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Thermal properties of cryo-ground fenugreek powder

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Abstract

Thermal properties, *viz*., specific heat, thermal conductivity and thermal diffusivity of fenugreek (cv. *AM-2*) powder were determined. Specific heat increased from 295.9 to 5794.4 J kg^{-1} K^{-1} with increasing temperature from -150°C to 100°C and moisture content from 5.5% to 25.2% d.b. and exhibited second order polynomial relationship. Thermal conductivity and thermal diffusivity ranged from 0.140-0.186 W m^{-1} K^{-1} and 8.13×10^{-6}-11.38×10^{-6} m^2 s^{-1}, respectively with increasing moisture content. Thermal conductivity and thermal diffusivity showed quadratic relationships with moisture content. Specific heat of fenugreek powder was significantly affected by moisture content and temperature ($P<0.01$), while thermal conductivity and thermal diffusivity were significantly affected by moisture content ($P<0.01$).

Keywords: differential scanning calorimetry, fenugreek, specific heat, thermal conductivity

Introduction

Fenugreek (*Trigonella Foenumgraecum* L.) is dried ripe fruit of an annual herb of *Leguminosae* family. It is used as a herb (leaves) and as a spice (seed). Seeds are small, hard, smooth and oblong and yellowish brown in colour. It contains many vital substances like proteins, starch, sugars, mucilage, mineral matter, volatile oil, fixed oil, vitamins and enzymes. It possesses medicinal properties and there is a significant hypoglycemic effect especially for diabetic patients (Blumenthal *et al*. 2000). Fresh tender leaves and shoots of fenugreek, eaten as vegetables, are rich in iron, calcium, protein, vitamins A and C.

Generally, mechanical process of grinding is used for size reduction or producing powder of agricultural materials including spices e.g. fenugreek. In this process, the temperature of the powder rises to as high as 90°C resulting in losses of essential oils, aroma and colour. Quality of powder can be retained using cryogenic grinding technique (Singh & Goswami 2000; 2006). For designing a cryogenic grinding system and for simulation and modelling of heat transfer phenomenon in

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the grinder, information on thermal properties are essential (Singh & Goswami 2000; 2006).

Several researchers have investigated thermal properties of agricultural materials using Differential Scanning Calorimetry (DSC) such as for gram (Dutta *et al*. 1988), cumin seed (Singh & Goswami 2000), borage seeds (Yang *et al*. 2002), minor millet grains and flours (Subramanian & Viswanathan 2003), guna seed (Aviara *et al.* 2008) etc. Cylindrical devices were used to employ one-dimensional, steady state heat transfer equation in cylindrical coordinates to ascertain bulk thermal conductivity of agricultural materials. A cylindrical device with a line heating source at centre has also been used to ascertain thermal conductivity of a variety of materials based on transient heat transfer analysis (Singh & Goswami 2000).

Information on thermal properties is useful for researchers, engineers, processors and other scientists who may make use for various applications in food processing and design of process equipments related to heat transfer e.g. simulation and modelling of heat transfer phenomenon in grinder and storage, and thermal modeling for determination of heat transfer coefficient etc. Hence, thermal properties of cryo-ground fenugreek powder were studied. Variation of specific heat with moisture content and temperature and that of thermal conductivity and diffusivity with moisture content at constant temperature (30°C) were also investigated.

Materials and methods

Sample preparation

Fenugreek (cv. *AM-2*) was procured from National Research Centre on Seed Spices, Ajmer, Rajasthan (India) in May 2009. Seeds were cleaned manually and broken, foreign matter, split, deformed and immature seeds were discarded for sample preparation.

Initial moisture content of fenugreek seed was determined by vacuum oven method (Ranganna 1986) using partial ground fenugreek and was found to be 11.2% d.b. (dry basis). Initially, seeds were stored at room temperature (25°C) for 2 to 3 weeks. For experimentation, four levels of moisture content (5.5%, 11.3%, 17.8% and 25.2% d.b.) were selected. To achieve desired low moisture content level, a predetermined quantity of fenugreek was dried in tray dryer at a temperature of 50°C. To achieve high moisture contents, calculated amount of water was added and mixed thoroughly to ensure uniform distribution of moisture. Samples were packed in low density polyethylene (LDPE) pouches and kept at 5°C for 48 h in refrigerator for uniform distribution of moisture. The pouches were taken out from refrigerator and allowed to equilibrate at room temperature for 2-3 h prior to experimentation.

Experimentation and observation

Experiments were conducted in Thermal and Physical Properties Laboratory at IIT, Kharagpur, India in September 2009. Conditioned fenugreek samples were ground in the grinder (Model Pulverisette 14, Fritsch Industries, Germany) using liquid nitrogen (LN_2) so that properties of fenugreek do not vary significantly. The ground fenugreek samples, thus obtained, were adjusted to four levels of moisture content (5.5%, 11.3%, 17.8% and 25.2% d.b.) for determination of thermal properties.

Specific heat of fenugreek samples was determined using DSC (model: NETZSCH DSC 204). DSC was calibrated for a range of -150°C to 350°C. To determine the specific heat, fenugreek samples were kept in an aluminium crucible in small quantity (between 13.0-15.2 mg) at all four moisture levels. Aluminium crucible was closed and run in DSC for the temperature range of -150-350°C. Under this experiment, thermograms were obtained and variation of specific heat with temperature were determined by the method reported by Singh & Goswami (2000; 2006) for each moisture content. Considering that most of the spice grinding (cryogenic as well as conventional) takes place between temperature ranges of -150°C to 100°C, the data was taken between -150°C to 100°C for analysis.

A thermal conductivity meter (Model: Kemtherm QTM-D3) was used for determination of thermal conductivity. Thermal conductivity meter was calibrated using standard reference plate. After calibration, a sample pan of volume 100 cm^3 was filled with fenugreek samples for determination of thermal conductivity. Weight of fenugreek sample in pan was also measured to calculate bulk density of the samples. Experiments were conducted in triplicate at four moisture levels at average sample temperature of 30°C in thermal conductivity meter and the mean values were used for the study.

Thermal diffusivity of fenugreek samples was calculated from experimentally obtained values of specific heat, thermal conductivity and density at 30°C using Eq.(1) (Singh & Goswami 2000):

$$\alpha_b = (k_b) / (\rho_b C_p) \quad (1)$$

where: α_b=bulk thermal diffusivity, $m^2\ s^{-1}$; k_b=bulk thermal conductivity, $W\ m^{-1}\ K^{-1}$; C_p=specific heat, $J\ kg^{-1}\ K^{-1}$ and ρ_b=bulk density, $kg\ m^{-3}$.

Statistical analysis

Thermal properties data were analysed using Statistica 6.0 and Microsoft Excel 2003 softwares for obtaining the variation of specific heat with temperature and moisture content. Analysis of variance (ANOVA) test was also performed (Table 1).

Results and discussion

Specific heat

Specific heat of fenugreek increased from 295.9 to 5794.4 $J\ kg^{-1}\ K^{-1}$ with increasing moisture content from 5.5-25.2% d.b. (Fig. 1). A similar trend was reported for the specific heat of guna seed (Aviara *et al*. 2008), clove (Singh & Goswami 2006), cumin seed (Singh & Goswami 2000), soybean (Aviara *et al.* 2003; Deshpande & Bal 1999), sheanut kernel (Aviara & Haque 2001) and borage seed (Yang *et al.* 2002). Specific heat was affected significantly ($P<0.01$) by moisture content and temperature (Table 1). Relationships of specific heat with temperature and moisture content (Table 2) will be helpful in predicting specific heat at different moisture content and temperature. Specific heat increased from 295.9 to 5794.4 $J\ kg^{-1}K^{-1}$ with increasing moisture content from 5.5-25.2% d.b. and temperature from -150 to 100°C (Figs. 1 & 2).

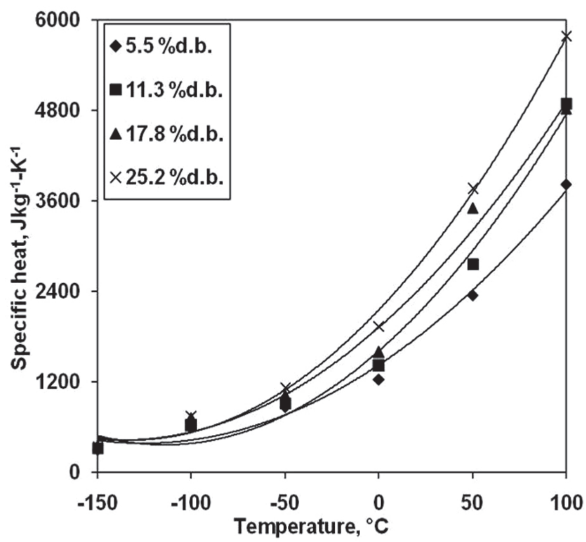

Fig. 1. Influence of temperature on specific heat of cryo-ground fenugreek powder (var. AM-2)

Table 1. ANOVA for specific heat, thermal conductivity and thermal diffusivity

Source	d.f.	Mean Square	F-value	p-value
Specific heat				
Moisture content	1	43146001	31.2*	1.19E-06
Temperature	1	44981469	32.5*	8.14E-07
Thermal conductivity				
Moisture content	1	435.23	12.1*	0.013289
Thermal diffusivity				
Moisture content	1	444.77	12.3*	0.01269

*Significant at $P<0.01$

F tabulated values at degree of freedom 1, 46 is 7.22 and 1, 6 is 5.99

Table 2. Second order regression equations for specific heat of cryo-ground fenugreek powder with respect to temperature and moisture content

Parameter		Regression equation	r^2
Moisture content, M (% d.b.)	5.5	$C_p = 0.066T^2 + 16.58T + 1421$	0.987
	11.3	$C_p = 0.095T^2 + 21.82T + 1611$	0.986
	17.8	$C_p = 0.08T^2 + 21.88T + 1917$	0.984
	25.2	$C_p = 0.099T^2 + 26.16T + 2157$	0.994
Temperature, T (°C)	-150	$C_p = -0.264M^2 + 10.65M + 242.6$	0.947
	-100	$C_p = 0.010M^2 + 7.819M + 554.0$	0.923
	-50	$C_p = 0.182M^2 + 8.007M + 814.8$	0.995
	0	$C_p = 0.681M^2 + 14.45M + 1140$	0.995
	50	$C_p = -1.795M^2 + 130.7M + 1641$	0.976
	100	$C_p = -0.969M^2 + 118.5M + 3332$	0.874

C_p=Specific heat; r^2=Coefficient of determination

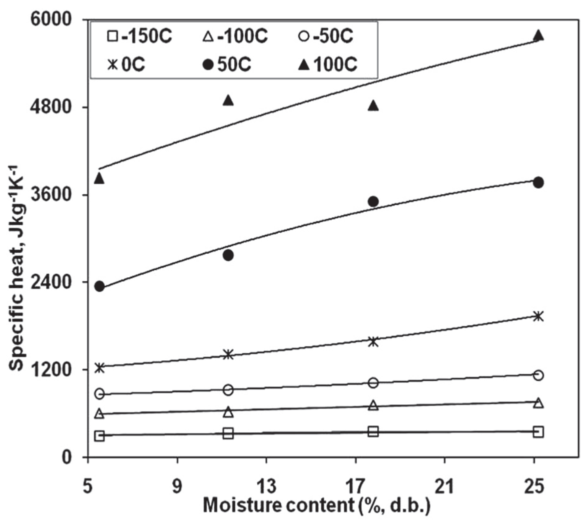

Fig. 2. Influence of moisture content on specific heat of cryo-ground fenugreek powder (var. AM-2)

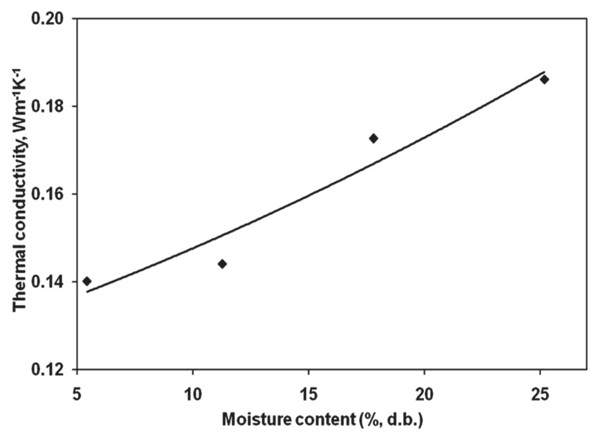

Fig. 3. Influence of moisture content on thermal conductivity of fenugreek sample at 30°C

Bulk thermal conductivity

Thermal conductivity increased from 0.140 to 0.186 W m^{-1} K^{-1} by increasing moisture content from 5.5-25.2% d.b. (Fig. 3). Similar trend was reported for guna seed (Aviara *et al*. 2008), cumin seed (Singh & Goswami 2000), sheanut kernel (Aviara & Haque 2001), borage seed (Yang *et al*. 2002) rough rice (Yang *et al*. 2003), and millet grains (Subramanian & Viswanathan 2003). It was affected significantly by moisture content at 1% level of significance (Table 1). The relationship between thermal conductivity and moisture content can be expressed by regression Eq (3):

$$k_b = 2\times10^{-5} M^2 + 0.0018M + 0.1273 \quad (r^2 = 0.94) \quad (3)$$

For 5.5% $d.b. \leq M \leq 25.2\%$ $d.b.$

Similar results were reported by Singh & Goswami (2000) for cumin seeds.

Bulk thermal diffusivity

Thermal diffusivity increased from 8.13×10^{-6} to 11.38×10^{-6} m^2 s^{-1} with increasing moisture content within studied moisture range (Fig. 4). It was affected significantly by moisture content at 1% level of significance (Table 1). Regression relationship between thermal diffusivity with moisture content can be represented by Eq. (4):

$$\alpha_b = -0.007M^2 + 0.3699M + 6.5521 \ (r^2 = 0.99) \quad (4)$$

For 5.5% *d.b.* $\leq M \leq$ 25.2% *d.b.*

In published literature, relationship between thermal diffusivity (α_b) and moisture content have been reported both in ascending (gram, Dutta *et al*. 1988) and descending [borage seeds, Yang *et al*. (2002) and cumin seed, Singh & Goswami (2000)] trends. Magnitude of α_b

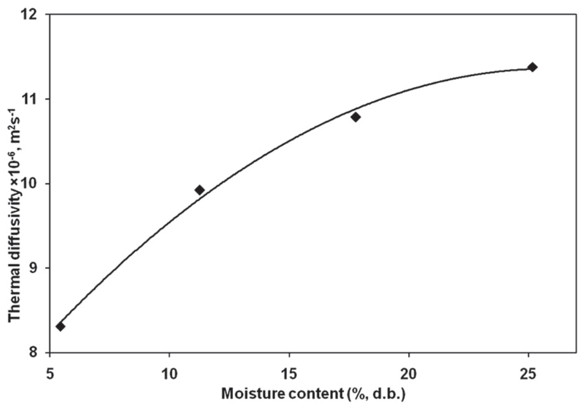

Fig. 4. Influence of moisture content on thermal diffusivity of fenugreek sample at 30°C

depends on the combined effect of k_b, ρ_b and C_p. When value of k_b increases faster than that of ρ_b and C_p at same temperature and moisture ranges, thermal diffusivity would increase with increase in moisture content.

Specific heat of cryo-ground fenugreek powder significantly increased from 295.9 to 5794.4 J $kg^{-1} K^{-1}$ with the increasing moisture content from 5.5-25.2% d.b. and temperature from -150°C to 100°C. Bulk thermal conductivity increased from 0.140 to 0.186 W $m^{-1} K^{-1}$ and bulk thermal diffusivity from 8.13 to 11.38 × 10^{-6} $m^2 s^{-1}$, with increasing moisture content from 5.5-25.2% d.b. at 30°C.

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