Relationship between thermal properties of canola pods (without seed) with moisture content, porosity and chemical composition of pods

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Abstract: Thermal properties of canola pods including coefficients of thermal conductivity, thermal diffusivity and specific heat and chemical composition of rapeseed pods were measured at three levels of conventional canola varieties cultivated in the north of Iran (Hyola 50, Hyola 401 and Hyola 420) and in three times before harvest, while harvest and post-harvest. Then the relationship between the thermal properties of canola pods with chemicals, moisture and porosity were investigated. Conductivity coefficient was resulted from linear thermal method, the specific heat was obtained from mixing method and diffusion coefficients were calculated by the formula. The results showed that changes of variety and time of sampling were significant on thermal conductivity coefficient and diffusion coefficient at the probability level of 1%. Changes of variety at the level of 1% and time changes of sampling at the level of 5% were significant on specific heat. As well as the interaction between the variety and time was effective on conductivity coefficient and thermal diffusivity coefficient at 1% level. It was also observed between thermal properties and porosity, the relationship was significant at 5% level. As well as the relationship between the thermal properties and chemical composition was significant at 5% level.

Keywords: thermal conductivity, specific heat, thermal diffusivity, canola pod, chemical composition, porosity

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1 Introduction

Canola with the scientific name of Brassica napus (Brassica napus L.) is an annual plant of the Brassicaceae family of mustard (Crusiferae), firm bush shaped with limited branching and grows medium to tall height during the growing season and the length of growing period of canola in early cultivars and spring planting is recorded from 90 to 150 days and in autumn sowing is from 200 to 330 days. Cassia of canola pods are long and slender with the length of 5 to 10 cm, which is composed of two half-pod pods separated from each other by a thin membrane wall. The membrane wall will be torn when the cassia ripens. It is noteworthy that canola forage in terms of digestible protein has good quality (Khajehpour, 2007).

In order to find a suitable model to predict the thermal properties of various products, knowing the chemicals and their thermal properties also seems essential. At first, several studies in the field of thermal properties of various products will be discussed. Then the conducted researches about the relationship between the chemical compositions and thermal properties are listed.

Azadbakht et al. (2013) studied soybean pods' thermal properties in terms of yield moisture content and temperature. They calculated specific heat through mixture approach; further, thermal conductivity coefficient and thermal diffusivity were measured through transient heat transfer method and formula, respectively. Increased temperature and moisture caused specific heat

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increases from 1.856 to 4.39 kJ $kg^{-1}{}^{\circ}K^{-1}$ as well as thermal conductivity coefficient from 0.038 to 0.338 W $m^{-1}{}^{\circ}C^{-1}$; in addition, at all temperature levels, by higher moisture, thermal diffusivity reduced.

Other scholars studied the moisture dependence on thermal properties of peanut pod, shelled peanut, and the skin observed that increasing the moisture may increase specific heat and heat thermal conductivity coefficient and decrease thermal diffusivity. In this research, specific heat measured through a vacuum calorimeter through mixing with hot water; transient heat thermal conductivity coefficient weighed by line heat source method and thermal diffusivity coefficient was measured using formula method (Bitra et al., 2010).

In a study, thermal properties of Guna seed were investigated and it was observed that with temperature and moisture increasing, specific heat and thermal conductivity coefficient increased and thermal diffusivity coefficient reduced (Aviara et al., 2008).

In a study of borage seeds (Borage) thermal properties; thermal conductivity coefficient was determined by using linear heat source, specific heat was obtained by using (DSC) method and thermal diffusivity coefficient was calculated by using the formula (Yang et al., 2002).

Other researchers studied the specific heat, thermal conductivity coefficient and thermal diffusivity coefficient of coffee fruit and observed that the specific heat and thermal conductivity increased linearly with the increasing moisture and thermal diffusivity coefficient decreases with the increasing of moisture (Casanova et al., 2013).

Bart-Plange et al. (2012) studied the dependence of thermal properties of cashew seed on moisture content and observed that with increasing moisture, specific heat, thermal conductivity coefficient and thermal diffusivity coefficient increased linearly (Bart-Plange et al., 2012) .
Fricke and Becker (2001) in the assessment of food thermo-physical models have explored the thermo-physical models quantitatively, by comparing collected data from comprehensive studies.

Akintunda (2008) in a study modeled the thermal properties of food components. In this study, simple models were provided to predict changes in the transport properties (transport properties) of food ingredients such as fat, carbohydrate, ash, fiber and protein.

Onita and Ivan (2005) estimated the specific heat and thermal conductivity of food by using only the levels of compounds (water, protein, fat, carbohydrates, fiber and ash). In fact, they presented a simple way to calculate the specific heat and thermal conductivity of food by using the chemical composition of food.

The aim of this study is to determine the thermal conductivity coefficient, specific heat and thermal diffusivity coefficient of canola pods and also to determine the chemical structure of canola pod and the relationship between these two factors. Another goal of this study is to determine the relationship between thermal properties, moisture content and porosity of the sheath. The results are usable in thermal properties modeling and also prediction of the value of the properties.

2 Materials and methods

2.1 Sampling

Initially, three canola varieties of Hyola 420, Hyola 401, and Hyola 50 selected from the farms of Aliabad-e Katul, Golestan province. Sampling was performed at three times of pre-harvest, harvest, and post-harvest. The intervals between harvest periods were four days. Normal canola pods were carefully removed by scissors placed in plastic bags kept at 3˚C in the refrigerator (Azadbakht et al., 2013).

The pods were sent to the laboratory of Agricultural Sciences and Natural Resources University of Gorgan. The samples were placed in an oven at 105˚C for 24 hours (Azadbakht et al., 2013). Next, pods' moisture was determined according to wet-based standard method. In sampling, as the varieties were different, the moistures were different, too. The moisture level is presented in Table 1.

Table 1 Wet- based moisture (in %) of various pod varieties in sampling times

	Post harvest	Harvest	Before harvest
Hyola 50	6.7039106	15.1005	34.14634
Hyola 401	14.93213	23.97201	36.25934
Hyola 420	8.2758621	10.71636	15.98975

Thermal conductivity coefficient, specific heat and thermal diffusivity coefficient of three varieties of canola (Hyola 50, Hyola 401 and Hyola) sampled at three times (before harvest, during harvest and post-harvest) were determined. Then the composition of canola pods and its porosity were measured and the relationship between the thermal properties of canola pods and chemical composition, porosity and moisture were obtained.

2.2 Thermal conductivity

Crop thermal conductivity coefficient shows the thermal quantity in which if there is temperature difference at both ends of the material, it may be conducted by the material thickness (W m^{-1} $^{\circ}C^{-1}$).

Canola pod thermal conductivity measured by the line heat source method (Mohsenin, 1980; Bitra et al., 2010; Singh and Goswami, 2000; Shrivastava and Datta, 1999; Vozárová, 2005; Azadbakht et al., 2013; Yang et al., 2002; Bart-Plange et al., 2012). This is the most common transient method used in food and agricultural products, which is proper for measuring heat thermal conductivity of agricultural products' masses (Salari kia, 2012). Measuring thermal conductivity, whether non-isolated wire or using thermal conductivity probe, is based on a line heat source with infinitesimal diameter, infinite length, and constant longitude heat located in a homogenous cylinder. Equation (1) presents temperature increasing as follows:

$$\Delta T = \frac{Q}{4\pi K}\left[\ln(t) + \ln\left(\frac{4\alpha}{r^2 e^{0.5772}}\right)\right] \quad (1)$$

Where, ΔT is increased temperature at distance r from probe of line heat source (˚C). t is the time for, s, and Q is heating power per probe length, W/m; K shows heat thermal conductivity, W m^{-1} $^{\circ}C^{-1}$, α is the heat thermal diffusivity m^2/s, and r is the distance from line (m) central vector.

Equation (1) demonstrates temperature difference (ΔT) versus time normal logarithm (ln t) equals:

$$S = Q.(4\pi K)^{-1} \quad (2)$$

Heat thermal conductivity is:

$$k = \frac{Q}{4\pi}\frac{\Delta \ln(t)}{\Delta T} \quad (3)$$

As $Q=IR^2$, the relation (3) can be written as (4):

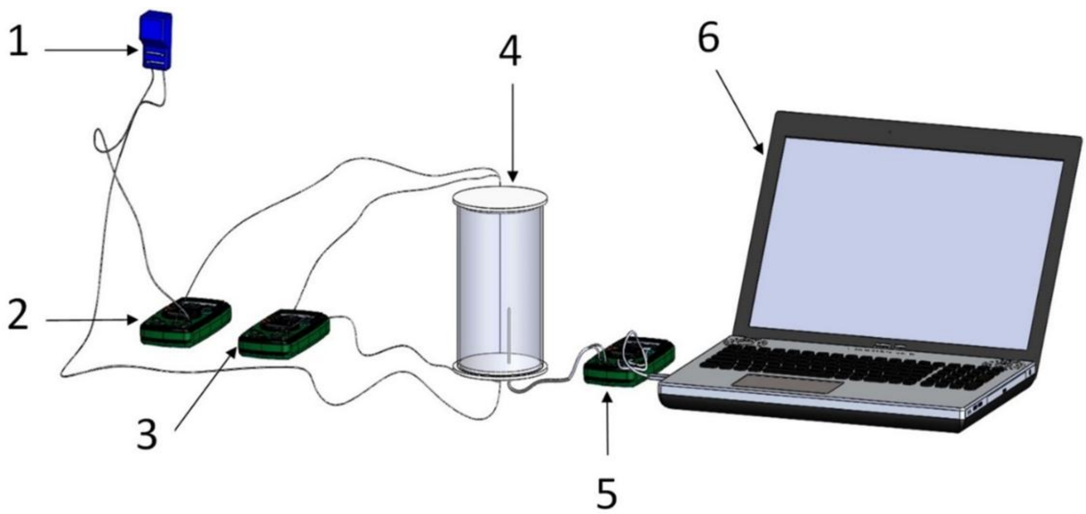
$$k = \frac{I^2 R}{4\pi s} \quad (4)$$

Where, R is thermal element electrical resistance per length, Ω/m;

I is the input current to heat source A.

The test transient heat transfer device (Figure 1) is constructed by a line heat source in PVC cylinder (height 300 nm and 110 mm diameter). The cylinder is enclosed by a 10 mm fiberglass at top and bottom. A Nichrome line, 0.127 mm in diameter, placed along the cylinder main vector connected to an adjustable D.C power source (500 mA, 1.5-12 V) (Bitra et al., 2010).

In order to measure the core line, a K-type thermocouple of STANDARD ST-941with the accuracy of 1˚C (made in China) applied, which was mounted on a base at a distance of 12 mm from heat line source. Within the test, it assumed the container temperature fixed (constant); therefore, a K-type thermocouple was embedded in the container outer surface representing temperature. Regarding data logger output recording temperature per second, the temperature value schematic chart was drawn in the time natural logarithm within the 600 seconds of the test. The slope and coefficient of determination (R^2) were measured for each sample. The heat thermal conductivity was determined using the charts in which R^2 value was larger than 0.990 (Azadbakht et al., 2013).



1-DC Power Supply, 2- Ammeter, 3-Voltmeter, 4-PVC Cylinder, 5-Thermometer, 6-Laptop

Figure 1 Line heat source device

2.3 Specific heat

The ratio of applied heat, Q, to the corresponding increased temperature, Δt, defined as the solid heat capacity. Indeed, it is mass specific heat referred as the solid heat capacity per solid mass unit (Mohsenin, 1980). Specific heat determined through using mixture method (Mohsenian 1980; Bitra et al., 2010; Ariara and Haque, 2001; Razavi and Taghizade, 2007; Shrivastava and Datta, 1999; Azadbakht et al., 2013; Bart-Plange et al., 2012).

In this method, the pod sample at given moisture and temperature placed in a calorimeter at a given specific heat including 200 g water at 100˚C. The canola pod specific heat calculated by the balance relation (Equation (5)) between the heat acquired or lost by water and calorimeter and the heat acquired or lost by the sample (Azadbakht, 2011).

$$C_s = \frac{C_w W_w (t_a - t_w) - C_c W_c (t_i - t_a)}{W_s (t_i - t_a)} \quad (5)$$

Where, C_s is the sample specific heat, kJ $kg^{-1}{}^\circ C^{-1}$; *Cw* is the water specific heat, kJ $kg^{-1}{}^\circ C^{-1}$; *Ww* water added mass, g, *Ta* the balance temperature, ˚C; Tw water initial temperature, ˚C; *Cc* is the calorimeter specific heat, kJ $kg^{-1}{}^\circ C^{-1}$; Wc is the calorimeter bucket mass, g; Ti sample initial temperature, ˚C; and Ww is the sample mass, g.

The accuracy of this method is based on this assumption that the heat lost is negligible. One way to meet this condition is to begin by calorimeter, which is a little colder than the peripheral. In this way, the heat acquired during the first test was compromised by the heat lost earlier (Mohsenin, 1980).

Determining calorimeter specific heat

Since the calorimeter container is made of a mixture of glass, metal, and insulated materials, its heat capacity was easily determined through experiment. To determine the calorimeter heat capacity (Hcal), some distilled water (m_c), was poured into the calorimeter; next, T_c temperature was recorded following some minutes once the water and calorimeter was balanced. Then, some distilled water at T_h temperature and m_h mass was added. T_c was recorded once the balance temperature was obtained. The calorimeter specific heat was attained by Equations (6) and (7).

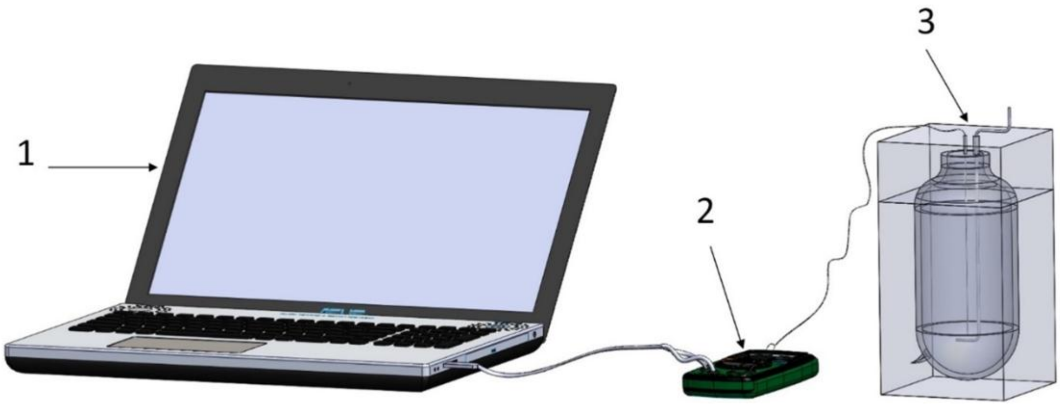
$$H_{cal} = \frac{m_h C_w (T_h - T_e) - m_c C_w (T_e - T_c)}{(T_e - T_c)} \quad (6)$$

$$m_{cal} C_{cal} = H_{cal} \quad (7)$$

It assumed an adiabatic system in which thermal loss is negligible at balance. C_w is the water specific heat within the given temperature range (Salari kia, 2012).

The calorimeter specific heat measured according to the aforementioned method in 5, which was 0.174 kJ $kg^{-1}{}^\circ C^{-1}$.

In order to measure canola pod specific heat at a constant pressure, the calorimeter as shown in Figure 2, first, was put in the refrigerator for cooling down. Therefore, the low lost heat is negligible. 200 g distilled water was boiled; then, was added to the calorimeter. Then, the temperature was measured and recorded. Next, 10 g of the sample was added to the calorimeter at a given temperature (room temperature). The mixture was allowed to thermally balanced. Then, finally, the pod specific heat was calculated using balance Equation (5).



1-Laptop, 2-Thermometer, 3-Calorimeter

Figure 2 Vacuum calorimeter

2.4 Thermal diffusivity

The pod thermal diffusivity obtained by Equation (8) (Ariara and Haque, 2001; Singh and Goswami, 2000; Azadbakht et al., 2013; Yang et al., 2002; Bart–Plange et al., 2012)

$$\alpha = \frac{K}{\rho C_p} \quad (8)$$

Where, α is the thermal diffusivity, m^2s^{-1}; K heat thermal conductivity, W m^{-1}°C^{-1}, ρ bulk density, Kg/m^3; C_p is the specific heat, J Kg^{-1}°C^{-1}.

To measure the density of cumulus, a cylinder with known mass and volume was filled with pods without a gap and then was weighed. With knowing the volume of a cylinder (diameter of 26.44 mm and height of 71.04 mm), the bulk density was obtained.

2.5 Chemical analysis of canola pods

Chemical analysis of samples was performed according to conventional methods and standards (Hosseini, 2007). These examinations were done in central laboratory of Agricultural Sciences and Natural Resources of Gorgan, Iran and laboratory of Agricultural Research Center of Golestan province.

2.5.1 Fat measurement by Soxhlet

About two grams of canola pods were weighed on a filter paper carefully and dried for three hours in an electric dryer. The contents of the paper were wrapped well in it, placed in the thimble in special pipe of fat extracting. Rounded bottom laboratory flask was dried and weighed carefully, and 100 mL of hexane was poured in it. After connecting to Soxhlet for six to eight hours it was heated lightly. After this period, hexane was evaporated and the flask was placed for 30 minutes in an oven at 100 ℃ and after cooling off, it was weighted and fat percentage was calculated by using Equation (9).

$$fat\ percentage = \frac{(falsk\ weight\ with\ fat - falsk\ weight\ without\ fat)}{gram\ weight\ of\ substance} \times 100 \quad (9)$$

2.5.2 Measuring of protein

Pods were weighed carefully and shed in a 500 mL flask. Catalyst tablet was added to the sample. Then the necessary amount of concentrated sulfuric acid was added to it. As a control sample, in one of the flasks all materials were poured. First, the flask was heated on a special machine gently and was rotated sometimes. After foaming subsided, heat was increased to boil solution well. The solution was cooled and diluted with a few milliliters of distilled water. Then it was transformed to the distiller. The digestion solution within the Keldal flask was poured into the distillation device through the funnel. Then sodium hydroxide solution was added to the digested solution by the funnel. By passing vapor from inside the machine, the distillation took 15 minutes. Condenser tube should be inside the boric acid solution. Flask containing distilled solution was lowered so that the condenser tube was located at top surface of the solution, and so the distillation was continued for two minutes. Then a solution of standard hydrochloric acid was titrated. Protein percent would be calculated through Equation (10):

$$protein\ percent = \frac{(\mathrm{CAVS} - \mathrm{CAVC}) \times acid\ normality \times 14 \times protein\ factor \times 100}{weight\ of\ sample \times 1000} \quad (10)$$

Where, CAVS= Consumed acid volume of a sample, CAVC= Consumed acid volume of control

2.5.3 Measurement of ash

Chinese crucibles were heated for half an hour in an electric furnace at a temperature of 500 ℃ and then cooled. In each Chinese crucible, about two grams of sample were weighed and burned on the flame. After all the smoke, the crucibles were placed in the furnace and changed to ash. Crucibles were cooled in a desiccator and after weighting the ash content was obtained of Equation (11):

$$ash\ percent = \frac{(crucible\ and\ ash\ weight - crucible\ weight) \times 100}{gram\ weight\ of\ sample} \quad (11)$$

2.5.4 Fiber measurement

Special containers for measuring fiber (Krosybl) were placed in a furnace for two hours at 400-500 ℃ and then were placed inside the oven by the laboratory tongs. After 20 minutes Krosybls were placed inside a desiccator to cool and then weighed. Krosybl containing sample was placed inside the fiber measurement device. Solution of the machine was put in special place, so that 1.25% wt solution of sulfuric acid was located in place of Reagent 1 and 1.25% wt sodium hydroxide was located in place of Reagent 2. Then 1.25 % wt sulfuric acid solution was put into the Krosybl and about one to two drops of Aktanol was added to the sample. And after boiling the solution in Krosybl, it was allowed to perform the acid digestion for 30 minutes. After acid digestion phase, by the drainage system, acid was removed from inside the Krvsybl and the samples were washed for three to four times with hot distilled water and distilled water was removed by the drainage system from Krosybl. 1.25 wt% solution of sodium hydroxide was added to the sample with a few drops of Aktanol and after boiling the solution inside the Krosybl, digestion was carried out for 30 minutes. After digestion step with Aktanol, by the drainage system, the Aktanol was removed from the Krosybl and sample was washed with hot distilled water for three to four times and hot distilled water was removed from the Krosybl by drainage system. Krosybls were removed from the device and put into the oven for 90 min at 130 ℃. Then the dishes were put in desiccator until they were cooled and then weighed (W1). In the next step Krosybls were placed inside the oven at 400-500 degrees for 4 hours and again dishes were weighed (W2). Percent of the fiber was obtained from Equation (12).

$$fiber\ percent = \frac{(W_1 - W_2) \times 100}{0.5 + \left(\frac{0.5 \times fat\ percent}{100}\right)} \quad (12)$$

It was obtained with the accumulation of moisture, fat, protein, fiber, ash and subtracting the obtained value from 100% amount of carbohydrate content.

2.6 Porosity

Each pod weight was measured by digital scale Kern with an accuracy of 0.01 g. Pan Balance method was used to determine the volume. Because the density of pods is less than water, pods were immersed in water with a thin wire. First the pod weight was determined (M1). Then the beakers weight with the water inside it was measured (M2). Then the weight of beakers was measured with pod and the water inside it (M3) and thus the volume was calculated according to the relationship of 13 and then particle density was computed with Equation (14) (water was at 25 ℃) (Ghajarjazi et al., 2015).

$$V = \frac{(M_3 - M_2)}{\rho_w} \quad (13)$$

$$\rho = \frac{M_1}{V} \quad (14)$$

To measure the density of substance a cylinder was filled with known mass and volume of pods without a gap among them and was weighed. With considering the volume of a cylinder (diameter of 26.44 mm and height of 71.04 mm), the bulk density was obtained (Ghajarjazi et al., 2015). Equation (15) was used to measure the porosity.

$$\epsilon = \frac{\rho_t - \rho_b}{\rho_t} \quad (15)$$

In Equation (15), (ρ_b) is bulk density and (ρ_t) is real density.

3 Results and discussion

3.1 Thermal conductivity coefficient

ANOVA table shows the effect of moisture, variety and the sampling time on the thermal properties (thermal conductivity coefficient, specific heat and thermal diffusivity coefficient are shown in Table 2).

Table 2 Analysis of variance of the Thermal properties of the canola pod (without grain)

Source of variation	Degrees of freedom	K	C	α
Moisture	1	0.18**	53.8**	3.76 ×10^{-12} **
Variety	2	0.002**	29.6**	4.64 ×10^{-12} **
Sampling Time	2	0.009**	0.44*	1.62 ×10^{-12} **
Variety × Time	3	0.001**	0.16 ns	1.39 ×10^{-12} **
Error	18	0.0001	0.095	1.39 ×10^{-13}

Note: ** Significant difference at 1% level (p <0.01), * Significant differences at 5% level (p <0.05), ns not significant

According to Table 2, moisture, number, time of sampling, as well as interaction among cultivars and sampling time at 1% probability had an impact on thermal conductivity coefficient. So tried to compare the average with LSD test and the results were recorded in Table 9.

As Table 3 shows; the maximum and minimum thermal conductivity are 0.36 and 0.112 (W m^{-1}°C^{-1}) and the Hyola 401 and Hyola 420 were respectively during the pre-harvest and post-harvest.

Table 3 Mutual effect of variety and sampling time on thermal conductivity

Sampling time	Variety		
	Hyola 50	Hyola 401	Hyola 420
Before harvest	0.34 aA	0.36 aA	0.26 bA
Harvest	0.204 aB	0.21 aB	0.12 bB
Post harvest	0.118 bC	0.18 aB	0.112 bB

Lowercase letters in each row, uppercase letters in each column represent no significant difference

As seen in Figure 3, Hyola 401 has the highest thermal conductivity coefficient and Hyola 420 has the lowest amount of thermal conductivity coefficient. The highest amount of thermal conductivity coefficient amount is before harvest and over time of sampling and reduction of the moisture content, thermal conductivity coefficient was reduced. The reason of moisture increasing with the increasing of thermal conductivity coefficient is that the thermal conductivity coefficient of water is higher than dry ingredients. This result is similar to most studies in this field. Bitra et al. (2010) in the investigation of the thermal conductivity coefficient of pods, seeds and thin shell of peanuts observed that with the increase of relative moisture, thermal conductivity coefficient of pod increased from 0.12 to 0.16, thermal conductivity coefficient of seeds increased from 0.15 to 0.19 and thermal conductivity coefficient of shell increased from 0.11 to 0.18 W m^{-1}°C^{-1}. Singh and Goswami (2000) in the study of thermal properties of cumin observed that with increasing moisture the thermal conductivity coefficient increased from 0.046 to 0.223 W m^{-1}°C^{-1}. SalariKia (2012) in the study of thermal properties of pistachio observed that with an increase in moisture, thermal conductivity range increased from 0.0166 to 0.0639 W m^{-1}°C^{-1}. Azadbakht et al. (2013) in the study of thermal properties of soybean pods observed that with an increase in moisture, thermal conductivity coefficient increased from 0.038 to 0.338 W m^{-1}°C^{-1}.

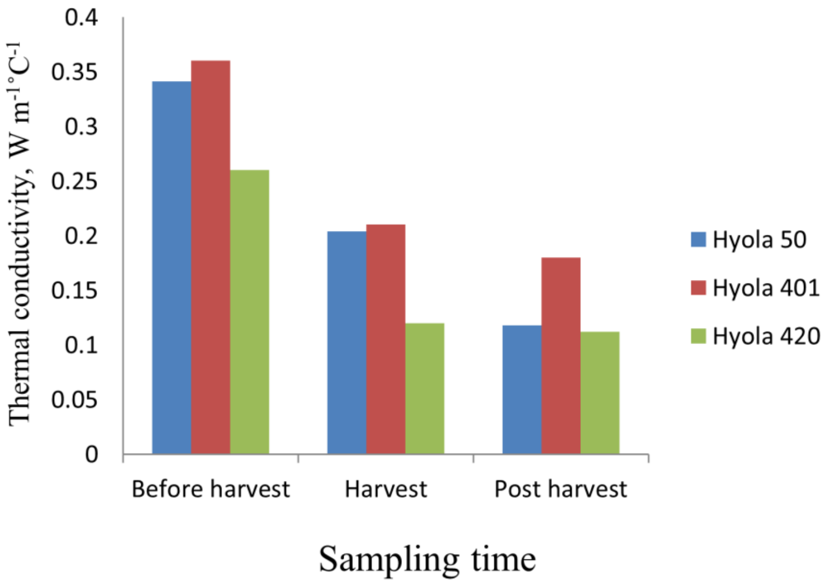


Figure 3 Mutual effect of varieties and sampling time on thermal conductivity

3.2 Specific heat

As seen in Table 2, moisture changes and variety of canola are effective at 1% on specific heat and sampling time changes were effective on the specific heat at 5% probability level. The interaction between cultivars and time had no significant effect on specific heat of canola empty pods.

According to Figure 4 Hyola 50 significantly had the most specific heat value than any other varieties and Hyola 420 had the minimum specific heat. Hyola 50 specific heat value kJ kg^{-1}°C^{-1} is 5.225, Hyola 401 is 2.618 kJ kg^{-1}°C^{-1} and Hyola 420 is 1.957 kJ kg^{-1}°C^{-1}.

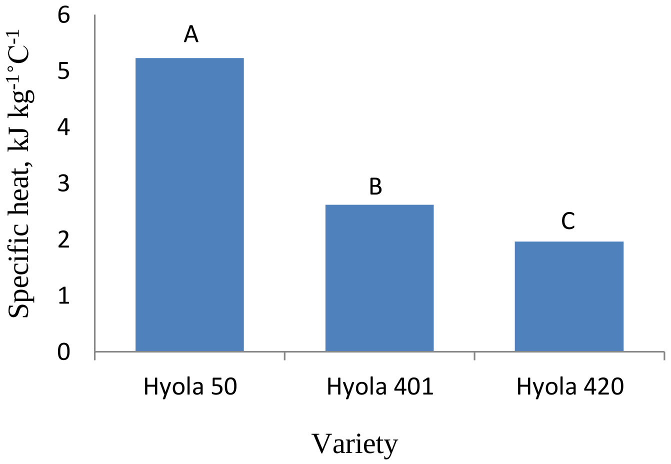


Figure 4 Effect of variety on specific heat

As shown in Figure 5 in the time before harvest, pods have the highest amount of specific heat that this amount was reduced over time by reduction of moisture content. Specific heat amount of time before harvest was 5.18 kJ kg^{-1}°C^{-1}, at harvest time was 2.85 kJ kg^{-1}°C^{-1} and during postharvest times was 1.76 kJ kg^{-1}°C^{-1}, respectively.

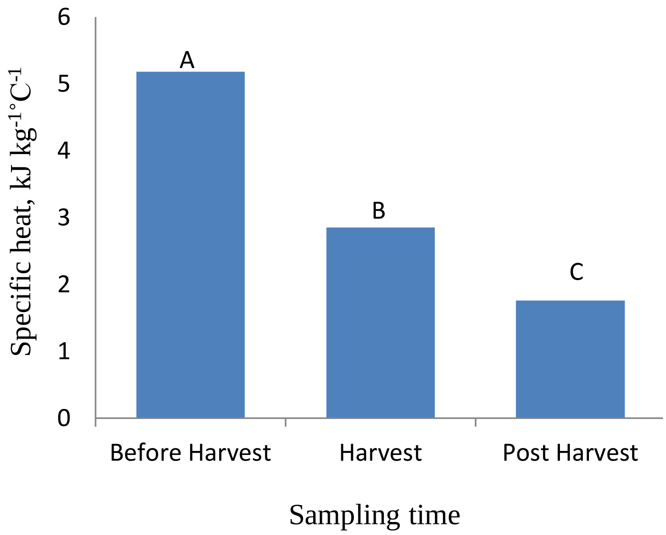


Figure 5 Effect of sampling time on specific heat

Bitra et al. (2010) in the study of specific heat of pod, seed and thin shell of peanuts observed that with increasing moisture, specific heat of pod increased from 2.1 to 3.3 (kJ kg^{-1}°C^{-1}) and specific heat of seed increased from 1.9 to 2.8 (kJ kg^{-1}°C^{-1}) and specific heat of skin increased from 2.7 to 4.1 kJ kg^{-1}°C^{-1}. Singh and Goswami (2000) in the study of thermal properties of cumin observed that the specific heat with moisture increase, increased from 1330 to 3090 J kg^{-1}°C^{-1}. Razavi and Taghizadeh (2007) in the review of pistachio specific heat observed that with increasing moisture, specific heat of all the digits increased in the range of 0.419 to 2.930 kJ kg^{-1}°C^{-1}. SalariKia (2012) in their study about thermal properties of pistachio observed that with increasing moisture, specific heat increased in the range of 0.0811 to 3.230 kJ kg^{-1}°C^{-1}. Azadbakht et al. (2013) investigated the thermal properties of soybean pods and observed that with increasing moisture, specific heat increased from 1.856 to 4.39 kJ kg^{-1}°C^{-1}. Casanova et al. (2013) investigated the thermal properties of coffee and observed that with the increasing of moisture, specific heat increased from 1.431 to 3.615 kJ kg^{-1} °K^{-1} for unripe fruit.

3.3 Thermal diffusivity

As Table 2 shows changes in moisture, variety, time of sampling as well as interaction between cultivars and sampling time at 1% probability level are effective on the thermal diffusivity coefficient. So the averages were compared through LSD test and the results are shown in Table 4.

According to Table 4, the highest and lowest coefficient of thermal diffusion 2.993×10^{-6} m^2/s and 2.996 × 10^{-7} m^2/s were related to Hyola 401 and Hyola 50 at the time after harvest and time before harvest respectively.

Table 4 Mutual effect of variety and sampling time on thermal diffusivity

Sampling time	Variety		
	Hyola 50	Hyola 401	Hyola 420
Before Harvest	2.996 ×10^{-7} aA	4.66 ×10^{-7} aB	8.82 ×10^{-7} aB
Harvest	4.126 ×10^{-7} bA	1.21 ×10^{-6} abB	1.46 ×10^{-6} aAB
Post Harvest	4.98 ×10^{-7} bA	2.993 ×10^{-6} aA	2.19 ×10^{-6} aA

Lowercase letters in each row, uppercase letters in each column represent no significant difference

As shown in Figure 6 the thermal diffusivity coefficient had the lowest amount before harvest. Thermal diffusivity coefficient increased with time and moisture loss in all varieties. Thermal diffusivity coefficient changes in cultivars were affected by the density changes. Aviara et al. (2008) in their study about guna seed observed that with the increase in moisture, thermal diffusivity coefficient reduced from 9.31 ×10^{-8} to 8.5× 10^{-8}. Casanova et al. (2013) investigated the thermal properties of coffee and have seen with an increase in moisture, thermal diffusivity coefficient was reduced from 1.671×10^{-7} to 1.044 × 10^{-7} m^2/s. Also Azadbakht et al. (2013) investigated the thermal properties of soybean pods, Aviara and Haque (2001) in the study of sheanut thermal properties, Darvishi et al. (2011) in search of seeds thermal properties and Aghbashlo et al. (2008) in determining the thermal properties of barberry reached to the similar conclusions.

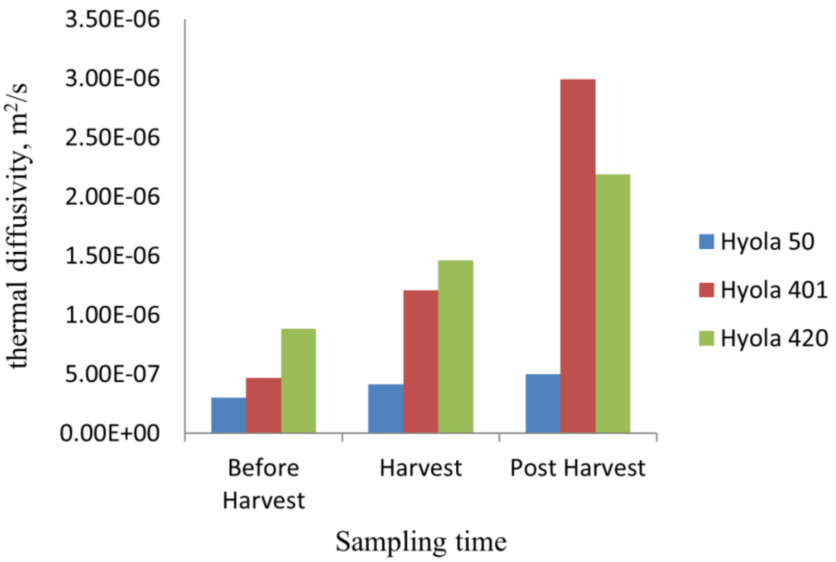


Figure 6 Mutual effect of varieties and sampling time on thermal diffusivity

3.4 The relationship between the thermal properties and moisture in pod

To study the relationship between variables, and especially to understand how two variables are dependent these relationships were used. Thus, as shown in Table 5, the interaction effect of moisture and thermal properties was studied and relationships for each of the different cultivars of canola pods come separately. Due to this relationship by measuring the moisture content of each canola its thermal properties will be gained. These relationships were obtained from Figures 7, 8 and 9.

Table 5 Relationships related to thermal properties calculation of canola pod (without grain) in different variety

Variety	K	R^2	C	R^2	α	R^2
Hyola 50	$K = -0.0002M^2 + 0.0118M + 0.1229$	1	$C = 0.0883M + 4.2897$	1	$\alpha = -7\times10^{-9}M + 5\times10^{-7}$	0.994
Hyola 401	$K = 0.0043M + 0.14$	0.995	$C = -0.0042M^2 + 0.2729x - 1.3616$	1	$\alpha = -5\times10^{-8}M + 3\times10^{-6}$	0.985
Hyola 420	$K= 0.008M + 0.1032$	0.999	$C = -0.0252M^2 + 0.7547M - 2.7746$	1	$\alpha = -5\times10^{-8}x + 2\times10^{-6}$	0.954

Note: C= Specific heat of soybean pod (kJ.kg^{-1} ℃$^{-1}$), K= Thermal conductivity of soybean pod (W.m^{-1} C^{-1}), α =Thermal diffusivity of soybean pod (m^{2}s^{-1})

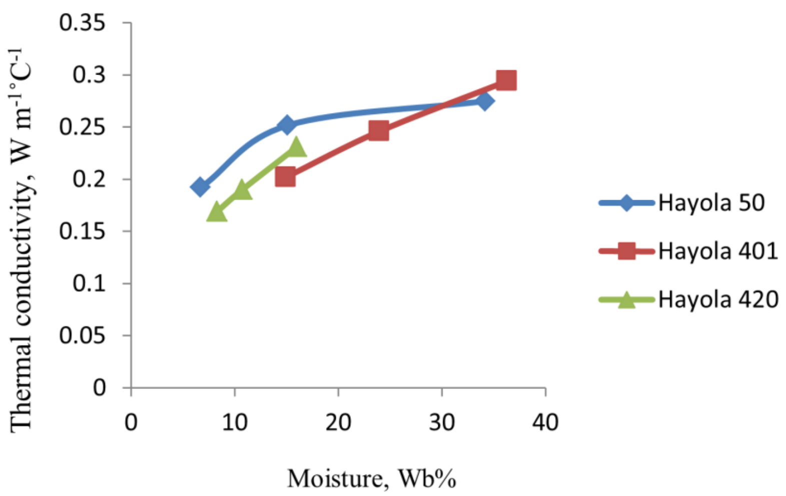


Figure 7 Thermal conductivity on different varieties and moisture

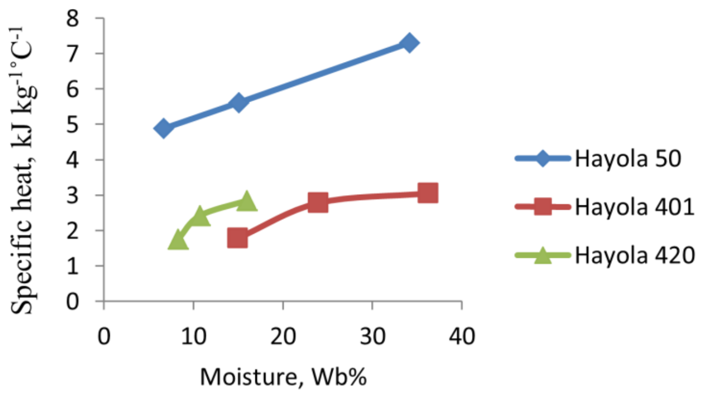


Figure 8 Specific heat on different varieties and moisture

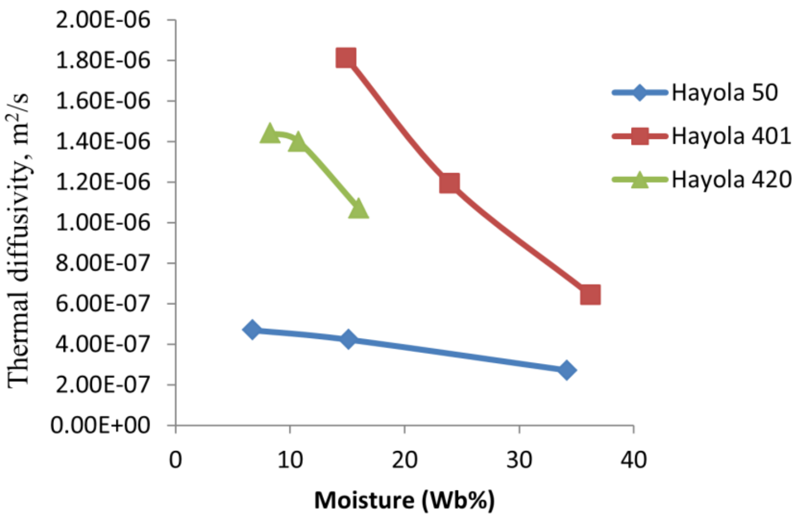


Figure 9 Thermal diffusivity on different varieties and moisture

3.5 The relationship between porosity and thermal properties of pod

The pores percent of a porous solid material is often required in the study of heat transfer. Thus the relationship between canola pod porosity and thermal properties was investigated through regression equation and the results were expressed as mathematical equations. Thus, having a porosity of the pod its thermal properties can be predicted.

According to Table 6 porosity at 5% level was related with a coefficient of thermal conductivity, specific heat and thermal diffusivity. Also it is shown that the porosity with coefficient of 0.00153 related directly to the thermal conductivity coefficient. It means that with the specified ratio by increasing the porosity, coefficient of thermal conductivity increases. The reason is that with the increase in moisture, porosity increases (Paksoy and Aydin, 2006). And the coefficient of thermal conductivity increases with the increasing of moisture.

Table 6 Analysis of regression of grain loss and thermal conductivity

Variable	Degree of freedom	Thermal conductivity	Specific heat	Thermal diffusivity
Porosity	1	0.00153*	0.00761*	-8.46×10^{-7}*
Intercept	1	0.153**	3.233*	1.01×10^{-6}*

Note: ** Significant difference at 1% level (p <0.01), * Significant differences at 5% level (p <0.05), ns not significant

According to Table 6 and according to the coefficients, between the porosity (ε) and the coefficient of thermal conductivity Equation (9) is established:

$$K = 0.153 + 0.00153\,\varepsilon \qquad (16)$$

As shown in Figure 10 by increasing the porosity, coefficient of thermal conductivity is increased. When the porosity is high, the moisture is high. Therefore with an increase in moisture, thermal conductivity is increased.

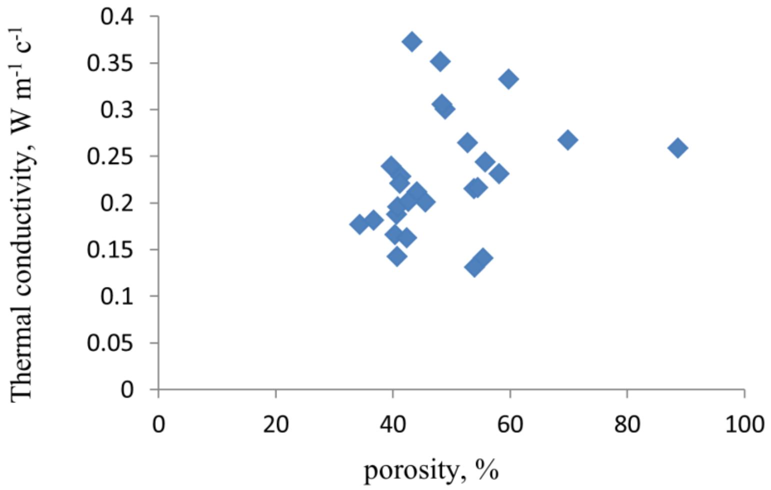


Figure 10 Thermal conductivity on different porosity

According to Table 6 the porosity ratio with coefficient of 0.00761 is directly related to the specific heat. It means that at a specified ratio by an increase of porosity, specific heat increases. The reason is that with the increase in moisture, porosity increases (Paksoy and Aydin, 2006). And with the increasing of specific heat, moisture increases.

$$C = 3.233 + 0.00761\,\varepsilon \qquad (17)$$

As shown in Figure 11, by increase in porosity, specific heat increased and this is because of an increase in moisture in high porosity.

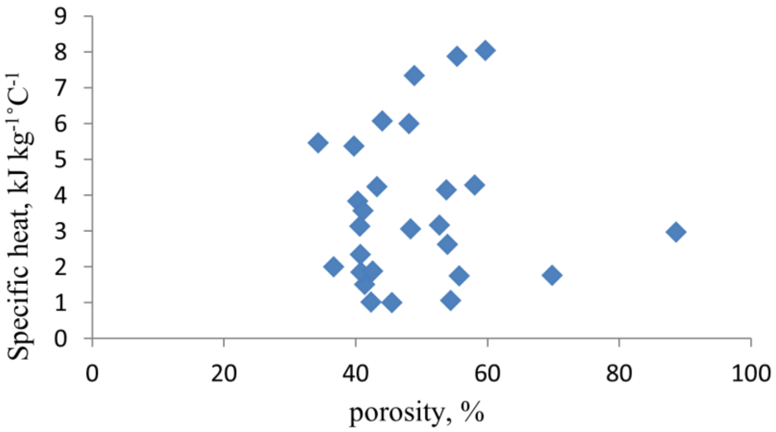


Figure 11 Specific heat on different porosity

Also, as shown in Table 6 the porosity by a factor of 8.46×10^{-7} is inversely related to the thermal diffusion coefficient. It means that at the specific ratio with the increasing of porosity, diffusion coefficient decreases. The reason is that with the increase in moisture, porosity increases (Paksoy and Aydin, 2006). And thermal diffusivity decreases with increasing moisture.

$$\alpha = (1.01 \times 10^{-6}) - (8.46 \times 10^{-7})\varepsilon \qquad (18)$$

As shown in Figure 12, with increasing porosity, thermal diffusivity coefficient decreased.

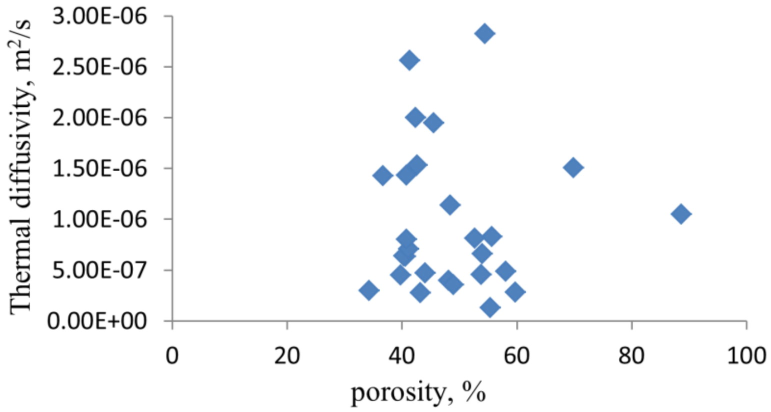


Figure 12 Thermal diffusivity on different porosity

3.6 Chemical analysis of canola pod

Chemical analysis of canola pods results are shown in Table 7. As can be seen between the different varieties of canola there are too many differences in chemical composition. These differences cause the differences in thermal properties of cultivars. The impact of each material on the properties is different and depends on the properties of the same composition and its weight percent.

As can be seen in Table 7, Hyola 50 contains the greatest amount of fat, protein and fiber. Hyola 401 contains the highest amount of moisture, and the least amount of fat, protein, ash and carbohydrates. Hyola 420 contained the highest amounts of ash and carbohydrates and had the lowest amount of fiber and moisture content.

Table 7 Chemical analysis of canola pods

Variety	Moisture, %	fat, %	Protein, %	Fiber, %	Ash, %	Carbohydrate, %
Hyola 50	15.1	8.898	1.97	39.9	8.51	25.622
Hyola 401	23.97	6.12	0.762	38.36	7.26	23.528
Hyola 420	10.71	7.949	1.686	36.23	9.65	33.775

As it was observed in the conductivity coefficient results the conductivity coefficient of Hyola 401 has been more than two digits. According to Table 7, Hyola 401 had the maximum amount of moisture. The coefficient of thermal conductivity can be increased by increasing the moisture content. Choi and Okos (1986) presented some relationships for the coefficient of thermal conductivity and according to them conductivity coefficient of carbohydrates and ash after the moisture are at a higher level than the other compounds. So we can say that the coefficient of thermal conductivity is under the influence of moisture and the more amounts of carbohydrates and ash could not overcome the effects of moisture.

In the study of the specific heat it was observed that Hyola 50 had the highest amount and the Hyola 420 had the lowest amount. In the study it was observed that the specific heat of compounds, it was observed that after moisture, protein, fat and fiber had the highest specific heat values respectively (Choi and Okos, 1986). According to Table 7 protein, fat and fiber in Hyola 50 were more than the amounts observed in Hyola 401 and in contrast the moisture content was less. Given the specific heat values, it can be said that the amounts of protein, fat and fiber were more effective than water. Due to the low water content and fiber, Hyola 420 had the least amount of specific heat.

In the study of the thermal diffusivity coefficient, it can be seen that its amount in Hyola 420 was more than Hyola 50. According to Table 7 major difference can be seen in the amount of carbohydrate between these two varieties. Given the amount of specific heat of carbohydrate, it can be said that the difference in thermal diffusivity was the effect of carbohydrate.

With the review of the regression relationship between thermal properties and the amount of chemical compounds weight of canola pods in different varieties and times Table 8 was obtained. Table 8 shows the regression coefficients of thermal properties of canola pods and its chemical structure. According to Table 8 the coefficient of thermal conductivity shown in the table, was directly proportional to moisture, fat, protein and carbohydrates and also it was inversely proportional to ash. Specific heat of canola pods was directly proportional to moisture, fat and carbohydrates and also it was inversely proportional to protein, fiber and ash. Thermal diffusivity coefficient was directly proportional to fiber and ash and inversely proportional to the moisture, fat, protein and carbohydrates.

Table 8 Analysis of regression of thermal properties and chemical compositions

Variable	**Degree of free**	K	C	α
Intercept	1	-16.47903**	17.02981*	1.3548×10^{-4} **
Moisture	1	0.14711*	0.70089*	-3.31×10^{-6} *
Fat	1	0.18779*	3.69175*	-5.05×10^{-6} *
Protein	1	0.09693*	-0.40155*	-1.373×10^{-5} *
Fiber	1	0.22385*	-1.21247*	4.59496×10^{-7} *
Ash	1	-0.18503*	-0.71869*	6.79×10^{-6} *
Carbohydrate	1	0.20855*	0.00705*	-3.45×10^{-6} *

Note: ** Significant difference at 1% level (p <0.01), * Significant differences at 5% level (p <0.05)

According to the table between the regression coefficients of thermal properties and chemical composition of pod, Equations (14), (15) and (16) are established. Thus, by knowing the chemical composition of canola pod and by using empirical Equations (19), (20) and (21) thermal properties can be predicted. Thermal properties of agricultural products are a function of temperature and the temperature amount has a huge impact on the thermal properties. Equations are presented to predict the thermal properties of canola pods at 25 ℃.

$$K=-16.47903+0.14711\,X_w+0.18779\,X_f+0.09693\,X_p+0.22385\,X_{fi}+0.20885\,X_c-0.18503X_a \quad (19)$$

$$C=17.02981+0.70089\,X_w+3.69175\,X_f-0.40155\,X_p-1.21247\,X_{fi}+0.00705\,X_c-0.71869X_a \quad (20)$$

$$\alpha=1.3548\times10^{-4}-(3.31\times10^{-6})X_w-(5.05\times10^{-6})X_f-(1.373\times10^{-5})X_p+(4.59496\times10^{-7})X_{fi}-(3.45\times10^{-6})X_c+(6.79\times10^{-6})X_a \quad (21)$$

Where, *Xw*, *Xf*, *Xp*, *Xfi*, *Xc*, and *Xa*, are respectively the weight percent of moisture content, fat, protein, fiber, carbohydrates and ash.

4 Conclusions

The thermal conductivity coefficient range was from 0.112 to 0.37 W m^{-1} °C^{-1}. Hyola 401 and Hyola 420 had the highest and lowest thermal conductivity coefficient, respectively. And in the time before harvest, this index was the highest. In fact Hyola 401 in the time before harvest due to high levels of moisture content for heat transfer had more conductivity.

Range of specific heat of canola pods was from 1.76 to 5.225 kJ kg^{-1} °C^{-1}. Hyola 50 and Hyola 420 had the highest and lowest specific heat. During the pre-harvest and post- harvest the most and least amount of specific heat was observed.

Range of thermal diffusivity of canola pods was from 2.996×10^{-7} m^2/s to m^2/s 2.993×10^{-6}. Hyola 401 and Hyola 50 had the largest and least amount of thermal diffusivity respectively. After harvest the most and before harvest time the lowest amounts were observed.

In study of moisture, thermal properties and porosity, it was observed that with increasing of moisture and the porosity, conductivity coefficient and specific heat and diffusion coefficient were reduced.

In the study of the relationship between thermal properties and chemical composition it was observed that the specific heat was directly proportional to the coefficient of thermal conductivity, moisture, fat, protein, fiber and carbohydrates and was inversely proportional to ashes. Special heat was directly proportional to moisture, fat and carbohydrates and was inversely proportional to protein, fiber and ash. Thermal diffusion coefficient was directly proportional to fiber and ash and inversely proportional to the moisture, fat, protein and carbohydrates.

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