Effect of successive adsorption-desorption cycles and drying temperature on hygroscopic equilibrium of canola

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Yang, W.H. and Cenkowski, S. 1993. **Effect of successive adsorption-desorption cycles and drying temperature on hygroscopic equilibrium of canola.** Can. Agric. Eng. **35**:119-126. Moisture sorption isotherms of both ambient-air dried (25°C) and heated-air dried (50°C) canola *Brassica napus* L. 'Westar' were measured up to the fifth adsorption-desorption cycle at the equilibration temperatures of 3.5, 25, and 40°C. Successive adsorption-desorption cycles and a raised drying temperature affected the hygroscopic equilibrium of canola in such a way that the isotherms were shifted downward, especially at relative humidities below 60%. Compared with those on higher-numbered cycles, the isotherms of ambient-air dried canola appeared irregular on the first and second adsorption-desorption cycles at relative humidities around 30%. The EMC data of canola exposed to successive adsorption-desorption cycles were fitted to the Halsey equation. The Halsey equation was statistically shown to describe marginally well the successively cyclic isotherms of canola. Constant *B* in the Halsey equation was found to vary little, while constant *C* changed considerably with increased numbers of adsorption-desorption cycles.

Les isothermes de sorption hydrique pour du canola *Brassica napus L.*, cv Westar séché à l'air ambiant (25°C) et séché à l'air chauffé (50°C) ont été mesurées jusqu'au cinquième cycle d'adsorption-désorption à des température d'équilibration de 3.5, 25 et 40°C. Les cycles successifs d'adsorption-désorption et une température de séchage élevée ont affecté l'équilibre hygroscopique du canola de sorte que les isothermes ont été abaissés, surtout à des humidités relatives inférieures à 60%. Comparativement à ceux associés à un grand nombre de cycles, les isothermes du canola séché à l'air ambiant ont paru irréguliers dans les premier et second cycles d'adsorption-désorption pour des humidités relatives autour de 30%. L'équation de Hasley a été ajustée aux données de teneur hydrique à l'équilibre (EMC) du canola exposé à des cycles successifs d'adsorption-désorption. L'équation de Halsey a statistiquement bien décrit les isothermes successivement cycliques du canola. La constante *B* de l'équation de Hasley a peu varié, alors que la constante *C* a changé considérablement en augmentant le nombre de cycles d'adsorption-désorption.

INTRODUCTION

Among cereal grains and oilseeds, canola has unique drying and rewetting kinetics, namely, its quick adsorption and desorption characteristics. The hygroscopic isotherms of rapeseed including canola have been measured by Pichler (1957), Timbers and Hocking (1974), Pixton and Warburton (1977), Rao and Pfost (1980), Pixton and Henderson (1981), Sokhansanj et al. (1986), and Otten et al. (1990) at equilibration temperatures ranging from 5 to 75°C. However, their measurements were confined to the isotherms corresponding to the first adsorption-desorption (A-D) cycle.

Cereals and oilseeds are commonly dehydrated using an ambient- or heated-air drying technique. The impact of these two drying methods on the hygroscopic equilibrium characteristics of crops is different due to the effect of drying kinetics. Tuite and Foster (1963) reported that the hygroscopic isotherms of corn dried at temperatures higher than 60°C were shifted downward when compared with those dried at ambient temperature. A similar shift in hygroscopic characteristics was observed for yellow-dent corn by Chen and Morey (1989a). One of the most significant effects of the downward movement of hygroscopic isotherms is increased susceptibility of crops to insect infestation and microbial growth during storage. It is not known whether drying temperature affects the hygroscopic equilibrium of canola in the same way.

The successive adsorption (rewetting) and desorption (drying) (A-D) cycles of crops deserve attention because of their frequent occurrence in drying, handling, processing, storage, and various research situations. A number of factors can cause successive A-D cycles to occur. Owing to its unique characteristics of taking in and releasing moisture quickly, canola in a swath is vulnerable to multiple drying and rewetting cycles due to rain or dew before threshing. Mixing different batches of canola prior to drying can cause moisture migration and redistribution (Carter and Farrar 1943). Rain, snow, and humid air from a roof leak or ventilation opening could cause adsorption or even 'wet pockets' to occur (Wallace and Sinha 1962; Muir et al. 1978, 1980). Likewise, desorption could take place in an exchange of moisture with dry air, especially in the locations close to leaks or openings in a storage bin. Temperature differentials have been reported to cause moisture movement (Anderson et al. 1943; Ampratwum and McQuitty 1970). Also, insect infestation can cause moisture unbalance in a grain bulk (Christensen and Kaufmann 1969). Heat generated within pockets of wet mouldy grain provides a favourable environment for further growth of microorganisms (Zhang et al. 1992). As a result, grain moisture can become even more unbalanced. Finally, in a laboratory environment during grain drying tests, researchers from time to time recycle the same grain by rewetting a sample that has already been exposed to drying.

It has been reported that successive A-D cycles have a significant effect on the moisture equilibrium characteristics of hygroscopic substances such as cellulose and its derivatives (Sheppard and Newsome 1929), activated rice grains (Rao 1941), wheat (Hubbard et al. 1957; Hart 1964; Chung and Pfost 1967), potato starch (Van den Berg et al. 1975), and rice (Benado and Rizvi 1985). Little is known about the effect of successive A-D cycles on the hygroscopic equilibrium of canola. Such information can be beneficial in optimizing drying, post-harvest handling, and processing-related operations for canola and improving quality control during storage.

The objective of this study was to investigate the effects of successive A-D cycles and drying temperature on the sorption isotherms of canola.

MATERIALS AND METHODS

Equipment

The experimental set-up (Fig. 1) consisted of an equilibrium moisture content (EMC) apparatus, heat exchanger, three-way valve and aquarium air pump (Hagen Inc., Montreal, PQ). These elements connected together with flexible plastic tubes formed a closed and airtight system. Six identical EMC apparatus were constructed. Each apparatus consisted of six plastic rings (10 mm in thickness and 95 mm in inner diameter). Each ring had a wire mesh attached to its bottom upon which a thin layer of canola was placed. A bulk polymer resistance humidity sensor, RH-2 (General Eastern, Inc., Watertown, MA) was installed in the top section of the EMC apparatus. The temperature of incoming and outgoing air was detected by the T-type thermocouples mounted in the top and bottom section of the EMC apparatus. The direction of the air stream was changed every six hours by switching the three-way valves. Each of the six EMC apparatus was filled with samples and placed in a temperature controlled chamber capable of maintaining constant temperature within 0.1°C. Relative humidity and temperature data for each EMC apparatus were continuously recorded over the equilibration period by a Hewlett Packard Data Acquisition/Control System (Model HP 341A). Prior to the tests, the RH-2 relative humidity sensors were calibrated using a Hygro-M1 dew point sensor (General Eastern Instruments, Inc., Watertown, MA).

Experimental procedure

Canola *Brassica napus* L. 'Westar' (1990 crop), purchased from a local supplier, was used. Canola kernels of 6.5% db (dry basis) initial moisture content were in sound and clean condition.

Four sets of experiments were conducted in this study. In the first set of experiments (treatment A), canola kernels were successively rewetted and dried at 25°C prior to the EMC tests. The EMC experiment was carried out at 25°C following each drying and rewetting cycle. In the second set of experiments (treatment B), canola kernels were successively rewetted and dried at 50°C and the EMC tests were conducted at 25°C following each drying and rewetting cycle. In the third set of experiments (treatment C), canola kernels were rewetted and dried five times at 25°C and the EMC tests were conducted at 40°C following each drying and rewetting cycle. In the fourth set of experiments (treatment D), canola kernels were rewetted and dried five times at 25°C prior to isotherm measurement at 3.5°C following each drying and rewetting cycle.

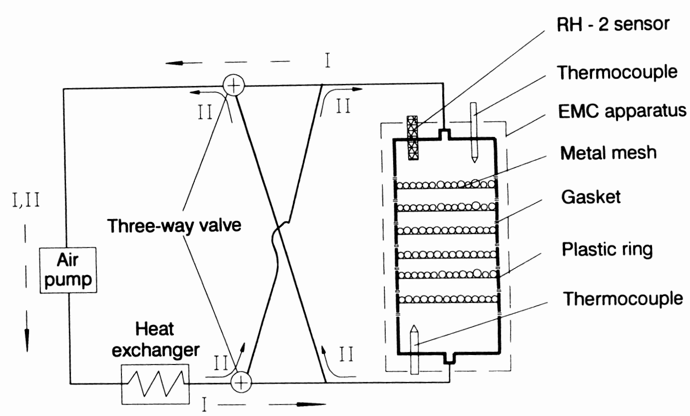

Fig. 1. Diagram of the equipment for EMC measurement.

The following procedure was used for drying and rewetting samples. A 5-kg sample of canola was adjusted to the moisture content of 20% db by adding a predetermined amount of distilled water. The sample was tumbled occasionally during the addition of water to ensure uniform distribution of moisture and then was stored at 8°C for 24 hours. This length of time was sufficient for moisture in the kernels to be evenly distributed (Sokhansanj et al. 1983). The moist canola bulk was dried in a thin layer drier at 25°C to a moisture content of about 7% db. During drying, 50-60 g samples were removed at predetermined time intervals to obtain a material of different initial moisture contents for EMC measurements. The remaining canola was transferred to a desiccator for further drying, where the moisture content was finally brought down to 4.5% db or lower. From this batch, about 400 g of the dried kernels were sampled and used together with the samples of different initial moisture contents to determine the sorption isotherms for the first drying and rewetting cycle. The second to fifth cycle of drying and rewetting procedure followed the same schedule. On the whole canola was rewetted and dried to the same moisture content limits of 20 and 4.5% db, respectively. The standard deviations for the resultant moisture contents were 0.6% db for the upper (20% db) and 0.2% db for the lower (4.5% db) limits.

The adsorption and desorption isotherms were obtained simultaneously by loading alternating dry and wet 15-20 g samples on the wire mesh of plastic rings. Moisture content determination followed the conventional ASAE oven method (ASAE 1991a).

Goodness-of-fit criteria

Chen and Morey (1989b) proved statistically that the two ASAE standardized isotherm equations (ASAE 1991b), the modified Henderson (Thompson et al. 1968) and the modified Chung-Pfost (Pfost et al. 1976) equations were not suitable for describing the hygroscopic isotherms of high oil and high protein products. They concluded that the modified Halsey equation (Iglesias and Chirife 1976) is a good model for high oil and protein products. In the present study, the EMC data of canola exposed to successive A-D cycles were fitted to the modified Halsey equation. Since the effect of equilibration temperature was not considered, the modified Halsey equation is in the form:

$$rh = \exp\left(- C/m^{B} \right) \tag{1}$$

where:

rh = relative humidity (fraction),

m = equilibrium moisture content (%db), and

B, C = constants.

The criteria used to assess the goodness-of-fit of the Halsey equation were: the mean relative percentage deviation (p), standard error of the predicted value (S.E.) (Chen and Morey 1989b), behaviour of the residual plot, i.e., randomly distributed (R.D.) or systematically patterned (S.P.), and the sum of residuals:

$$p = \frac{100}{N} \sum \frac{|Y - Y'|}{Y} \tag{2}$$

$$S.E. = \sqrt{\frac{\sum (Y - Y')^2}{df}} \tag{3}$$

where:

Y, Y' = measured and predicted values, respectively,

N = number of data, and

df = degrees of freedom.

RESULTS AND DISCUSSION

Evaluation of EMC measurements

The EMC measurements were evaluated in the following aspects: equilibration time required, verification of the isotherms obtained in this study with published data, and the repeatability of the EMC measurements.

The length of time required for equilibrium to be established varied from 8 to 24 h depending on various factors such as initial moisture contents of the wet and dry layers, equilibration temperatures, performance of the individual air pumps, and the frequency of switching the direction of air movement inside the EMC apparatus. As an example, Fig. 2 shows the relative humidity of the headspace of the six EMC apparatus as a function of time. The EMC tests were performed at 40°C. The time required for the samples to reach equilibrium, i.e., when the relative humidity reached a plateau, varied from 8 to 12 h at this temperature. To ensure the establishment of the equilibrium, canola samples were generally allowed to stay more than 24 h in the EMC apparatus. The time required for obtaining equilibrium was much shorter for canola than for some cereal grains such as corn, wheat, and barley. Sokhansanj et al. (1983) established that the tempering time required for moisture inside canola kernels to be evenly distributed at 2°C is only 4 h, while for corn, barley, and wheat, it is 122, 48, and 46 h, respectively.

The comparison of EMC data of the present study with the published data by Pixton and Henderson (1981), Sokhansanj et al. (1986), and Otten et al. (1990) is shown in Fig. 3.

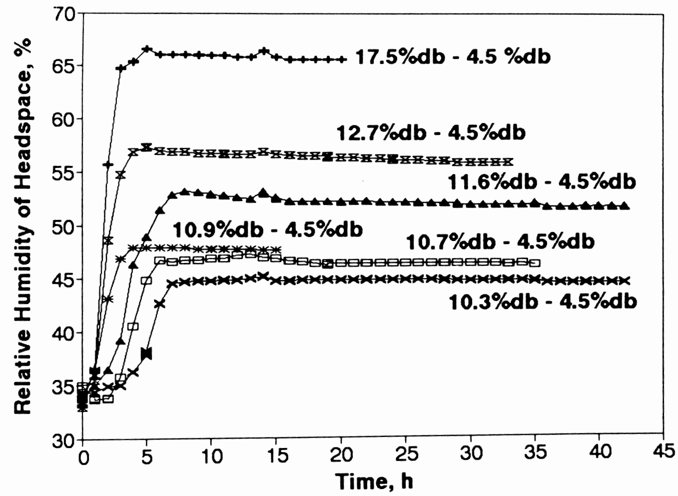

Fig. 2. Relative humidities of headspace in the EMC apparatus as a function of time. The numbers assigned to each curve indicate the moisture contents for the wet and dry layers at the moment of a sample loading into the EMC apparatus.

Because moisture sorption is usually an irreversible process which involves sorption hysteresis (Kingston and Smith 1964; La Mer 1967; Rizvi and Benado 1984; Kapsalis 1981, 1987), the adsorption and desorption data were distinguished and compared separately. The EMC data collected by Sokhansanj et al. (1986) and Otten et al. (1990) were the mixture of adsorption and desorption data and an attempt was made to separate the adsorption and desorption data based on the context of their experimental procedures. The desorption data in this study were found to be close to those of Otten et al. (1990). Both adsorption and desorption data were slightly higher than those of Pixton and Henderson (1981) in the intermediate-high relative humidity range. Generally, a good agreement among the data was obtained in the relative humidity range from 10% to 80%.

The repeatability tests were performed on triplicate samples exposed to the same conditions. Figure 4 shows both the adsorption and desorption isotherms at 25°C for the first to fifth cycles of the drying and rewetting treatment. Vertical error bars marked at each EMC point represent 95% confidence limits. Most confidence limits were so small that the error bars at the corresponding EMC symbols are not visible. Only a few EMC points had relatively large confidence limits. Standard deviations of most EMC measurements at various temperatures were less than 0.10% db. Among 186 EMC values, only twelve had standard deviations between 0.10 and 0.20% db and one beyond this range, as shown in Table I, where the isotherm data and their standard deviations corresponding to treatment A, B, C and D, respectively, are listed.

Behaviour of the hygroscopic isotherms

The isotherms of the canola exposed to treatment A for the first and second A-D cycles indicated some irregularity following concave and convex shape, respectively, in the vicinity of 30% relative humidity (Fig. 4). For the third, fourth and fifth A-D cycles, this irregularity disappeared

Table I: Equilibrium moisture contents of canola on successive adsorption and desorption cycle.

	Ads.	Des	Ads.	Des	Ads.	Des	Ads.	Des	Ads.	Des	Ads.	Des	Ads.	Des	Ads.	Des	Cycle
Treatment A																	
RH, %					64.4		57.7		47.8		35.3		19.4		13.0		
Mean, %db					9.52	9.80	8.03	8.27	6.93	7.19	5.79	5.92	5.09	5.35	4.69	4.79	1st
Std. Dev					0.11	0.20	0.12	0.10	0.08	0.06	0.02	0.07	0.06	0.04	0.03	0.06	
RH, %					67.8		59.7		52.8		40.8		29.7		18.2		
Mean, %db					9.85	10.06	8.22	8.52	7.21	7.39	6.06	6.26	5.49	5.62	4.64	4.76	2nd
Std. Dev					0.18	0.11	0.13	0.21	0.07	0.08	0.06	0.07	0.02	0.02	0.02	0.05	
RH, %					68.5		58.8		49.2		29.9		16.9		14.2		
Mean, %db					10.35	10.67	8.38	8.64	6.84	7.09	5.21	5.53	4.68	4.88	4.54	4.64	3rd
Std. Dev					0.03	0.04	0.03	0.04	0.06	0.06	0.01	0.03	0.01	0.01	0.00	0.02	
RH, %					68.8		57.0		48.3		33.8		24.8		12.7		
Mean, %db					10.20	10.52	7.92	8.22	6.63	6.96	5.42	5.78	4.81	5.19	4.22	4.41	4th
Std. Dev					0.02	0.01	0.04	0.02	0.05	0.11	0.04	0.06	0.03	0.03	0.03	0.01	
RH, %					69.6		58.4		47.5		39.4		27.4		17.1		
Mean, %db					10.38	10.68	8.16	8.48	6.49	6.75	5.67	5.93	4.89	5.15	4.54	4.70	5th
Std. Dev					0.04	0.05	0.05	0.04	0.06	0.04	0.03	0.05	0.03	0.04	0.04	0.02	
Treatment B																	
RH, %			78.4		75.1		69.7		64.6		59.7		49.6		34.5		
Mean, %db			14.95	15.41	12.78	13.54	10.96	11.34	9.15	9.70	8.04	8.66	6.51	7.44	5.39	6.06	1st
Std. Dev			0.04	0.02	0.06	0.02	0.02	0.01	0.01	0.05	0.01	0.06	0.04	0.05	0.04	0.06	
RH, %					69.6		64.1		63.3		54.2		48.1		41.3		
Mean, %db					10.66	10.84	9.06	9.53	9.03	9.44	7.11	7.92	6.54	7.19	5.97	6.73	2nd
Std. Dev					0.02	0.01	0.02	0.08	0.04	0.05	0.02	0.02	0.02	0.02	0.01	0.01	
RH, %	75.3		74.6		71.0		62.0		56.8		54.1		42.0		37.0		
Mean, %db	13.51	13.63	12.25	12.77	11.25	11.52	9.09	9.54	7.85	8.26	7.41	7.91	6.25	6.95	5.76	6.43	3rd
Std. Dev	0.01	0.03	0.03	0.04	0.06	0.03	0.01	0.01	0.09	0.02	0.02	0.04	0.04	0.04	0.02	0.04	
RH, %					70.1		65.6		57.5		46.6		43.0		35.8		
Mean, %db					10.83	11.14	9.74	10.16	7.89	8.34	6.53	7.10	6.31	6.86	5.65	6.30	5th
Std. Dev					0.03	0.01	0.01	0.02	0.02	0.02	0.02	0.04	0.03	0.04	0.02	0.04	
Treatment C																	
RH, %					72.3		64.4		55.1		46.9		44.9		34.0		
Mean, %db					11.17	11.65	8.85	8.97	7.39	7.49	6.15	6.32	5.90	5.98	5.27	5.23	1st
Std. Dev					0.07	0.04	0.02	0.06	0.04	0.02	0.03	0.02	0.07	0.07	0.03	0.06	
RH, %							71.5		63.5		55.0		47.9		45.6		
Mean, %db							11.26	11.61	8.71	9.04	7.11	7.18	6.13	6.44	6.01	6.08	3rd
Std. Dev							0.02	0.04	0.06	0.07	0.02	0.03	0.06	0.02	0.03	0.04	
RH, %					73.1		65.9		55.1		50.4		43.5		31.5		
Mean, %db					10.84	11.00	9.06	9.13	7.03	7.04	6.48	6.58	5.86	5.96	4.77	4.75	5th
Std. Dev					0.05	0.09	0.08	0.06	0.10	0.11	0.02	0.04	0.07	0.06	0.01	0.04	
Treatment D																	
RH, %			87.4		76.2		70.0		55.4		33.9		23.6		18.6		
Mean, %db			19.46	19.80	12.97	13.85	10.78	11.50	8.19	8.76	6.10	6.82	5.45	6.11	4.73	5.08	1st
Std. Dev			0.09	0.01	0.04	0.03	0.10	0.02	0.01	0.00	0.07	0.04	0.04	0.08	0.05	0.02	
RH, %					89.2		82.4		71.6		60.0		42.1		26.4		
Mean, %db					19.57	19.74	15.50	16.30	10.78	11.58	8.34	9.07	6.42	6.87	5.57	5.89	3rd
Std. Dev					0.10	0.12	0.00	0.02	0.01	0.00	0.02	0.01	0.07	0.02	0.01	0.00	
RH, %					85.1		74.6		65.1		45.7		31.3		25.6		
Mean, %db					17.58	17.97	11.69	12.47	9.24	9.78	6.61	7.20	5.45	6.00	4.96	5.30	5th
Std. Dev					0.01	0.11	0.01	0.10	0.02	0.01	0.00	0.03	0.06	0.00	0.00	0.01	

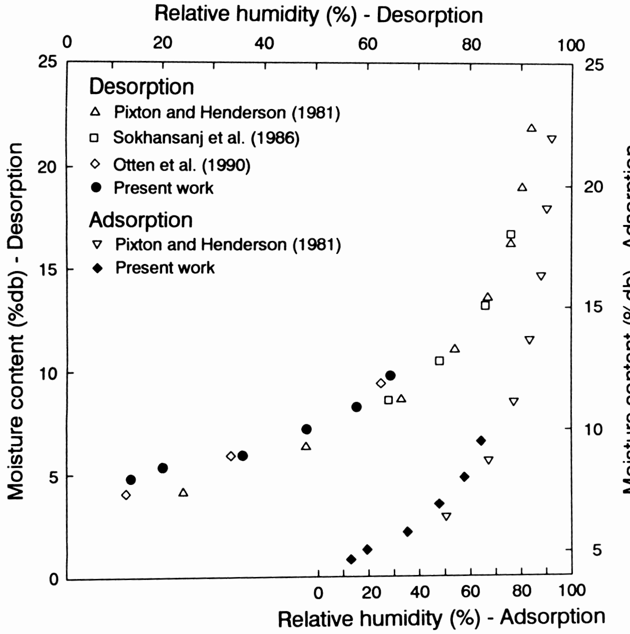

Fig. 3. Comparison of the present work with published data.

showing smooth exponential isotherms. Irregularity in isotherms was reported by Van den Berg et al.(1975) for potato starch at relative humidities near 30%. The unevenness in isotherms seemed unlikely due to experimental errors because the precision of the EMC measurements in our experiments was very high especially at relative humidity below 50% (Table I). Such behaviour would probably indicate certain kinds of characteristic mutations, such as a transition of the isotherm process (Van den Berg et al. 1975), a change in the properties of water-solute interaction, and/or an alteration in the elasticity of the kernel micropores. Above

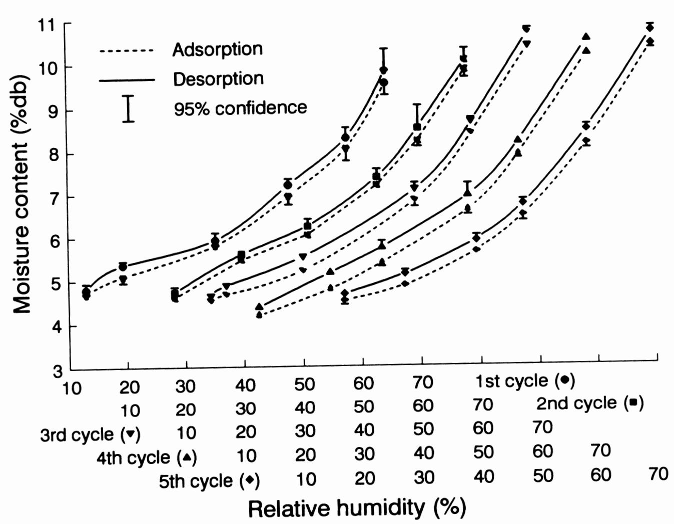

Fig. 4. Adsorption and desorption isotherms of Westar canola at 25°C on the first to fifth drying and rewetting cycles showing 95% confidence limits.

50% relative humidity, the isotherms in all cycles were almost parallel to each other.

Variations in sorptive capacity

Canola subjected to ambient- and heated-air drying showed sensitivity of its sorptive capacity to successive A-D cycles and drying temperature. Sorptive capacity of ambient-air dried canola was found to decrease with increasing number of A-D cycles in the low to intermediate relative humidity range. This is indicated by a downward shift of the isotherms for treatment A, C, and D. However, the sorptive capacity of canola dried at 50°C remained constant in spite of successive A-D cycles. This was demonstrated by the reproducibility of the hygroscopic isotherms for treatment B throughout all the A-D cycles (Table I).

Sorptive capacity of canola decreased after it was exposed to drying at 50°C. This was shown by the fact that the hygroscopic isotherms following the first A-D cycle for treatment B lay below those for treatment A in the low-intermediate relative humidity range. The decrease in the sorptive capacity of canola seeds as affected by the 50°C drying temperature or successive A-D cycles signified loss of its ability to entrap moisture.

It was postulated that a limit probably existed for the decrease in sorptive capacity due to environmental factors such as successive A-D cycles and elevated drying temperature. In treatment A, it was the successive A-D cycles rather than the ambient drying temperature (25°C) that caused the downward shift of the isotherms. In treatment B, the 50°C drying temperature might have already brought the decrease in the sorptive capacity of canola to its limit. This left no more room for successive A-D cycles to play their roles, so that the isotherms for treatment B remained almost consistent despite five consecutive A-D cycles.

Corn and canola show similar responses in sorptive capacity to elevated drying temperatures (Chen and Morey 1989a). The only difference is that variations in sorptive capacity occur mainly in the intermediate-high relative humidity range for corn, while largely in the low-intermediate relative humidity range for canola. Only slight downward shift was observed in the high-intermediate relative humidity range for canola (Table I).

The change in the sorptive capacity is important to the storage stability of crops. The downward shift of isotherms means that at the same moisture content, crops could reach an equilibrium at significantly higher relative humidity. This would render the canola more susceptible to microbial and insect infestation. The impact of sorptive capacity decrease due to elevated drying temperature or successive A-D cycles would be more pronounced on the storage stability of corn than canola, since the downward shift in isotherms occurred, as mentioned above, primarily in the high-intermediate relative humidity range (including the 60-70% relative humidity range which favours mould growth) for corn, while in the relative humidity range below 60% for canola. As a strategy against the effect of sorptive capacity decrease due to elevated drying temperature or successive A-D cycles on storage stability, canola should, in practice, be stored at a moisture content 1% db lower than normally considered safe.

Table II: Statistical analysis for the Halsey's equation as fitted to the equilibrium moisture data listed in Table I.

		B	*C*	Percent relative deviation	Standard error (%)	Sum of residual	Residual* behaviour
Isotherms at 25°C (Treatment A)							
1st Cycle	Adsorption	2.2097	56.213	8.86	1.20	0.066	S.P.
	Desportion	2.2123	60.602	9.39	1.31	0.072	S.P.
2nd Cycle	Adsorption	2.0205	36.362	3.98	0.74	0.041	S.P.
	Desportion	2.0185	38.325	3.68	0.67	0.037	S.P.
3rd Cycle	Adsorption	1,9875	35.567	9.71	1.22	0.067	S.P.
	Desportion	2.0194	40.716	7.46	1.02	0.056	S.P.
4th Cycle	Adsorption	1,8926	27.823	7.17	0.90	0.050	S.P.
	Desportion	1.9707	35.515	4.85	0.71	0.039	S.P.
5th Cycle	Adsorption	1.8333	24.440	8.06	1.19	0.065	R.D.
	Desportion	1.8643	27.868	6.92	1.06	0.058	R.D.
Isotherms at 25°C (Treatment B)							
1st Cycle	Adsorption	1.4169	10.372	3.81	0.93	0.060	S.P.
	Desportion	1.6315	18.896	2.76	0.70	0.045	S.P.
2nd Cycle	Adsorption	1.5231	12.900	1.69	0.49	0.027	S.P.
	Desportion	1.8436	28.571	1.43	0.38	0.021	S.P.
3rd Cycle	Adsorption	1.5428	14.296	1.97	0.48	0.036	R.D.
	Desportion	1.7361	23.971	2.67	0.64	0.048	R.D.
5th Cycle	Adsorption	1.6264	16.681	1.82	0.44	0.024	S.P.
	Desportion	1.8420	29.215	2.20	0.55	0.030	S.P.
Isotherms at 40°C (Treatment C)							
1st Cycle	Adsorption	1.5679	13.610	2.88	0.67	0.037	R.D.
	Desportion	1.5090	12.426	2.29	0.55	0.030	R.D.
3rd Cycle	Adsorption	1.3554	8.6901	1.15	0.33	0.014	R.D.
	Desportion	1.3361	8.6712	1.18	0.38	0.017	R.D.
5th Cycle	Adsorption	1.5952	13.782	1.18	0.28	0.015	R.D.
	Desportion	1.5757	13.460	1.15	0.34	0.019	R.D.
Isotherms at .3.5°C (Treatment D)							
1st Cycle	Adsorption	1.8889	32.944	3.64	0.59	0.038	S.P.
	Desportion	1.9717	45.966	6.59	0.94	0.061	R.D.
3rd Cycle	Adsorption	1.9480	34.398	4.30	0.96	0.053	R.D.
	Desportion	1.9545	39.674	3.29	0.75	0.041	R.D.
5th Cycle	Adsorption	1.7763	23.072	1.68	0.42	0.024	S.P.
	Desportion	1.8347	29.607	2.08	0.46	0.025	R.D.

*S.P. - systematically patterned
R.D. - randomly distributed

Goodness-of-fit criteria for the Halsey equation

Table II lists the constants *B* and *C* and the statistical criteria for the isotherms of canola exposed to the A-D cycles. Almost half of the isotherms tested had systematic patterns showing in their residual plots (Table II). This suggested that the Halsey equation was only a marginally good model for A-D isotherms of canola. Curve fitting results for the Halsey equation also showed that constant B in Eq. 1 varied little while constant C changed considerably with increased number of cycles. For example, for the adsorption isotherms with treatment A, constant B oscillated around 2, while constant C decreased with increased number of cycles (Table II). To obtain a better agreement between predicted and measured isotherms for canola that was exposed to multiple A-D cycles, Yang (1992) modified the Halsey equation. This will be discussed in a separate paper.

CONCLUSIONS

Hygroscopic isotherms of both ambient-air dried (25°C) and heated-air dried (50°C) canola (*Brassica napus*, L. 'Westar') have been measured at the equilibration temperatures of 3.5, 25, and 40°C up to five successive adsorption and desorption cycles. Based on these isotherms, the following conclusions were drawn:

1. Hygroscopic isotherms of canola were shifted downward, especially at the relative humidities below 60%, in response to successive adsorption and desorption cycles and 50°C drying temperature. This indicated a decrease in hygroscopicity of canola undergoing successive adsorption and desorption cycles and a drying process conducted at a raised temperature.
2. As a strategy against the effect of sorptive capacity decrease due to elevated drying temperature or successive A-D cycles on storage stability, canola should be stored at a moisture content 1% db lower than that normally considered safe.
3. It has been statistically shown in this study that the modified Halsey equation gave only marginally good fit to the successive cyclic isotherms of canola. It was found that the moisture exponent B in the equation varied little, while constant C changed considerably with increased number of adsorption and desorption cycles.

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