarium* at the early stages of storage. At 20°C, the number of seeds infected with *A. glaucus* increased with storage time. *Aspergillus candidus* Link and *Hormodendrum* were present in all the samples throughout the study, but were infrequent. *Fusarium* and A. Wentii Wehmer were present only in the early stages of storage. At 30°C also, *Fusarium* was found in the early stages of storage. The number of seeds infected with *A. glaucus* increased with storage time. At 40°C, *A. glaucus* was predominant next to *Penicillium* spp. in all the samples followed by *A. candidus* Link. The seeds with 15.0% initial moisture content had the highest number of seeds infected with *A. ochraceus*. *Fusarium*, *Hormodendrum* and *A. wentii* were present only during the early stages of storage.

Field fungi may be present in freshly harvested grain, while storage fungi develop on the stored grain if the storage conditions are poor (Muir and White 2001). *Penicillium* spp. and *Aspergillus* spp. are the predominant storage fungi in grain in Canada (Wallace and Sinha 1962). The invasion of grains by storage fungi is a direct cause of germination loss and some kinds of grains can survive a long time at rather high moisture contents and moderate temperatures, if kept free of storage fungi (Christensen and Kaufmann 1969).

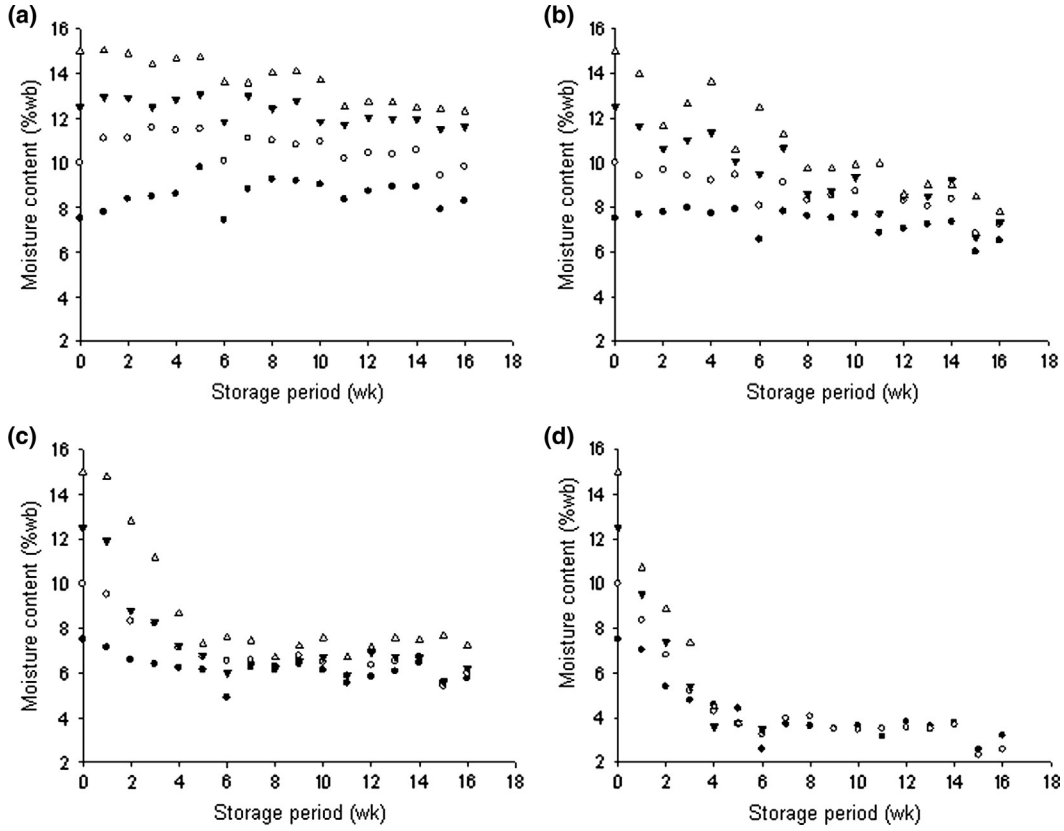

Fig. 2. Changes in moisture content of canola with respect to time (a) at 10°C, (b) at 20°C, (c) at 30°C, and (d) at 40°C (initial moisture contents (%) ●, 7.5; o, 10.0; ▼, 12.5; Δ, 15.0).

Free fatty acid value

Free fatty acids are produced by the breakdown of lipids by the process of hydrolysis caused by enzymatic secretions from the associated microorganisms on the grain. Spoilage of stored grains produces some intermediate products, such as free fatty acids. The characteristic odors and flavors of the fatty acids are evident after spoilage. At high moisture levels, where moulds proliferate, the stored grain may undergo drastic chemical changes approximately proportional to the moisture content. The production of the fatty acids in stored grains depends on the microflora (Christensen and Kaufmann 1969). Deterioration of stored grains is accompanied by an increase in FAV and hence the FAV can be used as a measure of

Table 5. Time of the first appearance of visible mould (wk) and respective germination (%) of canola.

nitial moisture content (% wb)		7.5	10	12.5	15
Temperature (°C)	Replicate				
10	a	_	_	_	5, 80
	b	_	_	_	5, 72
	c	_	_	_	5, 72
20	a	_	_	15, 76	3, 60
	b	_	_	15, 68	3, 60
	c	_	_	15, 64	3, 64
30	a	_	8, 76	4, 72	1, 76
	b	_	8, 72	4, 72	1, 72
	c	_	8, 52	4, 60	1, 76
40	a	10, 52	2, 60	1, 64	1, 72
	b	10, 76	2, 76	1, 76	1, 60
	c	10, 76	2, 52	1, 68	1, 72

deterioration and the future storability of grain. FAV is expressed in mg KOH required to neutralize the free fatty acids present in 100 g of moisture-free seeds.

Changes in FAV of the samples over time are shown in Tables 6–9. The initial FAV of the samples was 22.02 mg KOH/100 g of dry seed. At all the storage temperatures, the FAV increased with moisture content and storage period. At 30°C, the 15.0% moisture content samples had the highest FAV (above 400 mg KOH/100 g of dry seed) throughout the study and attained a maximum of 590 mg KOH/100 g of dry seed by the fourth week of storage. Moisture content, storage temperature and storage period had a significant effect on the FAV ($\alpha = 0.05$). Canola seeds have a high oil content (about 43%), which accounts for the high acidity during deterioration. Changes in the fat acidity values of all the samples stored at 40°C were less, which might be due to the predominance of bacteria degrading the free fatty acids. Free fatty acids content has a positive correlation with moisture and *Penicillium* spp. and a negative correlation with temperature (Wallace et al. 1983).

White et al. (1999) studied the quality changes in stored solin, high linolenic acid and standard flax seed and concluded that there was slight change in the oil composition during 6 months of storage of flax seed, when stored at high moisture content and the FAV increased with increasing moisture content, storage temperature and time.

Table 6. Free fatty acid values (mg KOH/100 g seed) of canola stored at 10°C ($n = 3$) for different storage periods.

Initial Moisture content (%)	Storage period (wk)								
	0	2	4	6	8	10	12	14	16
7.5	$22.02^{a*} \pm 1.5^{**}$	$49.39^{a} \pm 2.52$	$53.85^{a} \pm 5.57$	$33.93^{bc} \pm 8.93$	$31.39^{bc} \pm 3.87$	$27.14^{cd} \pm 1.45$	$31.40^{bc} \pm 3.90$	$32.21^{bc} \pm 1.47$	$34.77^{b} \pm 2.93$
10.0	$22.02^{e} \pm 1.5$	$56.02^{bc} \pm 9.24$	$69.34^{ab} \pm 5.54$	$31.39^{de} \pm 5.32$	$38.99^{cde} \pm 1.47$	$47.51^{bcd} \pm 2.93$	$40.70^{cde} \pm 13.46$	$50.88^{bcd} \pm 2.55$	$80.62^{a} \pm 33.89$
12.5	$22.02^{g} \pm 1.5$	$54.57^{de} \pm 3.34$	$66.38^{bc} \pm 0.07$	$50.03^{ef} \pm 2.92$	$41.57^{f} \pm 11.49$	$62.78^{cd} \pm 3.86$	$54.28^{de} \pm 8.94$	$73.81^{b} \pm 4.36$	$89.93^{a} \pm 1.51$
15.0	$22.02^{f} \pm 1.5$	$103.96^{e} \pm 28.79$	$239.74^{bcd} \pm 35.34$	$218.06^{cd} \pm 47.95$	$260.38^{abcd} \pm 40.81$	$270.57^{abc} \pm 41.95$	$205.26^{d} \pm 28.16$	$278.14^{ab} \pm 11.67$	$307.82^{a} \pm 32.94$

*Values with same superscripts in a row are not significantly different by least significant difference (LSD) comparison of means.
**Standard deviation.

Safe storage guidelines

The germinability of the grain is considered to be the first and foremost factor used to assess the quality of the stored product (Pomeranz 1992). Quality measurements must be simple enough to be used by farmers and fast enough to determine the condition of the grain bulks. Other quality measurements such as determination of FAV, mycotoxins, chitin and ergosterol content, and identification of microflora species, require training and expensive equipment. Moreover, germination can be affected even before the appearance of visible mould. Hence, a drop in germination is the best and most sensitive method of measuring grain quality during storage.

One shortfall in using FAV as a measure of deterioration is that a given species of mould may produce relatively large amounts of fatty acids and consume a portion of it, and hence the FAV may not be directly correlated with the grain deterioration or presence of mould (Christensen and Kaufmann 1969). Therefore, among the measured quality parameters, germination alone was taken into consideration in developing the estimated safe storage guidelines. If the germination begins to decrease, then the storage condition has to be considered unsafe and protective measures, such as drying or cooling, need to be taken (Schroth et al. 1998; Karunakaran et al. 2001).

The estimated safe storage guidelines for canola were developed based on the drop in germination and appearance of visible mould. If the germination was $>80\%$ of the initial germination (i.e., $>76.8\%$) and if there was no visible mould then the samples were considered safe. The number of weeks the samples remained above 80% initial germination without any visible mould was plotted against

Table 7. Free fatty acid values (mg KOH/100 g seed) of canola stored at 20°C ($n = 3$) for different storage periods.

Initial moisture content (%)	Storage period (wk) 0	2	4	6	8	10	12	14	16
7.5	$22.02^{g*} \pm 1.5$**	$49.41^{a} \pm 1.28$	$44.24^{b} \pm 2.20$	$33.08^{cde} \pm 5.07$	$29.69^{ef} \pm 1.46$	$31.39^{def} \pm 1.46$	$27.15^{f} \pm 1.46$	$36.47^{c} \pm 1.49$	$34.79^{cd} \pm 3.87$
10.0	$22.02^{d} \pm 1.5$	$60.44^{bc} \pm 1.28$	$63.39^{abc} \pm 5.58$	$53.42^{c} \pm 2.56$	$52.62^{c} \pm 19.10$	$64.47^{abc} \pm 8.23$	$48.36^{c} \pm 21.78$	$78.94^{ab} \pm 11.08$	$79.75^{a} \pm 3.89$
12.5	$22.02^{c} \pm 1.5$	$66.36^{b} \pm 2.25$	$141.50^{a} \pm 50.15$	$63.60^{b} \pm 11.08$	$68.71^{b} \pm 13.24$	$67.86^{b} \pm 21.63$	$70.41^{b} \pm 8.97$	$89.91^{b} \pm 5.26$	$83.16^{b} \pm 16.53$
15.0	$22.02^{g} \pm 1.5$	$236.76^{f} \pm 8.03$	$421.72^{a} \pm 11.19$	$256.99^{ef} \pm 51.37$	$296.86^{cd} \pm 25.89$	$280.87^{de} \pm 28.15$	$334.17^{bc} \pm 7.90$	$342.74^{b} \pm 9.70$	$304.50^{bcd} \pm 7.49$

*Values with same superscripts in a row are not significantly different by least significant difference (LSD) comparison of means.
**Standard deviation.

Table 8. Free fatty acid values (mg KOH/100 g seed) of canola stored at 30°C ($n = 3$) for different storage periods.

Initial moisture content (%)	Storage period (wk) 0	2	4	6	8	10	12	14	16
7.5	$22.02^{d*} \pm 1.5$**	$44.99^{b} \pm 6.39$	$55.30^{a} \pm 3.83$	$32.22^{c} \pm 1.46$	$25.44^{d} \pm 2.54$	$32.21^{c} \pm 1.46$	$41.56^{b} \pm 5.30$	$34.79^{c} \pm 1.76$	$44.12^{b} \pm 1.49$
10.0	$22.02^{f} \pm 1.5$	$73.02^{e} \pm 2.23$	$104.72^{ab} \pm 5.53$	$78.91^{cde} \pm 15.48$	$74.65^{de} \pm 12.55$	$86.47^{bcde} \pm 15.85$	$109.38^{a} \pm 14.13$	$98.38^{abc} \pm 7.24$	$95.03^{abcd} \pm 20.75$
12.5	$22.02^{c} \pm 1.5$	$84.01^{b} \pm 2.18$	$92.89^{ab} \pm 19.71$	$100.09^{ab} \pm 1.49$	$99.25^{ab} \pm 35.00$	$122.20^{a} \pm 15.47$	$112.01^{ab} \pm 22.19$	$103.52^{ab} \pm 0.04$	$82.25^{b} \pm 19.26$
15.0	$22.02^{g} \pm 1.5$	$494.73^{b} \pm 15.30$	$591.09^{a} \pm 54.63$	$379.15^{de} \pm 55.19$	$335.70^{ef} \pm 53.34$	$413.23^{cd} \pm 31.79$	$414.80^{cd} \pm 10.47$	$470.47^{bc} \pm 12.72$	$287.56^{f} \pm 43.02$

*Values with same superscripts in a row are not significantly different by least significant difference (LSD) comparison of means.
**Standard deviation.

Table 9. Free fatty acid values (mg KOH/100 g seed) of canola stored at 40°C ($n = 3$) for different storage periods.

Initial moisture content (%)	Storage period (wk) 0	2	4	6	8	10	12	14	16
7.5	$22.02^{f*} \pm 1.5$**	$52.37^{bc} \pm 1.28$	$77.42^{a} \pm 11.01$	$29.67^{ef} \pm 3.89$	$43.27^{d} \pm 2.08$	$37.30^{de} \pm 1.46$	$44.94^{cd} \pm 3.86$	$55.14^{b} \pm 3.93$	$37.30^{de} \pm 5.31$
10.0	$22.02^{c} \pm 1.5$	$73.71^{a} \pm 3.39$	$84.79^{a} \pm 14.39$	$51.73^{b} \pm 18.08$	$55.13^{b} \pm 6.38$	$52.58^{b} \pm 1.47$	$56.80^{b} \pm 2.95$	$78.04^{a} \pm 5.85$	$44.10^{b}1.51$
12.5	$22.02^{c} \pm 1.5$	$85.54^{b} \pm 2.55$	$91.55^{b} \pm 57.48$	$149.30^{a} \pm 1.47$	–	–	–	–	–
15.0	$22.02^{b} \pm 1.5$	$182.07^{a} \pm 59.07$	$159.58^{a} \pm 20.77$	–	–	–	–	–	–

*Values with same superscripts in a row are not significantly different by least significant difference (LSD) comparison of means.
**Standard deviation.

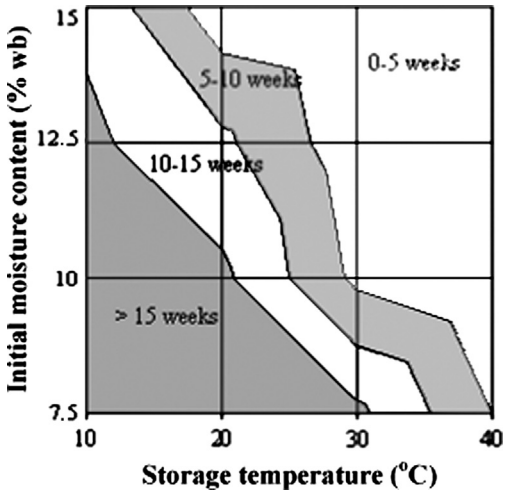

Fig. 3. Safe storage guidelines for canola based on 20% decrease in the initial germination and no visible mould. Periods of safe storage are indicated.

the initial moisture content and storage temperature to get the estimated safe storage-life guideline (Fig. 3).

The rate of deterioration increased with increasing initial moisture content and temperature. If the moisture content of the stored grain can be maintained at a sufficiently low level, then that grain can be stored for many years without any significant loss in quality (Tipples 1995).

There were no noticeable color changes in the stored canola samples except that the samples affected by different mold species became dull and white patches appeared on the seeds.

CONCLUSIONS

Safe storage guidelines for canola based on weeks in storage were developed with constant or changing initial moisture content and with storage temperature. At 10 and 20°C, the 15.0% moisture samples would have only 2 weeks to complete drying, whereas the 12.5 and 15.0% moisture samples stored at 30 and 40°C have less than one week for postharvest treatments before significant deterioration is detected.

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