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INVESTIGATION OF THE EFFECT OF DIFFERENT FACTORS ON THE THERMAL PROPERTIES OF BARBERRY PUREE

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Abstract: *For a precise designing of thermal processes, the determination of the thermal properties of foods is necessary. In this study, the thermal properties of barberry puree with five moisture content (25, 30, 35, 40 and 45%), different temperature (25, 35, 45, 50 and 55ºC), salt content (0, 0.5, 1, 1.5 and 2%), and sugar content (0, 10, 15, 20 and 25%) are measured. Results showed that all factors have a significant effect on the specific heat and thermal conductivity of barberry puree. Observations showed that the increase of temperature and the increase of the moisture content resulted in increasing the special heat of barberry puree. Data showed an inverse relationship between the salt percentage and the sugar content of the barberry puree and the specific heat of this product. According to this study, the thermal conductivity of barberry purée is affected by the salt and sugar percentage added to the formulation. The higher the percentage of added salt or sugar resulted in the reduction of the thermal conductivity of barberry puree. For the prediction of the effect of moisture, temperature, salt and sugar content on specific heat and thermal conductivity, regression models are chosen. The Coefficient of Determination (R^2) of the specific heat for temperature, moisture content, salt content and sugar content were 0.908, 0.909, 0.988 and 0.821, respectively. The Coefficient of Determination (R^2) of the thermal conductivity for temperature, moisture content, salt content and sugar content were 0.789, 0.938, 0.969 and 0.830, respectively. According to the results, the increase of temperature and moisture content resulted in increasing the magnitude of specific heat and thermal conductivity. Inversely, increasing salt content and sugar content in barberry puree formulation caused decreasing specific heat and thermal conductivity.*

Key words: *Thermal conductivity, Specific heat, Barberry puree.*

1. Introduction

Barberry (*Berberis vulgaris*) has both medicinal and edible consumption. This product contains organic acids and phenolic compounds. The cultivation area of barberry in Iran is 6000 hectares and the annual production of fresh barberry is

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22,000 hectares [1]. Determining the thermal properties of foods is necessary for designing thermal processes such as drying and other thermal processing. The thermal properties of food are affected by various factors such as composition of materials and process condition [10]. The modeling and optimization of the thermal processes has an important role in the suitable designing of thermal processes as well as in reducing energy consumption [9]. Mathematical models were applied for the determination of the dependence of thermal properties of food on various parameters such as moisture content [11]. Various thermal properties of foods have been investigated by the researchers, including those of lemon juice [12], sweet potato puree [4], soy [2], papaya puree [7], and pomegranate [6]. The purpose of this paper is to determine the specific heat and thermal conductivity of barberry puree in various formulations (moisture content, salt percentage and sugar content) as well as in different process temperatures and provide empirical models for the prediction of thermal properties.

2. Materials and Methods

2.1. Materials

Experiments were conducted to determine the specific heat and thermal conductivity of barberry puree in five levels of moisture (25, 30, 35, 40 and 45%), five temperature levels (25, 35, 45, 50 and 55°C), different percentages of salt (0, 0.5, 1, 1.5 and 2%) and different percentages of sugar (0, 10, 15, 20 and 25%). All experiments were performed triplicate. A regression model was used to determine the relationship between specific heat and thermal conductivity with test variables. In order to compare regression model feasibility, the standard error of regression was investigated and the model with the highest coefficient of determination and the lowest standard error of regression was selected.

2.2. Methods

2.2.1. Determination of the Moisture Content

The moisture content of barberry puree has been determined by means of the drying method. About 5 to 8 grams of the sample were placed in oven (102 ± 2ºC). Then the evaporated moisture content was calculated [6].

2.2.2 Specific Heat Determination

Specific heat determination was performed according to the method outlined by Kian Mehr et al. [6] and Tansakul and Lumyong [14].

2.2.3. Determination of the Thermal Capacity of the Flask

For the determination of the thermal capacity of the flask, the magnitude of temperature change of the warm distilled water in the flask is determined after the addition of a certain amount of distilled water to it, assuming that the system is adiabatic. The thermal capacity of the flask is determined according to the relationship [11]:

$$H_f = \frac{M_{cw}.C_w(T_e - T_{cw}) - M_{hw}.C_w(T_{hw} - T_e)}{(T_{hw} - T_e)} \quad (1)$$

2.2.4. Determination of the Thermal Capacity of the Capsule

The aluminum capsule used in this test had the following characteristics: 55 mm height, 20 mm inner diameter and 2 mm wall thickness. The temperature change of water in the flask was measured when the empty capsule (with a higher temperature) was placed inside the flask and the thermal capacity of the capsule was determined by the following relationship [11]:

$$H_c = \frac{(H_f + M_{cw} . C_w)(T_e - T_{cw})}{T_c - T_e} \quad (2)$$

2.2.5. Determination of the Specific Heat of Barberry Puree

The capsule containing the samples (various formulas of barberry puree) was placed in a flask containing distilled water and allowed to reach the test temperature (waiting time varied in the range of 5 to 45 minutes). The specific heat of the sample was calculated using the following equation [11].

$$C_p = \frac{(H_f + M_{cw} . C_w)(T_e - T_{cw}) - H_c(T_m - T_e)}{M_m(T_m - T_e)} \times 4.1868 \quad (3)$$

2.2.6. Determination of Thermal Conductivity

In this study, the transient-state heat transfer method was used to determine the thermal conductivity of barberry puree [6], [13].

2.2.7. Mathematical Modeling and Statistical Analysis

Statistical analyses were performed using the SPSS software (version 16).

3. Results and Discussion

3.1. Investigating the Effect of Temperature, Moisture, Salt Percentage and Sugar Content on the Specific Heat of Barberry Puree

In order to measure the effect of various factors (temperature, moisture content, salt percentage and sugar content) on the specific heat and thermal conductivity of barberry puree, a simple regression model was used. The fitting of the regression model on independent variables of temperature, moisture, salt content and sugar content and dependent variables (specific heat and thermal conductivity) were performed by means of statistical software and a summary of the results is rendered in Tables 1 and 2.

According to the results, the F and P values for the temperature variable were determined to be 128.629 and 0.000, respectively. The F and P values for moisture content are equal to 130.261and 0.000, respectively. These values represent a linear relationship between independent variables (temperature and moisture) with the dependent variable (specific heat). Also, the regression coefficient (R^2) for temperature and moisture content variables is 0.908 and 0.909, respectively. Regression equations are shown in Table 2.

Table 1 shows an inverse relationship between the salt percentage and the added sugar content of the barberry puree and the specific heat of this product. The F and p values of the salt content were 1075.328 and 0.000, respectively. For the sugar content, the F and p-value were equal to 14.114 and 0.000, respectively. The regression coefficient of determination (R^2) for the salt and sugar percentage and specific heat were 0.988 and 0.821, respectively.

Table 1

The results of regression models on the dependent variable of specific heat (C_p) of barberry puree and independent variables (temperature, moisture content, salt content and sugar content)

		Model coefficients	Standard coefficient	t	*P-value*	F	*P-value*	R^2
C_p	Regression constant	2.189	-	32.748	0.000	128.629	0.000	0.908
	Temperature	0.017	0.953	11.314	0.000			
	Regression constant	2.223	-	46.739	0.000	130.216	0.000	0.909
	Moisture	0.015	0.945	11.413	0.000			
	Regression constant	2.626	-	435.808	0.000	1075.328	0.000	0.988
	Salt content	-0.161	-0.994	-32.792	0.000			
	Regression constant	2.694	-	41.564	0.000	14.114	0.002	0.821
	Sugar content	-1.148	-0.721	-3.757	0.002			

Table 2 shows the regression equations and the relationship between the variables investigated with the specific heat of the barberry puree. According to this study, the addition of salt and sugar caused the reduction of specific heat in the barberry puree. Kara et al. [5] reported that an increase in moisture content of red lentil resulted in the increase of its specific heat and attributed this to the higher specific heat of water as compared to solid materials of food products.

Figures 1 and 2 showed that the increase of temperature and the increase of moisture content caused an increase of the special heat of barberry puree. Similarly, an increase in moisture from 25% to 45% caused an increase of the specific heat content from 2.64 to 2.92 $kJ \cdot kg^{-1} \cdot °C$ (Figure 1). As the temperature rises from 25°C to 55°C, the specific heat increased from 2.64 to 3.2 $kJ \cdot kg^{-1} \cdot °C^{-1}$ (Figure 2).

Table 2

Regression equations for the relationship between different characteristics of barberry puree and specific heat

Temperature [°C]	C_p=2.189+0.017X
Moisture content [%]	C_p= 2.223+0.015X
Salt content [%]	C_p= 2.626-0.16X
Sugar content [%]	C_p= 2.694-1.148X

C_p: Specific heat [$kj \cdot kg^{-1} \cdot °C^{-1}$]

The effects of temperature and moisture on specific heat in this study are consistent with the results of similar studies. Azadbakht et al. [2] reported that the specific heat of soybean pods was affected by moisture content and temperature.

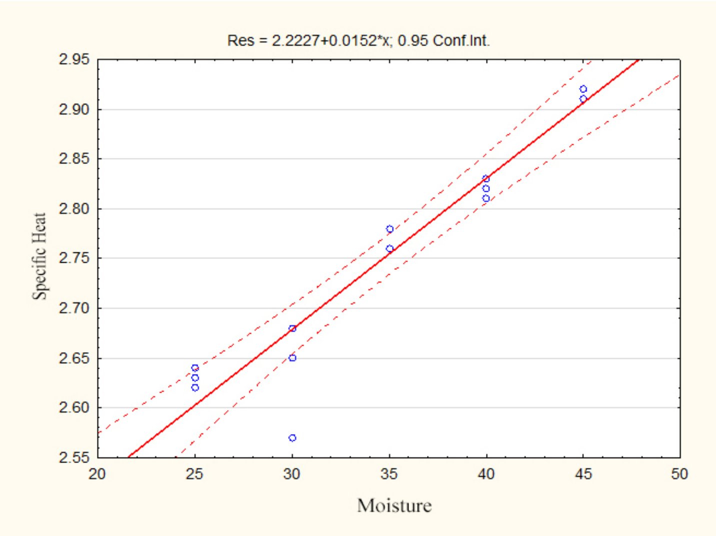

Fig. 1. *Regression model of moisture content and specific heat*

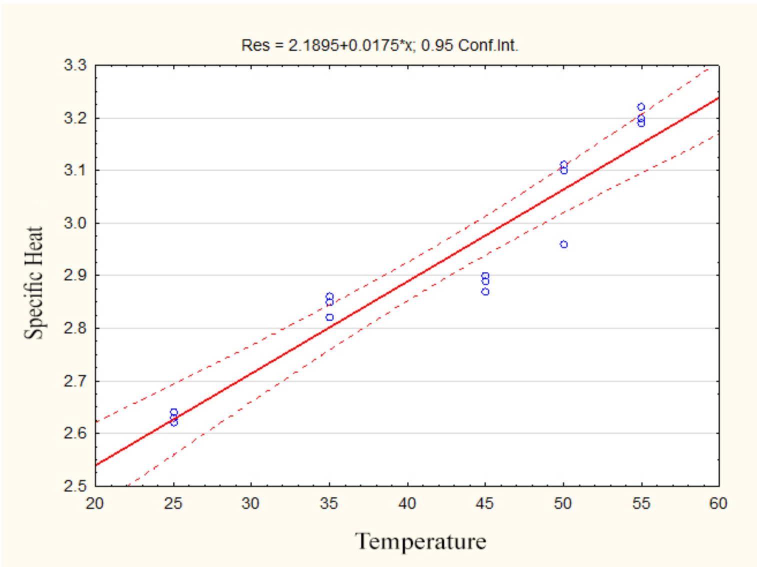

Fig. 2. *Regression model of temperature and specific heat*

3.2. Investigating the Effect of Temperature, Moisture Content, Salt Percentage and Sugar Content on the Thermal Conductivity of Barberry Puree

The effect of various parameters (temperature, moisture content, salt percentage and sugar content) on the thermal conductivity of barberry puree was assessed and results were showed in Table 3. Accordingly, temperature and moisture content had a direct effect on thermal conductivity. As these two factors increased, the thermal conductivity of barberry puree also increased. When increasing temperature, the thermal energy of the molecules increases, which increases the molecular movement and collisions between them, and resulted in increasing the heat transfer rate and in an increase of the thermal conductivity coefficient. The regression constant was 0.789 and 0.938 for temperature and moisture content, respectively.

Table 3

The results of regression models among dependent variable k of barberry puree and independent variables (temperature, moisture content, salt percentage and sugar content)

		Model coefficients	Standard coefficient	t	*P-value*	F	*P-value*	R^2
k	Regression constant	0.484	-	39.974	0.000	48.710	0.000	0.789
	Temperature	0.002	0.888	6.979	0.000			
	Regression constant	0.337	-	16.166	0.000	196.586	0.000	0.938
	Moisture	0.008	0.968	14.021	0.000			
	Regression constant	0.540	-	490.269	0.000	400.211	0.000	0.969
	Salt content	-0.018	-0.984	-20.005	0.000			
	Regression constant	0.547	-	126.119	0.000	63.477	0.000	0.830
	Sugar content	-0.210	-0.911	-7.967	0.000			

Villa-Wales et al. [15] showed that increasing the temperature caused the increase of thermal conductivity in the fruit juice of uvaia. Mahapatra et al. [8] stated that there was an increase of thermal conductivity of rice flour as the moisture content increased. This phenomenon was due to increasing the concentration of ionic and polar molecules at higher moisture content which resulted in an easier heat transfer in food, therefore to more thermal conductivity of food products [16].

In the present study, observations showed that the increase in the amount of salt or sugar added to barberry puree, resulted in decreasing thermal conductivity (Figures 3 and 4). According to this study, the thermal conductivity of barberry purée is affected by the salt percentage added to the formula. A rise in the percentage of added salt resulted in a decrease of the thermal conductivity coefficient in barberry puree (Figure 3). An increase in the amount of water in the foodstuff and a lower percentage of soluble materials resulted in a greater thermal conductivity. By solubilizing sugar and salt, the percentage of soluble materials in the barberry puree increased and thus caused a decrease of the thermal conductivity of the product. These results are in accordance with other researches.

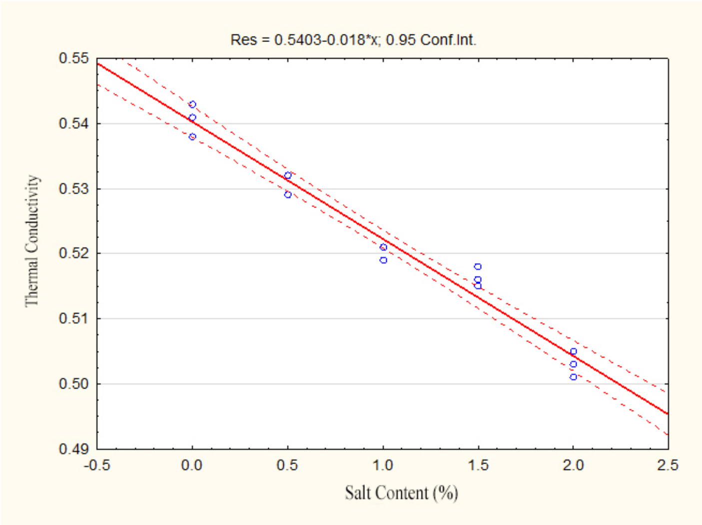

Fig. 3. *Regression model of salt percentage and thermal conductivity*

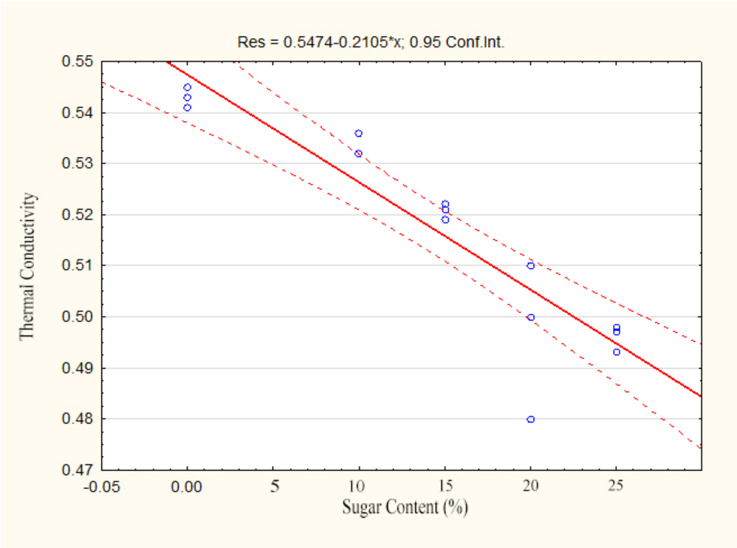

Fig. 4. *Regression model of sugar percentage and thermal conductivity*

Carvalho et al. [3] showed that higher salt concentration caused decrease of thermal conductivity in salt solutions. Accordingly, thermal conductivity of salt solution with 0.04 and 0.2% salt were 0.583 and 0.513W·m^{-1}·°C^{-1}, respectively.

In general, increasing salt concentration will reduce the amount of thermal conductivity. The specific heat of the water is 1cal/g°C and the specific heat of saturated salt solutions amounts to about 0.786cal/°C. By increasing the concentration of sodium chloride, the structure of hydrogen bonds of water is destroyed. As a result, the number of hydrogen bonds in the presence of salt is lower than in pure water. Most water molecules have also been found to be hydrated with salt ions, which reduce the ability of water molecules to absorb heat, resulting in a reduction in thermal properties such as thermal conductivity and specific heat in the presence of salt.

Sugar percentage also affects the thermal conductivity of puree. There is an inverse relationship between the added sugar content and the amount of thermal conductivity in this product. The thermal conductivity of barberry puree with 0% and 25% sugar content were 0.532 and 0.498W·m^{-1}·°C^{-1}, respectively (Figure 4). Carvalho et al. [3] reported that the thermal properties of saline solutions with different concentrations that increased salt concentration caused a decrease in thermal conductivity. Villa-Vélez et al. [15] showed that the addition of maltodextrin (0-28%) to fruit juice decreased thermal conductivity. The thermal characteristics of food products are mainly generated by the amount of water present in them and the structure of these compounds.

Table 4 shows the relationship between test variables (temperature, moisture, salt content and sugar percentage) and the thermal conductivity of barberry puree.

Table 4

Regression equations. Relationship between different characteristics of barberry puree and thermal conductivity

Temperature [ºC]	k= 0.484+0.002x
Moisture content [%]	k=0.337+0.008x
Salt content [%]	k= 0.54-0.018x
Sugar content [%]	k=0.547-0.21x

k: Thermal conductivity [W/m°C]

4. Conclusion

Temperature, moisture content, salt percentage and sugar content have a significant effect on the thermal properties (specific heat and thermal conductivity) of barberry puree. The determination coefficient (R^2) of linear models for the specific heat of barberry puree and the variables of temperature, moisture content, salt percentage and sugar were 0.908, 0.909, 0.988 and 0.821, respectively. The determination coefficient (R^2) of the linear model for thermal conductivity of barberry puree and the temperature, moisture percentage, salt percentage and sugar content were 0.789, 0.938, 0.969 and 0.830, respectively.

Conflicts of interest:

The author declares that there is no conflict of interests.

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Annex

Definition	Symbol	Unit
Specific heat	C_p	kJ/kg°C
Specific heat of water	C_w	cal/g.°C
Thermal capacity of capsule	H_c	cal/°C
Thermal capacity of flask	H_f	cal/°C
Thermal conductivity	k	w/m°C
Moisture content	M_c	%
Cold water weight	M_{cw}	g
Hot water weight	M_{hw}	g
Sample weight	M_m	g
Time	t	s
Temperature	T	°C
Capsule temperature	T_c	°C
Cold water temperature (in the flask)	T_{cw}	°C
Hot water temperature (in the flask)	T_{hw}	°C
Equilibrium temperature	T_e	°C
Sample temperature	T_m	°C
Temperature difference	$T\Delta$	°C