MANAGEMENT SCHEMES FOR CONTROL OF IN-BIN DRYING OF CANOLA

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INTRODUCTION

In-bin drying of canola is a popular practice on the Canadian Prairies. In these systems a fan continuously forces ambient air through the grain mass until grain is dried to a safe moisture content. Due to frequent incidences of unfavorable drying conditions, some of these drying systems are equipped with supplement heat to promote early drying. In addition to capital and operating costs, the supplement heat could potentially promote grain spoilage during drying and over-drying if drying is not managed properly.

To our knowledge, no previous research has been done on the best way of managing or controlling supplement heat and fan operation for in-bin canola drying in Canadian Prairies. Computer simulation is a powerful tool for the study and development of optimum drying schemes. The objective of this paper is to review available information pertaining to mathematical modelling of low temperature drying of canola.

Equilibrium Moisture Content of Canola

The moisture content of grain in equilibrium with its environment is the equilibrium moisture content (EMC). The EMC of grain canola has been determined by several investigators (Timbers and Hocking 1974, Pichler 1957, Rao and Pfost 1980, Pixton and Henderson 1981). Table 1 is a compilation of EMC data from several sources. The range of conditions covered by the available data is good and the experimental data agree well with data from different sources. Table-1 shows that while grain stores well at 60% relative humidity, its moisture content may exceed a safe level if the relative humidity of store exceeds 70%. The EMC, however, decreases as store temperature rises and so that minimizes the risk of grain spoilage at the critical relative humidity of 70%.

To facilitate the use of EMC data, an equation was developed using the compiled data. The equation is of the following form:

Table 1. Equilibrium moisture contents (%) of canola from several sources.

rh	Temperatures, °C									
%	5	10	15	20	25	30	35	40	60	80
10	-	-	-		-	-	-	2.1	1.3	0.6
20	4.8	-	4.0	-	3.9	-	-	2.9	1.8	0.6
30	-	-	4.9	4.8	-	-	4.7	3.3	2.1	0.8
40	6.1	-	5.8	5.5	-	-	-	3.8	2.5	1.2
50	7.6	6.2	6.1	7.1	7.0	-	6.1	5.0	3.0	1.7
60	8.6	8.2	7.5	-	7.5	-	-	6.2	3.8	2.4
70	10.2	9.2	9.6	-	9.0	-	7.9	7.5	5.2	3.3
80	11.7	10.8	11.5	-	11.3	11.1	-	11.0	10.0	7.5
90	16.6	16.0	15.9	15.9	15.3	-	15.1	15.0	11.3	9.0

$$EMC = \left[-\frac{\exp(3+0.03T)}{\mathrm{Ln}(rh)}\right]^{0.67} \qquad 1$$

where rh is the relative humidity of air in decimal and T is temperature of the air in degrees celsius (^oC). The calculated EMC is in decimal wet basis.

Drying Rate of Canola

Drying rate is an important parameter, particularly in hot air drying where the time of grain exposure to hot air is a limiting quality factor. Similar with the EMC, several researchers have experimented with the drying rate of canola, but unlike with the EMC, the drying data tested have been limited to higher temperatures, i.e., more than 30^{o}C. Since drying data are time dependent, their tabulation is extensive. Instead these data are presented in the form of drying equations. One drying equation which is used widely has the following form:

$$\frac{M-M_e}{M_o-M_e} = A\exp(-Bt) \qquad 2$$

Where M is the moisture content, M_e is the equilibrium moisture content (EMC), M_o is the initial moisture content, and t is drying time in hours. A and B are the drying constants. Their values depend on the grain moisture content (M), air temperature (T) and airflow rate (G):

$$A = 1.3532 - 0.00301\,M - 0.00751 - 0.5112\,G$$
$$B = 0.5086 - 0.00151\,M + 0.01030 - 0.2440\,G \qquad 3$$

Eq. 3 is valid for $13.7 \leq M \leq 25.0$, $30 \leq T \leq 60^oC$, and $0.21 \leq G \leq 0.53$ m/s . For comparison purposes, drying rates of canola and wheat are calculated and the results are tabulated in Table 2. The initial moisture content of the canola and wheat was assumed 18%, wet basis.

The EMC of canola at 30^{o}C and 50% rh is 5.0% and that of wheat for similar conditions is 12.7%. Table 2 shows that it takes about 12 hours for the canola to approach the EMC of 5% while wheat takes 120 hours to approach its EMC of 12.7%. Some researchers have stated that rapeseed dries eleven times faster than wheat. Data in Table 2 seem to agree with this assessment.

Table 2. Comparing the drying rates of canola and wheat at 30^{o}C air.

Hour	moisture content, %	
	Canola	Wheat
0	18.00	18.00
1	10.08	17.95
6	5.33	17.82
12	4.90	17.47
24	4.84	16.19
120	4.84	14.57

Resistance of Bulk Canola to Airflow

For successful drying and aeration of canola, sufficient airflow must be provided to insure grain is cooled and dried in time before grain is spoiled. The size and horsepower of the fan delivering the required airflow depend on the resistance of grain to airflow. The data relating the resistance of canola (expressed in pressure, Pa or in inches of water) versus air flow (expressed in volumetric airflow rate per unit area of floor, $m^3/s.m^2$ or CFM per square foot) have been worked out extensively. Table 3 is an example of these data for two types of bin fills: spout fill and spreader fill.

Table 3 shows that the spreader fill which causes more packed canola in the bin increases the resistance of canola to airflow by almost 50%. Increased moisture content decreases the resistance of grain to airflow due to a reduced bulk density at a higher moisture content. For practical purposes, however, we may neglect the effects of moisture content on resistance of grain to airflow and use the values in Table 2.

The data in Table 3 are for clean canola. The percent fine and chaff in the grain at the time of ventilation affect these data. The presence of chaff in the grain decreases the pressure while the presence of fine increases the pressure. The presence of chaff and fine in the canola also causes uneven airflow distribution. To facilitate the calculations of resistance of canola to airflow, the following equation has been developed:

$$\frac{\Delta P}{L} = \frac{5.22\text{x}10^4 Q^2}{\ln(1+7.27Q)} (1+1.75 f) \qquad 4$$

where ΔP is the resistance of grain to airflow in Pa, L is the height of the bin (up to the level of grain in the bin), Q is the airflow rate in m^3/s per square meter of the floor area, and f is the fraction of fines in the grain. If grain is clean then f=0. Eq. 4 is a standard equation used by the designers of low temperature drying systems to estimate the pressure required to push a given airflow into the bin. Once ΔP is calculated, the horsepower is estimated from:

$$HP = \Delta P\, Q\, A / 740 \qquad 5$$

Where A is the floor area in square meters. The calculated HP should be divided by the efficiency of the fan and motor. Usually a value of about 0.3 is used.

Table 3. Airflow rate and static pressure for Tobin canola at 6.5% moisture content

CFM per sq. ft	Inches of water per foot of bin height Spout fill	Spreader fill
0.1	0.02	0.03
0.5	0.05	0.10
1.2	0.09	0.16
2.3	0.13	0.27
4.7	0.25	0.52
9.0	0.47	0.99
18.0	1.10	2.25
40.0	2.82	5.82
100.0	7.80	-

Physical Parameters

The bulk density and porosity of canola depends on the method of fill and moisture content. Table 4 shows the bulk density of Tobin and Westar varieties as affected by the method of fill. Spreader fill causes a denser bulk by about 10%. Westar has a lower bulk density because of a larger seed size.

Thermal properties

The specific heat of canola is used to calculate the rate of heating and cooling of the grain and the heat storage capacity of grain. Muir et al. (1989) used the data of moysey to estimate the specific heat of canola as follows:

$$C=1265 + 30\,M + 5.95\,T \quad 5$$

Table 4. Summary of physical sizes and bulk density of two canola varieties.

	m.c. %	diam, mm	Bulk density, kg/m^3 Spout fill	Spreader fill
Tobin	6.5	1.5 (±0.025)	700	775
Tobin	14.5	-	688	759
Westar	6.7	1.8 (±0.008)	675	741

Where M is the seed moisture content in percent wet basis, and T is °C. The calculated specific heat is expressed in J/kg.°C. Thermal conductivity is used to calculate the transfer of heat in and out of the single kernel of grain or the transfer of heat within the bulk. The value of thermal conductivity for canola seeds varies from 0.08 to 0.12 W/m.°C, increasing with moisture content and decreasing with temperature. Moysey (1977) gives the thermal conductivity of variety of Torch as 0.1164 W/m.°C at 20°C and 10.5% moisture content. Bilanski and Fisher (1976) measured thermal conductivity of rapeseed as high as 0.1608 W/m.°C for 12% moisture content grain at 40°C. Variety of the rapeseed tested by Bilanski and Fisher was not reported.

Grain Spoilage During natural Drying

The storage stability of canola depends on the temperature, moisture content, and the time grain has been under unfourable storage conditions. Appelquist and Loof (1972) summarized the French and Swedish work on the safe storage times for rapeseed. They noted that rapeseed could be stored temporarily at higher moisture contents if ventilation was provided. Table 5 summarizes their data:

Table 5. Time limits for the safe storage of rapeseed as affected by the grain moisture content and temperature when grain is ventilated intermittently with cool air.

Moisture content,%	Temperature of the grain, °C 0	5	10	15
19	5 W	3 W	1 W	-
17	2 M	5 W	3 W	1 W
15	3 M	2 M	5 W	3 W
13	> 5 M	3.5 M	2 M	1.5 M
11	>5 M	>5 M	4 M	3 M
9	>5 M			

W = Weeks, M = Months

As the data in Table 5 indicate the safe storage of rapeseed depend strongly on the grain temperature and moisture content. Grain at 15% moisture content and 15°C may rot in three weeks, but grain cooled to 10°C and moisture reduced to 9% or lower stores for more than five months. Although much work is done on the potential of canola spoilage due to high temperature and moisture contents in the store, no concrete guidelines are yet available to be used in conjunction with drying and ventilation. Muir et al. (1989) developed the following equations to predict the safe storage time for canola:

$$\text{Log}_{10}\,\Theta = 6.224 - 0.302\,M - 0.069\,T \quad \text{for } M<11\%, \text{ and} \qquad 6$$

$$\text{Log}_{10}\,\Theta = 5.278 - 0.206\,M - 0.063\,T \quad \text{for } M\geq 11\%.$$

Where Θ is the storage time in days before the germination power of grain is reduced to 95%. M is the moisture content percent wet basis and T is grain temperature in °C. The validity of Eq. 6 has not yet been tested.

CONCLUSIONS

From the extensive literature review and preliminary analyses, it has become clear that the natural drying and storage of canola must be studied further. The most immediate problem is the lack of a reliable spoilage model for canola. The spoilage model relates the state of the grain in the store to its moisture content and its immediate environment. In order to develop a relationship for spoilage, it is imperative to have a validated drying and cooling model.

ACKNOWLEDGMENT

The work reported in this paper is funded in parts by operating grants to S. Sokhansanj by the Alberta Canola Growers Commission and the Natural Science and Engineering Research Council of Canada.

REFERENCES AND BIBLIOGRAPHY

Appelqvist, L.A. and B. Loof. 1972. Postharvest handling and storage of rapeseed. Ch. IV 60-100, in: Rapeseed. L.A. Appelqvist and R. Ohlson. Amsterdam, Elsevier.

Armitage, D.M. 1980. The effect of aeration on the development of mite populations in rapeseed. J. Stored Prod. Res. Vol. 16:93-102.

Cenkowski, S., S. Sokhansanj and F.W. Sosulski. 1989. Effect of drying temperature on green color and chlorophyll content of canola seed. J. Inst. Can. Sci. Technol. Aliment. 22, No.4.

Cenkowski, S., S. Sokhansanj and F.W. Sosulski. 1989. Effect of harvest date and swathing on moisture content and chlorophyll content of canola seed. Can. J. Plant Sci. 69:925-928.

Daun, J.K. 1987. Chlorophyll in Canadian canola and rapeseed and its role in grading. Proc. 7th Int. Rapeseed Congress, Poznan, Poland, May, 1987.

Jayas, D.S., S. Sokhansanj and N.D.G. White. 1989. Bulk density and porosity of two canola species. Trans. of the ASAE, Vol.32(1). St. Joseph, MI.

Jayas, D.S., S. Sokhansanj, E.B. Moysey and E.M. Barber. 1987. The effect of airflow direction on the resistance of canola (rapeseed) to airflow. Can. Agric. Vol. 29(2).

Jayas, D.S., S. Sokhansanj, E.B. Moysey and E.M. Barber. 1987. Airflow resistance of canola(rapeseed). Trans. of the ASAE, Vol.30(5). St. Joseph, MI.

Jayas, D.S. and S. Sokhansanj. 1989. Design data on resistance of airflow canola (rapeseed). Trans. of the ASAE, Vol. 32(1). St. Joseph, MI.

Jayas, D.S., S. Sokhansanj, E.B. Moysey and E.M. Barber. 1987. Distribution of foreign material in canola bins filled using a spreader or spout. Trans. of the ASAE, Vol. 29(2). St.Joseph, MI.

McKnight, K.E. and E.B. Moysey. 1973. The effect of temperature and airflow rate on the qulity of dried rapeseed. Trans. of the ASAE, 32(2):166-120. ASAE, St. Joseph, MI.

Mills, J.T. 1980. Quality change occuring in small lots of dry and moist rapeseed during storage. Can. J. Plant Sci. 60:831-839.

Mills, J.T. 1984. Storability of frost damaged canola. Agric. Can. Res. Station, 195 Dafoe Rd, Winnipeg, Manitoba R3T 2M9.

Mills, J.T. and G.J. Bollen. 1976. Microflora of heat-damaged rapeseed. Can. J. Botany. Vol. 54(24):2893-2902.

Mills, J.T., R.N. Sinha and H.A.H. Wallace. 1978. Multivariate evaluation of isolation techniques for fungi associated with stored rapeseed. The Am. Phytopathological Soc., 3340 Pilot Knob Road, St, Paul, MN 55121.

Mills, J.T. and R.N. Sinha. 1980. Safe storage periods for farm-stored rapeseed based on mycological and biochemical assessment. The Am. Phytopathological Soc. 70(6):541-547.

Moysey, E.B., J.T. Shaw and W.P. Lampman. 1977. The effect of temperature and moisture on the thermal properties of rapeseed. Trans. of the ASAE, Vol. 20(3):461-464. ASAE, St. Joseph, MI.

Nellist, M.E., D.V.H. Rees and S.J. Abrahams. 1970. The effect of drying air temperature on the quality of the seed of winter oil rape, Brassica Napus. Unpub. Dept. Note DN/HC/28/70, 1970,NIAE.

Patil, B.G. 1987. An investigation into the drying of oilseeds using ambient air and solar energy. Ph.D thesis. Lincoln College, Univ. of Canterburg, New Zealand.

Patil, B.G. land G.T. Ward. 1987. Effect of airflow rate, air temperature and initial moisture content on the drying of rapeseed and the development of a generalized prediction equation. Dept. of Agric. Eng., Lincoln college, Canterbury, New Zealand.

Pichler, H.J. 1956. Sorption isotherms for grain and rape. Landtechnische Forschung, 6(2):47-52.

Pixton, S.W. and S. Henderson. 1981. The moisture content - equilibrium relative humidity relationships of five varieties of Canadian wheat and of candle rapeseed at different temperatures. J. Storage Prod. Res. Vol. 17. Pergamon Press Ltd.

Rao, V.G. and H.B. Pfost. 1980. Physical properties related to drying 20 food grains. ASAE paper no. 80-3539. ASAE, St. Joseph, MI.

Reynolds, J.R. and C.G. Youngs. 1964. Effect of seed prearation on efficiency and oil quality in filtration extraction of rapeseed. J. Am. Oil Chem. 41:63-65.

Salunkhe, D.K. and B.B. Desai. 1986. Post-harvest biotechnology of oilseeds. Chapter 5: Rapeseed and mustard. CRC Press Inc., Boca, Raton, FL.

Sinha, R.N., J.T. Mills, H.A.H. Wallace and W.E. Muir. 1981. Quality assessment of rapeseed stored in ventilated and non-ventilated farm bins. Sciences Des Aliments, 1981, 1, no 2. Sokhansanj, S., D. Singh and J.D. Wasserman. 1984. Drying charateristics of wheat, barley and canola subjected to repetitive wetting and drying cycles. Trans. of the ASAE, St. Joseph, MI.

Sokhansanj, S., W. Zhijie, D. Jayas and T. Kameoka. 1986. Equilibrium relative humidity moisture content of rapeseed(canola) from 5 C to 25 C. Trans. of the ASAE, Vol. 29(3). St. Joseph, MI.

Sutherland, J.W. and T.F. Ghaly. 1980. Heated air drying of oilseeds. Proc. Agric. Eng. Conf. 1980, 203-208, Geelong, Australia.

Timbers, G.E. 1973. Thermal diffusivity and specific heat of rapeseed. Eng. Res. Service, Res. Branch, Agric. Can., Ottawa, Ont. K1A 0C6.

Timbers, G.E. 1975. Properties of rapeseed: thermal conductivity and specific heat. Can. Agric. Eng. 17:81-84.

Timbers, G.E. and R.P. Hocking. 1974. Vapour pressure and moisture equilibria in rapeseed. Eng. Res. Service, Res. Branch, Agric. Can., Ottawa, Ont. K1A 0C6.

Tkachuk, R., V.J. Mellish and J.K. Daun. 1988. Determination of chlorophyll in ground rapeseed using a modified near infrared reflectance spectrophotometer. J. Am. Oil Chem. Soc. 65: 381-385.