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MATHEMATICAL MODELING OF THIN LAYER DRYING OF CANOLA PODS

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ABSTRACT

Thin layer drying of canola pods variety (serw-10) was investigated. In conducting the thin layer experiments, the air velocity was held constant at 2.5 m/sec, six different levels of air temperature ranging from 45 to 70 ^{o}C, and four different levels of air relative humidity ranging from 30 to 60% were used.

The obtained results were fitted with six different examined mathematical drying models. The results showed that the Two terms drying model succeeded in describing thin layer drying curve of canola pods.

A multiple regression analysis was also used to describe the interaction effect of the drying air temperature and relative humidity on the constants and coefficients of this model.

INTRODUCTION

Oil crops are considered one of the important sources of nutrition for millions of people all over the world. As row material, it is used in the manufacturing of different products such as: artificial butter oil, soap gelercine, sweets. In addition, the residues of oil crops are used in forage concentrates manufacturing which is considered an important sources for the development of poultry and animal industry (Kholief *et al.*, 2009). On the other hands, there are over 350 species oil-producing plants and thousands of sub-species. Canola (*Brassica napus* L.) is one of the world's major sources of edible vegetable oil. Unlike soybeans, peanuts, and most other oilseeds, canola selected from several species belonging to the mustard family (Cruciferae or Brassicaceae) (Donald and Bassin, 1991). The leading producers of canola include the European Union, Canada, the United States, Australia, China and India (Anon, 2007).World production is growing rapidly, with FAO reporting that 48.97 million tones of rapeseed was produced.

In Egypt, about 1,129, 000 ton of oil is consumed annually but till now the production is only 153,000 ton. Which represent about 13.55% of all our needs (Oilseed situation and outlook 2002). On the other hand, oilseed rape (Canola) area, yield and production in Egypt during the season 2004 was 1627 fed, 0.752 ton/fed and 1224 ton, respectively (Agricultural ministry pamphlet, 2006).

Also, the great importance of canola and the great loss and damage during harvesting makes it necessary to have knowledge on the factors affecting the drying behavior of its pods.

Canola oil is high in oleic acid relative to other vegetable oils and has been competitive in price with other cooking oils. Edible rapeseed oil or canola oil has been used in some countries for the past two decades and was approved for human consumption in the USA by the food and drug administration in 1985. (Raymer *et al.*, 1990)

(Thomas 1984) indicated that, canola seeds are about 40 – 50 percent oil and may reach to 60 % in some variety. Canola can be removed from the field in a tough (less than10.1% moisture) or damp (greater than 12.5% moisture) condition. Harvest can be started earlier and the higher moisture levels may reduce mechanical losses due to pod shattering.

Meanwhile, higher oil contents require lower seed moisture levels for successful storage. Seed moisture contents may be adjusted for different oil contents for example, at 15.6° C canola with 50% oil content can be safely stored at 6.5% moisture content or less. As the oil content decreases, the safe moisture level increases. For seed with oil content of 40%, the safe moisture level at 15.6° C is 7.6%. Also, lower seed moisture and oil contents allow storage at higher temperatures. However, at temperatures greater that 77° F for extended periods of time, excessive free fatty acid may form (Mills, 1989).

On the other hands, it's difficult to obtain a universal drying equation, by which the drying mechanism or heat and mass transfer for any material can be described. However, thin layer drying systems must be properly designed in order to meet particular drying requirements of specific crops and to give satisfactory performance with respect to energy requirements (Steinfeld and Segal, 1986). Drying characteristics of the particular materials being dried and simulation models are needed in the design, construction and operation of drying systems. Several researchers have developed simulation models for natural and forced convection drying systems (Diamante and Munro, 1993, Dincer, 1996, Exell, 1980, Tırıs, *et al.*, 1994 and Zaman and Bala, 1989). In the cited literature, no work on the hot air – thin layer drying of canola pods were found. Therefore the objectives of this paper were to determine the effects of drying conditions on the drying behavior of canola pods and to study the applicability of six thin layer drying models to predict the drying curves of canola pods.

MATERIALS AND METHODS

Materials:

Canola pods used in this study was a full mature freshly harvested canola (serw-10). It was obtained directly from the field. It had initial moisture content ranged from 45 to 65 %(w.b.). The freshly harvested canola had been cleaned and were sealed in plastic sacks and stored in refrigerated room kept at 4 ^{o}C. Before any experimental run, the canola pods were taken out of the refrigerator and kept in the laboratory to attain room temperature.

Apparatus:

The experimental drying equipment which was used in this work were designed and constructed at the department of agricultural engineering, faculty of agriculture, Mansoura university by (Matouk, *et al.*, 2001). It was designed to allow the control of the air humidity and temperature and reduce turbulence of the air inside the drying chamber and ensure even distribution of the air around the sample tray. The drying chamber was also designed to provide an easy handling of the sample tray and ensure a minimal temperature gradient a cross the material bed.

General description of the drying apparatus:

Figure (1) shows the drying setup. It can be seen that atmospheric air was supplied by a centrifugal fan (1.3 kW) with straight impeller blades, which was fitted with a flow regulator. The air was then delivered to the bottom of the humidification tower. Water at controlled temperature was delivered from an electrically driven centrifugal pump (0.59 kW) to the top of the tower and then to the water tank to allow water circulation. The mixture of air and saturated water vapor passes from the top of the tower to the air heating unit and then to the drying chamber via a 20.32 cm (8 in.) diameter insulated steel pipe.

A detailed description of the dryer has been given by (Matouk *et al.*, 2001).

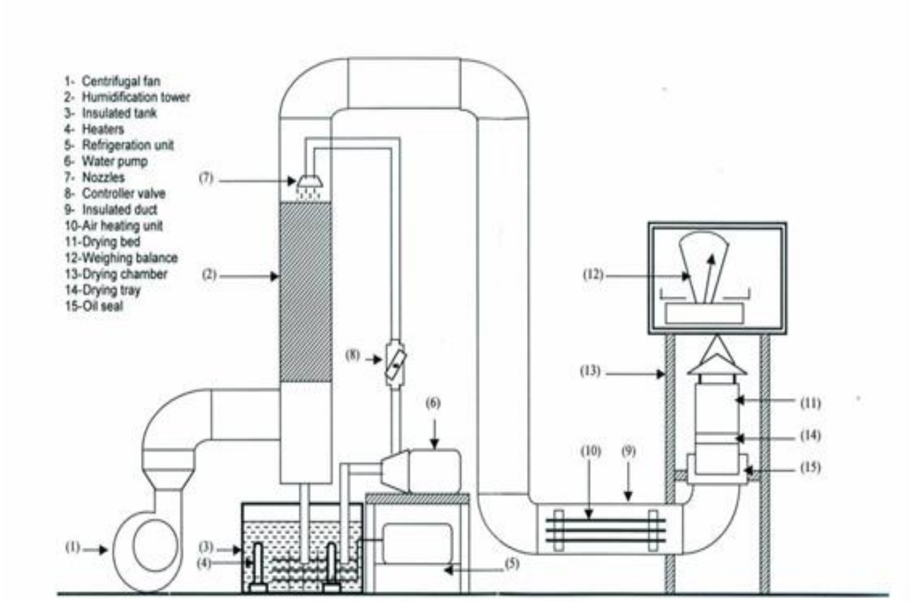

Fig. (1): Diagrammatic section of the convection drier.

Measurements:

During the course of the experiments several variables were measured. Most of these variables were recorded at the time of measurement.

Moisture content:

It is essential for any experimental work on drying to have an accurate method for determining the moisture content.

In this study, the moisture content of canola pods was determined by using a hot air drying oven set at 105 ^{o}C for 72 hr as used for sesame capsules by (Matouk, *et al.*, 1981).

It should be mentioned here that all moisture contents were expressed in dry basis unless otherwise specified.

Air velocity:

The drying air velocity was measured using digital anemometer (*Trotec T2000S*) connected with a velocity probe of 20 cm long and 1.2 cm diameter with measuring range from 0 to 20 m/sec and accuracy of o.o1 m/sec.

Air temperature and relative humidity:

A temperature and relative humidity meter (Trotec T2000S) was used for measuring both parameters during the experimental work. It has a measuring probe of 10.8 cm long and 1.2 cm diameter. The measuring temperature range of the meter is from -20 to 70 ^{o}C with accuracy of 0.1 ^{o}C , while the measuring range for relative humidity is from 0 to 98% with accuracy of 0.1%. The dew point temperature of the air was measured at the top of the humidification tower and used along with the dry bulb temperature of the air after passing through heating unit to check the measurement of the relative humidity.

Initial and final weight:

the weight of samples at the beginning and end of the experiments were obtained by using a weighting balance accurate to 0.01 gm.

Experimental procedures:

The variables of direct interest were the temperature and relative humidity of the drying air. To study the effect of these variables on drying rate, the other variables were held constant as follows:

1- Canola pods used in thin layer experimental were freshly harvested and kept in refrigerated room till the time of experiment. The initial moisture content of the canola pods ranged from 45 to 65 %(w.b.).

2- The drying air velocity was also held constant at 2.5 m/sec which less than the terminal velocity of canola pods.

In order to decrease the experimental errors and increase the sensitivity, each experimental run was repeated in three replicates and the average was considered.

In conducting the thin layer experiments, the air temperature was set at approximately 45, 50, 55, 60, 65 and 70 ^{o}C, and the air relative humidity at about 30%, 40%, 50% and 60%. Table (1) shows the values of air temperature and air relative humidity at which each experiment was conducted.

Table (1): Air temperatures and air relative humidity at which each drying experiment were conducted.

Run no.	Air temp., (°C)	Air relative humidity, (%)	Aver. Of air relative humidity, (%)	Run no.	Air temp., (°C)	Air relative humidity, (%)	Aver. Of air relative humidity, (%)
1	45	29.40		37	60	29.09	
2	45	29.55	29.48	38	60	29.09	29.05
3	45	29.48		39	60	28.96	
4	45	38.61		40	60	38.81	
5	45	38.61	38.54	41	60	38.81	38.57
6	45	38.41		42	60	38.10	
7	45	45.65		43	60	49.20	
8	45	48.65	47.69	44	60	49.43	49.31
9	45	48.77		45	60	49.31	
10	45	57.42		46	60	59.28	
11	45	57.42	57.42	47	60	59.14	59.14
12	45	57.42		48	60	59.00	
13	50	29.50		49	65	30.50	
14	50	29.65	29.50	50	65	30.44	30.41
15	50	29.36		51	65	30.30	
16	50	38.15		52	65	40.03	
17	50	38.24	38.24	53	65	40.03	40.03
18	50	38.34		54	65	40.03	
19	50	47.39		55	65	49.95	
20	50	47.50	47.50	56	65	49.95	49.88
21	50	47.62		57	65	49.73	
22	50	56.09		58	65	59.99	
23	50	55.95	55.91	59	65	59.99	59.90
24	50	55.68		60	65	59.72	
25	55	29.60		61	70	30.49	
26	55	29.24	29.36	62	70	30.43	30.43
27	55	29.24		63	70	30.36	
28	55	39.31		64	70	40.42	
29	55	39.41	39.28	65	70	40.42	40.36
30	55	39.13		66	70	40.24	
31	55	48.64		67	70	50.25	
32	55	48.99	48.64	68	70	50.25	50.18
33	55	48.29		69	70	50.03	
34	55	56.87		70	70	60.94	
35	55	57.28	57.19	71	70	61.34	60.99
36	60	57.42		72	70	60.68	

Thin layer drying experimental of canola pods:

Before an experimental run was started the whole of the apparatus was operated with a dummy sample for at least two hours. This period of time was essential for the conditioned air to stabilize and the air flow rate to be adjusted. After it was clear that the air temperature, air relative humidity and air flow rate had been stabilized, canola pods was distributed over a drying tray. At the same time five samples were taken in tins for moisture determination as mentioned above. Each tin was then covered with its lid and used later for the determination of the initial moisture content. As soon as this was ready, the dummy drying tray was removed from the drying bed and quickly replaced by the sample tray. The output from the weighting balance, which indicates the weight changes of the sample were all recorded every 5 minutes for the first two hour then every 10 min. until the weight loss had almost ceased, which indicated that the moisture content of the canola pods had approached equilibrium with the drying air. At the completion of each drying test the final weight of canola pods assessed and then the canola pods were used to determine the final moisture content as explained before.

Mathematical modeling of thin layer drying curves:

The drying curves obtained were processed to find the most convenient one among six different expressions defining drying rates presented by several authors. The moisture ratio, whoever was simplified by considering the final moisture content as the equilibrium moisture content as recommended by (Matouk, *et al.*, 2001).

The six models were:

1- Lewis's model:

$$MR = \exp(-kt) \quad \ldots\ldots(1)$$

Where:

$$MR = \frac{M - M_f}{M_o - M_f}$$

k: the drying constant, (1/min).
t: drying time, min.
M: moisture content at time t
M_o: initial moisture content
M_f: final moisture content

2- Henderson and Pabis's model:

$$MR = a\exp(-kt) \quad \ldots\ldots(2)$$

Where:

K and a: the drying constants.

3- Page's model:

$$MR = \exp(-kt^u) \quad \ldots\ldots(3)$$

Where:

K and u: the drying constants.

4- logarithmic model:

$$MR = a\exp(-kt) + c \quad \ldots\ldots(4)$$

Where:

K, a and c: the drying constants.

5- Two terms model:

$$MR = a\exp(-k_1 t) + b\exp(-k_2 t) \quad \ldots\ldots(5)$$

Where:

k_1, k_2, a and b: the drying constants.

6- Modified Henderson and Pabis's model:

$$MR = a\exp(-k_1 t) + b\exp(-k_2 t) + c\exp(-k_3 t) \quad \ldots\ldots(6)$$

Where:

k_1, k_2,k_3, a, b and c: the drying constants.

Also, Regression analyses were done by using the Statistical routine. The coefficient of correlation (r) was one of the primary criterion for selecting the best equation to define the drying curves (O'Callaghan *et al.*, 1971, Verma *et al.*, 1985 and Kassem, 1998). In addition to r, the various statistical parameters such as; reduced chi-square (x^2), mean bias error (MBE) and root mean square error (RMSE) were used to determine the quality of the fit. These parameters can be calculated as following:

$$\chi^2 = \frac{\sum_{i=1}^{N} (MR_{\exp.,i} - MR_{pre.,i})^2}{N - n} \qquad \text{.................(7)}$$

$$MBE = \frac{1}{N} \sum_{i=1}^{N} (MR_{pre.,i} - MR_{\exp.,i}) \qquad \text{.................(8)}$$

$$RMSE = \left[\frac{1}{N} \sum_{i=1}^{N} (MR_{pre.,i} - MR_{\exp.,i})^2 \right]^{1/2} \qquad \text{…………..(9)}$$

Where, $MR_{exp,i}$ stands for the experimental moisture ratio found in any measurement and $MR_{pre,i}$ is predicted moisture ratio for this measurement. N and n are the number of observations and constants, respectively (Pangavhane, *et al.*, 1999; Sarsavadia *et al.*, 1999).

The effects of initial and final moisture content, drying air temperature, the velocity and relative humidity of the air on the drying constants have been investigated in many studies (Agrawal and Singh, 1977, Henderson, 1974, Ozdemir and Devres, 1999, Pangavhane *et al.*, 1999, Yaldız and Ertekin, 2001, Yaldız *et al.*, 2001, Zhang and Litchfield, 1991). In this study, the constants and coefficients of the best fitting model involving the drying variables such as temperature and relative humidity of the drying air were determined. The effects of these variables on the constants and coefficients of drying expression were also investigated by multiple linear regression analyses

RESULTS AND DISCUSSION

Effect of Air Relative Humidity and Air Temperature on moisture content:

Figures (2 and 3) show the change in the moisture content of canola pods as a function in the change in air relative humidity at a constant air temperature and the change in the moisture content of canola pods as a function in the change in air temperature at a constant air relative humidity for a representative runs. The same trend of change was also found in all the runs

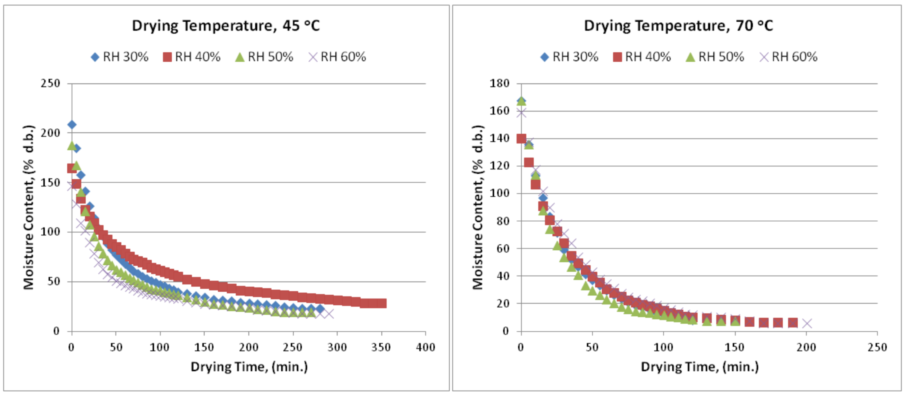

Fig. (2): Change in canola pods moisture content as related to drying time at different air relative humidity and constant drying air temperature.

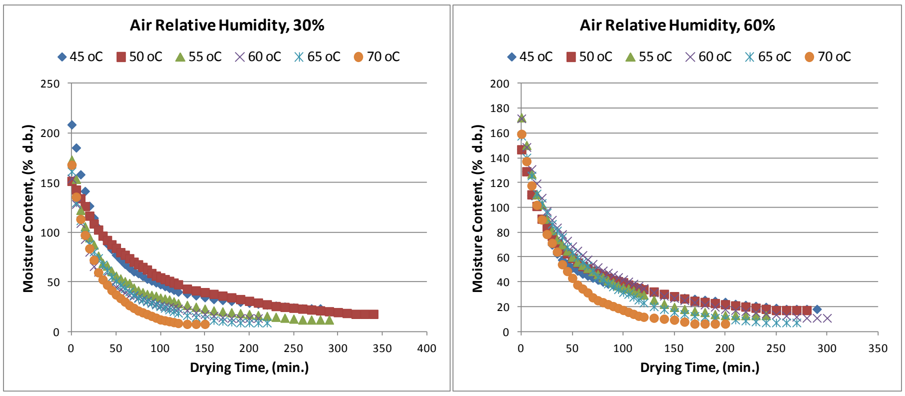

Fig. (3): Change in canola pods moisture content as related to drying time at different drying air temperature and constant air relative humidity.

Thin Layer Drying models:

The moisture ratio was calculated from the data points of all experiments, then curve fitting computations with the drying time were carried on the six drying models to find the most convenient one as we explained above by using Microsoft office Excel and MATLAB programs. Values of computed drying constants for each model were presented in table (2).

In order to compare between the six drying models, straight line was fitted by least square method to the values of the predicted and experimental values of moisture contents. The values of coefficient of correlation (r), chi-square (x^2), mean bias error (MBE) and root mean square error (RMSE) were then computed. Figure (4) shows the fitted straight line for the predicted and experimental values of moisture contents at drying air temperature of 45^{o}C and Air relative humidity of 30%.

Table (2): Values of computed drying constants for all drying models.

Air temp., (^{o}C)	RH., (%)	Lewis's model	Henderson and Pabis's model		Page's model	
		K	A	K	K	u
45	30	0.0153	0.9134	0.0146	0.0309	0.8701
	40	0.0124	0.9786	0.0123	0.0257	0.8674
	50	0.0166	0.7492	0.0148	0.0535	0.7679
	60	0.0168	0.6881	0.0145	0.0554	0.7716
50	30	0.0157	0.9235	0.0151	0.0357	0.8589
	40	0.0204	0.7657	0.0185	0.0624	0.7746
	50	0.0176	0.7021	0.0154	0.0684	0.7346
	60	0.0199	0.8484	0.0187	0.0407	0.8583
55	30	0.0194	0.6826	0.0168	0.0747	0.7363
	40	0.0203	0.8659	0.0192	0.0419	0.8513
	50	0.0223	0.8678	0.0211	0.0507	0.8333
	60	0.0195	0.9753	0.0191	0.0415	0.8437
60	30	0.0237	0.7819	0.0217	0.0667	0.7823
	40	0.0285	0.8816	0.0273	0.0592	0.8370
	50	0.0156	0.9419	0.0152	0.0361	0.8368
	60	0.0164	0.9010	0.0157	0.0399	0.8213
65	30	0.0241	0.9716	0.0238	0.0545	0.8235
	40	0.0267	0.9427	0.0258	0.0599	0.8353
	50	0.0201	1.1250	0.0211	0.0239	0.9571
	60	0.0214	1.0491	0.0217	0.0315	0.9279
70	30	0.0379	1.0944	0.0390	0.0504	0.9289
	40	0.0283	1.1716	0.0299	0.0228	1.0441
	50	0.0389	1.0074	0.0391	0.0502	0.9392
	60	0.0299	0.9195	0.0291	0.0446	0.9141

Continue

Air temp., (°C)	RH., (%)	Logarithmic model			Two Terms model				Modified Henderson and Pabis's model					
		a	k	c	a	k1	b	k2	a	k1	b	k2	c	k3
45	30	0.9212	0.0177	0.0264	0.3984	0.0667	0.6104	0.0111	0.2904	0.0604	0.3592	0.0123	0.3592	0.0123
	40	0.9080	0.0129	0.0190	0.3888	0.0627	0.6202	0.0100	0.4331	0.0445	0.2880	0.0352	0.2879	0.0352
	50	0.8771	0.0244	0.0525	0.4630	0.0552	0.5474	0.0099	0.5071	0.0617	0.2536	0.0113	0.2536	0.0113
	60	0.9070	0.0269	0.0537	0.5006	0.0458	0.5099	0.0091	0.6367	0.0478	0.1888	0.0102	0.1888	0.0102
50	30	0.9111	0.0181	0.0268	0.3629	0.0783	0.6437	0.0137	0.2746	0.0674	0.3657	0.0127	0.3657	0.0127
	40	0.8864	0.0279	0.0430	0.4100	0.0742	0.5956	0.0138	0.4422	0.0748	0.2795	0.0154	0.2795	0.0154
	50	0.8657	0.0259	0.0487	0.4224	0.0680	0.5834	0.0128	0.3969	0.0869	0.3444	0.0129	0.2616	0.0244
	60	0.9251	0.0248	0.0353	0.4307	0.0573	0.5774	0.0126	0.4834	0.0546	0.2636	0.0144	0.2636	0.0144
55	30	0.8704	0.0294	0.0477	0.3874	0.0918	0.6185	0.0165	0.4787	0.0843	0.2017	0.0233	0.3290	0.0142
	40	0.9164	0.0245	0.0321	0.3560	0.0843	0.6503	0.0165	0.3527	0.0761	0.3288	0.0162	0.3288	0.0162
	50	0.9064	0.0277	0.0371	0.3633	0.0805	0.6434	0.0164	0.3610	0.0847	0.3251	0.0176	0.3252	0.0176
	60	0.9312	0.0209	0.0316	0.3689	0.0719	0.6299	0.0155	0.4446	0.1438	0.3384	0.0637	0.2217	0.0765
60	30	0.8967	0.0319	0.0410	0.3408	0.1009	0.7205	0.0199	0.4985	0.0549	0.1952	0.1364	0.3053	0.0286
	40	0.9178	0.0351	0.0352	0.3318	0.1023	0.7159	0.0204	0.3950	0.0874	0.3067	0.0436	0.3067	0.0436
	50	0.8993	0.0167	0.0207	0.3001	0.0932	0.7032	0.0176	0.2335	0.0967	0.3851	0.0129	0.3851	0.0129
	60	0.8894	0.0186	0.0301	0.3206	0.0824	0.6822	0.0172	0.2956	0.0765	0.3529	0.0131	0.3529	0.0131
65	30	0.8939	0.0257	0.0221	0.2769	0.1316	0.7438	0.0229	0.2294	0.1631	0.3854	0.0201	0.3854	0.0201
	40	0.9208	0.0319	0.0278	0.2808	0.1220	0.7200	0.0225	0.3042	0.1483	0.3478	0.0206	0.3478	0.0206
	50	0.9661	0.0183	0.0285	0.2609	0.1020	0.7493	0.0213	0.0890	0.1930	0.4575	0.0177	0.4575	0.0177
	60	0.9480	0.0218	0.0171	0.2591	0.0998	0.7437	0.0209	0.1757	0.1067	0.4158	0.0181	0.4158	0.0181
70	30	0.9566	0.0365	0.0113	0.2235	0.1433	0.7769	0.0288	0.2224	0.1704	0.3827	0.0339	0.3827	0.0338
	40	1.0099	0.0258	0.0145	0.2735	0.1088	0.7740	0.0264	0.3462	0.0563	0.3314	0.0263	0.3314	0.0263
	50	0.9680	0.0407	0.0093	0.2239	0.1182	0.7718	0.0281	0.1821	0.1177	0.4096	0.0350	0.4096	0.0350
	60	0.9613	0.0329	0.0141	0.2347	0.1097	0.7650	0.0256	0.4439	0.0831	0.2662	0.0649	0.2910	0.0337

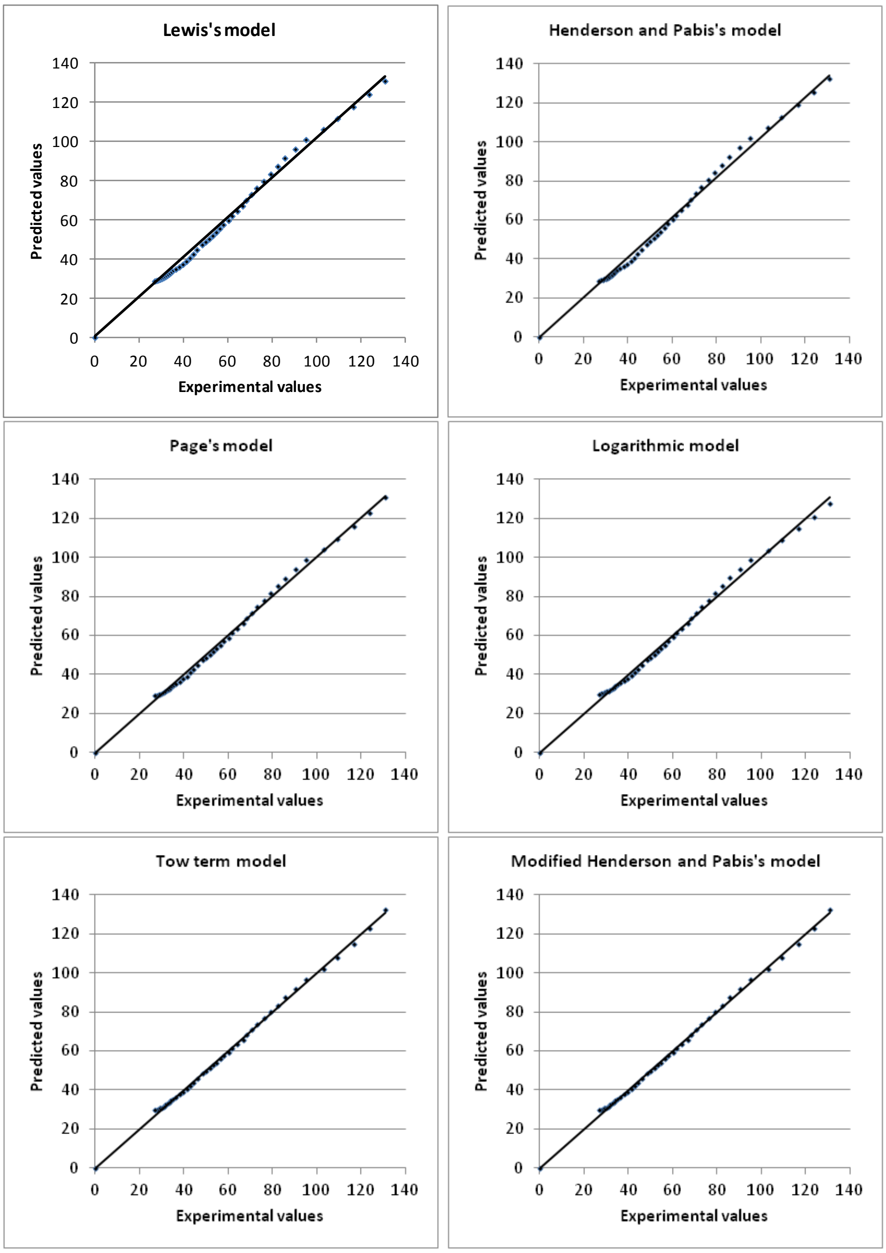

Fig. (4): The predicted and experimental values of moisture contents at drying air temperature of 45oC and Air relative humidity of 30%.

Similar pattern was also noticed for all drying runs. Table (3) also shows the values of coefficient of correlation (r), chi-square (x^2), mean bias error (MBE) and root mean square error (RMSE), for all drying runs and all drying models.

Table (3): Values of coefficient of determination (r), chi-square (x^2), mean bias error (MBE) and root mean square error (RMSE) for Lewis, Henderson and Pabis and Page models

Air temp., (°C)	RH., (%)	Lewis's model				Henderson and Pabis's model				Page's model			
		R^2	x^2	MBE	RMSE	R^2	x^2	MBE	RMSE	R^2	x^2	MBE	RMSE
45	30	0.9965	0.01754	0.01281	0.09961	0.9950	0.04234	0.02065	0.14910	0.9992	0.00953	-0.01222	0.07985
	40	0.9972	0.01522	0.00434	0.10154	0.9969	0.03163	0.00641	0.14409	0.9991	0.01688	-0.01865	0.12590
	50	0.9896	0.08210	0.04402	0.28224	0.9851	0.19757	0.06757	0.43232	0.9981	0.00727	-0.00831	0.05764
	60	0.9864	0.11241	0.05183	0.33065	0.9762	0.28964	0.08215	0.52408	0.9972	0.00061	-0.00370	0.02364
50	30	0.9957	0.01990	0.01451	0.11556	0.9952	0.04459	0.02142	0.16525	0.9991	0.00599	-0.01167	0.07530
	40	0.9905	0.05896	0.03952	0.23803	0.9860	0.14293	0.06060	0.36498	0.9990	0.00193	-0.00693	0.04175
	50	0.9869	0.11042	0.05182	0.32638	0.9795	0.27181	0.08018	0.50498	0.9988	0.00261	-0.00790	0.04974
	60	0.9954	0.02460	0.02475	0.14966	0.9938	0.05902	0.03789	0.22907	0.9988	0.00152	-0.00472	0.02885
55	30	0.9835	0.11163	0.05307	0.32842	0.9737	0.27954	0.08280	0.51234	0.9981	0.00122	-0.00523	0.03230
	40	0.9947	0.02020	0.02336	0.14013	0.9933	0.04464	0.03423	0.20528	0.9987	0.00168	-0.00589	0.03556
	50	0.9929	0.02491	0.02372	0.13716	0.9905	0.06133	0.03542	0.20489	0.9984	0.00165	-0.00646	0.03731
	60	0.9954	0.02619	0.00121	0.14643	0.9942	0.05034	0.00276	0.19762	0.9982	0.03020	-0.02028	0.12526
60	30	0.9906	0.04756	0.03592	0.20989	0.9862	0.11187	0.05455	0.31838	0.9988	0.00165	-0.00637	0.03731
	40	0.9921	0.02006	0.02201	0.12231	0.9892	0.05041	0.03287	0.18336	0.9981	0.00084	-0.00475	0.02550
	50	0.9958	0.01096	0.01195	0.07553	0.9959	0.02401	0.01722	0.10832	0.9988	0.01206	-0.01655	0.10518
	60	0.9950	0.01810	0.02053	0.13094	0.9949	0.03706	0.02900	0.18494	0.9989	0.00740	-0.01309	0.08350
65	30	0.9944	0.00704	0.01194	0.06691	0.9942	0.01266	0.01408	0.08424	0.9983	0.00579	-0.01289	0.07304
	40	0.9923	0.01365	0.01253	0.06793	0.9883	0.03441	0.01669	0.11810	0.9985	0.00513	-0.01058	0.06026
	50	0.9945	0.01029	-0.01340	0.07870	0.9947	0.02777	-0.02256	0.13265	0.9988	0.00586	-0.01233	0.07311
	60	0.9968	0.00548	-0.00169	0.06934	0.9955	0.01454	-0.00524	0.11329	0.9987	0.00292	-0.00877	0.05193
70	30	0.9976	0.00257	-0.00599	0.04058	0.9957	0.00733	-0.01149	0.06646	0.9986	0.00345	-0.01114	0.05445
	40	0.9987	0.01138	-0.01776	0.09729	0.9955	0.02979	-0.02822	0.15455	0.9996	0.00089	-0.00522	0.02856
	50	0.9987	0.00068	0.00361	0.02247	0.9986	0.00091	0.00284	0.02828	0.9994	0.00045	-0.00387	0.01955
	60	0.9981	0.00434	0.01011	0.05519	0.9970	0.01123	0.01597	0.08730	0.9995	0.00062	-0.00409	0.02159
Average		**0.99372**	**0.03234**	**0.01811**	**0.14304**	**0.99105**	**0.07822**	**0.02699**	**0.21724**	**0.99870**	**0.00534**	**-0.00923**	**0.05613**

continue

Air temp., (^{o}C)	RH., (%)	Logarithmic model				Tow Term model				Modified Henderson and Pabis's model			
		R^2	x^2	MBE	RMSE	R^2	x^2	MBE	RMSE	R^2	x^2	MBE	RMSE
45	30	0.9990	0.00716	-0.01214	0.07775	0.9998	0.01681	-0.01807	0.11742	0.9998	0.01773	-0.01807	0.11742
	40	0.9984	0.00090	-0.00333	0.02443	0.9997	0.02541	-0.02208	0.14877	0.9997	0.02664	-0.02205	0.14854
	50	0.0996	0.03149	-0.02571	0.16035	0.9996	0.01898	-0.01955	0.12737	0.9996	0.01997	-0.01954	0.12729
	60	0.9963	0.05752	-0.03621	0.23077	0.9995	0.01797	-0.01995	0.12724	0.9995	0.01901	-0.01995	0.12724
50	30	0.9974	0.00590	-0.01043	0.06672	0.9998	0.01111	-0.01518	0.09848	0.9998	0.01171	-0.01518	0.09845
	40	0.9957	0.01790	-0.02074	0.12484	0.9998	0.00589	-0.01188	0.07156	0.9998	0.00629	-0.01189	0.07158
	50	0.9945	0.02205	-0.02215	0.13941	0.9997	0.00743	-0.01280	0.08051	0.9998	0.00830	-0.01320	0.08305
	60	0.9977	0.01678	-0.02046	0.12308	0.9996	0.00987	-0.01552	0.09359	0.9996	0.01052	-0.01552	0.09361
55	30	0.9927	0.02372	-0.02381	0.14746	0.9996	0.00654	-0.01210	0.07502	0.9996	0.00713	-0.01232	0.07635
	40	0.9969	0.01046	-0.01530	0.09144	0.9996	0.00737	-0.01346	0.08068	0.9996	0.00787	-0.01346	0.08070
	50	0.9960	0.01381	-0.01933	0.11165	0.9995	0.01030	-0.01606	0.09263	0.9995	0.01105	-0.01606	0.09263
	60	0.9973	0.00795	-0.00276	0.08161	0.9991	0.00874	-0.01363	0.08118	0.9993	0.04021	-0.02460	0.15034
60	30	0.9959	0.02047	-0.02140	0.12262	0.9995	0.00600	-0.01091	0.06241	0.9995	0.00691	-0.01173	0.06704
	40	0.9960	0.01781	-0.02103	0.11509	0.9993	0.00765	-0.01459	0.07921	0.9993	0.00831	-0.01459	0.07923
	50	0.9972	0.00223	-0.00109	0.04015	0.9997	0.01305	-0.01669	0.10605	0.9997	0.01335	-0.01647	0.10462
	60	0.9964	0.00160	-0.00567	0.03606	0.9997	0.00732	-0.01273	0.08115	0.9997	0.00775	-0.01273	0.08118
65	30	0.9959	0.00065	-0.00177	0.01870	0.9996	0.00507	-0.01148	0.06550	0.9996	0.00545	-0.01148	0.06549
	40	0.9970	0.00821	-0.00876	0.06709	0.9996	0.00576	-0.01226	0.06861	0.9996	0.00601	-0.01226	0.06861
	50	0.9990	0.00033	0.00278	0.01641	0.9996	0.00437	-0.01031	0.06141	0.9996	0.00668	-0.01246	0.07395
	60	0.9980	0.00336	-0.00491	0.04958	0.9996	0.00567	-0.01183	0.06973	0.9996	0.00607	-0.01183	0.06972
70	30	0.9985	0.00049	-0.00324	0.01780	0.9994	0.00218	-0.00842	0.04148	0.9994	0.00240	-0.00837	0.04124
	40	0.9998	0.00032	-0.00259	0.01416	0.9997	0.00299	-0.00908	0.04975	0.9997	0.00324	-0.00908	0.04975
	50	0.9990	0.00148	-0.00701	0.03545	0.9997	0.00150	-0.00704	0.03561	0.9997	0.00166	-0.00704	0.03562
	60	0.9991	0.00348	-0.01034	0.05559	0.9997	0.00274	-0.00874	0.04644	0.9997	0.00304	-0.00880	0.04678
Average		**0.95972**	**0.01150**	**-0.01239**	**0.08201**	**0.99960**	**0.00878**	**-0.01352**	**0.08174**	**0.99961**	**0.01072**	**-0.01411**	**0.08543**

A general comparison based on the regression and the statistical analysis between observed and calculated values of moisture content for all drying models to assess the most proper drying behavior of canola pods was made. The results showed that the Tow terms model was the best model in describing the drying behavior of canola pods.

Further regressions were undertaken to account for the effect of the drying variables on both of the Two terms model constants k_1 and k_2, (min.$^{-1}$). The effects of temperature and relative humidity of the drying air on the coefficients of a and b (dimensionless) and drying constants k_1 and k_2 were also included in the model by multiple regression analysis as follows:

$a= 0.79247 – 0.00842\, T + 0.000695\, RH$ ……………. (10)

(SE = 0.02676, r = 0.991)

$b= 0.23396 + 0.00802\, T - 0.00068\, RH$ ……………..…. (11)

(SE = 0.02654, r = 0.941)

$K_1= -0.02527 + 0.002617\, T - 0.00079\, RH$ …………. (12)

(SE = 0.005785, r = 0.976)

$K_2= -0.01678 + 0.000654\, T - 0.000065\, RH$ …………. (13)

(SE = 0.000954, r = 0.988)

These expressions can be used to estimate the constants of the Two terms model within air temperature range of 45 to 70 ^{o}C and relative humidity range of 30 to 60% to predict the moisture content of canola pods at any time during the drying process with a great accuracy.

CONCLUSIONS

The following results may be drawn from the present work in which drying of canola pods by a convection drier have been studied.

1- Water removal from the canola pods in the drying process occurs in the falling rate period.
2- The Two terms model could adequately describe the thin layer drying behavior of canola pods. Various statistical parameters such as r, x^2, MBE and RMSE favored this model among others.
3- The multiple regression analysis which showed the effect of air temperature and relative humidity on the coefficients (a and b) and drying constants (k_1 and k_2) of the Two terms model with the effects of the drying air temperature and relative humidity gave ***r*** (0.991 and 0.941) and (0.976 and 0.988) respectively, and ***SE*** (0.02676 and 0.02654) and (0.005785 and 0.000954) which proved that, the Two terms model satisfactorily describe the drying behavior of canola pods in the ranges of 45‑70 ^{o}C temperature and 30‑60% air relative humidity.

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التقرير الصادر عن قطاع الشئون الاقتصادية بوزارة الزراعة واستصلاح الأراضي (2002) عن موقف البذور الزيتية ومستقبلها. (Oilseed situation and outlook, 2002).

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النمذجة الرياضية لتجفيف قرون الكانولا في طبقات رقيقة.

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تم دراسة تجفيف قرون الكانولا (صنف سرو 10) في طبقات رقيقة باستخدام هواء تجفيف عند سرعة 2.5 م/ث وست مستويات مختلفة من درجات الحرارة تراوحت بين 45 و70°م بالإضافة إلى أربع مستويات مختلفة من الرطوبة النسبية تراوحت بين 30 و60% وذلك لتحديد أنسب نموذج رياضي من ست نماذج تجفيف رياضية مختلفة لوصف سلوك التجفيف في طبقات رقيقة لقرون الكانولا.

ولقد أوضحت النتائج أن النموذج الأسي الثنائي هو أنسب نموذج لوصف سلوك التجفيف بدقة عالية كما أكدت النتائج المتحصل عليها من التحليل الرياضى والتحليل الإحصائي المستخدم اعتماد ثوابت التجفيف على كل من درجة الحرارة والرطوبة النسبية لهواء التجفيف ولقد تم استنتاج معادلات رياضية تربط بين ثوابت التجفيف وعلاقتها بدرجة الحرارة والرطوبة النسبية لهواء التجفيف المستخدم.

وبالتالي فإنه يمكن استخدام المعادلات المستنتجة من خلال برنامج حاسب آلى للتجفيف فى طبقات رقيقة لقرون الكانولا اعتمادا على تغير كل من درجة الحرارة واذلرطوبة النسبية لهواء التجفيف.

قام بتحكيم البحث

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