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Measurement and Prediction of Some Thermal Properties of 'Hashi' Camel Meat

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Abstract. Thermal conductivity and thermal diffusivity of 'Hashi' camel meat were measured and predicted over a temperature range from 5-45°C. Thermal conductivity and thermal diffusivity were determined using a line heat source probe. The obtained values for thermal conductivity varied from 0.482 to 0.494 W/m.°C and the percent standard errors varied from 3.2 to 5.2%. The thermal diffusivity values varied from 1.26×10^{-7} to 1.29×10^{-7} m^2/s and the percent standard errors varied from 8.7 to 12.3%. Experimental values of the 'Hashi' camel meat were compared with the thermal conductivities and thermal diffusivities calculated using different empirical models.

Introduction

The 'one-hump' dromedary camel (*Camelus dromedarius*), also known as the Arabian camel is adapted to life in the Arabian deserts by its structural qualities and by its ability to bite off and consume the thorny plants that grow there. It has a woolly coat, caramel in color that may look unkempt due to seasonal shedding; it also provides milk, hides, and meat.

The best camel meat comes from young male 'Hashi' camels. It is regarded as a delicacy in the Arabian diet, and is gaining popularity in arid lands where it is difficult to herd sheep, cattle and goats. The meat of young camel is widely consumed in the Central region of Saudi Arabia and is said to taste similar to veal. It is available directly from retail meat stores as fresh cooled cuts. Camel meat is a good source of protein and its amount is generally similar to the amount in beef, ranges between 18.71 and 19.52 g protein/100g meat [1].

Owing to the hot and harsh environmental conditions in the country as well as the absence of proper cooling and freezing installations, the shelf life of such meat is likely to be very short [2]. Thermal processing of meat including heating, cooling, and freezing have been extensively investigated for the preservation of beef, goat and other types of meat [3-8]. Values for the thermal 153 rties of camel meat are not available in the literature. The efficient design of ssing operations requires knowledge of the thermal properties of the product being processed.

Thermal conductivity and thermal diffusivity can be determined experimentally based on steady state or transient methods. Reidy and Rippen [9] and Singh [10] provided an extensive review of methods used for experimental determination of thermal conductivity and thermal diffusivity values. Based on experimental data, many empirical and semi-empirical models for predicting both properties have been suggested [11-13]. One of the most efficient and practical way to obtain the values of thermal properties for various process conditions is by using mathematical models which are based on major components of a specific food product [14]. Hence, the present study was undertaken to determine experimentally the thermal conductivity and diffusivity of fresh 'Hashi' camel meat over a temperature range from 5 to 45°C using a line heat source probe. Another objective was to compare measured conductivities and diffusivities with predicted values obtained from existing thermal property models.

Materials and Methods

The fresh meat of an 18 months old 'Hashi' Najdi camel was used throughout this work. It was purchased from a local meat company in Riyadh. The meat was taken from the 'red' muscles of the hip and thigh. All visible fat was removed from the muscle tissues before they were minced and subsequently analyzed. An ordinary household mincer/mixer was used for mincing and mixing when required. Both the mincing and mixing processes helped to render homogeneous minced meat with the least voids when filling into the test cylinders.

The apparatus

The single-needle KD2 thermal properties meter (Decagon Devices, Inc., Pullman, Washington, USA) was used to measure both the thermal conductivity and diffusivity simultaneously. The device is based on the line source probe theory as it uses a simple yet precise heating and monitoring system to measure the slope and intercept of the sample specific temperature rise vs. time curve. From this data, thermal conductivity and thermal diffusivity are derived. The basic theory behind the use of line source probe has been discussed previously by Hooper and Lepper [15] and Nix *et al*. [16].

The length and diameter of the needle are 60 and 0.9 mm, respectively. The ratio of the probe length to diameter is more than 60 giving an axial flow error of less than 0.035% [17]. The probe is heated at a constant rate and the change in temperature at the center of the food sample is noted at a short distance. The values of thermal conductivity (k) and diffusivity (α) are calculated by monitoring the dissipation of heat from a line heat source given a known voltage. Hobani and Elansari [18] have discussed the equations used for the calculation of these properties.

Experimental Procedure

Thermal conductivity and diffusivity values for 'Hashi' Najdi camel meat with moisture content 78% were measured over the temperature range 5 to 45°C. 'Hashi' meat samples were packed in copper tubes (15mm diameter) within minutes of mixing, and then the single needle was inserted into each sample through a hole in the copper tube lid. The meat samples were firm with no evidence of free water when placed in the copper tubes. Three samples for each temperature (5, 20, 35 and 45°C) were immersed in a controlled temperature water bath and allowed to equilibrate to the desired temperature over a period of 45-60 min. The probe was calibrated using 99.5% pure glycerol (WINLAB, Leicestershire, UK) as a reference material.

Results and Discussion

Thermal conductivity

Thermal conductivity experimental values for 'Hashi' camel meat at different temperatures appear in Table 1. Standard deviations (SD) ranged between 3.2 and 5.2%, with higher deviations found at higher temperatures.

Table 1. Thermal conductivity and diffusivity experimental values of 'Hashi' camel meat

Temperature (°C)	Thermal conductivity (*k*) (W/m.°C)	%SD	Thermal Diffusivity (*α*) ($\times10^{-7}$ m^2/s)	%SD
5	0.482	3.2	1.26	12.1
20	0.491	4.5	1.27	9.5
35	0.493	5.2	1.27	12.3
45	0.494	3.8	1.29	8.7

The proximate composition of lean raw meat taken from the leg of a 'Hashi' camel is presented in Table 2. The sum of the percentages of moisture content, protein, fat and ash does not necessarily equal 100% because the amounts of each of these components were independently ascertained [1].

Table 2. Proximate composition of 'Hashi' camel meat*

Meat Cut	Composition			
	Protein	**Fat**	**Moisture**	**Ash**
Thigh	18.88 ± 0.76	1.4 ± 0.4	78.4 ± 0.92	1.13 ± 0.1

*Mean (g/100 g) of a total of seven individual meat samples.

Four different empirical models were considered for the prediction of thermal conductivities of the 'Hashi' meat with the tested range of temperature and composition. Unlike other models, empirical models are commonly and widely used for their simplicity and accuracy [19]. The selected models were specifically developed for meat, Sorenfors [20] and Comini *et al*. [21] models were used for minced meat, Sweat [13] model was applied for a narrow temperature range above freezing because temperature is not included. The model is not accurate for the porous food containing air, and adding air as another component in this model is generally unsatisfactory. The model considers the Protein, Fat and Ash content, as a function of the thermal conductivity. Spells [22] model was considered by Pham [23] to obtain the conductivity of various kinds of meat. Comini *et al*. and Spells models deemed only the moisture content as the main parameter, which influenced the thermal conductivity. Sorenfors model, however, considered both the temperature and the water content as the influencing factors on thermal conductivity. To use these models, the values of thermal conductivities and densities of meat major components must be known. The thermal conductivities and densities of protein, fat, water and ash used in the models are listed (Table 3) using Choi and Okos models [14]. Thermal conductivity varies with chemical composition, density or porosity and temperature whilst the density of food materials depend mainly on temperature and compositions. Data on thermal conductivity and density obtained from prediction equations of the major food components of Choi and Okos [14] were used in the prediction of thermal conductivity of 'Hashi' camel meat using the four different empirical models considered for this study. Models equations used for the prediction of thermal conductivity are summarized in Table 4.

Table 3. Thermal conductivity (k) and density (ρ) of protein, fat, water and ash from Choi and Okos [14]

Temp.	Protein		Fat		Water		Ash	
	k (W/m.°C)	ρ (kg/m^3)	k (W/m.°C)	ρ (kg/m^3)	k (W/m.°C)	ρ (kg/m^3)	k (W/m.°C)	ρ (kg/m^3)
5	0.1849	1327	0.1672	923	0.5796	997	0.3229	2422
20	0.2019	1320	0.1257	917	0.6035	997	0.3008	2418
35	0.2177	1312	0.0842	911	0.6244	997	0.2774	2414

45	0.2275	1307	0.0564	907	0.6366	997	0.2611	2411

Sweat and Spells models were identical and the closest to the measured values where the error reached a minimal value of 0.61%. The Sorenfors model did not fit the measured values well with standard deviation range from the measured values of 13-33% at 25-50°C, though it was recommended specifically for meat. The Comini *et al*. model [21], however, shows reasonably good fit with a standard deviation error of 5.49%. Hence, the thermal conductivities of 'Hashi' camel meat can be predicted by Sweat and Spells models.

Table 4. Different models used for thermal conductivity (*k*) prediction

Model	Equation	*k* (W/m.°C)	Temp. range (°C)	%SD
Sorenfors	$k_e = 0.049 + 0.34X_w + 2.4\times10^{-3}T$	0.327- 0.423	25-50	13-33
Comini *et al.*	$k_e = 0.26 + 0.33X_w$	0.518	25-50	5.49
Sweat	$k_e = 0.58X_w + 0.155X_p + 0.25X_c + 0.135X_a + 0.16X_f$	0.487	25	0.61
Spells	$k_e = 0.08 + 0.52X_w$	0.487	0-60	0.61

The subscripts stand for various components: *w* = water, *p* = protein, *c* = carbohydrate, *a* = ash, *f* = fat, and *e* = estimated (predicted).

Thermal diffusivity

Experimental data for 'Hashi' camel meat thermal diffusivity at different temperatures are listed in Table 1. The experimental values varied from 1.26×10^{-7} to 1.29×10^{-7} m^2/s with percent standard errors ranging between 8.7 and 12.1%. Thermal diffusivities were found to slightly increase with increasing temperature, a behavior found with other moist foods [24]. Poulsen [25] reported a value of thermal diffusivity of 1.46×10^{-7} m^2/s for meat with a moisture content of 74% at a temperature range of 0-50°C, while Singh [10] reported values ranged from 1.23×10^{-7} to 1.33×10^{-7} m^2/s at the temperature rang of 40 to 65°C and 66 to 71% moisture contents.

Table 5, shows data of predicted thermal diffusivities using two different models selected to compare the predicted with experimental values. The first one was Riedel model [26], suggested for water rich liquid and solid foods containing at least 40% water in the temperature range of 0 to 80°C. The model was developed to predict the thermal diffusivity as a function of water content using a wide range of food products. Dickrson and Read [27] used this model to predict the thermal diffusivity of a variety of meat and found good agreement with experimental values. The second model was developed by Martens [28], where he used a regression analysis on 246 published values on thermal diffusivity of a variety of food products including meat. As can be seen from the percent standard errors for both models (Table 5), both models agreed well with the experimental data. Martens model is thought to be more applicable as it takes into consideration both the temperature and the moisture content.

Conclusion

Thermal conductivity and thermal diffusivity of 'Hashi' camel meat have been measured and modeled in the temperature range 5 to 45°C. Four different models and another two different ones were considered for the prediction of thermal conductivity

Table 5. Different models used to predict thermal diffusivity (α)

Model	Equation	α ($\times 10^{-7}$ m²/s)	% SD	Temp. (°C)
Riedel	$\alpha = 0.88\times10^{-7} + \left[\alpha_w - 0.88\times10^{-7}\right]\times X_w$	1.328	4.76	35
Martens	$\alpha = \left[0.057363 X_w + 0.000288\left(T + 273\right)\right]\times10^{-6}$	1.250	0.79	5
		1.293	1.57	20
		1.336	5.51	35
		1.365	6.20	45

The subscripts *w* stands for water.

and thermal diffusivity, respectively, in 'Hashi' camel meat. Among the first four models, Sweat and Spells models were found to give good thermal conductivity values and their accuracy is probably sufficient for most engineering computations. For thermal diffusivity, both models selected for the prediction were found to perform well over the selected range of temperature.

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القياس والتنبؤ ببعض الخواص الحرارية للحم الحاشي

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الرياض ١١٤٥١ ، المملكة العربية السعودية

(قدم للنشر في ١٤٢٣/١١/١٥هـ ؛ وقبل للنشر في ١٤٢٤/٤/٨هـ)

ملخص البحث. تم في هذه الدراسة قياس والتنبؤ بمعامل التوصيل الحراري ومعامل الانتشار الحراري للحم الحاشي باستخدام طريقة المصدر الحراري الخطي في مدى درجة حرارة تراوح من ٥ إلى ٤٥ْم وقد كان المحتوي الرطوبي للعينات المختبرة ٧٨% (علي أساس رطب).. تراوحت قيم معامل التوصيل الحراري من ٠,٤٨٢ إلى ٠,٤٩٤ وات/متر.ْم بخطأ قياسي تراوح من ٣,٢ إلى ٥,٢%، في حين تراوحت قيم معامل الانتشار الحراري من ١,٢٦×١٠$^{-٧}$ إلى ١,٢٩×١٠$^{-٧}$ م^{٢}/ث بخطأ قياسي

تـراوح مـن ٨,٧ إلـي ١٢,٣%. كـذلك تمـت مقارنـة القـيم المقاسـة مـع قـيم معامـل التوصـيل الحـراري ومعامـل الانتشـار الحـراري المحسـوبة مـن نمـاذج تجريبيـة مختلفـة. وتشـير نتـائج هـذه المقارنـة أنـه يمكـن تمثيـل قـيم معامـل التوصـيل الحـراري باسـتخدام نمـوذجي سـويت (Sweat) وسـبلز (Spells) بصـورة جيـدة. أمـا بالنسـبة لمعامـل الانتشـار الحـراري فإنـه يمكـن تمثيـل قيمـه باسـتخدام نمـوذجي ريـدل (Riedel) ومـارتنز (Martens) بصـورة جيدة كذلك.