International J. Seed Spices 3(2), July 2013:13-21

Effect of moisture content, screw and grinder speed on physical and thermal properties of fenugreek powder

P. Barnwal[1*], K. K. Singh[2], Alka Sharma[1], A. K. Choudhary[1], Chothani Hardik R[1], S.N.Saxena[3]

[1]FG&OP Division, CIPHET (ICAR), Ludhiana 141 004

[2]ADG (PE), ICAR, New Delhi

[3]National Research Centre on Seed Spices, Tabiji, Ajmer - 305 206, Rajasthan

Abstract

Experiments on grinding of fenugreek seed were conducted in a pin mill type spice grinder to investigate the effect of moisture content, feed rate and grinder speed on some dependent variables such as average particle size of the ground fenugreek powder, colour values (L, a and b), colour parameters i.e hue, chroma and browning index, thermal properties such as specific heat, thermal conductivity and thermal diffusivity. The particle size, colour parameters i.e L, a, b, hue, chroma and browning index of fenugreek powder varied from 0.345±0.001 - 0.390±0.002 mm, 71.13±0.51 – 83.03±1.41, 1.11±0.13 - 4.43±0.18, 27.45±1.51–32.36±2.14, 80.03±0.43-87.82±1.01°, 28.72 ± 1.17 – 32.36±1.70 and 41.22±3.11 – 66.85±4.34, respectively in moisture range of 6.4-13.6% db, screw speed (3-4 rpm) and grinder speed (8000 – 11000 rpm). The values of thermal conductivity, specific heat and thermal diffusivity of fenugreek powder, at 30°C within moisture range (6.4-13.6%db), screw speed (3-4 rpm) and grinder speed (8000 – 11000) rpm, varied significantly from 0.063 ± 0.003 - 0.077 ±0.002 W/m-K, 10.74 ± 0.098 - 16.64 ±1.24 kJ/kg-K 7.12× 10^{-9} - 10.70 × 10^{-9} m^{2-1}s, respectively.

Key words : Colour parameters, fenugreek, particle size, specific heat, thermal conductivity, thermal diffusivity.

Introduction

Fenugreek is used as a food and food additive as well as in medicines. Fresh tender pods, leaves and shoots are eaten as curried vegetable. As a spice, it flavours food. Powder of dried leaves is also used for garnishing and flavouring variety of food. Fenugreek extract is used as a flavouring agent of imitation maple syrup. It is one of the principal constituent of curry powder. The seeds are used in colic flatulence, dysentery, diarrhoea, dyspepsia, chronic cough and enlargement of liver and spleen, rickets, gout and diabetes. It is also used as a carminative, tonic, and aphrodisiac. In India, fenugreek is used as a lactation stimulant (Tiran, 18). Fenugreek contains high protein (25%), lysine (6.7 g/16 g N), soluble (20%) and insoluble (28%) dietary fibre contents besides being rich in calcium, iron, and â-carotene. The seeds are known to have hypoglycemic and hypocholesterolemic effects in human beings (Khosla *et al.,* 12).

Grinding is an important unit operation in processing of spices in which the size of the spices is reduced and their surface area is increased. Thus increasing the availability of important constituents such as oil inside the cells, fragrance and flavouring components. Power consumption in grinding, size reduction and increase in the surface area depends on the initial size, shape and strength of the particle or material; the kind of grinder or mill used for this unit operation and the fixing of operating parameter to running the grinder or mill such as temperature, size of sieve, number of rotor ribs etc (Das, 6). The colour is an important quality attributes to accept or reject the spices because it has appealing effect in the mind of consumer.

The knowledge of thermal properties viz. specific heat, thermal conductivity and thermal diffusivity are essential for simulation and modelling of heat transfer phenomenon in the grinder (Singh and Goswami, 17). The temperature and moisture content of agricultural materials greatly affect its thermal properties. Using differential scanning calorimetry (DSC) technique, the specific heat of agricultural materials can be measured as a function of temperature. Various researchers have investigated the thermal properties of agricultural materials using DSC such as for cumin seed (Singh and Goswami, 16), gram (Dutta *et al.,* 7), borage seeds (Yang *et al*., 19) etc. The variations in specific heat, thermal conductivity and diffusivity with moisture content have been reported.

Survey of literature revealed that t no published information is available on quality attributes such as colour parameters, grinding parameters and thermal properties of fenugreek powder. Hence, this study was

*Corresponding author: Email: pbarnwal@rediffmail.com

performed with the objective to determine the effect of moisture, feed rate (screw speed) and grinder speed on above mentioned parameters of fenugreek powder.

Material and methods

The fenugreek seeds were obtained from NRCSS, Ajmer. The seeds were cleaned manually to remove all foreign matter, dust, dirt, broken and immature seeds. The initial moisture content of the seeds was determined by vacuum oven method (temperature 70 °C and pressure 100 mm Hg) until a constant mass was obtained (Singh and Goswami, 16) and was 8.7% dry basis (db). The moisture content of fenugreek seeds were attuned to 6.4, 8.7, 11.1, 13.6% d.b. to determine the geometric properties, grinding parameters, thermal properties, medicinal and antioxidant properties. The fenugreek seeds were dried in a tray dryer at 55°C (recording moisture content at every 15 min interval) to achieve 6.4% moisture content (d.b.). The samples of the high level desired moisture contents were prepared by adding the amount of distilled water, *Q*, as calculated from the following relationship (Chakraverty, 3):

$$Q = W_i\left[\frac{M_f - M_0}{100 - M_f}\right] \quad (1)$$

where Q is the mass of water to be added (kg); W_0 is the initial mass of the sample (kg); M_0 is the initial moisture content of the sample (%, d.b.); and M_f is the desired moisture content of the sample (%, d.b.). Samples were packed in low density polyethylene (LDPE) pouches and kept at 5°C for 48 h in a refrigerator for uniform distribution of moisture throughout the seed (Sahay and Singh, 15). Before starting a test, the required quantities of the samples were taken out from refrigerator and allowed to equilibrate with to the room temperature for about 2 h.

Geometric properties of fenugreek seed

For each moisture content, the major (L), medium (W) and minor (T) dimensions of fenugreek seeds were measured in randomly selected 100 seeds using a digital vernier calliper with an accuracy of 0.01 mm. The arithmetic mean diameter (d_a) and geometric mean diameter (d_g) of the seeds was calculated by using the following relationship (Mohsenin, 13):

$$d_a = \left(\frac{L + W + T}{3}\right) \quad (2a)$$

$$d_g = (L \times W \times T)^{1/3} \quad (2b)$$

The sphericity, c, of fenugreek seeds was calculated by using the following relationship (Mohnsein, 13)

$$\text{..} = \frac{(LWT)^{1/3}}{L} \quad (3)$$

The surface area and volume of fenugreek seeds were determined using the following relationships (Jain and Bal, 9):

$$S = \frac{®BL^2}{2L - B} \quad (4)$$

$$V = \frac{®B^2L^2}{6(2L - B)} \quad (5)$$

Where,

$$B = (WT)^{0.5} \quad (6)$$

A laboratory grinder (M/s Hosakowa Alpine, Germany, Model: 100UPZ, three-phase motor, 3 HP, 10000 rpm) was employed for the grinding of prepared fenugreek seeds at ambient conditions.

The grinding of fenugreek seeds was carried out according to full factorial design with moisture conditioning 6.4-13.6% (db), screw speed (3-4 rpm) and grinder speed (8000-11000 rpm).

Particle size distribution of ground fenugreek powder was determined in duplicate using a vibratory sieve shaker with a set of Bureau of Indian Standards (BIS) sieves. Average particle size (D_p) of ground fenugreek powder were calculated (Singh and Sahay, 15) as follows:

Average particle size,

$$D_p = \left[0.135 \times \left(1.366\right)^{FM}\right] \quad (7)$$

Where, F.M. is fineness modulus.

Colour attributes of ground fenugreek powder

Colour (L, *a* and b) values of fenugreek powder were determined by using Hunter Colorimeter (model no. 45/0 L, U.S.A). 'L' is known as the lightness and extends from 0 (black) to 100 (white). The other two coordinates '*a*' and 'b' represents redness (+ *a* values) to greenness (" *a* values) and yellowness (+ b values) to blueness ("b values), respectively. Hue angle (h^0) is the attribute of the colour by means of which the colour is perceived. Chroma (C^*) is the attribute of colour used to indicate the degree of departure of the colour from gray of the same lightness. Browning index (BI) is the intensity of pure brown colour. h^0, C^* and BI is computed by using the following formulae (Gupta *et al*. 8):

$$Chroma = \sqrt{\left(a^2 + b^2\right)} \quad (8)$$

$$Hue = \tan^{-1}\left(\frac{b}{a}\right) \quad (9)$$

$$BI = \left[\frac{100(x - 0.31)}{0.17}\right] \quad (10)$$

Where,

$$x = \left[\frac{(a + 1.75)}{(5.645L + a - 3.012b)} \right] \quad (11)$$

Thermal properties of ground fenugreek powder

Specific heat of ground fenugreek powder was determined by using the Differential Scanning Calorimeter (DSC 6000 Perkin Elmer, USA). For determination of specific heat, the fenugreek powder samples were kept in an aluminium crucible (capacity 10 μL) in small quantity (5 -5.5mg). The aluminium crucible was sealed and run in the DSC for the temperature range of 10°C to 40°C. The DSC provided thermogram, in which ordinate shows the heat flow rate mW mg^{-1} as a function of time and temperature. Specific heat was determined from the thermogram according to the procedure given in Pyris software. All experiments were performed in triplicate and the mean values were reported.

Bulk thermal conductivity was measured by using portable thermal conductivity meter (Model: KD-2 PRO, Decagon Devices, Inc. USA). The thermal conductivity meter was calibrated with glycerine. The fenugreek powder was filled into 100 ml beaker, completely tapped and immediately a single needle probe (Model: KS-1, 1.3 mm diameter × 60mm long) of thermal conductivity meter was inserted in the sample at an average temperature of 30°C and reading was recorded at intervals of 2 min.

The average bulk density (ρ_b, kg/m^3) of fenugreek powder was determined by using standard method as described by Mohnsein (13) and it was expressed as the ratio of mass by volume.

The bulk thermal diffusivity of fenugreek powder was calculated from the obtained values of bulk thermal conductivity, specific heat and bulk density of fenugreek powder at an average temperature of 30°C using following formula (Singh and Goswami, 16):

$$\sim_b = \frac{k_b}{\circ_b C_p} \quad (12)$$

Where, α_b is the bulk thermal diffusivity in $m^2\ s^{-1}$, C_p is the specific heat in kJ $kg^{-1}\ ^oC^{-1}$, k_b is the thermal conductivity in W $m^{-1}\ ^oC^{-1}$ and ρ_b is the bulk density in kg m^{-3}.

Statistical analysis

Analysis of variance for geometric properties, grinding parameters, colour attributes and thermal properties were carried out using LSD of AgRes Statistical software (Version 3.01, Pascal International Software Solution, USA).

Results and discussion

Physical properties of fenugreek seed

All physical properties such as major, medium and minor dimensions; geometric mean diameter, sphericity, surface area, seed volume , angle of repose , porosity , thousand seed mass increased significantly from 3.83±0.32 – 4.44±0.28mm, 2.42±0.18– 2.80±0.23mm, 1.80±0.26–1.96±0.23mm, 2.55±0.16 – 2.89±0.14mm, 65±0.05 – 69±0.04%, 17.26±2.19 – 22.13±2.33 mm^2, 6.04±1.24-8.65±1.32 mm^3, 17.19±0.61 –20.46±1.09°, 41.58±0.15-43.35±0.26% and 159.87±0.63– 167.72±1.22g, respectively whereas bulk density and true density decreased from 767.79±1.92–717.04±3.25 and 1314.31±2.12-1265.83±0.48, respectively with increase in moisture content within the moisture range of 6.4-13.6% d.b. (Table 1 and 2). Similar trend for physical properties such as axial dimensions, geometric mean diameter, surface area, sphericity and kernel volume were reported for bay laurel seeds by Yurtlu *et al*., 20. The coefficient of friction is highest against plywood surface and lowest against glass surface (Table 3). The static coefficient of friction of fenugreek seeds on plywood sheet, mild steel sheet, iron sheet and glass sheet surfaces increased (Table 2) from 0.32±0.02-0.38±0.03, 0.26±0.02-0.30±0.02, 0.29±0.02-0.34±0.03 and 0.23±0.01–0.27±0.02, respectively for the moisture range of 6.4-13.6% d.b.. The similar increasing trends for static coefficients of friction were reported by Coskuner and Karababa (4), and Mollazade *et al*., (14) for coriander seeds and bay laurel seeds, respectively.

Particle size of fenugreek powder

Figure 1 represents the variation of average particle size of fenugreek powder with variable moisture content, screw and grinder speed which increased with increasing moisture content irrespective of screw and grinder speed. This may be due to the fact that moisture sorption is often coupled with increased cohesiveness, mainly because of inter particle liquid bridge formation. Moisture content thus affects the cohesive strength and arching ability of bulk materials. As the moisture content of powder increases, the adhesion and cohesion tend to increase which results in coarser grinding at higher moisture levels. Similar findings were reported by Jha and Verma (10) and Balasubramanian *et al*., (2) for makhana and pearl millet, respectively. The values of average particle size of fenugreek powder varied from 0.345 ± 0.001 - 0.390 ± 0.002 mm in moisture range of 6.4-13.6% db, screw speed (3-4 rpm) and grinder speed (8000 – 11000rpm).

Colour parameters of fenugreek powder

Figure 2 depicts the colour values (i.e L, *a* and b values) of fenugreek powder at variable moisture content, screw and grinder speed. L-value and b- value decreased whereas a-value increased with increase in moisture content at all screw speed and grinder speed (Figure 2). Decrease in L-value indicates darker product with increase in moisture content. This may be due to the fact that at higher moisture contents more energy is required to grind the material which may increase the temperature during grinding and leads to dark coloured fenugreek powder. However, the L and *a* values were found to vary significantly with moisture content and grinder speed whereas b and chroma values varied significantly with screw speed (Table 4). The browning index increased with increase in moisture content irrespective of screw and grinder speed. The hue angle varied significantly with

Table 1. Geometric properties of fenugreek

M.C (% d.b)	Major dimension (mm)	Medium dimension (mm)	Minor dimension (mm)	Geometric mean diameter (mm)	Sphericity (%)	Surface area (mm^2)	Volume (mm^3)
6.4	3.83±0.32[a]	2.42±0.18[a]	1.80±0.26[a]	2.55±0.16[a]	65±0.05	17.26±2.19[a]	6.04±1.24[a]
8.7	4.10±0.31[b]	2.54±0.18[b]	1.90±0.18[b]	2.70±0.12[b]	66.±0.04	19.32±1.72[b]	7.09±0.97[b]
11.1	4.33±0.32[c]	2.64±0.25[c]	1.93±0.19[b]	2.79±0.13[c]	67±0.04	20.69±1.88[c]	7.79±1.10[c]
13.6	4.44±0.28[d]	2.80±0.23[d]	1.96±0.23[b]	2.89±0.14[d]	69±0.04	22.13±2.33[d]	8.65±1.32[d]
F-values	53.82[*]	42.10[*]	6.94[*]	86.00[*]	2.39[NS]	83.79[*]	67.06[*]
$CD_{0.05}$	0.10	0.06	0.07	0.04	4.12	0.63	0.37

Table 2. Gravimetric and frictional properties of fenugreek

M.C (% d.b)	1000 seed mass (g)	Bulk density (kg/m^3)	True density (kg/m^3)	Porosity (%)	Angle of repose (°)	Coefficient of friction			
						Wood	Iron	Steel	Glass
6.4	159.87±0.63[a]	767.79±1.92[a]	1314.31±2.12[a]	41.58±0.15[a]	17.19±0.61[a]	0.32±0.02[a]	0.29±0.02[a]	0.26±0.02[a]	0.23±0.01[a]
8.7	162.48±0.43[b]	746.21±2.92[b]	1293.43±1.36[b]	42.31±0.22[b]	18.01±0.21[ab]	0.33±0.03[a]	0.31±0.03[a]	0.27±0.02[ab]	0.24±0.01[ab]
11.1	164.31±0.92[c]	727.53±2.20[c]	1277.52±1.47[c]	43.05±0.14[c]	18.63±0.50[b]	0.36±0.03[ab]	0.32±0.03[a]	0.29±0.01[bc]	0.26±0.03[bc]
13.6	167.72±1.22[d]	717.04±3.25[d]	1265.83±0.48[d]	43.35±0.26[d]	20.46±1.09[c]	0.38±0.03[b]	0.34±0.03[b]	0.30±0.02[c]	0.27±0.02[c]
F-values	66.00[*]	336.69[*]	749.07[*]	87.13[*]	13.42[*]	4.42[*]	3.52[*]	3.24[*]	5.45[*]
$CD_{0.05}$	1.29	3.88	2.45	0.27	1.21	0.03	0.03	0.02	0.03

Table 3. Analysis of variance for particle size and thermal properties of fenugreek powder

Source	Degrees of freedom	Mean square	F-value	*p*-value
Average particle size				
Moisture content	3	263×10^{-5}	831.31[*]	0.00
Screw speed	1	69×10^{-5}	21.81[*]	0.00
Grinder speed	1	34×10^{-5}	10.75[*]	0.00
Specific heat				
Moisture content	3	9.81	166.85[*]	0.00
Screw speed	1	14.26	242.65[*]	0.00
Grinder speed	1	9.13	155.38[*]	0.00
Thermal conductivity				
Moisture content	3	10.20×10^{-5}	13.61[*]	0.00
Screw speed	1	45.61×10^{-5}	61.07[*]	0.00
Grinder speed	1	30.12×10^{-5}	4.02[*]	0.00
Thermal diffusivity				
Moisture content	3	2.57	20.59[*]	0.00
Screw speed	1	0.85	6.86[*]	0.00
Grinder speed	1	10.95	87.66[*]	0.00

* Significant at $p=0.05$; NS Not significant

all the three parameters i.e moisture content, screw and grinder speed. The values of colour parameters of fenugreek powder i.e L, *a*, b, hue (°), chroma and browning index varied from 71.13±0.51 – 83.03±1.41, 1.11±0.13 - 4.43±0.18, 27.45±1.51–32.36±2.14, 80.03±0.43-87.82±1.01, 28.72±1.17–32.36±1.70° and 41.22±3.11 – 66.85±4.34 respectively in moisture range of 6.4-13.6% db, screw speed (3-4 rpm) and grinder speed (8000 – 11000 rpm).

Thermal conductivity

The variation in thermal conductivity of fenugreek at 30°C with varying moisture content, screw and grinder speed is shown in Figure 3. Thermal conductivity increased significantly with increasing moisture content irrespective of screw and grinder speed. The values of thermal conductivity of ground fenugreek powder increased from 0.063 ± 0.003 - 0.077 ±0.002 W/m-K at 30°C. Similar observation was also made by Darvishi and Zarein, (5) on sunflower seeds. High thermal conductivity at higher grinder speed may be attributed by lower particle size obtained at higher grinder speed. As the particle size decreased, surface to area ratio increased, thus conduct more heat leading to higher thermal conductivity. Similar increase in thermal conductivity with decreasing particles size of tomato powder was reported by Kadam *et al*., (11).

Specific heat

The specific heat of ground fenugreek powder was found to increase with increase in moisture content irrespective of screw speed and grinder speed (Figure 4). The results are in agreement of the findings reported for soya bean, *moringa oleifera* seed and *mucuna flagellipes* nut by Aviara *et al*., (1). The values of specific heat of fenugreek powder increased from 10.74 ± 0.098-16.64 ±1.24 kJ/kg-K at 30°C.

The analysis of variance for specific heat showed that grinding conditions i.e moisture content, screw speed and grinder speed significantly affected the specific heat of fenugreek powder at 5% level (Table 3).

Thermal diffusivity

The thermal diffusivity of fenugreek powder decreased with increase in moisture content irrespective of screw speed and grinder speed (Figure 5). This may be due to increase in bulk density of fenugreek powder irrespective of other grinding variables. The thermal diffusivity of fenugreek powder varied from 7.12×10^{-9} - 10.70×10^{-9} m^2/s at 30°C. However, the relationship between thermal diffusivity (α_b) and moisture content (M) has been reported in both ascending (Dutta *et al*. 7) and descending (Yang *et al*. 19,Singh and Goswami, 16) trends, as the magnitude of $á_b$ depends on the combined effect of k_b, ρ_b and C_p.

From present study it could be concluded that the quality attributes such as particle size, colour parameters, specific heat, thermal conductivity and thermal diffusivity were significantly affected by moisture content, screw speed and grinder speed. A higher speed of grinder resulted in fine particle size. The L-value decreased whereas browning index increased with increase in moisture content. Average particle size, specific heat and thermal conductivity increased with increase in moisture content whereas thermal diffusivity followed reverse trend.

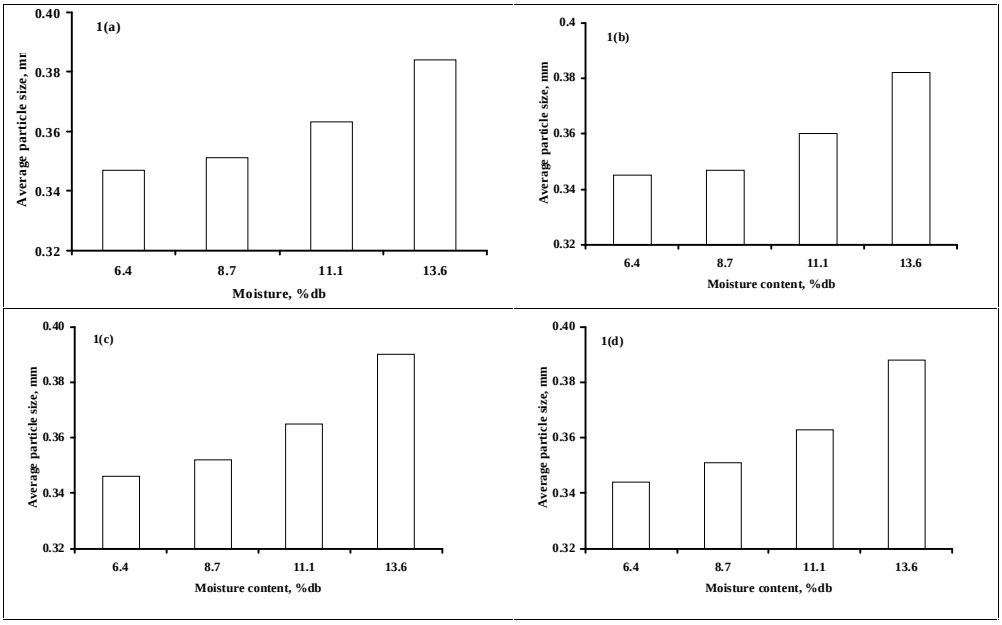

Figure 1. Effect of moisture content on average particle size of fenugreek powder at (a) screw speed: 3 rpm, grinder speed 8000rpm (b) screw speed: 3 rpm, grinder speed 11000rpm (c) screw speed: 4 rpm, grinder speed 8000rpm (d) screw speed: 4 rpm, grinder speed 11000rpm

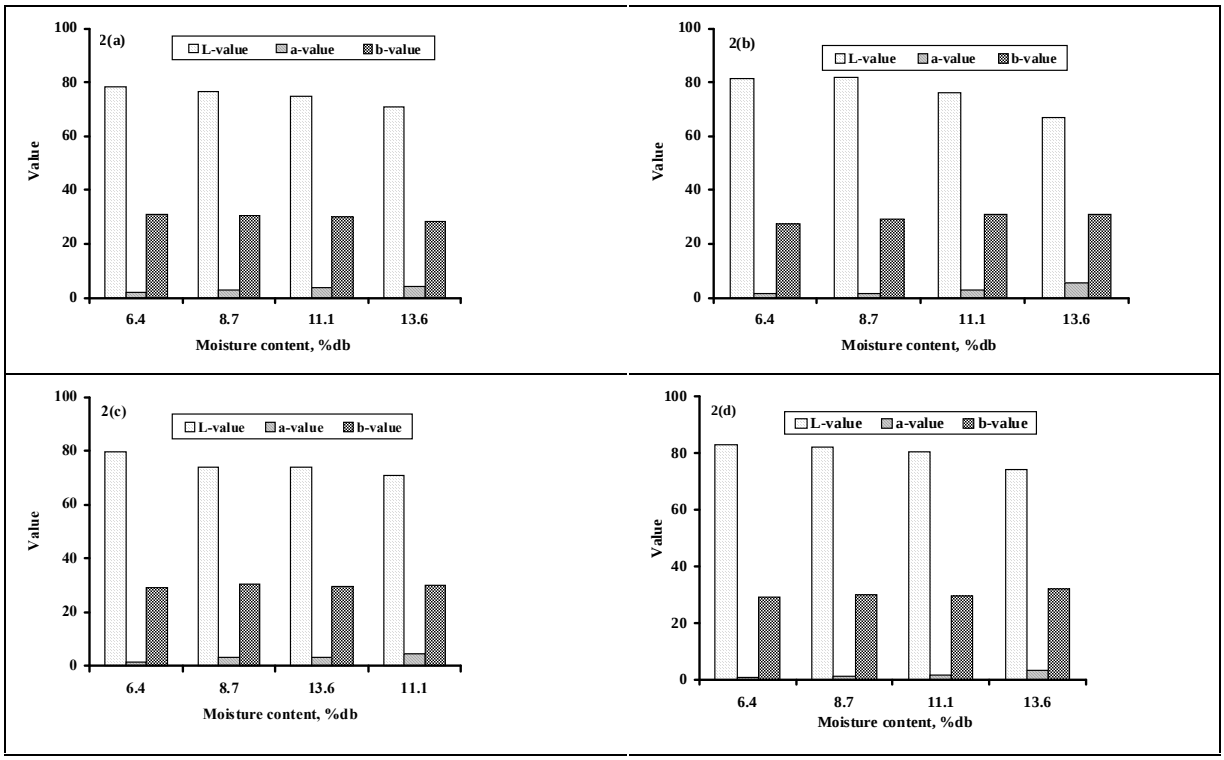

Figure 2. Effect of moisture content on colour values of fenugreek powder at (a) screw speed: 3 rpm, grinder speed 8000rpm (b) screw speed: 3 rpm, grinder speed 11000rpm (c) screw speed: 4 rpm, grinder speed 8000rpm (d) screw speed: 4 rpm, grinder speed 11000rpm

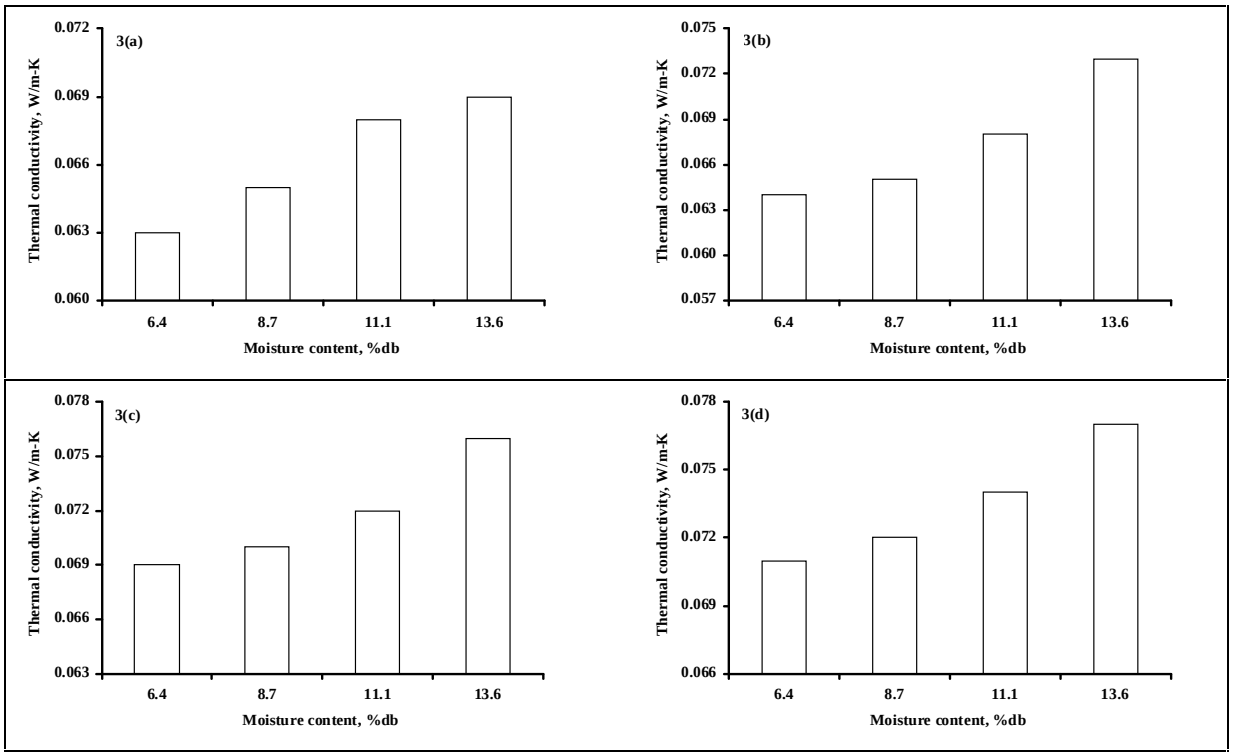

Figure 3. Effect of moisture content on thermal conductivity of fenugreek powder at 30°C at (a) screw speed: 3 rpm, grinder speed 8000rpm (b) screw speed: 3 rpm, grinder speed 11000rpm (c) screw speed: 4 rpm, grinder speed 8000rpm (d) screw speed: 4 rpm, grinder speed 11000rpm

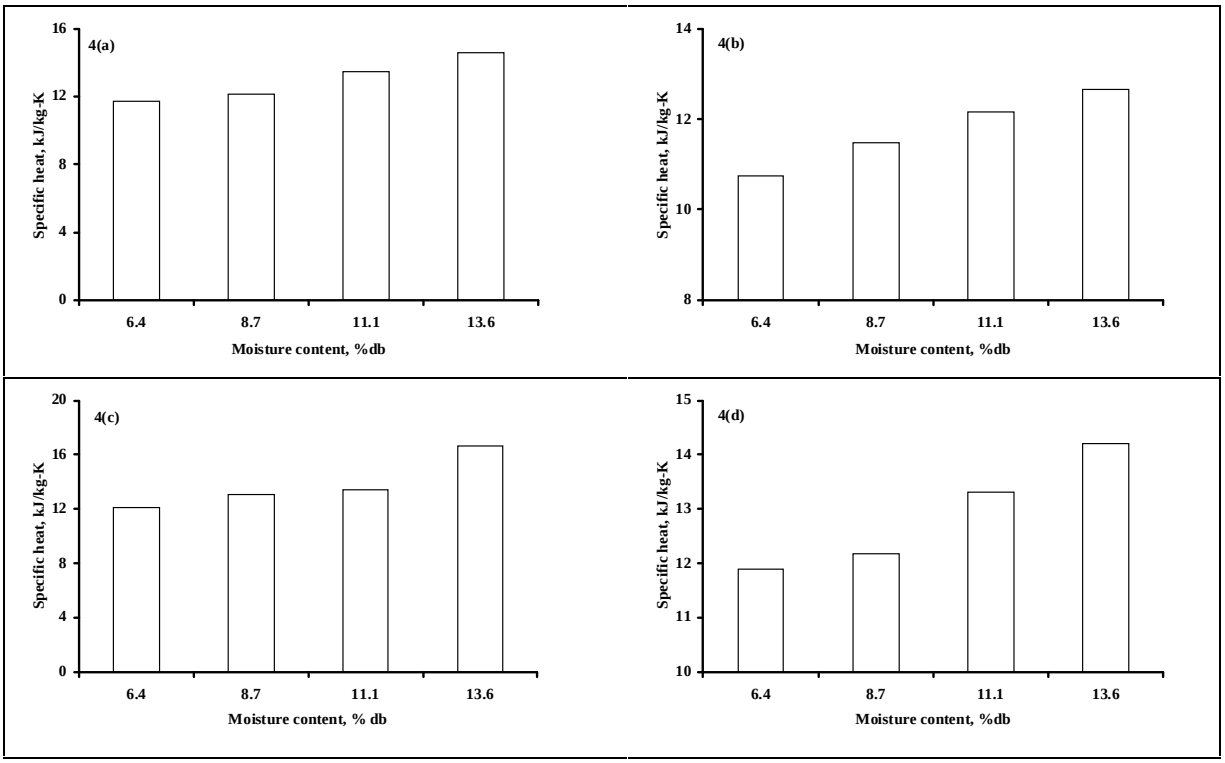

Figure 4. Effect of moisture content on specific heat of fenugreek powder at 30°C at (a) screw speed: 3 rpm, grinder speed 8000rpm (b) screw speed: 3 rpm, grinder speed 11000rpm (c) screw speed: 4 rpm, grinder speed 8000rpm (d) screw speed: 4 rpm, grinder speed 11000rpm

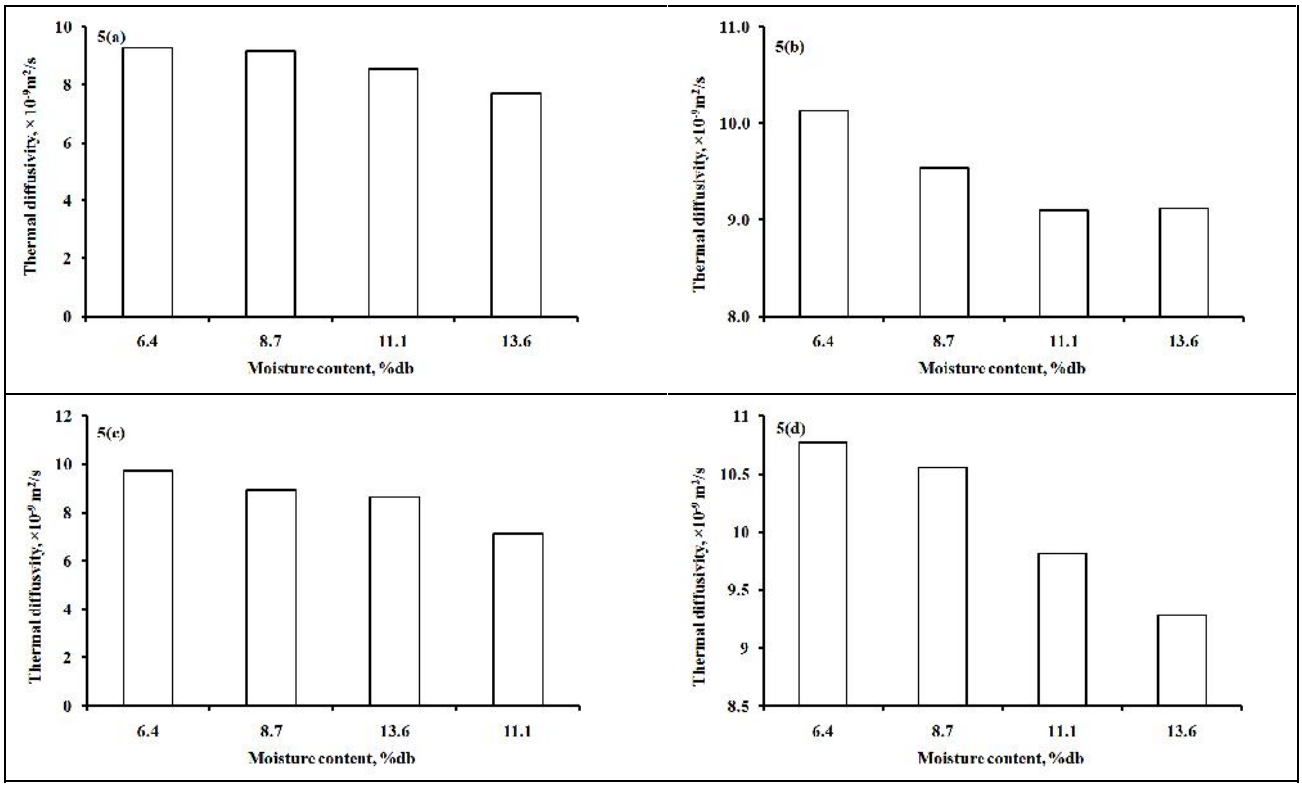

Figure 5. Effect of moisture content on thermal diffusivity of fenugreek powder at 30°C at (a) screw speed: 3 rpm, grinder speed 8000rpm (b) screw speed: 3 rpm, grinder speed 11000rpm (c) screw speed: 4 rpm, grinder speed 8000rpm (d) screw speed: 4 rpm, grinder speed 11000rpm

Table 4. Analysis of variance for colour parameters of fenugreek powder

Source	Degrees of freedom	Mean square	F-value	*p*-value
L-value				
Moisture content	3	203.46	70.13*	0.00
Screw speed	1	0.94	0.32	0.57
Grinder speed	1	308.45	106.33*	0.00
a-value				
Moisture content	3	16.14	170.08*	0.00
Screw speed	1	0.18	1.91	0.17
Grinder speed	1	24.20	255.04*	0.00
b-value				
Moisture content	3	1.63	0.60	0.61
Screw speed	1	16.39	6.02*	0.02
Grinder speed	1	5.14	1.88	0.17
Hue (°)				
Moisture content	3	64.74	128.89*	0.00
Screw speed	1	2.19	4.37*	0.04
Grinder speed	1	100.71	200.49*	0.00
Chroma				
Moisture content	3	0.93	0.34	0.79
Screw speed	1	15.24	5.67*	0.02
Grinder speed	1	3.01	1.12	0.29
Browning index				
Moisture content	3	201.21	13.43*	0.00
Screw speed	1	33.72	2.25	0.14
Grinder speed	1	208.13	13.90*	0.00

* Significant at p=0.05; NS Not significant

Acknowledgement

The authors wish to express sincere thanks to NAIP component IV, ICAR, India for providing financial assistance to carry out this work.

References

1. Aviara, A.N., Ehiabhi, S.E., Obafemi O.A., Surajudeen A,O., Pwanzadom P. P., Thlama, A., Onuh, A. O. 2011. Effects of moisture content and temperature on the specific heat of soya bean, moringa oleifera seed and mucuna flagellipes nut. *International J. of Agric. and Biolo Eng.* **4(1)**: 87.
2. Balasubramanian, S., Sharma, R., and Vijay S.R. 2011. Effect of moisture content and feed rate on size reduction of pearl millet. *Journal of Food Sci. and Eng*. 93-99
3. Chakraverty, A., 1988. Post harvest technology of cereals, pulses and oilseeds. India: Oxford & IBH publication (p. 177).
4. Coskuner Y., and Karababa E., 2007. Physical properties of coriander seeds. *J. Food Eng*., **80:** 408-416.
5. Darvishi, H., and Zarein, M. 2012. Thermal conductivity of sunflower seed as a function of moisture content and bulk density. *World Applied Sciences Journal* **18 (9)**: 1321-1325.
6. Das, H., 2005. Food processing operation analysi, Size reduction (Chapter 1). *Asian books private limited*, New Delhi, 1-20.
7. Dutta S K, Nema V K., and Bhardwaj R K. 1988 Thermal properties of gram. *J. of Agri. Eng. Res.* **39 (4):** 269-275.
8. Gupta, R.K., Kumar, P., Sharma, A and Patil, R.T. 2011. Color kinetics of aonla shreds withamalgamated blanching during drying. *International J. of Food Properties*, **14(6):** 1232-1240.
9. Jain, R. K., and Bal, S. 1997. Properties of pearl millet. *J. of Agric. Eng. Res*, **66**: 85–91.
10. Jha SN., and Verma BB. 1999. Effect of grinding time and moisture on size reduction of *makhana*. *J Food Sci Technol*. **36**: 446–448.
11. Kadam, D.M., Sharma, M., Chadha, S. and Wilson, R.A. 2012. Effect of particle size of foam mat dried tomato juice powder on various physical and sensory attributes. *American Society of Agricultural and Biological Engineers*, Dallas, Texas, July 29 - August 1, 2012.
12. Khosla P, Gupta DD., and Nagpal RK., 1995 Effect of *Trigonella foenum graecum* (fenugreek) on serum lipids in normal and diabetic rats. *Ind. J Pharm.* **27:** 89–93.
13. Mohsenin, N N. 1986 Thermal Properties of Foods and Agricultural Materials. (2nd ed.). *New York: Gordon and Breach,* 100-104.
14. Mollazade, K., Ahmadi, H., Khorshidi, J., Rajabipour, A., and Mohtasebi, S.S. 2009. Moisture-dependent physical and mechanical properties of cumin (*Cuminum cyminum* L.) seed. *International J. Agric and Biol Eng*. **2**: 49-56. No. 63–67.
15. Sahay, K.M. and Singh, K.K. 2004. Unit operation of agricultural processing. *Vikash publishing house Ltd*. New Delhi, 150-320.
16. Singh, K.K., and Goswami, T K. 2000 Thermal properties of cumin seed. *J. of Food Eng.* **45**: 181-187.
17. Singh, K. K., and Goswami T. K. 2006 Determination of specific heat of cloves using Differential Scanning Calorimetry. *J. of Agric. Eng.* **43(3):** 114-117.
18. Tiran, D. 2003. The use of fenugreek for breast feeding women. *Complement Ther. Nurs. Midwifery*, **9(3):** 155-156.
19. Yang, W., Sokhansanj, S., Tang, J., and Winter, P. 2002 Determination of thermal conductivity, specific heat and thermal diffusivity of borage seeds. *Biosystems Engineering*. **82 (2):** 169–176.
20. Yurtlu, Y.B., Yesiloglu, E., and Arslanoglu, F. 2010. Physical properties of bay laurel seeds. *International Agrophys*. **24**: 325-328.

Received : April 2013; Revised : June 2013; Accepted : June 2013.