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Moisture content modelling of thermal properties of persimmon (cv. 'Kaki')

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Abstract

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Persimmon is one of the tasty and sweet fruits with short shelf life. Thermal conductivity, thermal diffusivity and specific heat are necessary for storage, drying, packaging and designing of distillation machines. In this research, thermal conductivity and thermal diffusivity of persimmon were calculated using the line-heat source probe and Dickerson method. The experiments were conducted at four temperature levels of 40, 50, 60 and 70°C, and four moisture content levels of 37.77, 56.49, 70.47 and 88.42 (%, w.b). Results showed that the thermal conductivity of persimmon was improved by increasing temperature and moisture content of the samples. The effects of moisture content and temperature on thermal properties were highly significant. Regression equations were established which can be used to estimate thermal property values at different moisture content levels.

Keywords: thermal conductivity; thermal diffusivity; specific heat; line heat source

Persimmon is one of the tropical and subtropical fruits with monocotyledons. Fruit production and proliferation occurs via parthenogenesis and fertilization. Persimmon was grown in the nineteenth century in Europe (Liu et al. 2007). Today the fruit is cultivated not only in Japan and Vietnam but also is planted in Brazil, Iran, Lebanon, Spain, Italy, Tunisia and Algeria. There are about 3,000 different varieties of this fruit. The fruit shape is generally round and cordite. 'Fu kaki' (Fuy-Kaki) is known as a popular species of persimmon in Iran which has a rather large round fruit and is considered the most desirable variety of persimmon in terms of taste (Hazbavi 2010).

Specific heat capacity, thermal conductivity and thermal diffusivity are the main parameters of agricultural products for maintenance, production, drying, cooling, pasteurization and many thermal processes. These parameters are used in engineering and design of agricultural machines, which include thermal processes (Samimi Akhijahani, Khodaei 2013).

In physics, thermal conductivity (k) is property of an object that represents the ability of the object in heat transfer. This coefficient appears in the Fourier law. The SI unit of thermal conductivity is W/°C. Thermal conductivity coefficient, which is achieved by transient heat transfer in the laboratory, is applied in the control of processing machines (Mohsenin 1980).

Thermal diffusivity of heat transfer is a measure that represents the ability of a material to conduct heat compared with the ability of the same material in storage of thermal energy (Nalaini 2005).

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The quantity of heat penetration coefficient is expressed by the rate of heat passing through to the heat stored by the unit volume of material, and it is indicated by the symbol of α. Dickerson, the stationary and rotating Shrardayzyng methods are used to determine this coefficient directly (Reidy, Rippen 1971).

Specific heat capacity or heat capacity is the amount of heat which is required to raise the temperature of one degree of Celsius per kilogram (Mohsenin 1980). This factor is one of the useful properties of the construction and design of heating or food processing devices. When mass is considered as a base unit of a substance, *C* is considered as a symbol for heat capacity. Therefore, the SI unit of mass in engineering applications is expressed in kilogram (J/kg °C). Combination of calorimetric and differential thermal calorimetric methods can be utilized to obtain the coefficients experimentally.

Thermal conductivity of biological materials and food increases with increase in moisture content and density (Muramatsu et al. 2006; Opoku et al. 2006; Aviara et al. 2008; Perusella et al. 2010).

Specific heat and thermal conductivity coefficient of two varieties of date ('Khudary' and 'Sufri') was investigated in the temperature levels of 50 and 70°C and moisture contents of 18.31% to 62.52% for the 'Khudary' variety and 16.72% to 71.70% for the 'Sufri' variety. The result showed that specific heat and thermal conductivity coefficient of the 'Sufri' variety was greater than the date palm in given temperature and moisture levels (Hobani, Al-Askar 2000). Specific heat and thermal conductivity coefficient of barberry was studied under moisture content levels of 5.3, 4.19, 4.38 and 74.55% (d.b.) and temperature levels of 50 and 70°C. The results of experiments indicated that the specific heat of barberry varied within the range of 1.9653 to 3.2911 kJ/kg °C. The variation range of thermal conductivity coefficient was 0.1324 to 0.4898 kJ/ kg °C (Aghbashlo et al. 2008).

In order to design equipment and facilities for drying, preservation and processing of persimmon fruit for making industrial products such as jelly, candy, pastilles and coloured edible powder as well dried form of persimmon, it is necessary to consider the thermal conductivity, thermal diffusivity and specific heat. The information concerning specific heat, thermal diffusivity and thermal conductivity of persimmon fruit has not been published so far. Therefore, the objectives of this study were to determine thermal conductivity, thermal diffusivity and the specific heat of persimmon as well as to develop mathematical models for prediction of these thermal properties of persimmon fruit as a function of moisture content and temperature.

MATERIAL AND METHODS

Fresh persimmon samples ('Fuy-Kaki' cultivar) were randomly taken from the Karaj gardens, Iran. About 30 kg of samples were used in the experiments. They were placed in plastic bags and kept in refrigerator at a temperature of 4°C. In order to provide uniform mixture for tests, all the completely repined samples were mixed by household blender. Afterward, 20 g samples were dried in an oven at the temperature of 65°C for 24 h (Hazbavi, Minaei 2010). Moisture content of the obtained uniform mixture was 85.17 ± 0.02% wet basis. To prepare the mixture for thermal tests, mixed samples were placed in plastic bags and left in the refrigerator at a temperature of 4°C.

To achieve other moisture content levels, the samples were left exposed to the air. Moisture content levels of 70.47, 56.49, and 37.77% wet basis were thus achieved. The moisture content was calculated as follows (AOAC 1980):

$$M_c = \frac{w_0 - w_s}{w_0} \qquad (1)$$

where: M_c – moisture content (dimensionless); w_0 – initial weight (kg); w_s – dry weight (kg)

Moisture content and temperature levels which were used in this investigation are presented in Table 1. Moisture content and temperature levels are considered according to previous studies which

Table 1. Moisture content and temperature levels were utilized in this study

	1	2	3	4
Temperature (°C)	40	50	60	70
Moisture content (%, w.b)	37.77	56.49	70.47	85.17

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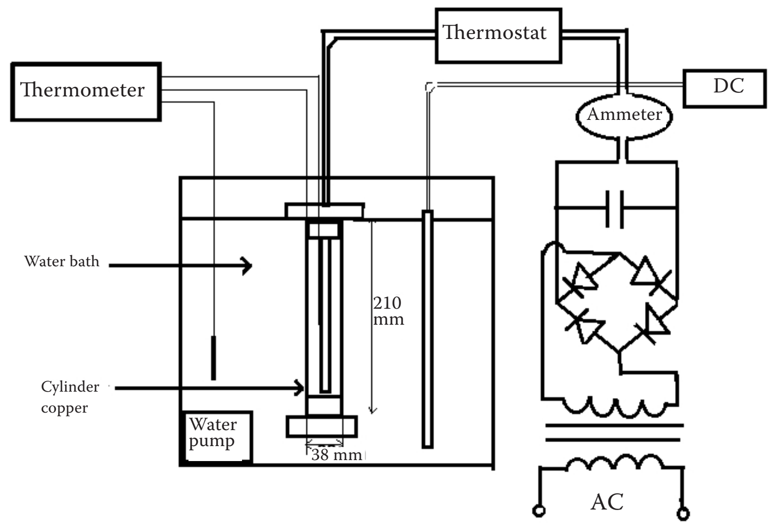

Fig. 1. A schematic diagram of an instrument used to obtain thermal conductivity coefficient (DC)

were carried out for fruits with initial moisture content of more than 80% (w.b.) (Aghbashlo 2008).

Bulk density is defined as mass per unit of volume of material. In this study, to measure the compactness of samples, a scaled beaker with the capacity of 50 ml was used. Specific volume of uniform mixture of persimmon was poured in the beaker and after carefully weighing by a scale with accuracy of 0.001 g, density was calculated using the following equation (Zewdu, Solomon 2007):

$$\rho = \frac{m}{v} \tag{2}$$

where: ρ – density (kg/m^3); m – mass of substance (kg); v – volume of substance (m^3)

To obtain the thermal conductivity coefficient, transient heat transfer method was applied. In this method, temperature difference between the core and shell materials caused heat transfer from the centre to the shell of material (Rao et al. 2005). Fig. 1 shows a schematic diagram of an instrument used to obtain thermal conductivity coefficient of mixed persimmon samples. As shown, a cartridge element was utilized as a heat source; it had a copper cylinder, equipped with a fireproof Teflon bonnet. After filling of cylinder with mixed persimmon, it was placed in a uniform temperature water bath to reach equilibrium condition. Afterwards, the electrical circuit was established and the temperature of the body and centre of cylinder were measured using two types of k thermocouples. A thermometer (Lutron TM-947SD, Taiwan) and a thermostat (Atbin Mega, Iran) were used to record the measured temperature values and to keep in the selected temperature, respectively. The ratio of

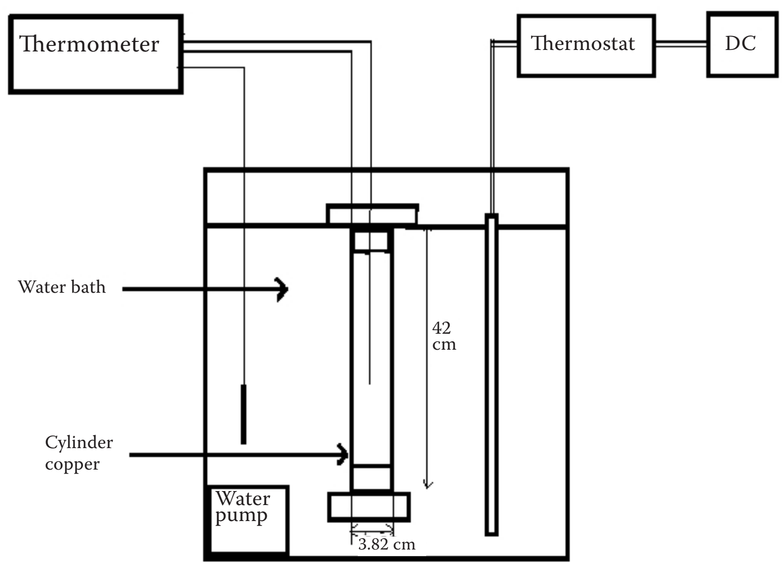

Fig. 2. A schematic diagram of approach used to measure the thermal diffusivity coefficient (DC)

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cylinder height to its diameter was considered big enough to include the radiant heat transfer. Thermal conductivity of the prepared samples was calculated as follows (Bart-Plang et al. 2012b):

$$k = \frac{Q}{4\pi(T_2 - T_1)} \ln \frac{t_2}{t_1} \quad (3)$$

where: k – thermal conductivity (W/m °C); $Q= I \times R^2$; I – the flow through the element (A); R – the element resistance (Ω); T_1, T_2 – initial and final temperature (°C); t_1, t_2 – time (s)

The thermal conductivity values of persimmon samples were determined by calculating the slopes of plotted curves of temperature changes against time ratio on a semi-logarithm graph. The experiment was replicated three times at each moisture content, temperature and moisture content level and the average value of thermal conductivity was calculated in each case.

To compute the thermal diffusivity coefficient, Dickerson method, as a useful and also convenient method, was applied in this research. To measure the coefficient, a cooper cylinder with Teflon cap was made with a height of 40 cm. After filling the cylinder with mixed persimmon, it was left in the oven at 40°C for an hour to achieve equilibrium condition. Two k-type sensors on the body and the centre of the cylinder body recorded the changes in temperature by connection to a thermometer of Lutron TM-947SD (Fig. 2). To transfer the heat from the surface to the sample centre, water with temperature of 70°C was utilized. Effective thermal diffusivity (α) was obtained from Eq. (5) as follows (Hobani, Al-Askar 2000):

$$\alpha = \frac{A_0 \times a^2}{4 \times (T_a - T_0)} \quad (5)$$

where: α – radius of the tank (m); T_a – temperature at a distance of centre of the tank (°C); T_0 –temperature in the centre of the tank (°C); A_0 – constant calculated as follow:

$$A_0 = \frac{T_{a2} - T_{a1}}{t_2 - t_1} \quad (6)$$

where: T_{a1} – temperature at time t_1 (°C); T_{a2} – temperature at the time t_2 (°C)

Specific heat of mixed persimmon samples was obtained using experimental data of thermal conductivity, thermal diffusivity and density according to the Eq. (7) (Hobani, Tolba 1995):

$$C = \frac{k}{\rho \times \alpha} \quad (7)$$

where: C – specific heat (J/kg °C); k – the thermal conductivity (J/kg °C), α – thermal diffusivity (m^2/s); ρ – bulk density (kg/m^3)

RESULTS AND DISCUSSION

Density

The plot of density of the mixed persimmon samples versus moisture content was presented in Fig. 3. As shown, density of samples decreased with increasing moisture content of sample. The obtained density in this study was ranged from 1.102233 to 1.139233 g/ml.

Bart-Plange et al. (2012b) studied the effect of density of 'Gros Michel' banana. The values were obtained within the range of 1376.2 to 1130.0 kg/m^3 due to changes in moisture content from 18.5 to 50.0% (w.b.). Cao et al. (2010) investigated density of wheat under different moisture content levels. They proposed quadratic equation of density (ρ) in terms of moisture content. With applying multiple regression, relationship of density with the moisture content (Mc) was expressed by the following model:

$$\rho = 0.015\text{Mc} - 2.639Mc + 1.216\rho \quad R^2= 0.9950 \quad (8)$$

Thermal conductivity

Fig. 4 illustrates the changes of thermal conductivity coefficient of persimmon samples under-

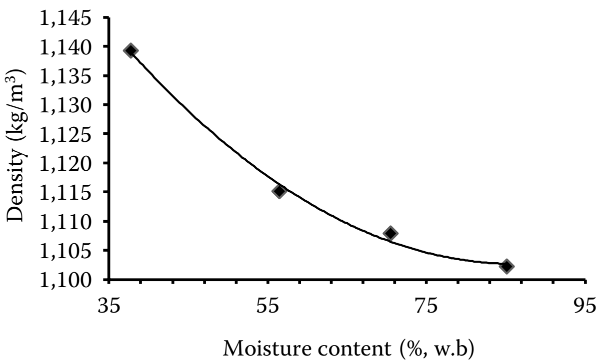

Fig. 3. Effect of moisture content on density of persimmon samples

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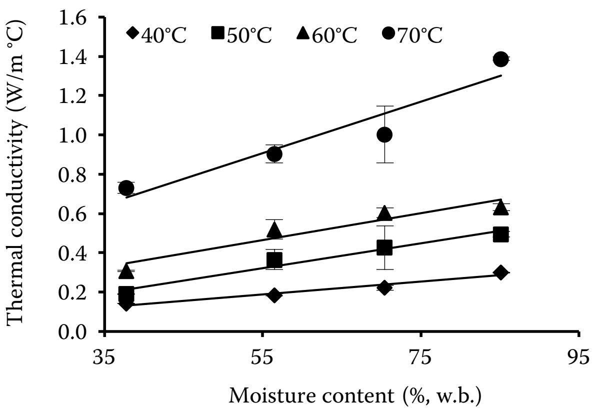

Fig 4. Effect of temperature and moisture content on thermal conductivity of persimmon samples

going thermal process against temperature and moisture content. As expected, thermal conductivity increased with an increase in temperature and moisture content. The gradient of thermal conductivity versus moisture content diagram in the temperature of 70°C was higher than other temperature levels. Since, the effect of temperature on the thermal conductivity was greater than moisture content. Minimum value of thermal conductivity was within the range of 0.14 to 1.3819 (W/m °C). The minimum value (0.14 W/m °C) belonged to temperature of 40°C and moisture content of 37.47%. Max. value of thermal conductivity (1.3819 W/m °C) was related to 70°C and 85.42%. Analysis of variance (full factorial and randomized

Table 2. Analysis of variance of study conditions for determination of density, thermal conductivity and thermal diffusivity

Source	Sum of squares	Mean square	*F*-value	Sign.
Density				
Corrected model	48,600.93	16,200.31**	56.69	0.000
Intercept	2.06×10^7	2.06 × 107**	7.21×10^4	0.000
Temperature	48,600.93	16,200.31**	56.69	0.000
Error	3,429.30	285.77		
Total	2.06×10^7			
Corrected total	52,030.231			
Thermal conductivity				
Corrected model	4.73	0.315**	13.47	0.000
Intercept	12.85	12.853**	549.40	0.000
Temperature	3.88	1.299*	55.53	0.000
Moisture content	0.69	0.229**	9.77	0.000
Temperature × moisture content	0.14	0.016ns	0.685	0.717
Error	0.75	0.023		
Total	18.33			
Corrected total	5.47			
Thermal diffusivity				
Corrected model	2,151.57	717.19**	71.13	0.000
Intercept	254,328.26	254,328.26**	2.52×10^4	0.000
Moisture content	2,151.57	717.19**	71.13	0.000
Error	80.66	10.01		
Total	256,560.49			
Corrected total	2,232.23			

*significance at 5%; **significance at 1%; ns – non significant

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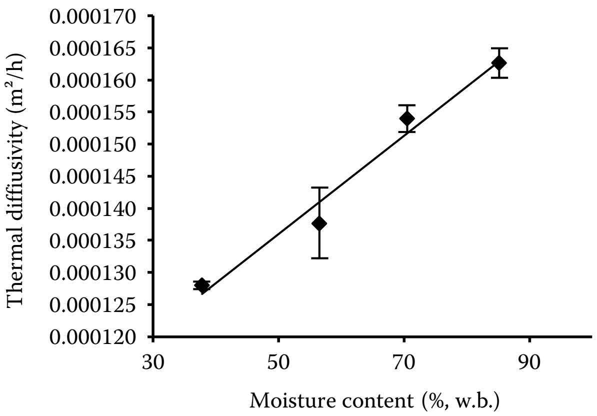

Fig. 5. Effect of moisture content on thermal diffusivity of mixed persimmon samples

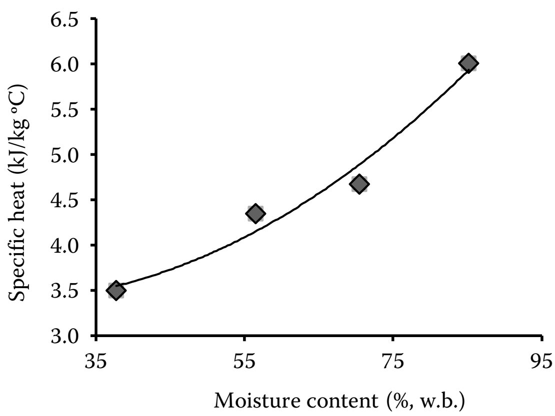

Fig. 6. Effect of moisture content on specific heat of mixed persimmon samples

design) of the research conditions for coefficient of thermal conductivity determination of mixed persimmon samples was performed by the SPSS software and the values are presented in Table 2. Water has the highest thermal conductivity among minerals, carbohydrates and ash (Rahman 1995). Therefore, more moisture content caused the higher value of thermal conductivity. Bart-Plange et al. (2012a) studied the effect of density, moisture and temperature on thermal conductivity of Grand cocoa beans and ground sheanut kernels. Thermal conductivity was obtained within the range of 0.0165, 0.0458 W/m °C in the moisture content range of 12.59 to 43.84% w.b. Kara et al. (2011) investigated the impact of pressure and moisture changes on thermal conductivity of safflower samples. In this research, according to the increase in sample moisture level, thermal conductivity was reported within the range of 0.106 to 0.137 W/m K in high and low pressure conditions, respectively. Gavrila (2005) studied the thermal conductivity of some dairy products in different temperature levels. Thermal conductivity values were achieved from 0.3656 to 0.5828 W/m K.

Table 3. Linear regression equations for thermal conductivity of persimmon sample versus temperature and moisture content

Temperature (°C)	Liner regression equation	R^2
40	$k = 0.013Mc + 0.187$	0.9040
50	$k = 0.006Mc + 0.086$	0.9040
60	$k = 0.006Mc – 0.026$	0.9600
70	$k= 0.003Mc + 0.010$	0.9540

Thermal diffusivity

The plot of thermal diffusivity of mixed persimmon samples versus moisture content is presented in Fig. 5. As shown, thermal diffusivity coefficient of samples has increased linearly due to an increase in sample moisture content. Thermal diffusivity obtained in this study ranged from 128×10^{-6} to 159×10^{-6} m^2/h. The minimum value of thermal diffusivity (128×10^{-6} m^2/h) was obtained in moisture content of 37.77% (w.b.) and the highest value (159×10^{-6} m^2/h) belonged to the moisture content of 85.17% (w.b.). A linear regression model was proposed to fit the data as follows:

$$\alpha = (1 \times 10^{-6})Mc + 8 \times 10^{-5} \quad R^2 = 0.9970 \tag{9}$$

The results of analysis of variance (full factorial and randomized design) of the research conditions for coefficient of thermal diffusivity determination of mixed persimmon samples are presented in Table 2.

A similar trend of thermal diffusivity for other food materials was reported by many researchers, such as for banana. Thermal diffusivity of banana samples was obtained within the range of 1.15×10^{-7} to 1.62×10^{-7} m^2/h due to changes in moisture rate from 18.5% to 50% (Bart-Plange et al. 2012b). In the similar study, Bart-Plange et al. (2012a) investigated thermal properties of cashew kernel under different moisture levels. A quadratic equation

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of thermal diffusivity in terms of moisture content was given for cashew kernel.

Specific heat

Changes of specific heat coefficient of mixed persimmon samples against moisture content are shown in Fig. 6. When the moisture content of samples increased, the specific heat increased nonlinearly. Specific heat values were obtained to be ranging from 3.50 to 6.01 kJ/kg °C. Also, the minimum value (3.50 kJ/kg °C) was computed at the moisture content of 37.77% (w.b.) and the max. value (6.01 kJ/kg °C) was achieved at moisture content of 85.17% (w.b.). The value of specific heat was found to increase with decrease in bulk density. These values are comparable with products such as wheat for which the specific heat values were reported to be ranging from 1.0972 to 5.533 kJ/kg °C for the temperature range of –10 to 110°C and moisture content range of 19.90% to 6.23% (d.b.) (Cao et al. 2010). Specific heat range of Gros Michel banana was 1,574 to 2,506.8 J/kg °C for the moisture content of 18.5 to 50.0% (w.b.) (Bart-Plange et al. 2012b). Equation (10) is presented to model specific heat coefficient of mixed persimmon with moisture content.

$$C = (1 \times 10^{-4})Mc - (9 \times 10^{-3})Mc + 3.24 \quad R^2 = 0.9790 \quad (10)$$

CONCLUSION

The effects of moisture content in the range of 37.77 to 85.17% and temperature in the range of 40 to 70°C on the thermal properties, i.e., density, thermal conductivity, specific heat, and thermal diffusivity of persimmon were determined in this study. It was concluded that an increase in moisture content of persimmon samples and an increase in temperature resulted in an increase in values of thermal conductivity. The temperature within the range of study has a significant effect. In addition, the influence of moisture content on thermal conductivity was even higher than that of temperature. Also increasing moisture content of persimmon samples resulted in a decrease in density values and an increase in thermal diffusivity and specific heat values. An empirical correlation for each thermal property of persimmon was proposed.

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