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Influence of varietal difference, temperature and particle size on thermal properties of cryoground coriander

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Abstract

The paper describes the thermal properties viz., thermal conductivity, specific heat and thermal diffusivity of cryoground coriander in temperature range from -35°C to 55°C. The effects of temperature and particle size and varietal difference of coriander on thermal properties was studied. There exists a non-linear increasing trend in thermal conductivity, specific heat and thermal diffusivity with respect to temperature at $p \leq 0.05$ and $p \leq 0.01$ significance levels.

Key words : *Coriandrum sativum L*., cryogenic grinding, partical size, temperature, thermal properties.

Introduction

Coriander (*Coriandrum sativum L.)* is one of the oldest spice crops in the world and belongs to family *Apiaceae*. It is widely distributed and mainly cultivated for its seeds. The plant is a thin stemmed, small, bushy herb i.e. 25 to 50 cm in height with many branches and umbels. Fruit (seed) is globular (3-4 mm diameter), when pressed breaks into two locules (www.indianspices.com). Coriander seeds are used as an ingredient in culinary, bakery products, curry powders, sausages and meat products. Medicinally, it is used to treat minor digestive problems, hemorrhoids, painful joints, dry coughs and bronchitis etc. Grinding of spices is done to obtain smaller particle size with good product quality in terms of flavour and colour. In conventional spice grinding system, when energy is used to fracture a particle into smaller size resulting in heat generation up to 90°C with loss of essential oil, flavour and colour leading to quality deterioration (Singh and Goswami, 2000). However, application of cryogenic grinding of coriander seeds retains its quality. Since thermodynamics of material related to heat transfer characteristics are essential for the design of cryogenic grinding system; thus, the understanding of thermal property of spice are important. These thermal properties are greatly influenced by temperature and moisture content of spices. Delgado (2001) emphasized the points to be considered while designing the equipment for effective processing as minimization of energy requirement, reliability, safety and product quality etc. Telis *et al.,* (2007) has determined the thermal conductivity of mango and papaya pulp and reported that thermal conductivity of both pulp was almost independent of temperature, above freezing point. However, in frozen state, thermal conductivity was strongly affected by temperature, such that the thermal conductivity increased with decrease in temperature. Many researchers have studied the thermal conductivity of coriander and anise seed using line heat source principle (Mohsenin 1980; Tavman and Tavman 1998). Heldman and Lund (1992) reported that the thermal property of food product is mainly a function of water content and structure. Subramanian and Viswanathan (2003) reported that thermal conductivity of millet and flour showed an increasing trend with the moisture content (10-30%, db). The effect of temperature on specific heat was generally not taken into consideration in early work with agricultural materials (Tang *et al.*, 1991; Singh and Goswami, 2000). Differential Scanning Calorimeter (DSC) has so far been the most accurate and rapid method for

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specific heat measurement as a function of temperature. The dynamic nature of DSC allows the determination of specific heat as a function of temperature. Tang *et al* (1991) reported that the specific heat increased in quadratic form with moisture content (2-35%, db) and linearly with temperature range (10-80°C). Hence, this study is to examine the effect of temperature (-35 to 55°C) and particle size (400 ± 25 µ, 175 ± 25 µ) on thermal property of different variety of coriander powder *viz.,* RCr-436, Shindhu, Sudha and Swathi.

Materials and methods

Sample preparation

Coriander seed was procured from the National Research Centre on Seed Spices (Ajmer, India). It was cleaned manually to remove foreign matter, broken, split, deformed and immature seeds for sample preparation. The initial moisture content of seed was determined (Ranganna, 1986) as 8.67 %, db. For experimentation, about 10 kg of coriander was taken for grinding using cryogenic grinder (100 UPZ, Hosokawa Alpine, Germany) at (below -50° C) using liquid nitrogen. The grinder speed (12000 rpm) and feed rate (2 kg/h) was kept constant, in order to minimize the effect of process variables.

Experimentation and observation

The particle size of cryoground coriander was determined using particle size analyzer (LA 950, Horiba, Japan) and graded in to two particle size *viz.,* 400±25µ, 175±25µ. The cryoground coriander was compacted (porosity 0.32±0.03) under direct compact device and equilibrated for 10±0.05 % moisture content, wet basis at various temperatures in a deep freezer (U 410-86, New Brunswick Scientific, England) and forced air driers. The porosity of the compacted sample was determined using gas pycnometer (model2: *Hymipyc* and make IQI, USA). The bulk density of ground coriander was determined using standard volumetric cylinder method (Balasubramanian and Viswanathan, 2011). A thermal conductivity meter (KD-2 PRO, Decagon Devices, Inc., USA) was used to determine the thermal conductivity of compact cryoground coriander sample in temperature range from -35°C to 55°C. It was calibrated using glycerine and thermal conductivity was checked for 0.285W/m-K. After calibration, the probe (KS-1) was inserted in the sample kept in a closed environment and recorded for every temperature. Specific heat was determined by using differential scanning calorimeter (Perkin Elmer 6000, USA) operated by Pyris software. Before conducting experiment, DSC was calibrated using indium at a scanning rate of 10°C/min. About 5 mg of cryoground sample was kept in an aluminium crucible (cap. 10ìL). The aluminium crucible was sealed hermitically and subjected to heating from -50°C to 55°C with a heating rate of 10°C/min and holding temperature of -50°C for 1 min using an empty pan as reference in nitrogen environment. The thermograph was obtained for variation of specific heat with temperature between -35°C and 55°C. Thermal diffusivity was calculated from thermal conductivity, specific heat and bulk density as per the following equation (Singh and Goswami, 2000)

$$\alpha = \frac{k}{\rho C_P} \qquad \ldots (1)$$

where, α is the thermal diffusivity (m²/s), k is the thermal conductivity (W/m-K), C_p is the specific heat (J/kg-°C) and ρ is the bulk density (kg/m³). All the experiments were repeated for five times.

Results and discussion

The experimental data of bulk density, porosity, thermal conductivity, specific heat and thermal diffusivity with respect to temperature, particle size and variety are represented in Table 1.

Thermal conductivity (k)

From the data, it can be observed that the thermal conductivity increased non-linearly with temperature from -35°C to 55°C for var. RCr-436 and var. Shindhu for both the particle size *viz.,* 400µ, 175µ, expressing a second order polynomial relationship (Table 3). Whereas, it showed a linear increasing trend for var. Shudha and var. Swathi with respect to particle sizes. Analysis of variance (Table 2) showed a significant effect on all variety (*viz.,* RCr-436, Shindhu, Shudha and Swathi), particle size (400µ, 175µ) and temperature on thermal conductivity of cryoground coriander at $p \leq 0.01$. However, in interaction terms the variety and particle size with temperature are not significant. Similar trend has been reported for rice flour (Mahapatra, 2011), guna seed (Aviara *et al.,* 2008), chickpea flour (Emami *et al.,* 2007), cumin seed (Singh and Goswami, 2000), soybean (Deshpande *et al.,* 1996), sheanut kernel (Aviara and Haque, 2001), borage seed (Yang *et al.,* 2002) and millet grains (Subramanian and Viswanathan, 2003).

Specific heat (C_p)

The specific heat of cryoground coriander for all four varieties RCr-436, Shindhu, Shudha and Swathi and their different particle sizes found to be increased non-linearly with respect to temperature (Table 1). The significant effect of variety (RCr-436, Shindhu, Shudha and Swathi) and particle size (400µ, 175µ) of cryoground coriander on

Table 1. Thermal property of cryoground coriander with respect to variety, temperature and particle size.

Temperature (°C)	Coriander Varieties							
	RCr-436		Shindhu		Swathi		Shudha	
	Particle size (μ)							
	400	175	400	175	400	175	400	175
Bulk density (kg/m^3)	385.72 (1.82)	362.52 (2.11)	382.48 (1.87)	357.88 (1.57)	379.70 (2.02)	357.15 (2.78)	389.72 (1.62)	359.52 (2.28)
Porosity (%)	0.32 (0.03)							
Thermal conductivity (W/m-K)								
-35	0.062[a]	0.069[a]	0.052[a]	0.063[a]	0.059[a]	0.065[a]	0.062[a]	0.063[a]
-30	0.063	0.069	0.052	0.064	0.059	0.066	0.062	0.063
-25	0.064	0.071	0.053	0.067	0.060	0.067	0.063	0.064
-20	0.064	0.072	0.054	0.067	0.061	0.068	0.063	0.065
-15	0.064	0.072	0.055	0.068	0.061	0.068	0.063	0.065
-10	0.065	0.073	0.056	0.068	0.062	0.068	0.064	0.066
-5	0.065	0.073	0.057	0.069	0.063	0.069	0.064	0.067
0	0.066	0.073	0.057	0.070	0.063	0.070	0.065	0.068
5	0.066	0.074	0.057	0.073	0.065	0.072	0.066	0.070
10	0.068	0.075	0.061	0.077	0.066	0.076	0.070	0.075
15	0.068	0.076	0.062	0.077	0.067	0.079	0.072	0.078
20	0.068	0.076	0.062	0.077	0.072	0.081	0.072	0.078
25	0.068	0.076	0.063	0.078	0.074	0.082	0.073	0.079
30	0.068	0.077	0.063	0.079	0.075	0.083	0.074	0.080
35	0.069	0.079	0.063	0.080	0.076	0.084	0.075	0.080
40	0.070	0.081	0.066	0.080	0.077	0.084	0.075	0.081
45	0.074	0.084	0.068	0.081	0.077	0.085	0.076	0.082
50	0.076	0.087	0.068	0.081	0.078	0.085	0.079	0.083
55	0.077[b]	0.089[b]	0.071[b]	0.083[b]	0.079[b]	0.085[b]	0.079[b]	0.084[b]
Specific heat (kJ/kg°C)								
-35	27.776	30.883	30.151	30.419	26.566	28.516	28.200	31.258
-30	27.814	31.086	30.475	30.742	26.750	28.977	28.315	31.452
-25	28.347	31.047	30.417	30.617	26.735	28.738	28.273	31.467
-20	28.002	30.882	30.279	30.483	26.587	28.570	28.244	31.206
-15	27.279[a]	30.742[a]	29.969	30.187	26.269[a]	27.458[a]	27.938[a]	31.096[a]
-10	27.328	30.744	29.812[a]	30.004[a]	26.356	28.286	27.961	31.097
-5	27.618	30.774	30.052	30.331	26.376	28.282	28.197	31.220
0	27.602	30.774	30.100	30.386	26.378	28.403	28.298	31.425
5	27.780	31.033	30.149	30.395	26.510	28.582	28.502	31.550
10	28.143	31.570	30.482	30.786	26.772	29.000	28.883[b]	31.625
15	28.711	32.337	30.929[b]	31.266[b]	27.218	29.693	28.759	31.686[b]
20	29.355[b]	33.534[b]	30.442	30.568	27.280[b]	29.754[b]	28.684	31.654
25	27.715	31.157	29.898	30.105	26.363	28.561	27.995	31.214
30	27.702	30.895	29.896	30.105	26.329	28.554	27.964	31.177
35	27.764	30.925	29.928	30.145	26.343	28.632	27.986	31.237

40	27.851	30.985	29.982	30.207	26.374	28.738	28.005	31.317
45	27.976	31.055	30.045	30.284	26.421	28.870	28.052	31.407
50	27.978	31.114	30.108	30.343	26.464	29.007	28.114	31.504
55	27.983	31.173	30.157	30.425	26.579	29.159	28.207	31.609
Thermal diffusivity (x$10^{-8}$$m^2$/s)								
-35	0.50[a]	0.62	0.47	0.62[a]	0.56	0.65[a]	0.59[a]	0.64
-30	0.51	0.61[a]	0.46[a]	0.62	0.55[a]	0.65	0.59	0.63[a]
-25	0.51	0.63	0.47	0.66	0.56	0.66	0.60	0.64
-20	0.52	0.64	0.48	0.66	0.57	0.68	0.60	0.66
-15	0.53	0.65	0.50	0.67	0.58	0.70	0.61	0.66
-10	0.54	0.66	0.51	0.68	0.59	0.68	0.62	0.67
-5	0.53	0.65	0.52	0.68	0.60	0.69	0.61	0.68
0	0.54	0.65	0.51	0.69	0.6	0.70	0.62	0.68
5	0.54	0.66	0.51	0.72	0.61	0.72	0.63	0.70
10	0.55	0.65	0.54	0.75	0.62	0.75	0.66	0.75
15	0.54	0.65	0.54	0.74	0.62	0.76	0.68	0.78
20	0.52	0.63	0.55	0.75	0.66	0.77	0.68	0.78
25	0.55	0.67	0.57	0.77	0.70	0.82	0.70	0.80
30	0.55	0.69	0.57	0.79	0.71	0.83	0.72	0.81
35	0.56	0.70	0.57	0.80	0.72	0.84	0.72	0.81
40	0.57	0.72	0.60	0.79	0.73	0.83	0.72	0.82
45	0.60	0.75	0.61	0.80	0.73	0.84[b]	0.73	0.83
50	0.61	0.77	0.61	0.80	0.74	0.84	0.76	0.83
55	0.62[b]	0.79[b]	0.64[b]	0.82[b]	0.74[b]	0.83	0.76[b]	0.84[b]

a: minimum, b: maximum and value in parenthesis are standard deviation.

specific heat was observed at 5% level, whereas, in case of temperature, it was at 1 % level. Many studies showed that there exists relationship between specific heat with increase in temperature and moisture content including borage seeds (Yang *et al.,* 2002); cumin seeds (Singh and Goswami, 2000); coriander and anise seeds (Hacikuru and Kocabiyik, 2008) and sheanut kernel (Aviara and Haque., 2001). Wunderlich (2005) explained this change as the need of additional energy to generate an increase in volume for allowing larger motion of molecules. The observed trend of specific heat within temperature range -35°C to 55°C could also be attributed to the latent heat of fusion of water molecules and retention of essential oil in cryoground coriander sample.

Thermal diffusivity (~)

Thermal diffusivity increased with the increase in temperature and followed a third order polynomial relationship (Table 3). The temperature and variety of coriander (RCr-436, Sindhu, Sudha and Swathi) was observed to have significant effect on thermal diffusivity at $p \leq 0.01$, whereas particle size (400µ, 175µ) affected thermal diffusivity at $p \leq 0.05$ (Table 2). For interaction terms, except particle size and temperature combination all other interactions are significant at $p \leq 0.01$. It is to mention here that the relationship between thermal diffusivity (á) with temperature and moisture content have been reported in literature in both ascending for gram (Dutta *et al.,* 1988) and descending for rice flour (Mahapatra, 2011), haylage (Jiang *et al.,* 1986) and borage seeds (Yang *et al.,* 2002).

Conclusion

Thermal property (k, C_p and α) of cryoground coriander powder were determined as a function of temperature, variety and particle size. It is found that the thermal property *viz.,* thermal conductivity and thermal diffusivity mostly increased non-linearly over mentioned temperature range, whereas, specific heat does not showed any clear

Table 2. Analysis of variance for thermal conductivity, specific heat and thermal diffusivity

Source of variation	Thermal conductivity (W/m-K)				Specific heat (kJ/kg°C)				Thermal diffusivity (x 10^{-8} m^2/s)			
	SS	DF	MS	F	SS	DF	MS	F	SS	DF	MS	F
V	0.006	3	0.002	50.76**	308.2	3	102.7	648.0**	1.703	3	0.568	1112.0**
PS	0.001	1	0.001	13.91**	368.2	1	368.2	226.3**	0.015	1	0.015	3.9*
T	0.011	18	0.001	21.00**	32.2	18	1.8	1.1*	0.994	18	0.055	7.904**
V x PS	0.001	3	0	6.52**	111.0	3	37.0	234.0*	0.053	3	0.018	4.7**
V x T	0.001	54	0.000	1.40ns	10.5	54	0.2	0.09ns	0.071	54	0.001	3.0**
PS x T	0	18	0	0.22ns	1.1	18	0.1	0.0ns	0.017	18	0.001	0.138ns
V x PS x T	0	54	0	19.00**	3.0	54	0.1	489.0**	0.030	54	0.001	75.0**

**Significant at 1% level, *Significant at 5% level, ns- Non-Significant, SS- sum of squares, DF- degree of freedom, MS- mean squares, V- variety, PS- particle size, T- temperature.

Table 3. Best fit equations for thermal properties of cryoground coriander powder

Variety	Particle size (µ)	Polynomial equation	R^2
Thermal conductivity (W/m-K)			
RCR-436	400	$2E\text{-}06x^2 + 0.0001x + 0.0728$	0.954
	175	$2E\text{-}06x^2 + 0.0001x + 0.0653$	0.929
Shindhu	400	$-9E\text{-}07x^2 + 0.0002x + 0.0721$	0.968
	175	$7E\text{-}07x^2 + 0.0002x + 0.0576$	0.976
Shudha	400	$0.0003x + 0.0705$	0.952
	175	$0.0002x + 0.0672$	0.954
Swathi	400	$0.0003x + 0.073$	0.941
	175	$0.0003x + 0.0656$	0.954
Thermal diffusivity (x10^{-8} m^2/s)			
RCR-436	400	$8E\text{-}07x^3 + 3E\text{-}06x^2 + 0.0002x + 0.6497$	0.955
	175	$6E\text{-}07x^3 - 6E\text{-}06x^2 + 0.0002x + 0.5358$	0.944
Shindhu	400	$-2E\text{-}07x^3 - 7E\text{-}09x^2 + 0.0027x + 0.7058$	0.977
	175	$1E\text{-}07x^3 + 3E\text{-}06x^2 + 0.0016x + 0.5168$	0.976
Shudha	400	$-8E\text{-}07x^3 + 2E\text{-}05x^2 + 0.0036x + 0.7016$	0.980
	175	$-3E\text{-}07x^3 + 2E\text{-}05x^2 + 0.0022x + 0.6315$	0.980
Swathi	400	$-8E\text{-}07x^3 + 2E\text{-}05x^2 + 0.0034x + 0.7149$	0.971
	175	$-6E\text{-}07x^3 + 3E\text{-}05x^2 + 0.0028x + 0.6038$	0.973