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Thermal properties of different pulses

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■ **ABSTRACT :** Thermal properties determination studies were conducted at five levels of grain moisture content *i.e.*, 11.1, 13, 18, 23 and 25.07 per cent and temperature levels of 12.9, 17, 27, 37, 41.1°C.The maximum bulk thermal conductivity are obtained for these pulse grains for the combination pigeon pea, green gram and Bengal gram moisture content and temperature 18 per cent and 27 °C, respectively. The minimum bulk thermal conductivity are obtained for pigeon pea, black gram, green gram and for the combination moisture content and temperature 11.1 per cent and 27°C. Whereas, minimum bulk thermal conductivity is obtained for bengal gram for the combination moisture content and temperature 18 per cent and 12.9°C. The maximum thermal diffusivity is obtained for these pulse grains for the combination of moisture content and temperature 18 per cent and 27°C, respectively. The minimum bulk thermal diffusivity are obtained for pigeon pea and black gram for the combination moisture content and temperature 11.1 per cent and 27 °C. Whereas, minimum bulk thermal diffusivity are obtained for green gram and bengal gram for the combination moisture content and temperature 27 per cent and 37 °C. The maximum specific heat are obtained for pigeon pea and black gram for the combination moisture content and temperature 23 per cent and 17 °C, respectively. Whereas, maximum specific heat for green gram and bengal gram are obtained for the combination of moisture content and temperature 23 per cent and 37 °C and 18 per cent and 27 °C, respectively. The minimum specific heat is obtained for pigeon pea, black gram and green gram for the combination of moisture content and temperature 18 per cent and 27 °C. Whereas, minimum specific heat is obtained for bengal gram for the combination moisture content and temperature 11.1 per cent and 27 °C.

■ **KEY WORDS :** Moisture content, Temperature, Thermal properties, Statistical analysis

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Pulses are the important constituents of diet for large number of an Indian people where majority of population is vegetation. These supply the major portion of protein requirement of the human body. Pulses are major sources of protein in human and animal diet. In India per capita availability of pulses is much lower as against the moderately recommended intake. India counts for 35 per cent pulses cultivation and 26 per cent production of world. In India pulses are grown on 25 millions hectares yield about 15 millions tones (FAO, 1996), annually.

Many of these pulses one subjected to various types of thermal processing before they are placed at the disposal of consumers. The thermal properties have multiple applications in food engineering particularly to the researchers and designers of the food products and large amount of food preparations. These properties are used in heat transfer calculation and to establish critical control point during different processes. These properties are also employed in food technology as control index and to compare the efficiency of equipments and industrial plants. In addition, they are used to control low material during process aspect and concepts are provided simple method too. The knowledge of thermal properties *viz.*, specific heat, thermal conductivity and thermal diffusivity for thermal process of food grain are essential engineering data for control and analysis of many processing operations (Mohsenin, 1978).

These properties are dependent on the moisture content and temperature in case of biological materials.

In situation where heat transfer occurs of unsteady state *i.e.*, change with time, thermal properties are important parameters used to characterize the heat and mass transfer ability of the biological materials.

Pulses drying researchers have developed elaborative method and have extensively studied the drying of shelled corn and other pulses. Most, if not all of the principles governing the drying and storage studies of the other grain has been lack of basic thermal properties data. Some rules of thumb guidelines for evaluation of thermal properties of these grains exist but any drying and storage study using these guideline would be rough approximation.

Current theories do not provide a satisfactory mean for the independent calculation of accurate value of thermal properties of the biological materials. Experimental difficulties arise from the existence of complex mechanism of heat and mass flow from the necessity of measuring small temperatures differences accurately and from satisfying rigid boundary conditions. In biomaterials this problem is further compounded due to presence of free moisture pores heterogeneity of structure and anisotropic properties of constituent materials.

Knowledge of thermal properties of pulses will enable to calculate the exact heat requirement for drying temperature distribution in pulses, mass and other related design data and such data is scored in the literature. Hence it was decided to study and determine the thermal properties of major pulses grown in the Vidarbha region.

Study was undertaken to determine the values of bulk thermal conductivity, bulk thermal diffusivity and specific heat in relation to the effect of grain moisture content and temperature for pigeon pea, green gram, black gram and Bengal gram grain.

■ METHODOLOGY

Experiments was conducted on four types of pulses *viz.*, Cajanus cajan variety CII, *Cicer arietinum* (variety Chaff), *Phaselus aureus* (variety AKMTF 8803) and *Phaseolus mungo* (variety TAU 1), to determine value of thermal properties *i.e.*, thermal conductivity, thermal diffusivity and specific heat all different five moisture level and in combination of different five temperature level by using response surface methodology.

Table A : Combinations of factors for second order differential equation

Sr. No.	Moisture content, %	Temperature, -°C
1.	-1.0	-1.0
2.	-1.0	1.0
3.	1.0	-1.0
4.	1.0	1.0
5.	-1.414	0.0
6.	1.414	0.0
7.	0.0	-1.414
8.	0.0	1.414
9.	0.0	0.0
10.	0.0	0.0
11.	0.0	0.0
12.	0.0	0.0
13.	0.0	0.0

The grain for these varieties were obtained from Central Research Station, Dr. Panjabrao Deshmukh Krishi Vidyapeeth, Akola harvested in 1999. On these varieties, the tests were performed at five levels of grain moisture content *i.e.*, 11.1, 13, 18, 23 and 25.07 per cent and temperature levels of 12.9, 17, 27, 37, 41.1 in combinations as shown in Table A. The experiments were conducted randomly grouping for the moisture content.

Sample preparation:

After obtaining grain samples 7 kg each were cleaned and sorted by screening. After preparing sample for experiment, initial moisture content was determined for decision of adding moisture on dry basis. Sundried samples were moistened with calculated quantity of water by (Ww) using the following formula

$$W_w = \frac{[100 + (Md_2 + W_1)]}{[100 + Md_1]} - W_1$$

where, W_1 is the initial weight of the sample, Md2 is the initial moisture content of the sample, and Md2 is the final desired moisture content of grain.

This quantity of water was added to the dry sample and then it was conditioned to raise the moisture content to the desired level. These rewetted grain lot were sealed in high density polyethylene bag of size 40*30 cm which were kept on side wet gunny bag for 10 hr at room temperature and then conditioned in refrigerator at temperature 5 ± 2°C for 10 days are stirred regularly at an interval of two days to ensure uniform rewetting. Moisture content of pulses was determined by using standard hot air oven method.

Thermal conductivity:

Bulk thermal conductivity of these prepared pulses was determined by the transient heat flow method in infinite mass by a line heat source of the constant strength.

Bulk thermal conductivity can be calculated using transient theory of heat source and another. Secondary method is one dimensional steady state heat flow method but this method had been reported to have the disadvantage that long time is required to attain the steady state and there may possible migration of moisture due to temperature difference maintained across the grain for long period. Both these difficulties can be avoided by using transient heat flow method for finding the thermal conductivity of different pulses.

It was calculated using the following formula (Sharma & Thompson, 1973):

$$K = \frac{0.2389I^2 R \times I_n \left(t2/t1\right)}{4\Pi(T_2 - T_1)}$$

Bulk thermal diffusivity:

Bulk thermal diffusivity of grain sample was determined by using Dickerson's apparatus. An experiment apparatus was designed by Dickerson (1965) to measure this property of food. Thermal diffusivity can be determined using following method. But these methods are not applicable experimentally.

– least square method
– use of heat penetration curve
– use of time temperature curve
– use of analytic solution

Dickerson's method was suitable to calculate thermal diffusivity of grain pulse. An experiment apparatus consist of thermal diffusivity tube and a constant temperature water bath which was continuously stirred by a stirrer operated by 40 watt electric motor. The temperature of water bath was controlled by using heating coil which was dipped in water. The thermometer was used to monitor the temperature of water. The calibrated thermistor was located at the center and an inside surface wall of tube to measure diffusivity. This thermistor monitored the temperature history when the tube filled with sample was exposed to water bath at a constant rate. Dickerson derive the following equation to compute thermal diffusivity from this experimental apparatus.

$$\alpha = \frac{SR^2}{4(T_s - T_c)}$$

where, α is the thermal diffusivity (m^2/s), S is the constant slope of temperature verses time, R is the radius of tube, Tc is the central temperature and Ts is the surrounding temperature.

Temperature time data was collected and a slope of temperature versus time was calculated which was used in above equation to calculate diffusivity.

Before starting the test the tube was filled with 250 g sample of known temperature and moisture content and both top and bottom of the tube were insulated. The thermister were situated as described and this assembly was kept in constant temperature 50°C. The stirrer was allowed to stir water and the temperature at starting of test and at interval of 10 min for duration of one and half hour was noted by using multimeter. This procedure was repeated for the sample for decided moisture content and temperature.

Specific heat:

The Specific heat of these samples was determined by the method of mixture. The sample of known weight and temperature was dropped into calorimeter of known heat capacity and temperature containing water of known temperature and heat capacity. The equilibrium temperature for this measure of sample was then recorded by using thermometer.

The following expression was used to calculate heat capacity of grain.

$$C_{p_1} = \left[W \Delta t_2 C_{p_2} + C_{p_3} \Delta t_2 \left(W_3 - W_2\right)\right] / W \Delta t_1$$

where, Cp_1, Cp_2 and Cp_3 were specific heat of sample, calorimeter and water, respectively.

$\Delta t_{1 = t3 - t2}$

$\Delta t_{1 = t1 - t3}$

t_1 – temperature of sample, t_2 – temperature of calorimeter and

t_3- equilibrium temperature

W_1 – weight of sample

W_2 – weight of calorimeter with stirrer

W_3 – weight of calorimeter with stirrer and water

To calculate the specific heat following step were followed during experiment.

– Accurate weight of sample was taken
– The exact weight of calorimeter with stirrer was taken
– Calorimeter with stirrer and water was weighed
– Temperature of grain was noted
– Temperature of water in calorimeter was noted
– Equilibrium temperature attended by mixture was noted after stirring the mixture continuously
– Specific heat of calorimeter was 0.092 cal/g°C. (Cp_2) was known
– Specific heat of water Cp_3 was known to be 1.0 cal/g°C

The sample procedure was repeated for other sample at its respective moisture content and temperature.

Calibration of thermistor:

Calibration of these two thermistors was carried out by using B.O.D. incubator which is also known as temperature controller. These two thermistors of respective capacity which was indicated as thermistor 'A' and thermistor 'B' was kept in B.O.D. incubator. Two terminals of each of each thermistor were joined to the respective multimeter separately to record the temperature in the form of resistance. The temperature reading was directly read on the B.O.D. incubator.

RESULTS AND DISCUSSION

The effect of moisture content and temperatures was studied on the four variety of pulses grain namely pigeon pea, black gram and Bengal gram. This chapter deals with the details of observation analysis, and mathematical model equation.

Calibration of thermistor:

Two thermistor (A and B) with different resistances were used for recording the temperatures of grain and heat source. There calibration was done carefully. The observed data for calibration is given in Table 1.

$T_A = 42.86 - 2.334\,R$

and $T_B = 43.24 - 2.158\,R$

The effect of moisture content and temperature on thermal properties of pulse grain was studied using a response surface method and second order polynomial equations as

Table 1 : Calibration data for thermistor

Temperature, °C	Thermistor A	Thermistor B
5	17.721	16.223
10	15.403	14.081
15	13.086	11.093
20	10.769	9.796
25	8.451	7.653
30	6.164	5.510
35	3.817	3.368
40	1.500	1.225
45	-0.817	-0.916
50	-3.134	-3.069
55	-5.451	-5.201
60	-7.769	-7.344
65	-10.086	-9.487
70	-12.408	-11.629
75	-14.721	-13.772
80	-17.038	-15.914
85	-19.355	-18.057
90	-21.673	-20.199
95	-23.990	-22.342
100	-26.307	-24.485

statistical tools.

Table 2 shows the observer data during experimentation of moisture temperature effect in combination of different levels. Further multiple regression equations was carried out between the independent variables indicated above and the three responses *i.e.*, thermal properties. The partial regression coefficients are presented in Table 3.

Accordingly, for black gram the three mathematical model each for thermal properties can be enumerated as below.

Bulk thermal conductivity,

$$Y_k = 0.303+0.009x_1+0.0167x_2-0.063x_1^2-0.065x_2^2-0.001\,x_1x_2$$

Bulk thermal diffusivity

$$Y_á = 0.245-0.0048x_1-0.0048x_1+0.0036x_2-0.065x_1^2-0.069x_2^2-0.0052\,x_1x_2$$

Specific heat

$$Ycp = 1.39+0.069x_1+1+0.037x_2+0.208x_1^2+0.344x_2^2-0.03\,x_1x_2$$

Table 4 shows the analysis of variance for all these equations, which indicate that all the models have satisfactory values of correlation coefficient and are significant as is obvious from the F values obtained from the statistical analysis.

Table 2 : Observed data for thermal properties of pulses

Sr. No.	Moisture content, x_1	Temperature, x_2	Pigeon pea: Thermal conductivity (Y_1), (W/m°)	Pigeon pea: Diffusivity*10^{-6} (Y_2) m^2/s	Pigeon pea: Specific heat (Y3) (Cal/g-°C)	Black gram: Thermal conductivity (Y_1), (W/m°)	Black gram: Diffusivity*10^{-6} (Y_2) m^2/s	Black gram: Sp. heat
1.	-1	-1	0.174	0.133	1.808	0.174	0.133	1.82
2.	-1	1	0.186	0.129	1.91	0.186	0.129	1.91
3.	1	-1	0.189	0.109	2.075	0.189	0.109	1.98
4.	1	0	0.200	0.084	2.89	0.20	0.084	1.95
5.	-1.414	0	0.150	0.102	1.501	0.15	0.102	1.51
6.	1.414	0	0.181	0.124	1.78	0.181	0.124	1.76
7.	0	-1.414	0.123	0.082	1.82	0.123	0.082	1.82
8.	0	1.414	0.201	0.123	1.99	0.201	0.123	1.99
9.	0	0	0.231	0.179	1.33	0.205	0.254	1.24
10.	0	0	0.241	0.180	1.35	0.298	0.236	1.21
11.	0	0	0.231	0.178	1.36	0.312	0.261	1.22
12.	0	0	0.235	0.179	1.37	0.299	0.237	1.52
13.	0	0	0.235	0.177	1.34	0.302	0.236	1.56
				Green gram			Bengal gram	
1.	-1	-1	0.174	0.125	1.84	0.174	0.125	1.84
2.	-1	1	0.18	0.124	1.93	0.18	0.124	1.92
3.	1	-1	0.12	0.067	2.109	0.12	0.067	2.10
4.	1	0	0.15	0.056	3.26	0.149	0.056	2.26
5.	-1.414	0	0.16	0.107	1.78	0.158	0.107	1.77
6.	1.414	0	0.19	0.096	2.20	0.19	0.096	2.20
7.	0	-1.414	0.20	0.095	2.56	0.199	0.095	2.55
8.	0	1.414	0.10	0.068	1.78	0.1	0.068	1.78
9.	0	0	0.259	0.129	1.22	0.26	0.128	2.56
10.	0	0	0.259	0.129	1.25	0.197	0.13	2.77
11.	0	0	0.259	0.128	1.26	0.298	0.134	2.67
12.	0	0	0.258	0.127	1.28	0.286	0.139	2.38
13.	0	0	0.258	0.129	1.24	0.289	0.141	2.41

Table 3 : Partial regression coefficient for mathematical model for thermal properties of different pulses

Sr. No.		Pigeon pea			Black gram		
		Conductivity	Diffusivity	Specific heat	Conductivity	Diffusivity	Specific heat
1.	b_0	0.181	0.115	1.79	0.303	0.245	1.39
2.	b_1	0.014	0.007	0.222	0.009	-0.005	0.069
3.	b_2	0.015	0.012	0.157	0.016	0.004	0.037
4.	b_{11}	-0.003	0.002	-0.006	-0.063	-0.065	0.208
5.	b_{22}	-0.009	0.003	-0.184	-0.065	-0.069	0.344
6.	b_{12}	-0.004	-0.021	0.215	-0.001	-0.006	-0.03
		Green gram			Bengal gram		
1.	b_0	0.259	0.259	1.349	0.266	0.135	2.56
2.	b_1	0.005	-0.051	0.205	-0.005	-0.018	0.151
3.	b_2	-0.014	-0.13	0.145	-0.013	-0.006	-0.106
4.	b_{11}	-0.044	-0.43	0.245	-0.048	-0.016	-0.298
5.	b_{22}	-0.056	-0.56	0.377	-0.060	-0.026	-0.208
6.	b_{12}	-0.058	-0.575	0.178	-0.006	-0.003	0.02

Table 4 : Statistical analysis for multiple regression

Sr. No.		Conductivity		
		R^2	SE	'F' values
1.	Pigeon pea	0.744	0.014	4.072
2.	Black gram	0.959	0.018	33.54
3.	Green gram	0.847	0.029	7.706
4.	Bengal gram	0.746	0.043	4.134
		Diffusivity		
1.	Pigeon pea	0.801	0.0107	5.658
2.	Black gram	0.952	0.0201	27.559
3.	Green gram	0.847	2*91*10-9	7.706
4.	Bengal gram	0.834	0.016	7.009
		Specific heat		
1.	Pigeon pea	0.555	0.341	1.753
2.	Black gram	0.901	0.129	12.796
3.	Green gram	0.803	0.258	5.697
4.	Bengal gram	0.764	0.219	4.555

The thermal conductivity of black gram, pigeon pea, green gram and Bengal gram are presented in Table 2 which indicate the thermal conductivity of black gram lies between 0.123 to 0.312 W/m^{0}C. Whereas for pigeon pea, green gram, Bengal gram are found to be 0.123 to 0.241 W/m^{0}C, 0.1 to 0.259 and 0.1 to 0.298 W/m°C, respectively. Similarly, thermal diffusivity for these pulses are lies between 0.032*10^{-6} to 0.179*10^{-6} m^2/sec green gram 0.084*10^{-6} to 0.261*10^{-6} for black gram and 0.056*10^{-6} to 0.129*10^{-6} m^2/sec from green gram, 0.056*10^{-6} to 141*10^{-6} m^2/sec for Bengal gram, respectively. For moisture content level range between 13 to 25.07 per cent and for temperature level 17 to 41.1^{0}C.

Conclusion:

The maximum bulk thermal conductivity are obtained for these pulse grains for the combination pigeon pea, green gram and Bengal gram moisture content and temperature 18 per cent and 27^{0}C, respectively.

The minimum bulk thermal conductivity are obtained for pigeon pea, black gram, green gram and for the combination moisture content and temperature 11.1 per cent and 27^{0}C. Whereas, minimum bulk thermal conductivity is obtained for bengal gram for the combination moisture content and temperature 18 per cent and 12.9^{0}C.

The maximum thermal diffusivity is obtained for these pulse grains for the combination of moisture content and temperature 18 per cent and 27^{0}C, respectively.

The minimum bulk thermal diffusivity are obtained for pigeon pea and black gram for the combination moisture content and temperature 11.1 per cent and 27^{0}C.

Whereas, minimum bulk thermal diffusivity are obtained for green gram and bengal gram for the combination moisture content and temperature 27 per cent and 37^0C.

The maximum specific heat are obtained for pigeon pea and black gram for the combination moisture content and temperature 23 per cent and 17^0 C, respectively. Whereas, maximum specific heat for green gram and bengal gram are obtained for the combination of moisture content and temperature 23 per cent and 37 °C and 18 per cent and 27^0C, respectively.

The minimum specific heat is obtained for pigeon pea, black gram and green gram for the combination of moisture content and temperature 18 per cent and 27^0 C. Whereas, minimum specific heat is obtained for bengal gram for the combination moisture content and temperature 11.1 per cent and 27^0C.

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