J. Agric. Sci. Mansoura Univ., 32 (4): 2627 - 2640, 2007

THERMAL PROPERTIES OF SOME OIL PRODUCING CROPS

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ABSTRACT

The thermal properties such as specific heat, thermal conductivity, thermal diffusivity and volumetric heat transfer coefficient for three different oil producing crops (sunflower variety Giza 102, soybean variety Giza 111 and canola variety Serow 55) were determined at five different levels of seeds moisture content and temperature. The results show that, the specific heat was found to be both seeds moisture content and temperature dependent. Its value increased linearly with the increasing of both seeds moisture content and temperature for all studied crops. Also, the seeds moisture content had higher effect on seeds specific heat than that of seeds temperature. Thermal conductivity and thermal diffusivity were increased with the increase of seeds moisture content while, thermal diffusivity decreased linearly with the increasing of seeds temperature for all studied crops. Also, the volumetric heat transfer coefficient was increased linearly as the air flow rate and air temperature increased.

Mathematical relationships were also developed for the different studied crops to relate the change in seeds moisture content, temperature and mass air flow rate with the obtained values of all thermal properties.

INTRODUCTION

Specific heat, thermal conductivity and thermal diffusivity are the most important moisture-dependent thermal properties. Knowledge of these thermal properties provides a basis to predict the behavior of the grain during storage. This knowledge also considered very important for designers how are concerning with thermal processing equipment.

It is essential to have knowledge of the thermal properties of the oil seeds crops in order to effectively develop the processes and equipment needed in the drying, storage and thermal processing of the product

Aviara and Haque, (2001) The values of specific heat, thermal conductivity and thermal diffusivity of shea nut kernel were determined and their variation with moisture content investigated. Specific heat was found to be both moisture and temperature dependent. Its value increased linearly with moisture content and temperature in the moisture and temperature range of 3.32±20.70% (db) and 303±363 ^{o}K, respectively. Thermal conductivity and thermal diffusivity also increased linearly with moisture content in the above moisture range, within the temperature range of 347.5±349.5^{o}K. Regression equations which could be used to reasonably predict the values of these properties at specified moisture content were established.

Yang *et. al.,* (2002) also, determined thermal conductivity, specific heat capacity and thermal diffusivity of borage (Borago officinalis) seeds at temperatures ranging from 6 to 20^{o}C and moisture contents from 1.2 to 30.3% w.b. The thermal conductivity was measured by the transient technique using a line heat source. The maximum slope method was used to analyze the line source heating data for thermal conductivity determination. The specific heat capacity was measured by different scanning calorimetry. They found also, that all measured thermal properties were increased with the increase of both seeds moisture content in the range of 1.2 to 30.3% w.b and seeds temperature in the range of 6 to 20°C.

Elustondo *et. al.,* (2001) mentioned that, the thermal conductivity determination by means of the thermal probe is a classical non-stationary method, suitable for foodstuffs because of the relatively short period of time and the small temperature rise required during experimental measurements.

The various thermal properties, specific heat, thermal conductivity and thermal diffusivity were determined for both the grains and flours of some varieties of millet in the moisture content range of 10–30% by Subramanian and Viswanathan, (2003). They observed an increase in specific heat for both grains and flours, with an increase in moisture content. The thermal conductivity of the millet grains and flours increased from 0.119 – 0.223 W/m.° K and from 0.026–0.128 W/m.° K, respectively, in the moisture range of 10–30%. They also noticed that as the moisture content increased from 10 to 30% (wb), thermal diffusivity of millet grains decreased from 0.731×10^{-3} to 0.55×10^{-3} m^2/h and that of their flours ranged from 0.820×10^{-3} to 0.592×10^{-3} m^2/h.

Also, Matouk *et. al.,* (2006 a,b) also measured thermal properties (specific heat, thermal conductivity and thermal diffusivity) of different varieties of rice, corn, wheat and barely. They concluded that all of these properties are moisture dependent. They also developed mathematical models describing the dependence of these properties on the moisture content of the grain

A mathematical model based on dynamic heat and mass balances was developed by (Iguaz *et. al.,* 2004) to simulate the grain and air temperature and moisture content in a rough rice storage bin with forced cool air ventilation. Validation was performed by comparing predicted and measured grain temperature in an experimental 1.3m diameter bin ventilated with air at 10°C. Predicted grain temperatures were in close agreement with measured ones with standard error of estimate from 0.29 to 0.38°C. The model and parameters used in the model are applicable for temperature prediction purposes. Using the model it is possible to predict the grain temperature and moisture and the time needed to cool the stored grain under different ventilation conditions.

Matouk *et. al.,* (2006 c) determined the heat transfer coefficient for wheat, corn, rice and barely. They found that, heat transfer coefficient increased with the increase of mass air flow rate at the range of 0.791 to 3.39 $kg/m^2.s$. They concluded that, the relationship between heat transfer coefficient and the value (G.Ta/Pa) at the studied range of air mass flow rate was found to be on the form of power function for all varieties of the studied crops.

The main object of this work was to determined thermal properties for the seeds of three oil producing crops which are sunflower, soybean and canola and to describe mathematically there dependence on moisture content and temperature

MATERIALS, EQUIPMENT AND METHODS

Materials:

Samples of the investigated crops (Sunflower variety Giza 102, Soya bean variety Giza 111 and Canola variety Serow 55) shown in Fig (1) were obtained from the research station of Agricultural Research Center (ARC), Al-Gimmeza, Experimental station, Gharbiea Governorate, to grantee the purity of the selected varieties. These varieties were selected based on its recent coverage area and the expected future expansion according to Ministry of Agriculture yearly bulletins (MALR, 2005 a,b). The samples were cleaned to remove impurities, immature kernels and foreign materials. The seeds of each variety were then stored in a burlap sacks inside a ventilated storage room.

Fig (1): A photo for different studied crops

Equipment:

Seeds moisture-conditioning apparatus:

The seeds moisture-conditioning apparatus was designed by (Matouk, *et. al.,* 2004a) and used in this study to obtain the desired levels of moisture content for different experiments.

Drying oven:

A drying oven model (Binder-Ed-53, Germany) with temperature range of (5-240 $^oC \pm 1$ ^oC) was used to determine the seeds moisture content

Digital balance:

A digital balance model (MFD-K1000920, Japan) with maximum reading of 200 g and accuracy of 0.01 g was used to determine the mass of small samples.

Specific heat apparatus:

The method of mixture was used for determining the specific heat of different studied crops. This method involved determining the temperature change of the water contained in a calorimeter when a known quantity of test material is added to it at a known temperature after equilibrium state between the test material and water is attained.

The detailed description of the apparatus used for the experimental work was presented by (Matouk, *et. al.,* 2006a)

Thermal conductivity meter:

In this study a digital thermal conductivity meter provided with a line heat source thermal conductivity probe which was developed by (Matouk *et. al.,* 2006b) according to that developed by (Hooper and Lepper 1950) was used to measure thermal conductivity of the studied seeds.

Thin layer dryer:

In this study, forced air dryer was used to dry the seeds samples at four different air temperature levels (40, 50, 60, and 70 ºC) in order to get the reconditioned samples to determine the volumetric heat transfer coefficient. The dryer was consisted of air supply unit, air conditioning unit, heating unit and drying chamber. The detailed description of the dryer was given by (Matouk, *et. al.,* 2001).

Methods:

3.3.2. Seeds moisture content:

The oven drying method was used for determining seeds moisture contents of the different studied varieties of each crop according to **(ASAE standards, 2003)**. The oven temperature, heating time and sample weight are listed in Table (1).

Table (1): Oven temperature, heating time and sample size for three different oil seeds.

seed	Oven temperature, ºC.	Heating time, hr.	Sample weight, g.
Canola	130	4	10
Soybean	103	72	15
Sunflower	130	3	10

Specific heat:

Specific heat determination test for the different studied crops was carried out at five different levels of seed temperature which ranged from 40 to 80ºC. The test was conducted by placing 50 g sample which moisture content was predetermined in glass test tubes (5 cm diameter, 20 cm long) and sealed with a rubber stopper. The thermometer probe was inserted through the center of the stopper until it reaches the middle of the seeds depth to measure the seeds temperature. The glass test tubes were then heated by placing them vertically inside the water path which set at the desired temperature level and it was left until reaching a constant final temperature. The seeds were then rapidly transferred into the thermos flask which contained 70g of distilled water (the required amount to cover the seeds) after recording the temperature of the water in the flask and immediately sealed while allowing the temperature meter probe to pass through it. The thermos flask and contents were then shaked for about 5 to 10 seconds to ensure that the seeds and water mixed well.

The temperature of the seeds-water mixture was recorded every second until reaching a final steady mixture temperature which usually taken from 30 to 40 seconds. Three replicate of each test were carried out and the specific heat was taken as an average of the three replicates.

It should be mentioned that, since the thermos flask is a composite of different materials (glass, metal and insulated material) it was preferable to determine the water equivalent, which is defined as the mass of water having a thermal capacity equal to that of the thermal flask.

The specific heat of seeds was then determined by following equation:

$$C_{pg} = \frac{(m_w + m_{eq})(t_{wg} - t_{iw})\, x\, C_{pw}}{m_g\,(t_{ig} - t_{wg})} \quad \ldots\ldots\ldots\ldots\ldots(1)$$

Where:

C_{pg} = specific heat of the seeds kJ/kg.°K
t_{wg} = final seeds-water temperature, °C
m_g = mass of seeds, kg
t_{ig} = initial seeds temperature, °C
m_{eq} = mass of water equivalent, kg.
m_W = mass of water, kg
C_{pw} = specific heat of water, kJ/kg.°K
t_{iw} = initial temperature of water, °C

Thermal conductivity:

The thermal conductivity of the studied crops was determined according to (Matouk, *et. al.,* 2006b) by using line heat source method at five different levels of seeds moisture content ranging from 7.35 to 23.7 % (w.b.), from 9.52 to 24.64 % (w.b.) and from 7.11 to 25.72 % (w.b.) for sunflower, soybean and canola seeds, respectively. The measuring procedure depends upon placing the sample of seeds in a hollow stainless-steel cylinder 300 mm high and 150 mm in diameter. The seeds were heated by inserting the thermal conductivity probe through the axis of the cylinder.

The thermal conductivity of seeds was then determined by following equation:

$$K = \frac{Q}{4\pi(T_2 - T_1)} Ln\left(\frac{t_2}{t_1}\right) \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(2)$$

The term Q could be calculated as:

$$\mathbf{Q = I^2 R} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (3)$$

where:

K = thermal conductivity of the material, kW/m. °C
T_1 = temperature at time t1, (°K)
T_2 = temperature at time t2, (°K)
t = time, sec
I = current intensity, (A)
R = electrical resistance, (Ω)

Heat transfer coefficient:

The procedure used for determining heat transfer coefficient was described in details by (Matouk, *et. al.,* 2006c). this method depends on drying the seeds to equilibrium at certain temperature. Then the seeds were allowed to cool at room temperature. After cooling the seeds were heated at this temperature (to insure that the drying rate will be zero) for 5 min after which the temperature of grain was recorded. The experiment was repeated at four different temperature ranging from 40 to 70 °C.

The volumetric heat transfer coefficient of seeds was then determined by following equation:

$$\mathbf{h_{cv}} = -\left(\frac{\mathbf{C_{pg}}\ \rho}{\mathbf{t}}\right)\mathbf{Ln}\frac{\mathbf{T_a}-\mathbf{T_g}}{\mathbf{T_a}-\mathbf{T_{gi}}} \quad \text{.....................} (4)$$

Where:

h_c = film heat transfer coefficient W/m^2.ºK.
h_{cv} = volumetric heat transfer coefficient kJ/m^3.sec.ºK.
V = seeds volume, m^3.
A = seeds surface area, m^2.
A_s = specific surface area, m^2/m^3.
T_a = absolute air temperature, ºK.
T_{gi} = initial seeds temperature, ºK.
T_g = final seeds temperature, ºK.
ρ = bulk density, kg/m^3.
C_{pg} = specific heat of seeds, kJ/kg.ºK.
t = time, sec.

Thermal diffusivity:

In this study no attempt has been made to measure the value of thermal diffusivity of the studied crops directly, but it was calculated indirectly from the measured values of specific heat and bulk density (Matouk *et. al.,* 2006b).

Equation (3.35) relates the thermal diffusivity with these variables as follows:

$$\alpha = \frac{\mathbf{K}}{\mathbf{C_{pg}}\ \mathbf{x}\ \rho} \quad \text{................}(5)$$

Where:
α = thermal diffusivity, m^2/sec.
K = thermal conductivity, kW/m.°K
C_{pg} = specific heat, kJ/kg.°K
ρ = bulk density of seeds, kg/m^3.

RESULTS AND DISCUSSIONS

Specific heat:

As shown in Figs (2 and 3), the specific heat for sunflower seeds increased from 1.768 to 2.274 kJ/kg.°C, from 1.867 to 2.283 kJ/kg.°C, from 1.996 to 2.309 kJ/kg.°C, from 2.028 to 2.329 kJ/kg.°C and from 2.083 to 2.380 kJ/kg.°C at seeds temperature levels of 40, 50, 60, 70 and 80 °C, respectively, with the increasing of seeds moisture content from 6.423 to 22.967 % (w.b.). Also, the specific heat values increased from 1.768 to 2.083 kJ/kg.°C, from 1.886 to 2.117 kJ/kg.°C, from 2.067 to 2.182 kJ/kg.°C, from 2.167 to 2.277 kJ/kg.°C and from 2.274 to 2.380 kJ/kg.°C at seeds moisture content levels of 6.423, 10.524, 14.489, 19.148 and 22.967% (w.b.), respectively, with the increasing of seeds temperature from 40 to 80 °C.

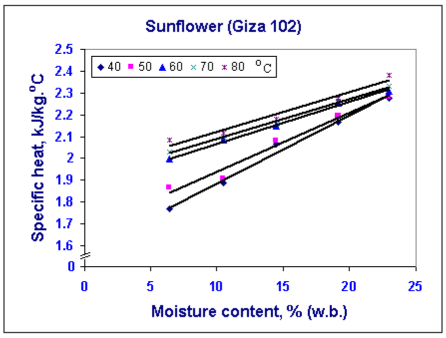

Fig. (2): Effect of moisture content on specific heat of sunflower seeds at different temperature levels.

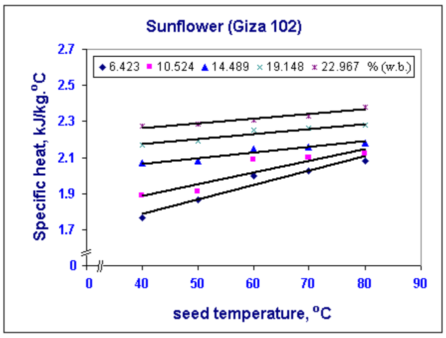

Fig. (3): Effect of seeds temperature on specific heat of sunflower seeds at different moisture content levels.

The same trends of increasing specific heat with the increase of both seeds moisture content and temperature were also noticed with the other studied crops. Therefore multiple regression analysis was employed to describe the dependence of specific heat on both seeds moisture content and seeds temperature. The regression equations were as follow:

For sunflower seeds:

C_{pg} = 1.5191 + 0.02265 (MC) + 0.004594 (T_g) ………….. (6)
(SE = 0.04176 ; R^2 = 0.935)

For soybean seeds:

C_{pg} = 1.9817 + 0.0247 (MC) + 0.00295 (T_g) …………….. (7)
(SE = 0.01424; R^2 = 0.989)

For canola seeds:

C_{pg} = 2.1448 + 0.0292 (MC) + 0.00355 (T_g) …………….. (8)
(SE = 0.0615; R^2 = 0.920)

For sunflower kernels, crushed soybean and crushed canola, Fig (4) showed that the specific heat depend on temperature and varied linearly with the increase of temperature. The measured values of specific heat were ranged from (2.052 to 2.252 kJ/kg.ºC), from (2.352 to 2.684 kJ/kg.ºC) and from (2.433 to 2.551 kJ/kg.ºC) for sunflower kernels, crushed soybean and crushed canola.

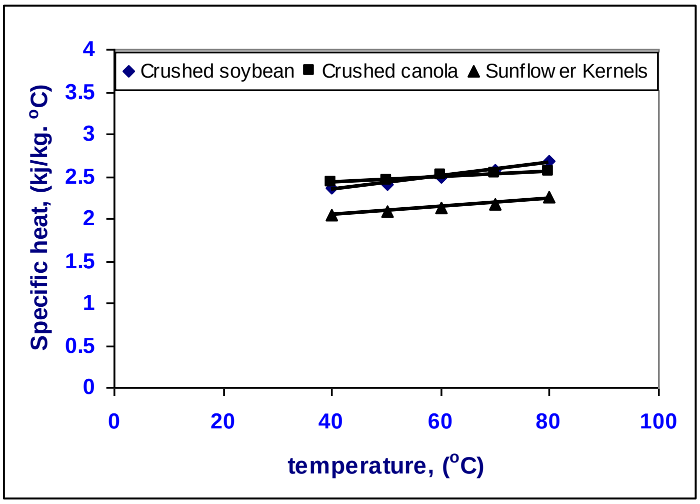

Fig (4): Effect of seeds temperature on specific heat for sunflowerkernels, crushed soybean and crushed canola.

Generally, the results showed that the seeds moisture content has the greatest effect on seeds specific heat than the seeds temperature.

It should be mentioned also that theses results are in line with those obtained by Aviara and Haque, (2001) and Yang *et. al.,* (2002) for shea nut and borage seeds, respectively.

Thermal conductivity:

In general, for all studied crops the results showed that the thermal conductivity increased linearly with the increase of seeds moisture content as shown in Fig (5). For sunflower seeds, the determined thermal conductivity increased from 0.32721 to 0.437694 W/m.°C. with the increase of seeds moisture content from 7.35 to 23.7 % w.b.

However, for soybean seeds, the thermal conductivity increased from 0.50092 to 0.0.5877 W/m.°C. with the increase of seeds moisture content from 9.52 to 24.644 % w.b.

Similarly, for canola, the thermal conductivity was also increased from 0.5496 to 0.7422 W/m.°C. with the increase of seeds moisture content from 7.11 to 25.722 % (w.b.), respectively.

Simple regression analysis was then applied and the regression equations for the three crops were in the form of:

K = a + b (M.C) ………………………..………………… (9)

Where:

K = Seeds thermal conductivity, W/m.°C

a and b = constants

The regression constants for the obtained regression equation were tabulated for all studied crops as presented in Table (2).

Meanwhile, the measured values of thermal conductivity for sunflower kernels, crushed soybean and crushed canola were found to be 0.5009

W/m.ºC, 0.5496 W/m.ºC and 0.6087 W/m.ºC, at moisture contents of 6.33, 9.52 and 7.11 % (w.b.) respectively.

This result is also matching with those obtained by Elustondo *et. al.,* (2001); Aviara and Haque, (2001) and Matouk *et. al.,* (2006b**)** for millet, shea nut and rice, corn, wheat and barely, respectively.

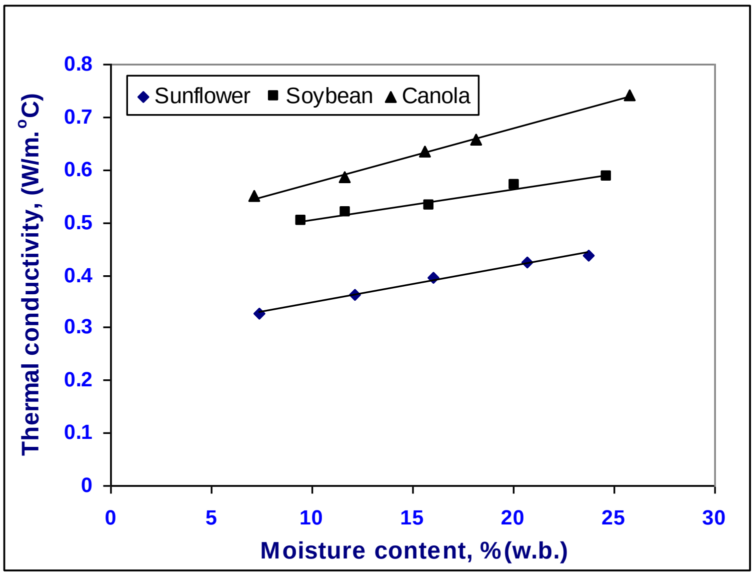

Fig (5): Effect of moisture content on thermal conductivity of sunflower, soybean and canola seeds.

Table (2): Regression parameters of equation (9) which relate the change in seeds thermal conductivity to the change in seeds moisture content.

Crop	**Range of seeds M.C. % w.b.**	**Regression parameters**		
		q	**w**	**R^2**
Sunflower	**7.35 – 23.7**	0.2791	0.0069	0.989
Soybean	**9.52 – 24.644**	0.4465	0.0058	0.978
Canola	**7.11 – 25.722**	0.4712	0.0104	0.997

Thermal Diffusivity:

Inspection of the results showed that thermal diffusivity of all studied crops was increased with the increase of moisture content while decreased with the increasing of seeds temperature.

Figs (6 and 7) show the effect of increasing both moisture content and temperature on thermal diffusivity of soybean seeds.

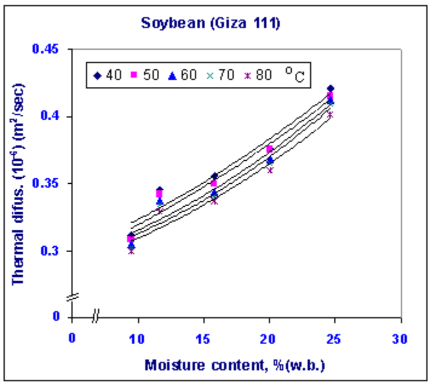

Fig (6): Effect of moisture content on thermal diffusivity of soybean seeds at different levels of temperature

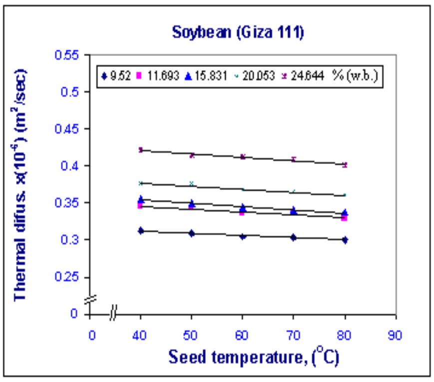

Fig (7): effect of seeds temperature on thermal diffusivity of soybean seeds at different levels of moisture content

The same trends of increasing thermal diffusivity with the increase of seeds moisture content and decrease of temperature were also noticed with the other studied crops. Therefore multiple regression analysis was employed to describe the dependence of thermal diffusivity on both seeds moisture content and seeds temperature. The regression equations were as follow:

For sunflower seeds:

α = [0.406533 + 0.008542 (MC) - 0.001005 (T_g)] x 10^{-6} .…..…. (10)

(SE = 0.01549; R^2 = 0.929)

For soybean seeds:

α = [0.27625 + 0.006269 (MC) - 0.000412 (T_g)] x 10^{-6} ……….. (11)

(SE = 0.008671; R^2 = 0.949)

For canola seeds:

α = [0.33043 + 0.003715 (MC) - 0.000454 (T_g)] x 10^{-6} ……….. (12)

(SE = 0.009643; R^2 = 0.877)

Meanwhile, for sunflower kernels, crushed soybean and crushed canola, Fig (8) showed that the thermal diffusivity is clearly depend on temperature and it was linearly decreased with the increase of temperature at the same moisture content. The measured values of thermal diffusivity for different studied crops were ranged from 0.420401 x 10^{-6} to 0.461375 x 10^{-6} m^2/s, from 0.509185 x 10^{-6} to 0.580905 x 10^{-6} m^2/s and from 0.535735 x 10^{-6} to 0.561722 x 10^{-6} m^2/s for sunflower kernels, crushed soybean and crushed canola, respectively.

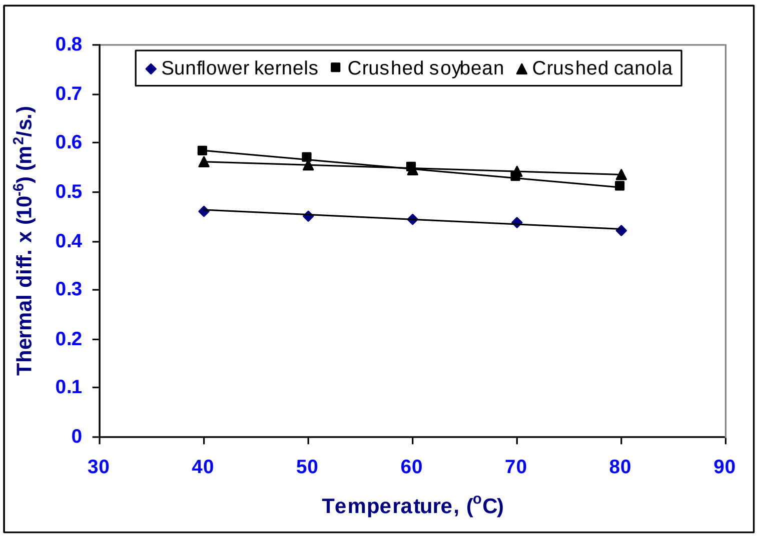

Fig (8): Effect of seeds temperature on thermal diffusivity of the crushed canola seeds.

On the other hands, the results of regression analysis show a direct simple linear relationship between temperature and the thermal diffusivity of the studied crops as follows:

For sunflower kernels:

α = [0.5014 – 0.001 (T_g)] x 10^{-6} ; (R^2 = 0.973) ……………………… (13)

For crushed soybean:

α = [0.6552 – 0.0018 (T_g)] x 10^{-6}; (R^2 = 0.996) ……………………… (14)

For crushed canola:

α = [0.5884 – 0.0007 (T_g)] x 10^{-6}; (R^2 = 0.975) ……………………… (15)

This result is line with that obtained by Aviara and Haque, (2001); Yang *et. al.,* (2002) Matouk *et. al.,* (2006b) for shea nut and borage seeds and rice, corn, wheat and barely, respectively.

Volumetric heat transfer coefficient (h_{cv}):

As previously mentioned the seeds of different studied crops were dried to the equilibrium state with air stream and then cooled to room temperature, so the drying rate dm/dt becomes zero during the heating process.

In this study, the seeds were dried to the equilibrium state with air at 70°C and the values of heat transfer coefficient were measured at different air velocities ranging from 0.5 to 2.5 m/sec and different air temperatures ranging from 40 to 70 °C.

Specific gravity and specific heat for each studied crop at the equilibrium moisture content were calculated from the previously presented data. The obtained results had confirmed that, the volumetric heat transfer coefficient was increased as the air flow rate and air temperature increased. The measured values of the volumetric heat transfer coefficient for different studied crops were ranged from (4312.321 to 8357.027 W/m^2.°K), (7586.445 to 13445.170 W/m^2.°K), (9936.227 to 16925.640 W/m^2.°K) and (9024.13 to

15816.44 W/m^2.ºK) for sunflower seeds, sunflower kernels, soybean seeds and canola seeds respectively.

Figs 9 and 10 show the effect of mass air flow rate and air temperature on the volumetric heat transfer coefficient for canola seeds.

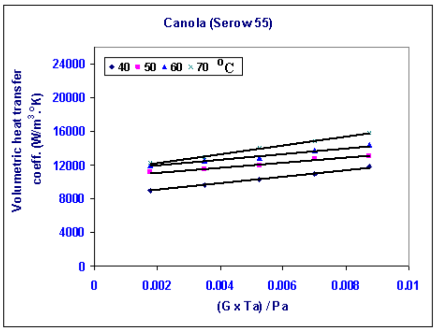

Fig (9): Effect of mass air flow rate on heat transfer coefficient of canola seeds at different levels of air temperature

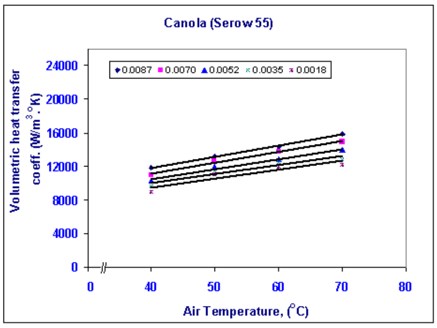

Fig (10): Effect of air temperature on heat transfer coefficient of canola seeds at different levels of mass air flow rate.

Similar trends were also noticed for sunflower seeds and kernels and soybean seeds.

A multiple regression analysis was then proceeded to describe the dependence of heat transfer coefficient on both mass air flow rate and air temperature. The regression equations for all the investigated crops could were as follow:

For sunflower seeds:

$$h_{cv} = 466.3718 + 80.46224\ (T_a) + 243473.5\ \left(\left[\frac{G\,.\,T_a}{P_{at}} \right] \right) \ldots\ldots\ (16)$$

(SE = 166.4916; R^2 = 0.978)

For sunflower kernels:

$$h_{cv} = 2330.109 + 105.1613\ (T_a) + 389168.3\ \left(\left[\frac{G\,.\,T_a}{P_{at}} \right] \right) \ldots\ldots\ (17)$$

(SE = 269.362; R^2 = 0.971)

For soybean seeds:

$$h_{cv} = 4050.77 + 118.8203\ (T_a) + 480587.1\ \left(\left[\frac{G\,.\,T_a}{P_{at}} \right] \right) \ldots\ldots\ (18)$$

(SE = 319.4468; R^2 = 0.970)

For canola seeds:

$$h_{cv} = 3244.142 + 125.3318\ (T_a) + 418276.8\ \left(\left[\frac{G\,.\,T_a}{P_{at}} \right] \right) \ldots\ldots\ (19)$$

(SE = 362.8587; R^2 = 0.959)

It should be also mentioned that these result is matching with those obtained by Matouk *et. al.,* (2006c) for rice, corn, wheat and barely**.**

CONCLUSION

1- The specific heat increased linearly with the increasing of both seeds moisture content and temperature for all studied crops. Also, the seeds moisture content has higher effect on seeds specific heat than that of seeds temperature. The recorded specific heat were ranged from (1.768 to 2.38 kJ/kg.°C), (2.325 to 2.797 kJ/kg.°C) and (2.419 to 3.11 kJ/kg.°C) for sunflower, soybean and canola seeds respectively. On the same time the specific heat for sunflower kernels, crushed soybean and crushed canola were ranged from (2.052 to 2.252 kJ/kg.ºC), (2.352 to 2.684 kJ/kg.ºC) and (2.433 to 2.551 kJ/kg.ºC) respectively.

2- Thermal conductivity was increased linearly with the increase of seeds moisture content for all studied crops. The determined values of thermal conductivity were ranged from (0.32721 to 0.437694 W/m.°C), (0.50092 to 0.05877 W/m.°C) and (0.5496 to 0.7422 W/m.°C) for sunflower, soybean and canola seeds respectively. Meanwhile, the measured values of thermal conductivity for sunflower kernels, crushed soybean and crushed canola were found to be 0.5009, 0.5496 and 0.6087 W/m.ºC, at moisture contents of 6.33, 9.52 and 7.11 % (w.b.) respectively.

3- The thermal diffusivity was increased with the increase of moisture content. While, it was decreased linearly with the increasing of seeds temperature for all studied crops. The recorded thermal diffusivity values were ranged from (0.36025 x 10^{-6} to 0.53686 x 10^{-6} m^2/s), (0.29974 x 10^{-6} to 0.42102 x 10^{-6} m^2/s) and (0.33275 x 10^{-6} to 0.41691 x 10^{-6} m^2/s) for sunflower, soybean and canola seeds respectively. While, it was ranged from (0.420401 x 10^{-6} to 0.461375 x 10^{-6} m^2/s), (0.509185 x 10^{-6} to 0.580905 x 10^{-6} m^2/s) and (0.535735 x 10^{-6} to 0.561722 x 10^{-6} m^2/s) for sunflower kernels, crushed soybean and crushed canola respectively.

4- The volumetric heat transfer coefficient was increased linearly as the air flow rate and air temperature increased. The measured values of the volumetric heat transfer coefficient were ranged from (4312.321 to 8357.027 $W/m^2.^{o}k$), (7586.445 to 13445.170 $W/m^2.^{o}k$), (9936.227 to 16925.640 $W/m^2.^{o}k$) and (9024.13 to 15816.44 $W/m^2.^{o}k$) for sunflower seeds, sunflower kernels, soybean seeds and canola seeds respectively.

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الخصائص الحرارية لبعض المحاصيل المنتجة للزيت

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تم تعيين الخصائص الحرارية المتمثلة في الحرارة النوعية ومعامل التوصيل الحراري ومعامل الانتشار الحراري ومعامل إنتقال الحرارة الحجمي لثلاثة من المحاصيل المنتجة للزيت وهي عباد الشمس صنف جيزة 102 وفول الصويا صنف جيزة 111 والكانولا صنف سرو 55 عند خمس مستويات مختلفة من المحتوى الرطوبي ودرجات الحرارة. ولقد أوضحت النتائج أن الحرارة النوعية للبذور المختلفة تعتمد على كل من المحتوى الرطوبي ودرجة حرارة البذور حيث زادت قيم الحرارة النوعية خطياً مع الزيادة في كل من المحتوى الرطوبي ودرجة الحرارة لمختلف المحاصيل التي تم دراستها كما أوضحت النتائج أيضاً أن التغير في المحتوى الرطوبي للبذور كان له التأثير الأعلى عنه في حالة تغير درجة حرارة البذور. أيضاً أوضحت النتائج أن قيم كل من معامل التوصيل الحراريزادت خطياً بينما زادت قيم معامل الانتشار الحراري تربيعياً للمحاصيل المختلفة بزيادة المحتوى الرطوبي للبذور بينما انخفضت قيم معامل الانتشار الحراري خطياً بزيادة درجة حرارة البذور. كما أظهرت النتائج أيضاً أن قيم معامل انتقال الحرارة الحجمي للبذور موضع الدراسة قد زادت خطياً بزيادة كل من معدل سريان الهواء ودرجة الحرارة.

أيضاً تم تطوير بعض العلاقات الرياضية والتي تصف طبيعة التغير في قيم الخصائص الحرارية المختلفة تبعاً للتغير في المحتوى الرطوبي ودرجات الحرارة ومعدلات سريان الهواء للمحاصيل موضع الدراسة.