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Determination of thermal properties of cryo- ground cinnamon powder

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Abstract

In this study, thermal properties, *viz.*, specific heat, thermal conductivity and thermal diffusivity, of cryo- ground cinnamon powder (var. *Navasree*) were investigated. Cinnamon samples were ground using a cryogenic grinder at low temperature (generally below -50°C) using liquid nitrogen (LN_2), having a grinder speed of 12000 rpm and 1 kg h^{-1} feed rate. The specific heat varied from 46.60-58.04 kJ kg^{-1}°C within the temperature and moisture ranges of -100 - 100°C and 6.4-19.0% dry basis, respectively. Thermal conductivity and thermal diffusivity varied from 0.055 to 0.884 W m^{-1}°C and 0.35×10^{-8} - 7.23×10^{-8} m^2 s^{-1}, respectively in the temperature and moisture ranges of -40-60°C and 6.4-19.0% db. The specific heat, thermal conductivity and thermal diffusivity showed quadratic relationships with temperature and moisture content and were significantly affected by moisture and temperature at 5% level of significance.

Keywords: cinnamon, cryogenic grinding, specific heat, thermal diffusivity

Cinnamon (C*innmomum zeylanicum,* family *lauraeae)* is native to Sri lanka and India. It is extensively used as a spice or condiment in the form of small pieces or ground form. It is principally employed in cookery as a condiment and flavouring material. Cinnamon barks contain essential oil (0.5-1.0% of its composition) (Anon 2013). It is being largely used in the preparation of some kinds of desserts, chocolate, candies, tea and liqueurs. Cinnamon contains antioxidant activity and also antimicrobial properties (Baratta *et al.* 1998; Jayaprakasha *et al.* 2003). Grinding is one of the most common unit operations which are used to prepare ground agricultural materials. Cinnamon bark can be converted to powder by the mechanical process of grinding which increases the temperature to as high as 42- 95°C (Singh & Goswami 1999), which leads to losses of essential oils and quality deterioration. Cryogenic grinding is a novel and innovative grinding technique which helps in maintaining good colour, flavour, aroma and volatile oil of the ground product (Singh & Goswami 1999).

Thermal properties of agricultural materials are greatly affected by its temperature and moisture content. In general, specific heat is represented by a function of moisture content using linear

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relations (Mohsenin 1980). In earlier work, the effect of temperature on specific heat of agricultural materials was generally not considered (Singh & Goswami 2000). The differential scanning calorimetry (DSC) facilitates the measurement of specific heat as a function of temperature. Various investigators have studied the thermal properties of agricultural materials using DSC and thermal conductivity meter such as for cumin seed (Singh & Goswami 2000), gram (Dutta *et al.* 1988), minor millet grains and flours (Subramanian & Viswanathan 2003). The effect of moisture content and temperature on the specific heat of potato using DSC was studied by Wang & Brennan (1993). Thermal properties of cryogenic ground cinnamon powder is useful for further cinnamon food applications. Therefore, the objective to this study was to investigate the effect of moisture and temperature on some major thermal properties such as specific heat, thermal conductivity and thermal diffusivity of cryogenicaly ground cinnamon powder.

The experiments were conducted at Central Institute of Post Harvest Engineering and Technology, Ludhiana.

Cinnamon barks (var. *IISR Navasree*) were procured from Indian Institute of Spices (IISR), Kozhikode, Kerala for present study. Barks were cleaned manually to remove undesirable material and broken into smaller pieces and passed through BSS 10 sieve (width opening: 1.676 mm). The initial moisture content of cinnamon bark was determined by the vacuum oven method (Ranganna 1986) at a temperature of 80°C and pressure of 100 mm Hg until a constant weight was obtained. The initial moisture content of cinnamon barks was found as 10.6% db. The moisture contents of broken cinnamon bark were tuned to 6.4%, 10.0%, 13.6% and 19.0% db. The samples were dried in vacuum drying oven at 72°C (recording moisture content at every 15 min interval) to achieve 6.4% and 10% db moisture content. To achieve 13.6% and 19% db moisture content, calculated amount of distilled water was mixed with broken cinnamon barks (Barnwal *et al.* 2010) and were kept at 5°C in a refrigerator for one week to allow uniform moisture distribution. The prepared samples (400 g) were ground in a lab model cryogenic grinder (Model: 100 UPZ, Hosokava Alpine, Germany, below -50°C) using liquid nitrogen (LN_2) at 1 kg h^{-1} feed rate and 12000 rpm grinder speed. The cryogenic ground cinnamon powder samples were packed in sealed, moisture free and water proof flexible polythene bags for further determination of thermal properties.

Specific heat (C_p, J kg°C^{-1}) of the cryogenic ground cinnamon samples at all moisture content were determined by using the Differential Scanning Calorimeter (DSC 6000 Perkin Elmer, USA) operated by Pyris software. Prior to experiments, DSC was calibrated using indium at scanning rate of 10°C min^{-1}. For determination of specific heat, the cryogenically ground cinnamon bark samples were kept in an aluminium crucible (capacity 10 μL) in small quantity (5.0-5.5 mg). The aluminium crucible was sealed and run in DSC for temperature range of -100°C to +100°C. The thermograph was obtained for variation of specific heat with temperature. All experiments were performed in triplicate and the mean values were reported.

Bulk thermal conductivity (k_b, W m°C^{-1}) was measured by using a portable digital thermal conductivity meter (Model: KD-2 PRO, Decagon Devices, Inc. USA). The cryogenically ground cinnamon powder was filled into 100 mL beaker and tapped, then the beakers were covered using aluminium foils and stored over night in a deep freezer (Model: U 410-86, New Brunswick Scientific, England) at -50°C to obtain the values of thermal conductivity below 0°C. For the higher temperature i.e. above 0°C, the samples were put in recirculatory type tray dryer (BTPL, Kolkata, India) at 60°C for 6 h. The thermal conductivity meter was calibrated using glycerine. After calibration, the sample was taken out from the deep freezer and immediately the single probe needle (KS-1, 1.3 mm diameter × 60 mm long) of the thermal conductivity meter was inserted in the sample and data were recorded at interval of 2 min from the digital thermal conductivity meter.

Average bulk density (ρ_b, kg m^{-3}) of cryogenically ground cinnamon powder at different moisture levels were determined by using standard method as described by Mohnsein (1980) and it was expressed as the ratio of mass (kg) by volume (m^3) of the cinnamon powder sample.

Bulk thermal diffusivity of cryogenically ground cinnamon powder was calculated from experimentally obtained values of specific heat, bulk thermal conductivity and bulk density using Eq. (1) (Singh & Goswami 2000):

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

where, α_b is bulk thermal diffusivity ($m^2 s^{-1}$), k_b is bulk thermal conductivity (W m°C^{-1}), C_p is specific heat (J kg°C^{-1}) and ρ_b is bulk density (kg m^{-3}).

Analysis of variance and regression analysis was carried out by using Microsoft Excel 2003 software to determine the correlation between the thermal properties, temperature and moisture content.

Variation of specific heat with temperature (-100-100°C) at all moisture contents is shown in Fig. 1. The specific heat of cryo-ground cinnamon powder was found to first decrease and then increase with increase in temperature to 100°C. This may be due to the fact that at lower temperatures there is less degrees of freedom i.e the water molecules move at a slower rate preceding the decrease in specific heat. The specific heat followed a second order

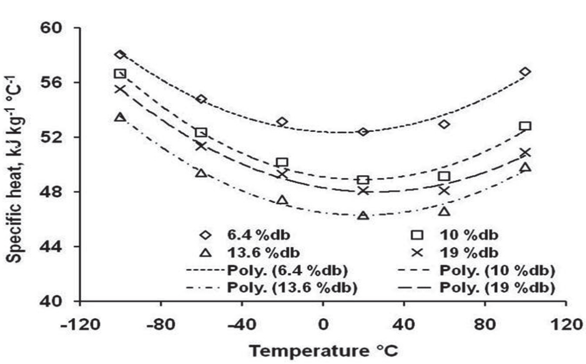

Fig. 1. Variation in specific heat of cryo-ground cinnamon powder with temperature

polynomial relationship with temperature at all the moisture contents. Nevertheless, other research workers (Tang *et al.* 1991; Wang & Brennan 1993) observed linear relations of specific heat with temperature for other agricultural materials. Specific heat was found to be a second order polynomial for all the temperatures. Non linear correlation was also reported by other researchers (Dutta *et al.* 1988; Hsu *et al.* 1991). The average values of specific heat varied from 46.12-57.92 kJ kg^{-1}°C in the range of temperature -100 to 100°C and moisture range of 6.4-19.0% db.

From Fig. 2 it was observed that the thermal conductivity increased with increase in moisture content. Similar trend was reported for thermal conductivity of cumin seed (Singh

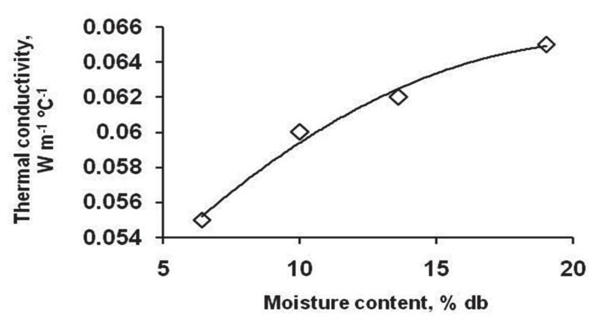

Fig. 2. Variation in thermal conductivity of cryo-ground cinnamon powder with moisture content at 35°C

& Goswami 2000) and millet grains (Subramanian & Viswanathan 2003). The thermal conductivity of cryogenically ground cinnamon powder samples at an average temperature of 35°C increased from 0.055-0.065 W m^{-1}°C with increase in moisture content from 6.4-19% db. The analysis of variance (Table 1) for thermal conductivity showed that both temperature and moisture content significantly affected thermal conductivity at 5% level. The thermal conductivity at given temperature followed second order polynomial relationship at all moisture contents under study (Table 2). The thermal conductivity followed quadratic relationship for all the temperatures at all the moisture contents (Table 3). Similar results were reported by Singh & Goswami (2000) for cumin

Table 1. ANOVA for specific heat, thermal conductivity and thermal diffusivity of cryo-ground cinnamon powder

Source	d.f.	Mean Square	F-value
Specific heat			
Moisture content	3	87.634	80.346*
Temperature	4	6.402	5.307*
Thermal conductivity			
Moisture content	3	1.932E-02	3.199*
Temperature	4	1.410	233.454*
Thermal diffusivity			
Moisture content	3	1.645E-03	4.762*
Temperature	4	8.060E-15	133.439*

*Significant at $P<0.05$

Table 2. Regression analysis of thermal properties with temperature at different moisture content

Sl. No	Thermal properties	Moisture (% db)	Regression equation	R^2
1	Thermal conductivity	6.4	$k = 7E\text{-}05T^2 - 0.009T + 0.300$	0.97
		10	$k = 9E\text{-}05T^2 - 0.010T + 0.332$	0.98
		13.6	$k = 6E\text{-}05\,T^2 - 0.010\,T + 0.427$	0.97
		19	$k = 0.0001\,T^2 - 0.0100\,T + 0.2960$	0.99
2	Specific heat	6.4	$C_p = 0.0005\,T^2 - 0.0089\,T + 52.3916$	0.96
		10	$C_p = 0.0006\,T^2 - 0.0213\,T + 49.1165$	0.98
		13.6	$C_p = 0.0005\,T^2 - 0.0198\,T + 46.4842$	0.98
		19	$C_p = 0.0005\,T^2 - 0.0245\,T + 48.3024$	0.99
3	Thermal diffusivity	6.4	$\alpha = 5E\text{-}12\,T^2 - 6E\text{-}10\,T + 2E\text{-}08$	0.96
		10	$\alpha = 7E\text{-}12\,T^2 - 7E\text{-}10\,T + 2E\text{-}08$	0.98
		13.6	$\alpha = 4E\text{-}12\,T^2 - 8E\text{-}10\,T + 4E\text{-}08$	0.96
		19	$\alpha = 9E\text{-}12\,T^2 - 8E\text{-}10\,T + 3E\text{-}08$	0.99

seed. The average values of thermal conductivity varied from 0.055-0.884 W m°C^{-1} in the temperature range of -45-60°C and moisture range of 6.4-19.0% db.

From Fig. 3 it is clear that the thermal diffusivity decreased with increase in temperature at all moisture contents. The relationship between temperature and thermal diffusivity at different moisture contents was found to be polynomial (Table 2). Similar trend was observed by Kouchakzadeh & Tavakoli (2009) for Iranian pistachios. The thermal diffusivity of cryogenically ground cinnamon powder samples at an average temperature of 35°C

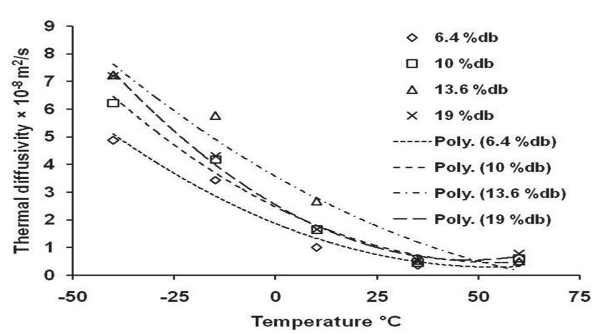

Fig. 3. Variation in thermal diffusivity of cryo-ground cinnamon powder with temperature

increased (Fig. 4) from 0.35×10^{-8}-0.57×10^{-8} m^2 s^{-1} with increase in moisture content from 6.4-19% db. The variation in thermal diffusivity

Table 3. Regression analysis of thermal properties with moisture at different temperatures

Sl. No	Parameter	Temperature	Regression equation	R^2
1	Thermal conductivity	-40	$k=-0.002M^2 + 0.0706\ M + 0.4507$	0.99
		-15	$k=-0.005\ M^2 + 0.114\ M + 0.021$	0.70
		10	$k=-0.004\ M^2 + 0.103\ M - 0.316$	0.82
		35	$k=-6E-05\ M^2 + 0.002\ M + 0.043$	0.98
		60	$k=-0.001\ M^2 + 0.030\ M - 0.128$	0.70
2	Specific heat	-100	$C_p=0.089\ M^2 - 2.275\ M + 68.84$	0.81
		-60	$C_p=0.109\ M^2 - 2.804\ M + 67.92$	0.93
		-20	$C_p=0.119\ M^2 - 3.045\ M + 67.33$	0.96
		20	$C_p=0.129x^2 - 3.313\ M + 67.79$	0.98
		60	$C_p=0.130\ M^2 - 3.373\ M + 68.60$	0.99
		100	$C_p=0.126\ M^2 - 3.402\ M + 72.81$	0.98
3	Thermal diffusivity	-40	$\alpha=-4E-10\ M^2 + 1E-08\ M - 1E-09$	0.99
		-15	$\alpha=-5E-10\ M^2 + 1E-08\ M - 3E-08$	0.80
		10	$\alpha=-4E-10\ M^2 + 1E-08\ M - 3E-08$	0.84
		35	$\alpha=-2E-11\ M^2 + 6E-10\ M + 6E-10$	0.99
		60	$\alpha=-7E-11\ M^2 + 2E-09\ M - 1E-08$	0.70

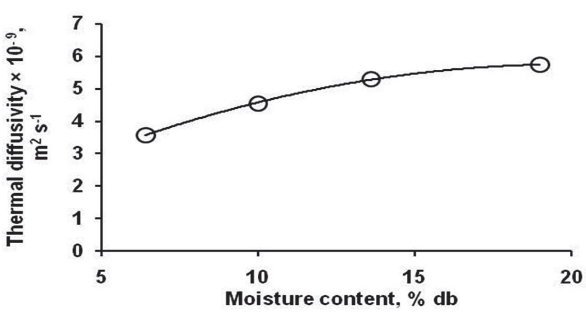

Fig. 4. Variation in thermal diffusivity of cryo- ground cinnamon powder with moisture content at 35°C

with moisture content at all the temperatures exhibited a second order polynomial relationship. However, the relationship between thermal diffusivity (α_b) and moisture content (M) have been reported in literature in both ascending [e.g. for gram (Dutta *et al.* 1988)] and descending [e.g. for cumin seed (Singh & Goswami 2000)] trends. From Eq. (1), it is clear that the magnitude of α_b depends on the combined effect of k_b, ρ_b and C_p. For the material where the value for k increases faster than that for ρ_b and C_p in the same temperature and moisture ranges, such as for gram thermal diffusivity would increase with increase in moisture content (Dutta *et al.* 1988).

The analysis of variance (Table 1) for thermal diffusivity showed that both temperature and moisture content significantly affected the thermal conductivity at 5% level. The average values of thermal diffusivity varied from 0.35×10^{-8} to $7.23 \times 10^{-8}\ m^2\ s^{-1}$ in the temperature range of -40-60°C and moisture content 6.4-19.0% db.

From this study, it was observed that specific heat of cryo-ground cinnamon powder varied from 46.12-57.92 kJ kg°C^{-1} with increase in moisture content from 6.4-19% db and temperature from -100-100°C. It was affected significantly ($P<0.05$) with moisture content and temperature. The thermal conductivity of cryo-ground cinnamon powder increased from 0.055-0.065 W m°C^{-1} with the increase in moisture content from 6.4-19% db at 35°C. Its variation showed a quadratic relationship with moisture content and it was affected significantly by moisture content. The thermal diffusivity of cryo-ground cinnamon powder increased from 0.35×10^{-8} to $0.57 \times 10^{-8}\ m^2\ s^{-1}$ at 35°C with increasing moisture content from 6.4-19.0% db. It was affected significantly by moisture content at 5% level of significance and its variation showed a quadratic relationship with moisture content.

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