Carbon dioxide production and deterioration of stored canola

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Pronyk, C., Muir, W.E., White, N.D.G. and Abramson, D. 2004. **Carbon dioxide production and deterioration of stored canola**. Canadian Biosystems Engineering/Le génie des biosystèmes au Canada **46**: 3.25-3.33. Storage experiments were conducted under adiabatic conditions using canola (*Brassica napus* L.) at three moisture contents (m.c.) of 10, 12, and 14% wet mass basis and two temperature regimes of 25 to 30ºC and 30 to 35ºC. Quality of the canola was related to levels of microflora, germination, fat acidity values, and carbon dioxide production. The phenomenon known as the "sweating process" was not observed as the respiration data showed no difference ($P > 0.05$) between freshly harvested canola and canola that was dried, cooled, and stored for more than six months. Carbon dioxide production was dependent on storage time, moisture content, and temperature ($P < 0.001$) and increased with increasing levels of each. Germination was modelled using CO_2 production, moisture, and temperature data. Carbon dioxide production rates at the time of a drop to 95% germination were 500 mg d^{-1} kg^{-1} dry matter for 14% m.c., 192 mg d^{-1} kg^{-1} d.m. for 12% m.c., and 185 mg d^{-1} kg^{-1} d.m. for 10% m.c. canola between 30 and 35ºC and 290 mg d^{-1} kg^{-1} d.m. for 14% m.c. and 172 mg d^{-1} kg^{-1} d.m. for 12% m.c. canola between 25 and 30ºC. These CO_2 production rates may be taken as the maximum safe rates for sound canola under the conditions described above. First signs of visible mold did not always precede a 5% drop in germination. The carbon dioxide production of canola was lower than that for wheat at the same water activity and temperature. **Keywords**: canola, deterioration, carbon dioxide, sweating process, germination, modeling, storage life.

Des essais d'entreposage ont été réalisés avec du colza (Brassica napus L) sous des conditions adiabatiques à trois teneurs en eau (t.e.) de 10, 12 et 14% sur une base humide et deux régimes de températures de 25 à 30 et 30 à 35 ºC. La qualité du colza était reliée aux niveaux de microflore, germination, valeurs d'acides gras et à la production de dioxide de carbone. Le phénomène de processus de transpiration n'a pas été observé car les données de respiration n'ont pas montré de différence ($p > 0.05$) entre le colza fraîchement récolté et le colza qui avait été séché, refroidi et entreposé durant plus de six mois. La production de dioxide de carbone était proportionnelle au temps d'entreposage, à la teneur en eau et à la température ($p < 0.001$). La germination a été modélisée en utilisant la production de CO_2 et les données de teneur en eau et de température. Les taux de production de dioxide de carbone lorsque la germination devenait inférieure à 95% étaient 500 mg j^{-1} kg^{-1} matière sèche à 14% t.e., 192 mg j^{-1} kg^{-1} m.s. à 12% t.e. et 185 mg j^{-1} kg^{-1} m.s. à 10% t.e. pour le colza entre 30 et 35ºC et 290 mg j^{-1} kg^{-1} m.s. à 14% t.e. et 172 mg j^{-1} kg^{-1} m.s. à 12% t.e. pour le colza entre 25 et 30ºC. Ces taux de production de CO_2 peuvent être considérés comme les taux maximums sécuritaires pour du colza sain sous les conditions décrites précédemment. Les premiers signes visibles de moisissure n'ont pas toujours précédés une diminution de 5% de la germination. La production de dioxide de carbone du colza était plus faible que pour le blé pour les mêmes échanges d'humidité et températures. **Mots clés**: colza, détérioration, dioxide de carbone, processus de transpiration, germination, modélisation, durée d'entreposage.

INTRODUCTION

Canada is the world's second largest producer of canola (low erucic acid oil, low glucosinolate meal, rapeseed) and its production has more than doubled from 3.2 million tonnes in 1990 to a high of 8.8 million tonnes in 1999 (FAO 2002). Almost half of Canada's production is exported to other countries throughout the year at values exceeding 890 million US dollars (FAO 2002). Before canola is exported, it can be stored for periods of up to a year or more on the farm when it should be monitored for deterioration so that remedial action can be taken if necessary. Stored canola must not be allowed to spoil as heat-damaged and deteriorated canola has little value because the oil produced from these seeds is of poor quality (Paetkau and Lapp 1972).

Adverse changes may occur rapidly in freshly harvested canola with the seeds going through a period of post-harvest maturation and active respiration known as the "sweating process" or "post-harvest ripening" (Adolphe 1979; Mills 1989; Paetkau and Lapp 1972; Trisvyatskii 1969). The sweating process theorizes that freshly harvested seeds are still metabolically active, so their heat production and respiration are still very high. When this seed is stored in an enclosed bin without aeration, high levels of respiration will increase the moisture and temperature of the bulk causing the canola to spoil. It is said that this period of active respiration may continue up to six weeks after harvest (Adolphe 1979), at which time the seeds will become largely dormant if moisture and temperature of the seeds is low enough (Mills 1989).

All living organisms respire, including canola seeds and the microflora and organisms that consume them. The main causes of deterioration in stored canola are microfloral infection and mites (Brogan 1986). Mites prefer moist and moldy grain so they are not a problem until after the canola has already become moldy (Sinha and Wallace 1977). As well, respiration of the canola seeds is negligible when compared with the respiration of the microflora growing on them (Hummel et al. 1954). As molds consume the canola, it is possible for the different substrates of carbohydrates, protein, or lipids to be consumed. Under aerobic conditions, the combustion of a typical carbohydrate, D-Glucose, and a typical lipid, tripalmitin, will result in different respiration equations (Pomeranz 1992):

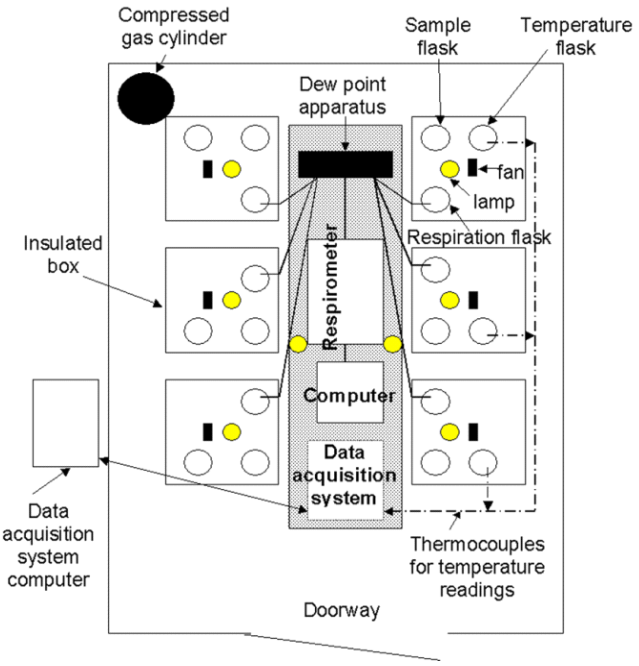

Fig. 1. Layout of equipment inside the environmental chamber and insulated boxes.

D-Glucose:

$$C_6H_{12}O_6 + 6O_2 \rightarrow 6CO_2 + 6H_2O + 2835\ kJ \quad (1)$$

Tripalmitin:

$$\left(C_{15}H_{31}COO\right)_3 C_3H_5 + 72.5\,O_2 \rightarrow$$

$$51CO_2 + 49H_2O + 31890\,kJ \quad (2)$$

As molds consume the canola, dry matter is converted to CO_2, water, and heat. The loss of dry matter is a loss of profits for farmers when the time comes to sell their crop because of reduction in the saleable mass of the crop. According to White et al. (1982a), determination of dry matter loss in rapeseed, unlike wheat, is not practical because the seed is composed of approximately 43% oil, 23% protein, and 34% carbohydrates (Moysey 1973) making it difficult to determine which substrate is being consumed and which respiration equation is applicable. The production of water increases the moisture content of the canola and along with the produced heat promotes increased microfloral growth and spoilage. The production of CO_2 has the potential to be an indicator of microfloral levels and spoilage of stored canola.

Many researchers have observed the relationship between spoilage of stored grain and increased levels of carbon dioxide (Al-Yahya 1999; Karunakaran et al. 2001; Lacey et al. 1994; Mills 1980; Muir et al. 1980, 1985; White et al. 1982a, 1982b). In addition, there has been extensive research done in determining the deterioration and storability of rapeseed and canola (Mills 1980; Mills and Sinha 1980; Mills et al. 1978; Sinha and Wallace 1977; White et al. 1982a). Methods used to determine the deterioration and storability have examined visible mold, microfloral species present, number of seeds infected with mold, free fatty acids, conductivity related to cell electrolyte leakage, pH, moisture content, storage temperature, insect and mite infestations, odor, color of crushed seeds, and seed germination. These methods show deterioration after it has occurred and do not predict spoilage or storability. As well, they often require expert knowledge, long testing times, or they are largely subjective. Using CO_2 production as a quick and reliable method for determining quality of stored canola would be beneficial to farmers to help prevent deterioration and help predict the potential for storage losses of canola.

The objectives of this study were: (1) to mathematically model the storage life of canola as indicated by a reduction in germination based on measured factors of storage time, moisture, and carbon dioxide production; (2) to measure carbon dioxide production of respiring canola and associated microflora and to relate these measurements to the grain condition indicated by germination, microfloral infection, and fat acidity; and (3) to observe whether the "sweating process" in freshly harvested canola is a post-harvest maturation process of canola or is the result of moisture and heat transfer in any bulk of canola at the same moisture content, temperature, and level of microfloral infection.

MATERIALS and METHODS

Grain and treatments

Storage experiments were conducted using canola (*Brassica napus* L., cultivar 'LG3295') at three moisture contents of approximately 10, 12, and 14% wet mass basis and two temperature regimes of 25 to 30ºC and 30 to 35ºC. Freshly harvested canola was obtained directly from a farmer near MacDonald, Manitoba on August 29, 2000. All moisture contents were determined using the oven-dry method (ASAE 1993) by weighing 10 g of seed into an aluminum dish and drying the sample at 130ºC for 4 h. Samples were conditioned by adding the appropriate amount of distilled water to bring it up to the desired moisture content (10, 12, and 14%) and were stored for 24 h at the desired initial temperature for the trial. Throughout the experiment, carbon dioxide production, germination, microfloral infection, and fat acidity were measured as indications of quality of the canola.

Testing was conducted on the freshly harvested samples starting on August 30, 2000 for the temperature regime of 30 to 35ºC at an initial temperature of 30ºC to compare with canola that was dried and stored at least six months to observe whether the "sweating process" is a post-harvest maturation process or is the result of moisture and heat transfer in any bulk of canola at the same moisture content, temperature, and level of microfloral infection. Due to equipment limitations, only two samples could be tested for respiration per day so the second and final samples were tested on August 31 and September 1, 2000, respectively. For this trial, all three moisture contents were tested at once. Later trials for stored samples consisted of a single moisture content being tested at a time. However, the 10% m.c. samples were only run at the 30 to 35ºC temperature regime to compare with the freshly harvested samples due to time and equipment restraints.

Experimental apparatus

Storage tests were performed in six 450 x 470 x 510 mm insulated boxes constructed inside an environmental chamber with three insulated flasks per box (Fig. 1). Canola samples of 600 g were placed in identical 1-L insulated flasks labeled

temperature and sample flasks. The sample flask contained canola that was tested for germination, microflora, and fat acidity values (FAV). The temperature flask was used to monitor the heat production of the canola. The third insulated flask used to measure carbon dioxide production, labeled respiration flask, was filled with only 200 g of canola as any more would produce too much carbon dioxide at higher moisture contents and exceed the capacity of the respirometer. The respiration and temperature flasks were not tested while the respiration experiment was run because they needed a constant mass of canola to determine CO_2 production. The experiment was considered completed when it was confirmed that seed germination had decreased to 85% or lower.

Temperatures were continuously monitored using thermocouples and a Datascan 7010 data acquisition system (Firmware v2.0 Measurement Systems Ltd., Newbury, Berkshire, UK). There were seven thermocouples per box, with three thermocouples placed in the temperature flask and four placed outside the flask. Adiabatic conditions were maintained by turning on a fan and halogen flood lamp (GE, 75-W, 1050-Lumen, indoor long-neck tracklight) if the temperature difference was greater than 0.5ºC between the box and canola in the temperature flask. The temperature of the canola was allowed to rise by 5ºC above the initial temperature of the experiment before it was cooled. This was done for the duration of the experiment so that heat production could be calculated at a later time while carbon dioxide production was measured under an approximately constant temperature.

Carbon dioxide production was measured in the respiration flasks over a 3-h period, using a Micro-Oxymax respirometer (Model V 6.03, Columbus Instruments International Corporation, Columbus, OH). This respirometer is a closed loop system that measures CO_2 concentration using a single beam, nondispersive infrared sensor. The respirometer equipment consists of a sample pump, a dew point apparatus, and CO_2 sensor. The pump drew air from the respiration flask through the dew point apparatus, which removed the moisture and returned it to the respiration flask. The air was then passed through the CO_2 sensor where the concentration was determined before it was returned to the respiration flask. The respirometer was run for 3 h with readings taken every 20 min and carbon dioxide production calculated as the change in CO_2 concentration between readings adjusted to standard temperature and pressure conditions (STP at 1 atm and 273 K). A tank of compressed air (0.035% CO_2), which was used to purge the sensors after each reading, served as a reference gas sample for the respirometer and was used to purge the sample container when the CO_2 concentration exceeded 0.95% (CO_2 sensor limit) in the air-stream.

Carbon dioxide production was measured frequently at the beginning of the experiment to check for the sweating process and less frequently at later times. For the 10 and 12% m.c. samples, respiration was measured once every 3 d for the first 2 weeks and once every 6 d for the remainder of the experiment and for the 14% m.c. samples carbon dioxide production was measured every 3 d for the duration of the experiment.

To maintain aerobic conditions the flasks were refreshed from five to seven times a week for a period of 2 to 3 min with an aquarium pump that had an air-flow rate of 0.5 L/min. To prevent drying of samples with the refresh air, the air was humidified before entering the flasks by bubbling it through saturated salt solutions of KCl for 12% m.c. samples and $K_2Cr_2O_4$ for 14% m.c. samples (Winston and Bates 1960).

Grain quality assessment

Germination of the canola was determined by placing 50 seeds on Whatman No. 3 filter paper in a petri dish with 5.5 mL of distilled water (Wallace and Sinha 1962). The plates were covered and incubated in a growth chamber at 25ºC for 4 d, then the plates were uncovered and incubated for another 3 d. The number of seeds germinated was counted and recorded as percentage germination.

Mold identification and infection rates were determined at the beginning and conclusion of each experiment. Microfloral identification and infection rates were determined for each sample by preparing three plates of 50 seeds on Whatman No. 3 filter paper in a petri dish with 5.5 mL of 7.5% aqueous sodium chloride solution (Mills et al. 1978). The incubation regime is the same as that for germination. After 7 d the microfloral species growing on the seeds were identified and infection rates determined.

Fat acidity values (FAV) were determined at the beginning, approximately 1/3 and 2/3 of the storage period, and conclusion of each experiment. A Goldfisch extractor (LabConco Corporation, Kansas City, MO) was used with petroleum ether to extract seed oil and to determine FAV on 4.5 g of dried and finely ground sample (AACC 2000; Schroth 1996). Following titration of extracted oil in a TAP solution (50% toluene, 50% ethanol (95%), and 0.04% phenolphthaline) with 0.0197 N potassium hydroxide, the FAV was calculated as milligrams KOH needed to neutralize the free fatty acid in 100 g of dried grain.

RESULTS and DISCUSSION

Microflora

Initial microflora counts showed that canola seeds were infected with high levels of pre-harvest molds *Alternaria alternata* (Fr.) Keissler and *Cladosporium* sp. (Tables 1 and 2) and low levels of storage molds *Aspergillus glaucus* group, *Aspergillus candidus* Link, and *Penicillium* spp. These are the common species of microflora as seen by other studies of stored canola and rapeseed (Mills 1980; Mills and Sinha 1980; White et al. 1982a). There was a high initial infection with *A. candidus* for three samples, which can be attributed to natural variability of the canola sample being used. *Alternaria alternata* and *Cladosporium* are both common field fungi and do not damage the seed during storage whereas the presence of the other molds is of a concern because they are storage molds that will decompose the canola. During storage there was a succession of species with pre-harvest fungi being replaced with storage fungi (Tables 1 and 2). Final microflora counts showed that canola at 10 and 12% m.c. had nearly 100% infection with *A. glaucus* group except for the freshly harvested 12% m.c. sample. High levels of *A. candidus* and *Penicillium* spp. were associated with 12 and 14% m.c. canola. This is consistent with the literature, which shows that *A. glaucus* group grows at a lower relative humidity than *A. candidus* and *Penicillium* spp. (Sauer et al. 1992).

One of the important signs of deterioration is the first visible sign of molding. When averaging values for freshly harvested

Table 1. Microfloral infection for trials using freshly harvested canola.

Moisture content (%)	Temperature (°C)	Sampling period	Microfloral infection (% of seeds)*				
			Cladosporium	*Alternaria alternata*	*Aspergillus glaucus* gr.	*Aspergillus candidus*	*Penicillium*
14	30 - 35	initial	36 ± 1.8	74 ± 3.8	2 ± 1.0	2 ± 0.8	2 ± 0.8
		conclusion	0 ± 0	0 ± 0	34 ± 13.4	94 ± 2.4	70 ± 2.1
12	30 - 35	initial	28 ± 3.8	55 ± 5.3	6 ± 1.4	30 ± 2.7	2 ± 0.6
		conclusion	0 ± 0	1 ± 0.3	32 ± 3.6	96 ± 2.1	53 ± 11.7
10	30 - 35	initial	20 ± 5.0	55 ± 3.5	5 ± 0.7	18 ± 4.2	5 ± 1.8
		conclusion	0 ± 0	0 ± 0	98 ± 1.3	28 ± 4.9	1 ± 1.0

* Mean ± standard deviation, n = 3 plates of 50 seeds

Table 2. Microfloral infection for trials using that had been stored before testing.

Moisture content (%)	Temperature (°C)	Sampling period	Microfloral infection (% of seeds)*				
			Cladosporium	*Alternaria alternata*	*Aspergillus glaucus* gr.	*Aspergillus candidus*	*Penicillium*
14	30 - 35	initial	14 ± 1.2	53 ± 2.5	7 ± 1.2	20 ± 1.8	6 ± 1.0
		2/3	0 ± 0	5 ± 1.3	91 ± 2.3	82 ± 3.0	8 ± 2.2
		conclusion	0 ± 0	2 ± 0.5	86 ± 2.4	84 ± 4.1	77 ± 6.2
12	30 -35	initial	27 ± 2.0	56 ± 2.4	2 ± 0.5	4 ± 0.5	4 ± 0.6
		2/3	0 ± 0	4 ± 0.9	99 ± 0.5	6 ± 0.5	0 ± 0
		conclusion	0 ± 0	1 ± 0.4	99 ± 0.8	16 ± 3.5	18 ± 4.7
10	30 - 35	initial	14 ± 1.3	45 ± 1.7	6 ± 1.1	3 ± 0.6	5 ± 0.9
		conclusion	0 ± 0	2 ± 0.5	100 ± 0.2	5 ± 0.9	2 ± 0.5
14	25 - 30	initial	19 ± 1.2	61 ± 2.1	7 ± 2.1	5 ± 0.7	2 ± 0.5
		2/3	0 ± 0	5 ± 0.7	95 ± 0.9	69 ± 4.2	2 ± 0.8
		conclusion	0 ± 0	4 ± 0.6	46 ± 6.7	97 ± 0.9	23 ± 5.0
12	25 -30	initial	27 ± 1.4	53 ± 2.2	4 ± 0.8	2 ± 0.6	3 ± 0.7
		2/3	0 ± 0	10 ± 1.4	90 ± 2.5	46 ± 8.8	42 ± 5.9
		conclusion	0 ± 0	1 ± 0.4	95 ± 0.8	63 ± 3.6	22 ± 2.0

* Mean ± standard deviation, n = 3 plates of 50 seeds

and stored samples, mold became visible within 6 d for 14% m.c., 9 d for 12% m.c., and 54 d for 10% m.c. canola at 30 to 35ºC. These values increased to 7 d and 12 d for 14 and 12% m.c. samples, respectively, when stored at 25 to 30ºC.

Germination

Even though respiration trials for each box were run until the seed germination in each sample flask reached 85%, the final germination values were often lower (Fig. 2). This is due to the length of time it takes to determine germination after a sample has been taken. Germination counts for trials were sometimes not determined until several more respiration trials had been conducted and more germination samples taken. For all trials, germination dropped well below 85% before the experiment was stopped. This shows the limitations of using germination tests for determining the deterioration of canola if one wants to prevent storage losses, because the state of the canola is only shown 1 wk after the determination of germination is started.

A plot of the germination data showed that the data followed an asymmetric sigmoid pattern (Fig. 2). The data were fitted using a five-parameter logistic function using the nonlinear regression package in SigmaStat (V 2.0, Jandel Scientific, San Diego, CA). The asymptotic maximum was fixed at 98% to represent the average maximum germination of the samples in this experiment and the asymptotic minimum was set to zero to represent the lowest germination possible. The equation was solved separately for each temperature regime and moisture content and is given as:

$$Y = \frac{98}{\left[1+\left(\frac{\theta}{c}\right)^{b}\right]^{e}} \tag{3}$$

where:

Y = germination (%)
θ = storage time (d), and
b,c,e = coefficients (Table 3).

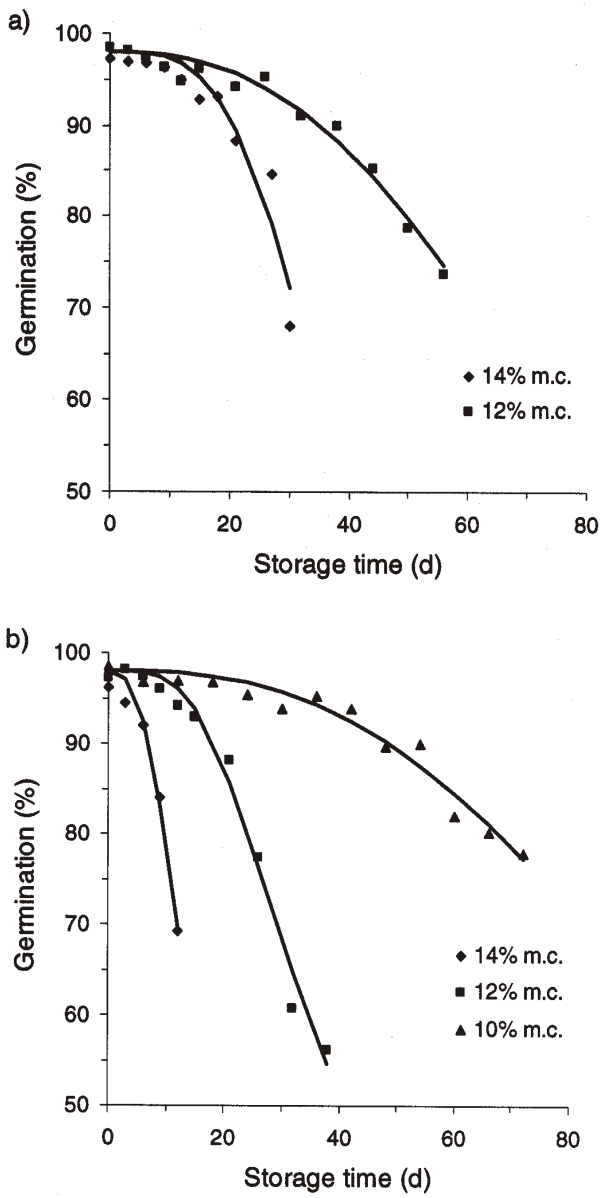

Fig. 2. Germination of canola stored at three moisture contents and two temperature regimes: (a) 25 to 30°C; (b) 30to 35°C. Points represent average experimental values and lines represent the fitted equation, Eq. 3.

Table 3. Coefficients of the germination equation (Eq. 3) for canola.

Temperature (°C)	Moisture content (%)	Coefficients			R^2
		b	c	e	
25 - 30	14	3.47	73.43	7.00	0.96
	12	2.51	233.97	10.04	0.99
30 - 35	14	2.58	37.26	6.50	0.99
	12	3.71	26.01	0.36	0.99
	10	2.70	156.92	2.06	0.98

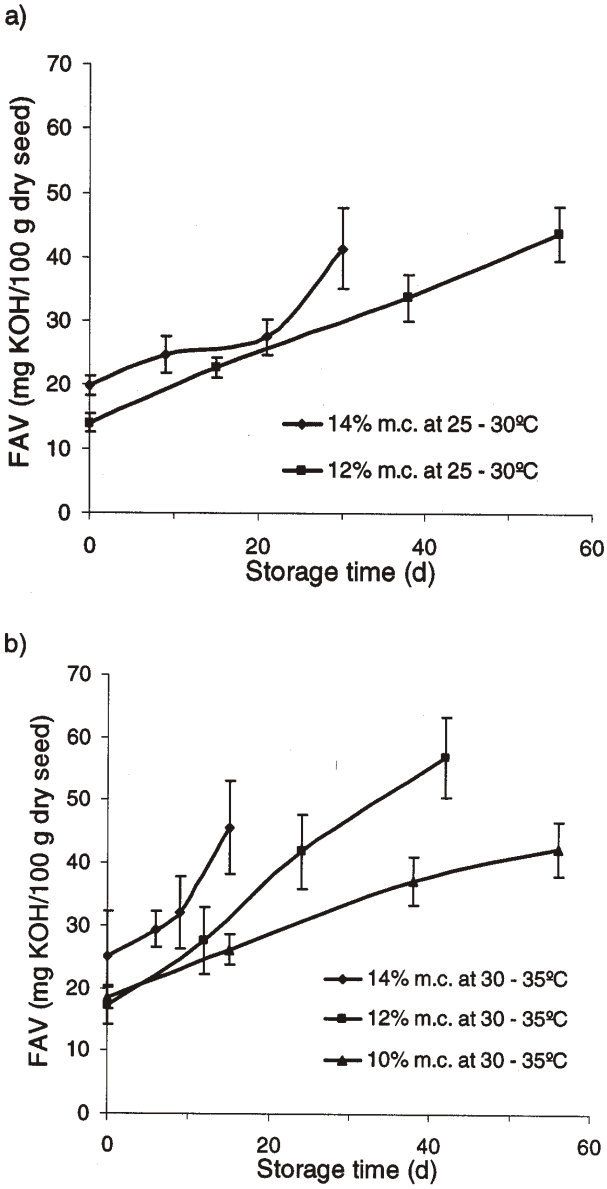

Fig. 3. Fat acidity values (FAV) of canola stored at three moisture contents and two temperature regimes: (a) 25 to 30°C; (b) 30 to 35°C.

Fat acidity values

Free fatty acids formed by enzymatic activity of fungi consuming the seed represent a loss in oil quality of canola. For the experiment, the FAV of the samples increased with storage time, moisture, and temperature (Fig. 3). All samples started with levels below 20 mg KOH/100 g dry seed, except for the 14% m.c. sample stored between 30 and 35ºC, which had a FAV of 25. When seed had spoiled and germination dropped below 90%, FAV had risen to above 30 mg KOH/100g dry seed, except for the 14% m.c. sample stored between 25 and 30ºC. Similar values for FAV were obtained in studies by Mills and Kim (1977) and Mills and Sinha (1980). At low temperatures there was little difference between the samples of 12 and 14% m.c., which is probably the result of reduced fungal activity on the seeds.

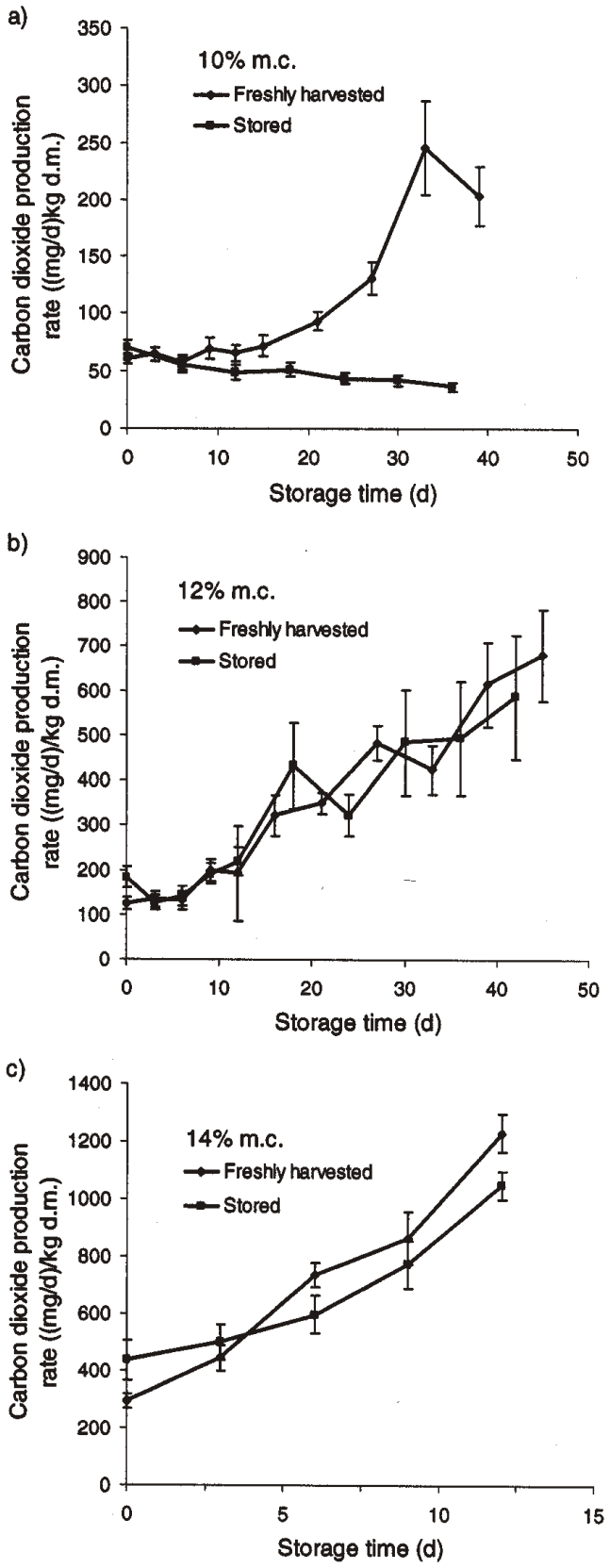

Fig. 4. Carbon dioxide production rates for freshly harvested and stored canola of 10, 12, and 14% m.c. at temperatures between 30 and 35°C.

Allowable storage time

The time until a 5% drop in germination has been reached is often taken as the safe storage time (White et al. 1982a). For this experiment, germination dropped to 95% in 3 d for 14% m.c., 10 d for 12% m.c., and 24 d for 10% m.c. canola between 30 and 35ºC and in 12 d for 14% m.c. and 26 d for 12% m.c. canola between 25 and 30ºC. These times were longer than predicted by White et al. (1982a) but could be related to different microfloral species and initial levels of infection. Safe storage times on this basis do not always precede the first visible signs of mold. In this experiment safe storage times are less than or equal to the number of days until the first appearance of mold for the high temperature regime and more than the number of days for the low temperature regime.

The allowable storage time until a drop in germination to 95% was calculated using average temperatures of 32.5 and 27.5ºC for the high and low temperature regimes, respectively, and following the form of allowable storage time equations from White et al. (1982a). A multiple linear regression was conducted and the resulting equation was:

$$\log_{10} \theta_5 = 6.83 - 0.212\,M - 0.102\,T \qquad (4)$$

where:

θ_5 = estimated storage time (d) until a 5% drop in germination
M = moisture content of seeds (% wet mass basis), and
T = temperature (ºC).

Moisture and time were both significant ($P < 0.05$) in predicting storage time and the coefficient of determination (R^2) was 0.985.

Sweating process

Carbon dioxide data (Fig. 4) for freshly harvested and stored canola between 30 and 35ºC were compared to determine if there is a post-harvest maturation process in canola known as the "sweating process". Data for each day and moisture were compared using SigmaStat and a *t*-test with the null hypothesis that the means of the populations were the same (i.e. there is no sweating process). In some cases the data failed the tests for normality and constant variance so a Mann-Whitney Rank Sum test was used instead because assumptions of normality and constant variance are not necessary. Tests showed that there was no significant difference ($P > 0.05$) for 12 and 14% m.c. except for 12% m.c. and day 0 (Figs. 4b and 4c). In this case the respiration was lower for the freshly harvested sample, which should be higher if the sweating process existed. The 10% m.c. samples showed no significant difference for the first 12 d at which time the freshly harvested samples had a significantly higher CO_2 production than the stored samples ($P < 0.05$) (Fig. 4a). However, a moisture check of the respiration flask for the stored sample showed that the sample dried out over the course of the experiment.

These results show that any increase in respiration of stored canola is only a function of moisture content, temperature, and fungal infection of that bulk. Bins with a low average moisture content and temperature that display symptoms of the sweating process probably have localized regions in the bulk where the canola is wetter or hotter than the surrounding canola. Canola of high moisture may be collected from wet spots in the field, immature areas of the field, dockage, or from harvesting early

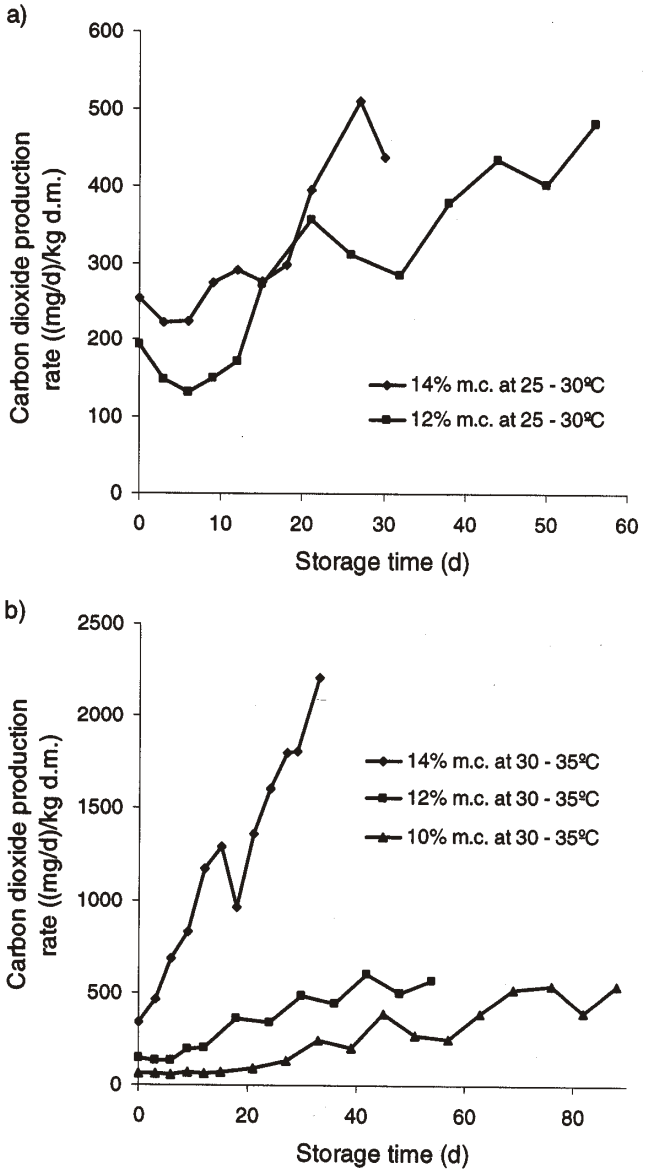

Fig. 5. Average carbon dioxide production rates for canola stored at three moisture contents and two temperature regimes: (a) 25 to 30°C; (b) 30 to 35°C.

in the morning or late evening when dew is forming on the kernels. These conditions may result in a load of moist canola being stored in the bin that would actively respire and could be confused with a sweating process occurring in the whole bin.

Carbon dioxide production

Respiration data from the freshly harvested and stored trials between 30 and 35ºC were combined because there was no significant difference between the two treatments for carbon dioxide production, while germination, FAV, and microfloral levels were also similar. All carbon dioxide production data were standardized to milligrams of CO_2/d per kg dry matter for analysis. The exception was the 10% m.c. trials, where only the freshly harvested respiration data were used because the respiration flasks in the stored trials dried out. Results show that CO_2 production increased with storage time, moisture content, and temperature after a small time lag except for 14% m.c. samples in the high temperature regime (Fig. 5). The same phenomenon was seen by Lacey et al. (1994) in studies of wheat, rapeseed, and linseed. The end of these lag times corresponds very closely with the time until a drop to 95% germination where deterioration begins to occur more rapidly and respiration should increase as molds consume the seed coat, affecting germination. Carbon dioxide production rates at the time there was a drop to 95% germination were 500 mg d^{-1} kg^{-1} d.m. for 14% m.c., 192 mg d^{-1} kg^{-1} d.m. for 12% m.c., and 185 mg d^{-1} kg^{-1} d.m. for 10% m.c. canola between 30 and 35ºC and 290 mg d^{-1} kg^{-1} d.m. for 14% m.c. and 172 mg d^{-1} kg^{-1} d.m. for 12% m.c. canola between 25 and 30ºC. These CO_2 production rates may be taken as the maximum safe rates for sound canola under the conditions described above.

A backward stepwise regression conducted on the CO_2 production data using storage time, moisture content, and temperature as independent variables found all to be significant ($P < 0.001$). Equation 5 was developed using SigmaStat to predict CO_2 production ($R^2 = 0.765$):

$$\log_{10} RCO_2 = -1.521 + 0.0462T + 0.0159\theta - 0.0000699\theta^2 + 187M \quad (5)$$

where:

RCO_2 = predicted rate of CO_2 production per unit dry mass of seed (mg d^{-1} kg^{-1} d.m.).

Germination based on CO_2 production

It would be beneficial to ascertain grain quality without having to wait the week it takes to plate and incubate seeds to determine germination. Calculating germination from CO_2 production without knowledge of the storage life would be a benefit to managers of grain-handling facilities who may not know the storage history of the grain coming in. As well, farmers would benefit from the quick determination of quality to be able to make immediate management decisions to remedy any unfavorable storage conditions. An equation to predict germination using measured CO_2 production was derived using SigmaStat as:

$$Y = 100 - 0.0512\,MRCO_2 + 2.489\,M - 2.118T + 0.0435T^2 \quad (6)$$

where:

$MRCO_2$ = measured rate of CO_2 production per unit dry mass of seed (mg d^{-1} kg^{-1} d.m.).

Comparison of CO_2 production of canola with wheat

Carbon dioxide production for wheat collected by Karunakaran et al. (2001), using the same respirometer, was compared with data collected in this study. Data for wheat at 18 and 19% m.c. at a constant temperature of 25ºC were selected because they had water activities (a_w of 0.84 and 0.89, respectively) that were similar to canola at 12 and 14% m.c. stored at temperatures between 25 and 30ºC as calculated with the Modified Henderson equation (ASAE 1997). Even though both grains started with low levels of *A. glaucus* group, *A. candidus*, and *Penicillium* spp., CO_2 production of wheat was more than that of canola (Fig. 6). This occurred even though the wheat was stored at a constant 25ºC and the canola was maintained between 25 and 30ºC. However, the germination of the wheat

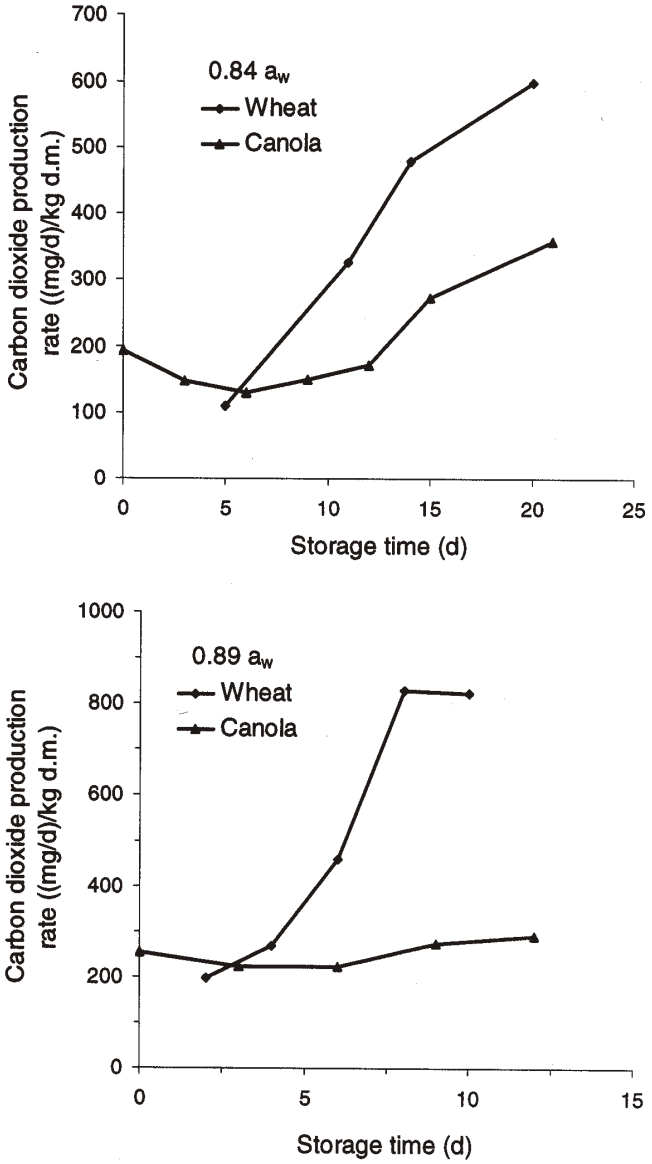

Fig. 6. Carbon dioxide production rates of wheat (data from Karunakaran et al. (2001) at a constant temperature of 25°C) and canola at water activities (a_w) of 0.84 and 0.89 between 25 and 30°C.

dropped below 35% for both a_w whereas the canola only fell to 95%. Studies by Lacey et al. (1994) also found that respiration of oilseeds was less than that of cereal grains but no mention of levels of germination was made. It would be expected that respiration of canola, with its greater surface area to volume ratio allowing for rapid gas exchange with the atmosphere would be greater than wheat; but it was not, possibly due to the inability of molds to thrive on lipids (Wallace 1973) or that respiration is proportional to kernel size with canola seeds being smaller than wheat seeds (Lacey et al. 1994) at about 4 mg per seed and 37 mg per seed, respectively.

CONCLUSIONS

The storage life and quality of stored canola can be modelled based on storage time, moisture, and carbon dioxide production. Respiration data from freshly harvested canola and canola that has been dried, cooled, and stored for more than six months before testing were not statistically different. The sweating process is not a usual post-harvest maturation process, but is the result of moisture and heat transfer in any bulk of canola at the same moisture content, temperature, and microfloral infection.

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