Determination of thermal properties of the Cavendish banana peel as a function of temperature and moisture

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Abstract: The three most important characteristics of heat transfer in materials are thermal conductivity, thermal diffusivity and specific heat capacity. The thermal conductivity of banana peel was measured with a linear heat source. The specific heat of banana peel was obtained with a calorimeter. The thermal diffusivity coefficients were obtained by using mathematical equations. The results showed that the effect of moisture content and temperature on the thermal conductivity coefficients, specific heat and thermal diffusivity coefficients was significant at 1%. By increasing temperature, the thermal conductivity coefficients have increased in all moisture content. By reducing the moisture content the thermal conductivity coefficients were reduced in all temperature level. Highest thermal diffusivity coefficients took placed in 85.39 (w.b.%) moisture content and 45˚C temperature. The lowest thermal diffusivity happened at moisture content of 65.58 (w.b.%) and 35˚C temperature. The lowest specific heat value was in moisture 65.58 (w.b.%) and the temperature 25˚C. Also increasing the moisture content and temperature has increased the thermal diffusivity coefficients.

Keywords: thermal conductivity, banana peel, thermal diffusivity, specific heat

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1 Introduction

There are some well-recognized fruits and vegetables that are easily rotted due to their high moisture content. This exposes them to blight, microbial attack and as a result post-harvest damages within the moisture range of 30% - 50% (Ikrang and Okoko, 2014). Banana is the fourth most important food in the world, after rice, wheat and corn, with the production equal to 80 million ton in year 2006 (Tapre and Jaine, 2012). All sections of the banana tree contain medicinal applications; original anti-fungal and antibiotics can be found in skin and pulp of a fully ripe banana (Sampath et al., 2012). Thermal conductivity, thermal diffusion, and specific heat capacity are the important three engineering properties of materials which affect heat transfer properties. These parameters are necessary for studies on heating, drying and cooling of food processes (Yang et al., 2002). Accurate prediction about freezing and melting of foods and their constituent materials are important for food industry. The so called “Thermal transfer coefficient” is used to predict the food behaviors. Thermal transfer coefficient is calculated from data about the thermal conduction property (Harris and Levchenko, 2012). In a study by Bart-Plang et al. (2012a) on thermal properties of GrosMichel banana grown in Ghana, the thermal conductivity coefficient of banana was reported to vary from 0.249 W/m/˚C to 0.458 W/m.˚C, while thermal diffusivity coefficient varied from $1.15\times10^{-7}m^2/s$ to $1.62\times10^{-7}m^2/s$ and specific heat varied from 1574 kJ/kg/˚C to 2506 kJ/kg/˚C. As a result, specific heat, thermal conductivity coefficient and thermal diffusivity coefficient increased with increase in the moisture content. Mariani et al. (1994) conducted a study titled “Apparent thermal diffusivity estimation of the banana during drying using inverse method”. The study showed that a small change in the temperature and moisture content of banana caused a sudden change in

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the thermal diffusivity, such that decrease in the moisture decreased the thermal diffusivity (Mariany et al., 2005). Thermal conductivity and thermal diffusivity of whole green (unripe) and yellow (ripe) *Cavendish* bananas under cooling conditions were obtained (Erdogdo et al., 2013). Thermal conductivity and thermal diffusivity increased from 0.302 W/m/˚C to 0.338 W/m/˚C and from 1.442×10^{-7} m^2/s to 1.5×10^{-7} m^2/s, respectively. These values using literature data and additional experiments where the experimental data and simulation while banana peel effect on the cooling rate as described were compared. In a study Ikegwo and Ekwu (2009), thermal properties of some tropical fruits such as bananas were studied. The results show that the thermal properties of all samples, including bananas increased with increasing moisture. Low thermal diffusion to the fruit show the low thermal conductivity of the fruit. Perussello et al. (2010) have a study on thermal conductivity and its relationship with the moisture. The aim of this study was to develop a line heat source probe to measure the thermal conductivity of the food products. In this study, the heat source probe was used to measure the thermal conductivity of banana and its relation to the moisture content in the range of 63 (w.b.%) and 85 (w.b.%) were investigated. Thermal conductivity values obtained recurring 0.3 to 0.55 W/m/˚C.

Mohsenin (1980) reported values of 0.481 W/m/˚C for thermal conductivity of banana 75.7 (w.b.%) moisture content, 27˚C temperature and 980 kg/m^3 density. Ofory and Hayford (2011) studied thermal properties of varieties of banana cultivated in Ghana. Thermal conductivity of Gros Michel variety was from 0.249 W/m/˚C to 0.458 W/m/˚C and for Cavendish variety varied from 0.317 W/m/˚C to 0.543 W/m/˚C. Thermal diffusivity of Gros Michel was 1.5×10^{-7} m^2/s to 1.62×10^{-7} m^2/s and for Cavendish variety was 1.29×10^{-7} m^2/s to 1.7×10^{-7} m^2/s. As a result, in both of varieties the thermal conductivity and thermal diffusivity increased with increasing moisture content. In a study by Harris and Levchenko (2012) titled “Thermal Conductivity Characterization of Fruits and Honey”, they examined thermal properties of honey and some other fruits including banana. Finally, they concluded that the fruits are complex solid materials, with water being the most important constituent parts of them. The thermal conduction of fruits is expected to be similar to that of water. Therefore, it is of no surprise that the thermal conduction coefficient for fruits varies within 0.54 W/m/k to 0.56 W/m/k, which is 90% similar to that of water. Banana contains lower level of water content (74% of its weight) compared to other fruits in this study. Thus, its thermal conduction coefficient was also smaller to that of other studied fruits; except for the apple which was due to the apple fibers, because the fibers have much smaller thermal conduction coefficient than that of water.

One of the important parts of the fruit, is peel, which must be examined. Much research has been done on the thermal properties of pith but on the peel of fruits such as banana limited research has been done. While the peel of the fruit (bananas) much impact on operations such as handling and marketable fruit, and so on. Purpose of this study was to calculate the thermal properties of peel of Cavendish banana, including thermal conduction coefficient, thermal diffusivity coefficient and specific heat and also to examine the relationship of these three properties with temperature and moisture in order to obtain the information required to construct the maintenance and processing devices related to this product, including drying and cooling equipment.

2 Materials and methods

2.1 Preparing the samples and the test method

First, sufficient number of Cavendish bananas was purchased from the local market in Gorgan city, Iran. Then, the bananas were skinned and moisture of the skin was measured by wet-based standard weight method. Different moisture levels of bananas were gained by drying in existing dryer in bio-system mechanic lab in Gorgan University of natural resources and agricultural sciences in Gorgan city, consecutive weighing and calculating the weight difference until the desired moisture level are achieved (Golmohammadi et al., 2013). Eventually, the required wet-based moisture content for each test was measured in percent using initial sample weight(G_{dm} + G_w), the lost moisture weight (G_w)and dried sample weight(G_{dm}), according to Equation (1) (Velayati et al., 2011).

$$M_w = \frac{G_w}{G_{dm} + G_w} \times 100 \qquad (1)$$

2.2 Determination of thermal conductivity

In order to study thermal conduction coefficient using conventional linear heat source method, a wire-heat thermal conduction device was used. To make a measurement, the probe was embedded in the banana skin. In fact, the temperature increase in the radial direction was examined and the heat conduction coefficient was obtained by using Equation (2) (Hobani and Al-Askar, 2000). Following a brief transient period, the plot of the temperature versus the natural logarithm of time became linear. The thermal conductivity could be calculated from the relation

$$K = \frac{Q}{4\pi\ (T_2 - T_1)} \ln \frac{t_2}{t_1} \qquad (2)$$

Where:

K, the thermal conduction coefficient of sample (W/m/˚C)

Q, power dissipation by heat wire (W/m)

t_1 and t_2: time since probe heater was energized

T_1, temperature of probe thermocouple at initial time t_1 (˚C)

T_2, temperature of probe thermocouple at initial time t_2 (˚C).

The thermal conduction device (Figure 1) is composed of a PVC cylinder with diameter of 150 mm and height of 200 mm which is completely sealed to prevent transfer of heat and moisture. The nichrome wire was located at the center of the fiber glass insulation. The element wire was heated by a power supply (Omega, model:PD-30V-5A-S, made in Korea). A voltage meter (Mastech, model: mas 830 L, made in china) was installed in parallel with the element to measure the voltage passing through the circuit and an ammeter (Similar model voltmeter) was used in series in the circuit.

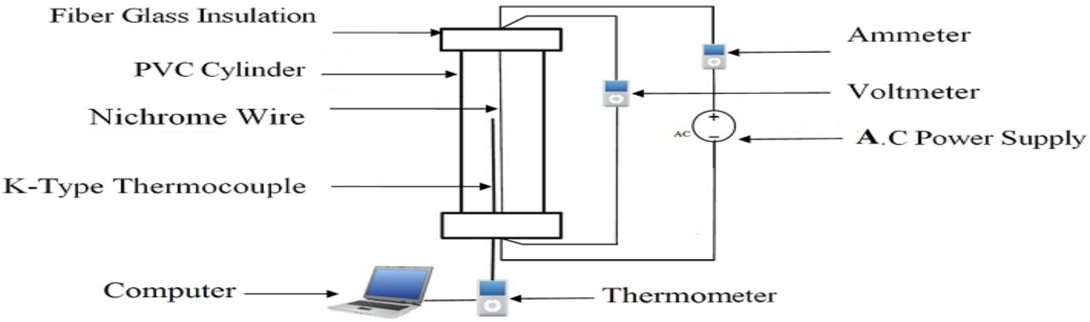

Figure 1 Linear heat source components for measuring thermal conductivity coefficient

In order to measure the core line, a thermometer (Model: Su-503bB, made in China) applied, which was mounted on a base at a distance of 30 mm from heat line source. Because in practice the temperature field is limited to a narrow range around the probe. Regarding data logger output recording temperature per second, the temperature value schematic chart was drawn in the time natural logarithm within the 6200 s of the test. The slope and coefficient of determination (R^2) 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).

2.3 Determination of specific heat

In order to study the specific heat, a hybrid method that had high accuracy was used, though being simple. In this method, the sample with specific temperature and volume was placed inside the calorimeter (Figure 2) containing water with higher temperature. The calorimeter was composed of a vacuum flask calorimeter, a thermometer, k-type thermometer, polystyrene insulation, computer and an agitator.

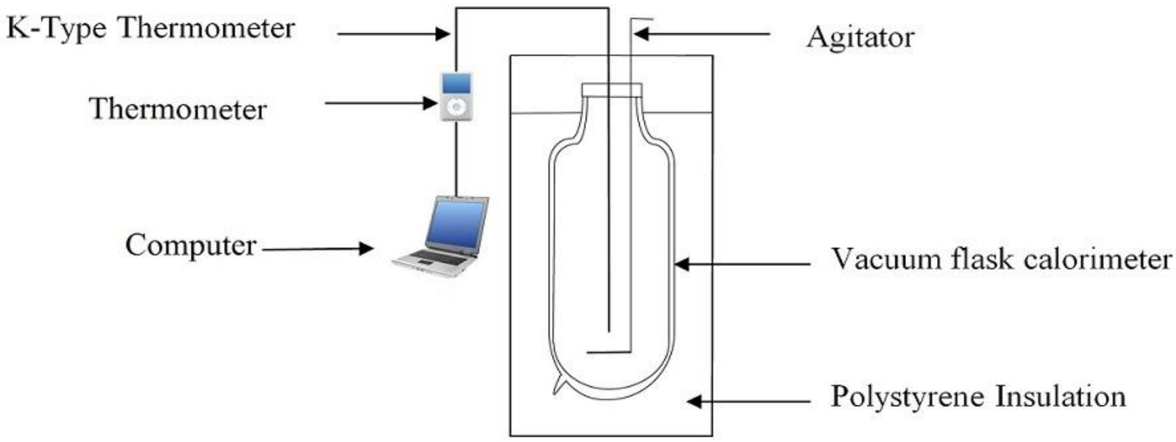

Figure 2 Calorimeter components for determining specific heat

2.3.1 Determining calorimeter specific heat

According to the law of conservation of energy, the total energy at the end of the experiment is equal to the energy at the beginning of the experiment. This can be expressed by Equation (3):

$$q_{metal} = q_{water} + q_{calorimeter} \qquad (3)$$

$$Heat\ change = mass \times specific\ heat\ capacity \times temperature\ change.$$

Heat change (q) represents the amount of energy expressed by: $q = M \times C \times \Delta T$, where $M = mass$ (g), $C = specific\ heat\ (J/g/°\mathrm{C})$, and $\Delta T = change\ in\ temperature$ (°C)

This can be solved for Ccalorimeter or Ccal, for short, as Equation (4):

$$Mmetal \times Cmetal \times \Delta Tmetal = (Mwater \times Cwater \times \Delta Twater) + (Mcal\ x\ Ccal\ x\ \Delta Tcal) \qquad (4)$$

Rearranging Equation (5) and Equation (6):

$$Mmetal \times Cmetal \times \Delta Tmetal = (Mwater \times Cwater \times \Delta Twater)) + (Hcal \times \Delta Tcal) \qquad (5)$$

$$(Hcal \times \Delta Tcal) = (Mmetal \times Cmetal \times \Delta Tmetal) - (Mwater \times Cwater \times \Delta Twater) \qquad (6)$$

The value of $C = 1J/g/°\mathrm{C}$ for water, by definition. Since the water and the calorimeter both start and end at the same temperature, $\Delta Tcal = \Delta Twater$. Substituting in Equation (7):

$$\mathrm{Hcal} = \frac{(\mathrm{M_{Banana\ skin}\ x\ CBanana\ skin\ x\ \Delta TBanana\ skin}) - (\mathrm{Mwater\ x\ \Delta Twater})}{\mathrm{\Delta Twater}} \qquad (7)$$

Since the calorimeter container is made of a mixture of glass, metal, and insulated materials, its heat capacity easily determined through experiment. To determine the calorimeter heat capacity (Hcal), some distilled water, mc, poured into the calorimeter; next, Tc temperature recorded following some minutes once the water and calorimeter balanced. Then, some distilled water at $\mathrm{T_h}$ temperature and $\mathrm{m_h}$ mass added. Once the balance temperature obtained, then Tc is recorded. The calorimeter specific heat attained by Equation (8) and Equation (9) (Salarikia, 2012).

$$H_{\mathrm{cal}} = \frac{\mathrm{m_h C_w (T_h - T_e) - m_c C_w (T_e - T_c)}}{\mathrm{(T_e - T_c)}} \qquad (8)$$

$$\mathrm{m_{cal} C_{cal}} = H_{cal} \qquad (9)$$

The equation was using the mass of the banana skin. So the porosity will not influence the result.

2.3.2 Determining sample specific heat

The hot water with specific mass was poured inside the calorimeter and the temperature was recorded by a thermometer connected to a computer. Then, the sample with specific temperature and mass was poured inside the calorimeter container and after the temperature reached equilibrium state, the specific heat was measured using Equation (10) (Mohsenin, 1980).

$$C_p = \frac{C_w W_w (T_e - T_w) - C_c W_c (T_i - T_e)}{W_s (T_i - T_e)} \qquad (10)$$

Where:

C_p, sample specific heat (kJ/kg/˚C)
C_w, the specific heat of water (kJ/kg/˚C)
W_w, the weight of water added (g)
T_e, temperature balance (˚C)
T_w, added water temperature (˚C)
C_c, the specific heat of calorimeter (kJ/kg/˚C)
W_c, the weight of calorimeter (g)
T_i, the temperature of the sample (˚C)
W_s, Sample weight (g).

Thermal diffusivity was obtained using the thermal conduction coefficient and the specific heat according to Equation (11) (Mohsenin, 1980).

$$\alpha = \frac{K}{\rho\, C_p} \qquad (11)$$

Where:

α, the thermal diffusivity of sample (m^2/s)
K, the thermal conduction coefficient of sample (W/m/˚C)
C_p, the specific heat of sample (kJ/kg/˚C)
ρ, the bulk density of sample (g/cm^3).

In order to measure bulk density, a cylinder, given volume and mass, filled by banana peel, with no distance between them, and weighted. As the volume was given, the bulk density is obtained.

Preparation of data and amount determination by the software Excel 2010, Statistical analysis software SAS 9.2 and three-dimensional design by software SolidWork 2012 for testing were performed.

3 Results and discussion

Results obtained from analysis of variance of effect of moisture and temperature on thermal properties of the banana peel including thermal conduction coefficient, thermal diffusivity coefficient and specific heat are presented in the Table 1. Results of this table indicate that effect of moisture and temperature on thermal conduction coefficient was significant at 1% level and moisture on thermal diffusivity coefficient was significant at 1% level, but the effect on specific heat was not significant. Also, effect of temperature and moisture on thermal conduction coefficient and thermal diffusivity was significant at 1% level, Interaction moisture and temperature on specific heat was significant at 1%. Gelatinization at high temperature takes place via carbohydrate molecules with the molecules of the constrained free water. Greater water on the limited water content on the skin decreased the specific heat. Increased heat conduction with increase in the moisture and temperature might be due to higher heat conduction of water with respect to the dry matter in the sample with air-filled pores. By increasing the thermal conduction coefficient, the thermal diffusivity increased according to Equation (11). A similar result indicating the significant effect of temperature and moisture on thermal conduction coefficient and comparing the effects of temperature and moisture on thermal diffusivity coefficient was demonstrated in the studies by Bart-plane et al. (2012a), Yang et al. (2002) and Hobani and Al-Askar (2000).

Table 1 Results of variance analysis of moisture and temperature effects on thermal conduction coefficient, thermal diffusivity coefficient and specific heat of banana peel

Source of variation	Degree of freedom	Thermal conduction coefficient (W/m/˚C)	Thermal diffusivity coefficient (m^2/s)	Specific heat(kJ/kg/˚C)
Moisture	2	0.14^{**}	$1.26\times10^{-13**}$	1.75^{ns}
Temperature	2	2.76^{**}	$3.73\times10^{-14\ ns}$	$1.06^{\ ns}$
Temperature ×Moisture	4	0.08^{**}	$3.05\times10^{-13**}$	12.24^{**}
Error	4	0.009	1.33×10^{-14}	1.01

Note: Respectively **,* significant difference in 1% and 5% levels and ns indicates lack of significance.

Result of comparing the effects of temperature and moisture on thermal conduction coefficient of banana peel is presented in Table 2. It can be concluded from this table that increase in the temperature and moisture increased the heat conduction coefficient and similarly decrease in the moisture and temperature decreased the heat conduction coefficient. Because the decreased water level in the banana skin caused the fiber to increase, thus the amount of heat transfer decreased, due to lower heat conductivity of fiber compared to water. The reason for lower heat conductivity of fiber is the grater air-filled pores after the decrease in the moisture. Decrease in the moisture decrease or even dry up the water inside the pores of the skin, thus leaving the pores empty (heat conductivity of the air is much lower than the water). Similar results were reported in studies by Bart-plange et al. (2012), Darvishi et al. (2012) and Sadeghi et al. (2008).

Table 2 Comparative results of average of and the standard deviation mutual effect of moisture and temperature on thermal conduction coefficient

	Temperature (˚C)		
Moisture (w.b.%)	25	35	35
85.39	0.27 ± 0.004^{Ab}	0.56 ± 0.1^{Ab}	1.68 ± 0.15^{Aa}
71.64	0.26 ± 0.01^{Ab}	0.51 ± 0.04^{Ab}	1.2 ± 0.2^{Ba}
65.58	0.24 ± 0.03^{Ac}	0.45 ± 0.007^{Ab}	1.11 ± 0.02^{Ba}

Note: The same capital letters in each column and same small letters in each row shows no significance.

According to Figure 3, decrease in the moisture decreased the thermal conductivity coefficient which was due to the decreased moisture in the banana peel, because water has greater thermal conductivity coefficient compared to the dry matter in the banana peel (Harris and Levchenko, 2012). When the banana peel dries up, without compressing the skin, percent of the pores in the skin increases. At any moisture level, increase in the temperature increases the thermal conduction coefficient which is because of dried peel of the fruit without compression which increase the percent of pores in the peel which allows for greater and simpler thermal transfer. The greatest thermal conductivity coefficient of banana peel was related to the moisture level of 85.39 (w.b.%) at 45 ˚C. The lowest thermal conduction coefficient was related to moisture level of 65.58 (w.b.%) at 25 ˚C.

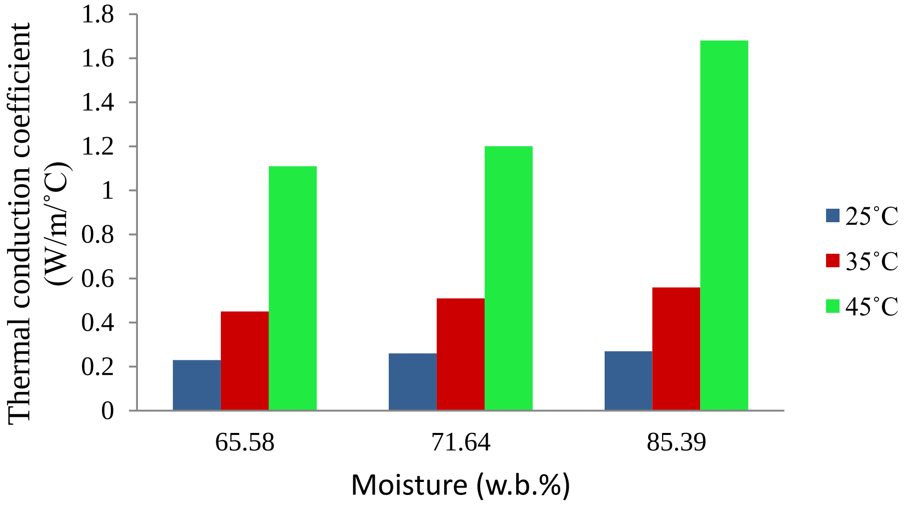

Figure 3 Mutual effect of moisture and temperature on thermal conduction coefficient of banana peel

Result of comparing the average effect of moisture and temperature on thermal diffusivity coefficient is presented in Table 3. It can be concluded that increase in the moisture and temperature increased the thermal diffusivity coefficient. According to Equation (6), value of thermal diffusivity coefficient was directly related to the thermal conduction coefficient and inversely related to the specific heat and bulk density. Since the specific heat did not have significant relation with temperature and moisture, increasing the temperature and moisture increased the thermal conduction coefficient, decreased the bulk density and then the value of thermal diffusivity coefficient first increased with respect to the temperature and moisture. This result was in agreement with the results reported by Hobani and Al-Askar (2000) and Yang et al. (2002).

Table 3 Comparative results of average and the standard deviation of mutual effect of moisture and temperature on Thermal diffusivity coefficient

	Temperature (˚C)		
Moisture (w.b.%)	25	35	45
85.39	$5.13\times10^{-7}\pm3\times10^{-8\ \mathrm{Ab}}$	$5.76\times10^{-7}\pm5\times10^{-8\ \mathrm{Ab}}$	$6.26\times10^{-7}\pm7\times10^{-8\ \mathrm{Aa}}$
71.64	$0.56\times10^{-7}\pm1\times10^{-8\ \mathrm{Bc}}$	$1.93\times10^{-7}\pm5\times10^{-9\ \mathrm{Ba}}$	$3.93\times10^{-7}\pm2\times10^{-8\ \mathrm{Aa}}$
65.58	$0.75\times10^{-7}\pm9\times10^{-9\mathrm{Bb}}$	$1.1\times10^{-7}\pm5\times10^{-8\ \mathrm{Bb}}$	$3.06\times10^{-7}\pm8\times10^{-8\ \mathrm{Aa}}$

Note: The same capital letters in each column and same small letters in each row shows no significance.

It can be concluded from the Figure 4 that the greatest thermal diffusivity was related to moisture of 85.39 (w.b.%) at 45˚C. The lowest thermal diffusivity occurred at moisture level of 71.64 (w.b.%) and 25˚C. Thermal diffusivity with increasing temperature and moisture increased. Similar results were observed in the study Hobani and Al-Askar (2000) and Azadbakht et al. (2013). The sample constituents react on decreasing to give rise to intermolecular and intermolecular cleavages which produce highly cross linked macromolecular structures. Due to these changes, swelling and softening of starch and denaturation of protein occur, which reduces the ability of dough to conduct heat (Seruga et al., 2005). By decreasing the thermal conduction coefficient, the thermal diffusivity decreased according to Equation (6).

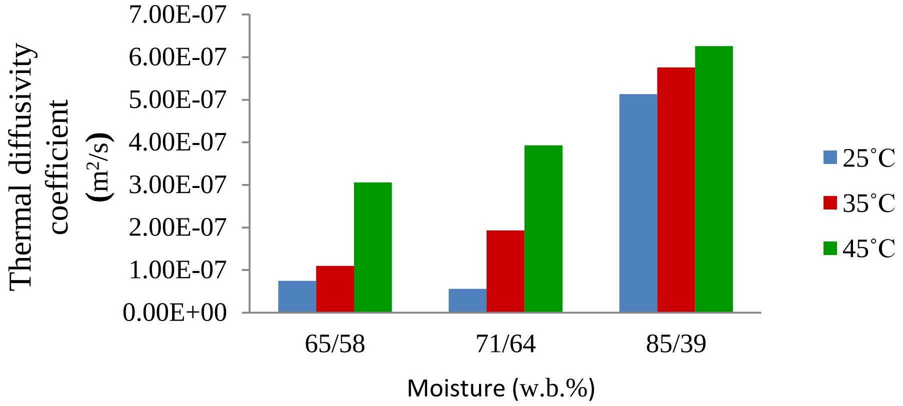

Figure 4 Mutual effect of moisture and temperature on thermal diffusivity coefficient of banana peel

Result of comparing the effects of temperature and moisture on specific heat of banana peel is presented in Table 4. It can be concluded from this table at 25˚C with increasing moisture 65.58 (w.b.%) to 71.64 (w.b.%) specific heat value increased. As well as the banana peel specific heat at a temperature of 35˚C with moisture increases. Similar results in research Bart-plang et al. (2012), Darvishi et al. (2012) and Aviara and The Hague (2008) have been observed. This behavior may be due to rising water on the surface of the peel. But at 45˚C observed that moisture does not affect the specific heat. It can be concluded from this table due to moisture on the specific heat of banana peel more than the temperature effect, the result of research that Azadbakht et al. (2013) and Shryvasta and Datta (1999) have been obtained.

Table 4 Comparative results of average and the standard deviation of mutual effect of moisture and temperature on specific heat

	Temperature (˚C)		
Moisture (w.b.%)	25	35	35
65.58	0.38 ±0.07^{Bb}	0.72 ±0.2^{Cb}	3.11 ±0.6^{Aa}
71.64	4.64 ±0.8^{Aa}	2.56 ±0.1^{Ba}	3.69 ±0.9^{Aa}
85.39	3.59 ±0.7^{ABa}	4.57 ±0.9^{Aa}	3.9 ±0.4^{Aa}

Note: The same capital letters in each column and same small letters in each row shows no significance.

From Figure 5 it can be concluded in moisture 65.58 (w.b.%) specific heat increases with increasing temperature and the moisture 71/64 (w.b.%) in 35˚C specific heat value decreases. In moisture 85.39 (w.b.%), temperature increase does not affect the specific heat. The lowest specific heat value was in moisture 65.58 (w.b.%) and the temperature 25˚C.

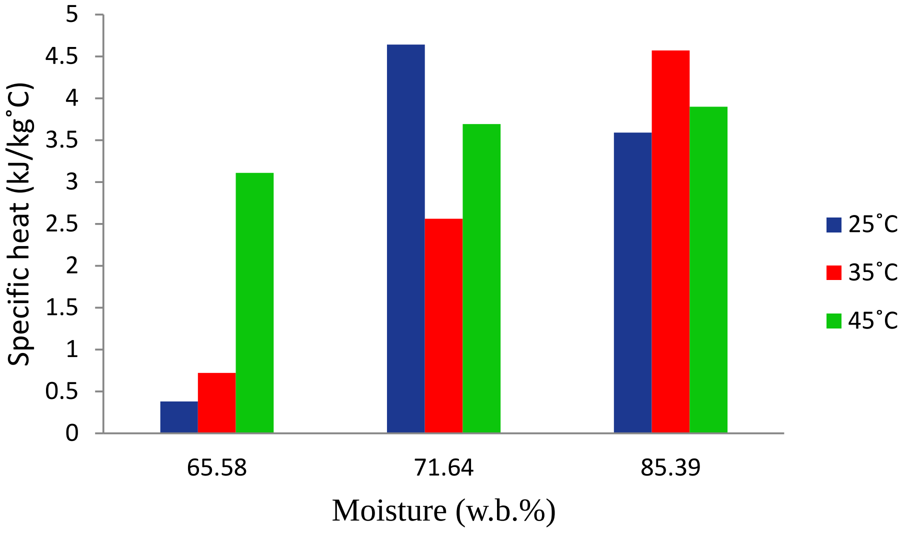

Figure 5 Mutual effect of moisture and temperature on specific heat of banana peel

4 Conclusions

Results of this research indicated that increase in the moisture and temperature increased the thermal conduction coefficient and thermal diffusivity coefficient. The lowest value of the specific heat in moisture 65/58 (w.b.%) and 25˚C tests occurred, this moisture and temperature is very suitable for drying. The lower is the thermal conduction coefficient, the greater would be the insulation; and thus in order to store in the storage room, the banana peel must have greater insulation property. For this reason, it can be concluded that low temperature and low moisture in this study was suitable for storing fruits in the storage room. The greatest and smallest thermal diffusivities coefficient were related to moisture levels of 85.39 (w.b.%) at 45˚C and 71.64 (w.b.%) at 25˚C, respectively. Then, at 25˚C, smaller heat would reach the fruit peel and the moisture level of 71.64 (w.b.%) produced more desirable results, than other moisture levels used in this study. On the other hand, temperature of 45˚C and moisture level of 85.39 (w.b.%) were better than other temperature and moisture in this study for the drying process; because in this condition, the greatest thermal diffusivity took place. It can be concluded that it is more desirable to keep the fruits in a storage room with lower moisture and temperature, because heat is among the factor that changes color of the banana and consequently causes to banana to rot. Lower moisture is also among factors effective on increasing the storage period of banana; because if the moisture content increases in the fruit, disease and rotting would also increase in the fruit.

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