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THERMAL PROPERTIES OF DIFFERENT FORMS OF PIGEON PEA AT SELECTED MOISTURE CONTENTS

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Key words: *Thermal conductivity, Moisture content, Pigeon pea, Unhusked, Specific heat*

Abstract– The three forms of pigeon pea viz. unhusked, husked and split form dhal taken for determination of thermal properties viz. thermal conductivity, thermal diffusivity, thermal effusivity, thermal resistivity and specific heat at different moisture contents ranging from 10% to 20% mc. (10%, 16%, 18% and 20%). The pigeon pea grains in all its three forms were subjected to moisture content determination using hot air oven method. The pigeon pea grains were added with water to make up the moisture content by distilled water addition using formula method. Then moisture content were determined using hot air oven method. Thermal properties were determined using lab model thermal conductivity meter. Thermal conductivity range of value in dehusked pigeon pea is 0.056 to 0.06W/m °k, in unhusked pigeon pea is 0.049-0.059W/m°k ranging in moisture content from 10% to 20%. The thermal conductivity values increases from 0.056 to 0.06W/m°k in dehusked and in unhusked it increases from 0.049 to 0.059W/m°k from 10% to 20% mc. In unhusked the thermal conductivity values are lower as compared to dehusked pigeon pea and it varies with moisture content also. At low moisture content of 10% and in unhusked the lowest is found this may be due to the presence of outer layer and with less moisture the level of conductivity is low. This is not the same result as in thermal resistivity and in dehusked range is 1681-18.02KJ/kg °C, in unhusked the range of values is 16.88-20.3 KJ/kg °C Specific heat is less in unhusked pigeon pea, 2.46KJ/kg °C. Thermal effusivity range is 11.80-12.22Ws/m^2°k in de -husked and in unhusked, 11.00-12.07Ws/m^2°k. Thermal effusivity increases with increase in moisture content from 10% mc to 20% mc. Thermal conductivity decrease in unhusked pigeon pea is 5% as compared to dehusked pigeon pea. Thermal resistance in dehusked is 7.32% less as compared to unhusked pigeon pea. Thermal effusivity of dehusked, 4.58% is more as compared to unhusked pigeon pea. Specific heat in dehusked pigeon pea, 2.0% as compared to unhusked pigeon pea. Thermal diffusivity of unhusked pigeon pea is less by 9.76% as compared to dehusked pigeon pea. The values were significant at 5% level of significance and analysis were done using SPSS-16.0 software and design expert software, 12.0 version.

INTRODUCTION

Pulses are the important constituents of diet for large number of an Indian people and 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 accounts 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 tonnes (FAO, 1996), annually. Many of these pulses are subjected to various types of thermal processing before they are placed at the disposal of consumers. The thermal

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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. Also, in the food industry, thermal properties are important parameters to determine in designing equipment or its parts, and, in computer simulation, to analyze, optimize, and control of the temperature during the elaboration, storage, transport and commercialization of foods is very important. 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, 1980). These properties are dependent on the moisture content and temperature in case of biological materials. Thermal conductivity, thermal diffusivity and specific heat capacity are three important engineering properties of a material related to heat transfer characteristics. These parameters are essential in studying heating, drying and cooling processes for borage seeds. Thermal properties of many agricultural and food products have been reported in the literature, and most of these data are compiled by Polley *et al.* (1980) and ASAE (2001) for engineering research and design purposes. Often, the physical properties of biological materials are dependent on the moisture content, which would affect the performance and the adjustment of the equipment. Therefore, the effect of moisture content on the physical properties of agricultural materials is an important consideration in postharvest management and operations for the processing of food and agricultural products. Knowledge of the thermal properties of agricultural materials is essential for modeling, optimization and design of practices and processing equipment for operations based on heat treatment, including dehydration, bleaching, cooking, heating, cooling, vaporizing and freezing (Alagusundaram *et al.,* 1991)

MATERIALS AND METHODS

The pigeon pea grains were procured from the market and subjected to dehulling in a dehuller and the unhusked, husked and split were separated manually. Three different forms of pigeon pea viz. without dehusking, with dehusking and split form were taken for the study. Thermal conductivity was found out using TLS-100 Portable thermal conductivity meter that is simple in operation and the temperature range used were in the range of 40°C to 100°C. The desiccators containing the samples were evacuated to 700 nm Hg vacuum and kept at 10°C for hydration of the samples by maintaining a relative humidity of 95.5% (Hall, 1957). The moisture content of the equilibriated/ hydrated sample was determined by oven drying method (AACC, 1969). The bulk was manually cleaned to remove foreign matter, dust, dirt, broken and immature grains and then sampled for experiment. Pigeon pea at 4 different moisture contents of 10%, 16%, 18% and 20% were made using distilled water addition by formula method. The samples of the desired moisture contents were prepared by adding the amount of distilled water as calculated from the following relation (Sacilik *et al.,* 2003)

$$Q=W_I(M_{f-}M_i)/(100-M_f)$$

where, Wi , is the initial mass of sample in kg; Mi, is the initial moisture content of sample in % w.b.; and Mf , is the final moisture content of sample in % w.b.

Initial moisture content was determined using hot air oven method. Final moisture content were found out for the pigeon pea samples after equilibriation of the moisture after storing in the refrigerator at 0 °C for 10 days. Statistical analysis were done by SPSS 16.0 version. Thermal conductivity, thermal diffusivity and specific heat capacity each can be measured by several well established methods (Mohsenin, 1980; Dickerson, 1965), but measuring any two of them would lead to the third through the relationship $\alpha= K/\rho C_p$ where α is the thermal diffusivity, k is the thermal conductivity, ρ is the bulk density and cp is the specific heat. The bulk density (5), thermal conductivity (k), specific heat capacity (Cp) and diffusivity (α) of pigeon pea seeds were studied at varied (MC) moisture content (%) level. The thermal effusivity (þ)was determined as a function of thermal conductivity and specific heat capacity $\rho = \surd\rho\ k\rho aCp$. The bulk density ($\rho_b$) was determined by filling a container with sample at a constant rate and weighing the contents. (M) The volume of the container was estimated with the dimensions of the container. (V) The bulk density is the ratio of the mass of a sample to its total volume. ρ_b=M/V. Fig.3 shows the thermal conductivity apparatus.

RESULTS AND DISCUSSION

The three forms of pigeon pea viz. unhusked, husked and split form dhal taken for determination of thermal properties viz. thermal conductivity, thermal diffusivity, thermal effusivity, thermal resistivity and specific heat at different moisture contents ranging from 10% to 20% mc. (10%, 16%, 18% and 20%). The pigeon pea grains in all its three forms were subjected to moisture content determination using hot air oven method. The pigeon pea grains were added with water to make up the moisture content by distilled water addition using formula method. Then moisture content were determined using hot air oven method. Thermal properties were determined using lab model thermal conductivity meter Thermal conductivity range of value in dehusked pigeon pea is 0.056 to 0.06W/m°k, in unhusked pigeon pea is 0.049-0.059W/m°k ranging in moisture content from 10% to 20%. The thermal conductivity values increases from 0.056 to 0.06 W/m°k in dehusked and in unhusked it increases from 0.049 to 0.059W/m°k from 10% to 20%mc. In un-husked the thermal conductivity values are lower as compared to dehusked pigeon pea and it varies with moisture content also. Thermal parameters of seed moisture content and temperature give an insight in the development and prediction of models that meet the needs of process design models, it also determine the thermal load of a particular product during handling.

At low moisture content of 10% and in unhusked the lowest is found this may be due to the presence of outer layer and with less moisture the level of conductivity is low. This is not the same result as in thermal resistivity and in dehusked range is 16.81-18.02KJ/kg°C, in unhusked the range of values is 16.88-20.3KJ/kg%c. Specific heat is less in unhusked pigeon pea, 2.46 KJ/kg°C. Thermal effusivity range is 11.80-12.22Ws/m^2°k in dehusked and in unhusked, 11.00-12.07Ws/m^2°k. Thermal effusivity increases with increase in moisture content from 10% mc to 20%mc. Thermal conductivity decreases in unhusked pigeon pea is 5% as compared to dehusked pigeon pea. Thermal resistance in dehusked is 7.32% less as compared to unhusked pigeon pea. Thermal effusivity of dehusked, 4.58% is more as compared to unhusked pigeon pea. Specific heat in dehusked pigeon pea, 2.0% as compared to unhusked pigeon pea. Thermal diffusivity of unhusked pigeon pea is less by 9.76% as compared to dehusked pigeon pea. The values were significant at 5% level of significance and analysis were done using SPSS-16.0 software. It is observed that thermal diffusivity increases for low moisture content levels and it decreases as moisture content increases. This trend has been reported by Kostaropoulos and Saravacos, 2009 in different foods. They found that for low moisture contents, as moisture content increases, the pores and capillaries of the solid filled with air that is gradually displaced by absorbed water. Heat is released by water adsorption in the solids and the thermal diffusivity increases. However, for higher moisture content levels, capillaries are filled gradually with water, thermal diffusivity is reduced since the thermal diffusivity of liquid water is lower than that of air. Results of work on minor millet grains and flours showed that by increase in moisture from 10 to 30% (w.b.) specific heat and thermal conductivity increase from 1.33 to 2.4KJkg^{-1}°C^{-1} and 0.119 to 0.223 W m^{-1}°K^{-1} respectively, but thermal diffusivity decrease from 0.734 to 0.55 m^2 h^{-1} (Subramanian and Viswanathan, 2003)

Work of researchers on timothy hay illustrated that increase in moisture in range of 7.7% to 17.1% will cause increase in thermal conductivity and thermal diffusivity from 0.284 to 0.061Wm^{-1}°C^{-1} and 1.024 to 3.031×10^{-7}m^{2}S^{-1}, respectively (Opoku *et al.*, 2006) Also, reports has shown thermal conductivity increase of barely, lentils, and peas as follow, 0.16 to 0.232Wm^{-1}°K^{-1}, 0.187 to 0.249Wm^{-1}°K^{-1} and 0.187 to 0.25 Wm^{-1}°K^{-1} respectively. In all of them range of moisture increase from 9 to 23% (Alagusundaram *et al.*, 1991). Moisture content in cereal products has an imperative effect on the specific heat due to heat of absorption and specific heat of water (Tang, *et al.*, 1991). The thermal conductivity of grain is a measure of its ability to transmit heat. This is in good agreement with the fact that thermal conductivities of food materials vary between that of water (kwater = 0.614 W/m °C at 27 °C) and that of air (kair = 0.026W/m °C at 27 °C), that are the most and the least conductive components in foods, respecttively. The thermal conductivity values of the other food components fall between these limits. (Nouri Jangi *et al.*, 2011). This is in agreement with the three forms of pigeon pea, split being the least followed by dehulled and then unhulled. Fig.1 shows the thermal properties of pigeon seed at different moisture contents.

Effect of different moisture contents

At 10% mc for thermal diffusivity, 11.11% increase in unhulled pigeon pea than that of split pigeon pea, 3.44% increase in dehulled than that of split pigeon pea, 8.88% increase in unhulled than that of dehulled pigeon pea is noticed. Fig. 9 shows the thermal effusivity and thermal conductivity of unhulled pigeon pea sample at different moisture contents. It is because of the fact that at lower moisture content the storage of electric energy is more in unhulled than that of split pea. At 10% mc, for specific heat, 7.61% increase in dehulled than that of unhulled pigeon pea, 38.53% increase in dehulled compared to split pigeon pea, 33.47% increase in unhulled pigeon pea compared to split pigeon pea. Table 1 shows the different thermal properties of unhusked pigeon pea at 4 different moisture contents.

At 10%mc, thermal effusivity, 2.18% increase in unhulled pigeon pea than that of dehulled pigeon pea 33.10% increase in dehulled than that of split pea, 34.56% increase in unhulled compared to split pigeon pea. Fig. 10 shows the thermal resistivtiy and thermal conductivity of unhulled pigeon pea

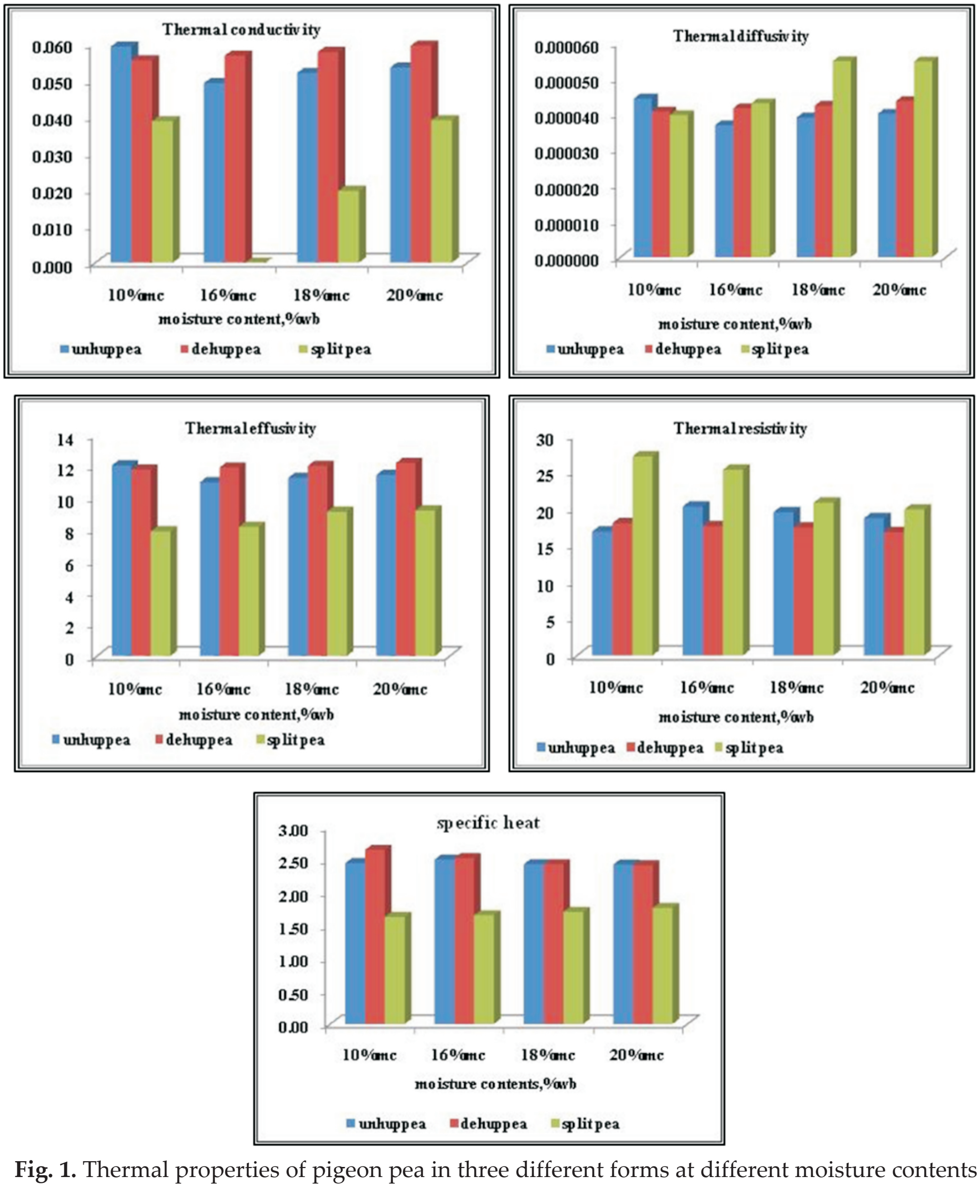

Fig. 1. Thermal properties of pigeon pea in three different forms at different moisture contents

sample at different moisture contents. At 10%mc, 37.8 % increase in split pigeon pea than that of unhulled pigeon pea, 33.60 % increase in split pigeon pea than that of dehulled pigeon pea, 6.33% incr -ease in dehulled pigeon pea than that of unhulled pigeon pea. Fig.1 thermal properties of pigeon pea in three different forms at different moisture contents. At 16%mc in thermal diffusivity, the percentage increase in unhulled than that of split pigeon pea, 13.95% the percentage decrease in unhulled than that dehulled is 11.90%, percentage increase in split than that of dehulled pigeon pea is 2.33%. Fig.11 shows the specific heat and thermal conductivity of unhulled pigeon pea sample at different moisture contents. At 16%mc, in specific heat 0.87% increase in dehulled pigeon pea than that of unhulled pigeon pea, 34.51% increase in dehulled than that of split pea, 33.93% increase in unhulled than that of split pea. At 16% mc,in thermal effusivity, 7.83% increase in dehusked pigeon pea than that of unhusked pigeon pea, 31.50% increase in dehulled than that of split pigeon pea, 25.68%

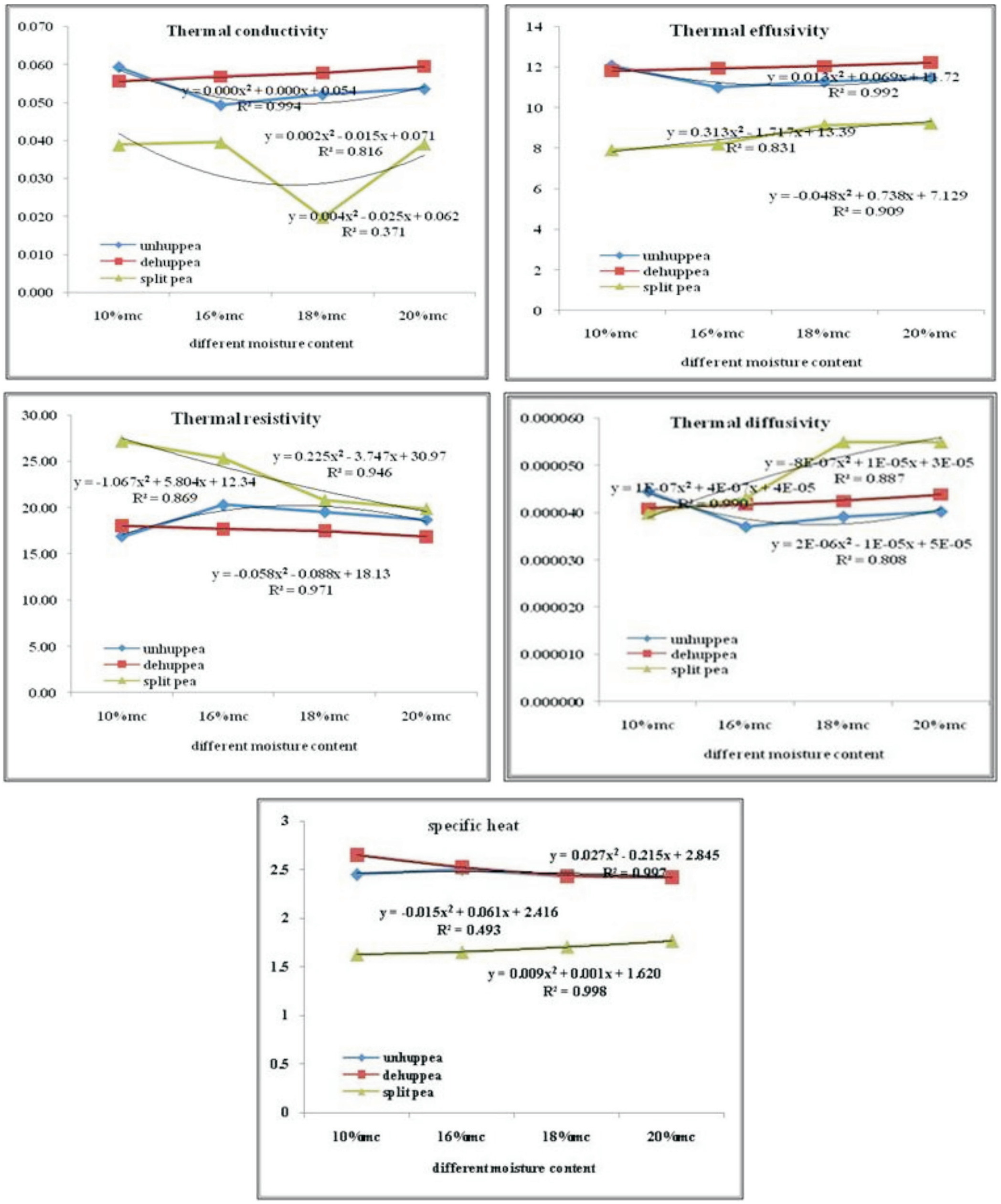

Fig. 2. Thermal conductivity, thermal effusivity, thermal resistivity,specific heat and thermal diffusivity of three different forms of pigeon peaEffect of different forms of pigeon pea:

increase in unhulled than that of split pigeon pea. Table 2 shows the different thermal properties of dehusked pigeon pea at 4 different moisture contents.

At 16%mc in thermal resistivity, 30.40%, increase in split than that of dehulled pigeon pea, 19.79% increase in spit than that of unhulled pigeon pea, 13.22% increase in unhulled pigeon pea than that of dehulled pigeon pea. Fig.12 shows the thermal effusivity and thermal diffusivity of unhulled pigeon pea sample at different moisture contents. At 18%mc for thermal diffusivity, 29.09% increase in split pea than that of unhulled pigeon pea,23.64% increase in split pea than that of dehulled pigeon pea, 7.14% increase in dehusked pigeon pea than that of unhulled pigeon pea. At 18%mc, specific heat, 26.52% increase in unhulled than that of split pigeon pea, 29.87% increase in dehulled than that of split pea, 004% increase in dehulled pigeon pea than that of unhulled pigeon pea. At 18% mc, thermal effusivity, 6.30% increase in dehulled pigeon pea than that of unhulled pigeon pea, 24.08% increase in dehulled pigeon pea than that of split pigeon pea, 18.98 % increase in unhul -led than that of split pigeon pea. Fig.13 shows the thermal resistivity and thermal diffusivity of unhulled pigeon pea sample at different moisture contents. At 18%mc,thermal resistivity, 6.17 % increase in split pigeon pea than that of unhulled pigeon pea, 16.34% increase in split pea than that of dehulled pigeon pea, 10.73% unhulled pigeon pea is increased than that of dehulled pigeon pea.

At 20%mc in thermal diffusivity, 20% increase in split pigeon pea than that of dehulled pigeon pea, 27.27% increase in split pigeon pea than that of unhulled pigeon pea,9.09% increase in dehulled than that of unhulled pigeon pea. Fig.14 shows the specific heat and thermal diffusivity of unhulled pigeon pea sample at different moisture contents. At 20% mc, in specific heat, 0.45% increase in unhulled than that of dehulled pigeon pea, 27.22% increase in unhulled than that of split pea, 26.89% increase in unhulled than that of split pigeon pea. Fig. 15 shows the thermal resistivity and thermal

Table 1. Different thermal properties of unhusked pigeon pea at 4 different moisture contents

		Unhusked			Pigeonpea		
SNo.	mc(%wb)	BD	Ther.con.	Ther.diff.	Spec. heat	Ther.effus	Ther.res
1	10%mc	1326.12	0.059	0.000045	2.453	12.07	16.88
2	16%mc	1355.59	0.049	0.000037	2.508	11.00	20.30
3	18%mc	1317.28	0.052	0.000039	2.437	11.28	19.53
4	20%mc	1314.33	0.054	0.000040	2.432	11.47	18.69
5	mean	1328.33	0.054	0.000040	2.457	11.45	18.85
6	max.	1355.59	0.059	0.000045	2.508	12.07	20.30
7	min.	1314.33	0.049	0.000037	2.432	11.00	16.88
8	sd	18.16	0.004	0.000003	0.035	0.45	1.47
9	sem	6.86	0.002	0.000002	0.017	0.23	0.74
10	cv	0.014	0.08	0.08	2.110	0.04	0.08
11	p-val	0.00	0.00	0.00	0.00	0.00	0.00

Table 2. Different thermal properties of dehusked pigeon pea at 4 different

		Dehusked			Pigeon pea		
SNo.	mc(%wb)	BD	The.cond	The.diff.	Specheat	Ther.effus	Ther.res.
1	10%mc	1435.16	0.056	0.000041	2.655	11.80	18.02
2	16%mc	1367.38	0.057	0.000042	2.530	11.94	17.62
3	18%mc	1317.28	0.058	0.000042	2.437	12.04	17.44
4	20%mc	1308.44	0.060	0.000040	2.421	12.22	16.81
5	mean	1357.06	0.057	0.000040	2.511	12.00	17.47
6	max.	1435.16	0.060	0.000040	2.655	12.22	18.02
7	min.	1308.44	0.056	0.000040	2.421	11.80	16.81
8	sd	31.78	0.002	0.000001	0.108	0.18	0.50
9	sem	18.35	0.001	0.000001	0.054	0.09	0.25
10	cv	0.02	0.03	0.03	0.043	0.01	0.03
11	p-val	0.00	0.00	0.00	0.000	0.00	0.00

effusivity of unhulled pigeon pea sample at different moisture contents. At 20%mc thermal effusivity, 6.19% increase in dehulled than that of unhulled pigeon pea, 24.55% increase in dehulled than that of split pea, 19.58 % increase in unhulled pigeon pea than that of split pigeon pea. Fig.16 shows the specific heat and thermal effusivity of unhulled pigeon pea sample at different moisture contents. At 20% mc thermal resistivity the 15.54% increase in split pea than that of dehulled pigeon pea, 6.07% increase in split pigeon pea than that of unhulled pigeon pea, 10.08% increase in unhulled pigeon pea than that of dehulled pigeon pea**.** Fig. 17 shows the specific heat and thermal resistivity of unhulled pigeon pea sample at different moisture contents.

Among the three forms of pigeon pea tested, unhusked pigeon pea thermal resistance is more by 7.3% than that of dehusked pigeon pea,thermal resistance is more by 19.06% in split pigeon pea than that of unhusked pigeon pea, split dehusked pigeon pea is 24.99% of dehusked pigeon pea. Table 3 different thermal properties of split pigeon pea at 4 different moisture contents. Thermal effusivity in split dehusked pigeon pea is less by 28.25% than that of dehusked pigeon pea, dehusked pigeon pea is 4.58% more than that of unhusked pigeon pea, split pea is less by 24.80% than that of unhusked pigeon pea in thermal effusivity. Table 1 shows the different thermal properties of unhusked pigeon pea at 4 different moisture contents. Fig. 2 shows the thermal conductivity, thermal effusivity, thermal resistivity, specific heat and thermal diffusivity of three different forms of pigeon pea. Fig. 8 shows the thermal diffusivity and thermal conductivity of unhulled pigeon pea sample at different moisture contents.

Among the moisture content tested in three forms of pigeon pea, viz. unhusked, dehusked and split pigeon pea for thermal conductivity, at 10% mc, split pea is 33.90% less than that of unhusked pigeon pea, 5.08% increase in dehusked than that of unhusked, 30.36% increase in dehusked over that of split pigeon pea, at 16%mc,18.37% is more in unhusked than that of split pigeon pea, 14.04% is more in dehusked than that of unhusked pigeon pea,29.82% increase in dehusked over that of split pigeon pea, at 18%mc, 61.54% increase in split pigeon pea than that of unhusked pigeon pea, 65.52% increase in dehusked pigeon pea than that of

Table 4. 1) split pigeon pea

Regression Equation
1) ther.cond. = 0.04 - 0.00067 diff mc, R-sq=8.8%
2) the.diff. = 0.000022 + 0.000002 diff mc, R-sq=78.48%
3) Specheat =1.490 + 0.012 diff mc, R-sq=79.46%
4) ther.effus = 6.38 + 0.13 diff mc, R-sq=80.10%
5) ther.res=35.17 - 0.74 diff mc, R-sq=84.59%
6) bd=805.8 + 6.80 diff mc, R-sq=79.46%

2) dehulled pigeon pea
Regression Equation
1) ther.cond = 0.051 + 0.00036 diff mc, R-sq=87.64%
2) ther.diff=0.000038 + 0.000000 diff mc, R-sq=86.77%
3) Specheat=2.9031 - 0.02453 diff mc, R-sq=97.01%
4) ther.effus.= 11.389 + 0.0382 diff mc, R-sq=87.62%
5) ther.res.= 19.187 - 0.1072 diff mc, R-sq=84.28%
6) bd=1569.2 - 13.26 diff mc, R-sq=97.01%

3) unhulled pigeon pea
Regression Equation
1) ther.cond.= 0.06421 - 0.000670 diff mc, R-sq=47.05%
2) ther.diff.= 0.000048 - 0.000000 diff mc, R-sq=46.22%
3) Specheat=2.4906 - 0.00207 diff mc, R-sq=6.60%
4) ther.effus.= 11.389 + 0.0382 diff mc, R-sq=87.62%
5) ther.res.= 19.187 - 0.1072 diff mc, R-sq= 84.28%
6) bd=1346.9 - 1.16 diff mc, R-sq=7.04%

Table 3. Different thermal properties of split pigeon pea at 4 different moisture contents

		Split dehusked			Pigeonpea		
SNo.	mc(%wb)	bd	The cond.	The diff.	Speche at	Ther. effus	Ther. res.
1	10%mc	882.32	0.037	0.000040	1.632	7.90	27.14
2	16%mc	895.87	0.040	0.000043	1.657	8.18	25.32
3	18%mc	923.75	0.050	0.000055	1.709	9.14	20.82
4	20%mc	956.87	0.050	0.000055	1.770	9.22	19.90
5	mean	914.70	0.04	0.000048	1.692	8.61	23.29
6	max.	956.87	0.05	0.000055	1.770	9.22	27.14
7	min.	882.32	0.04	0.000040	1.632	7.90	19.90
8	sd	32.98	0.01	7.89E-06	0.061	0.67	3.49
9	sem	16.49	0.00	3.945E-06	0.031	0.34	1.74
10	cv	0.04	0.16	0.16	0.036	0.08	0.15
11	p-val	0.00	0.00	0.00	0.000	0.00	0.00

split pigeon pea, 10.34% increase in dehusked than that of unhusked pigeon pea, at 20%mc, 27.78% split pea is less than unhusked pigeon pea,10% increase in dehusked than that of unhusked, 35% increase in dehusked than that of split pigeon pea. Table 2 shows different thermal properties of dehusked pigeon pea at 4 different moisture contents. Fig.4 different thermal properties of different forms of pigeon pea. Specific heat is less in split pigeon pea,1.69 KJ/kg°k followed by unhusked, 2.51 KJ/kg°k and then by dehusked pigeon pea, 2.46 KJ/kg°k. This indicates the split pigeon pea requires less heat during drying purposes followed by unhulled and dehulled pigeon pea. These values were lower than those of various sizes of oil bean seed (2.14–5.32 kJ kg-1 K-1) (Oje and Ugbor, 1991; Ogunjimi *et al.,* 2002). Table 3 shows different thermal properties of split pigeon pea at 4 different moisture contents. Thermal diffusivity quantifies a material's ability to conduct heat relative to its ability to store heat (Stroshine and Hamann, 1994). The values obtained for three forms of pigeon pea were 3.70x10^{-5}m^{2}s^{-1}, in unhulled form, 4.4x10^{-5}m^{2}s^{-1} in dehusked form, 5.5x10^{-5}m^{2}s^{-1}, in split form. The values obtained in the current study for barley grains, were close to that of cumin seed (6.53×10^{-8} – 16.64×10^{-8} m^{2}s^{-1}) at temperatures from –50 °C to 50 °C and moisture content of 7.8 % db. (Singh and Goswami, 2000).

Fig. 3. Thermal conductivity apparatus

The thermal diffusivity, D, was calculated based on the measured values of the specific heat and thermal conductivity and using the standard formula for diffusivity as mentioned above. These data are useful for the adjustments of drying rate, for the calculations of the economical drying time and for the determination of energetic balances of drying processes. Moisture content is the important factor affecting thermal properties of biological materials. Fig. 5 shows the different thermal properties of pigeon pea at 4 different moisture contents.

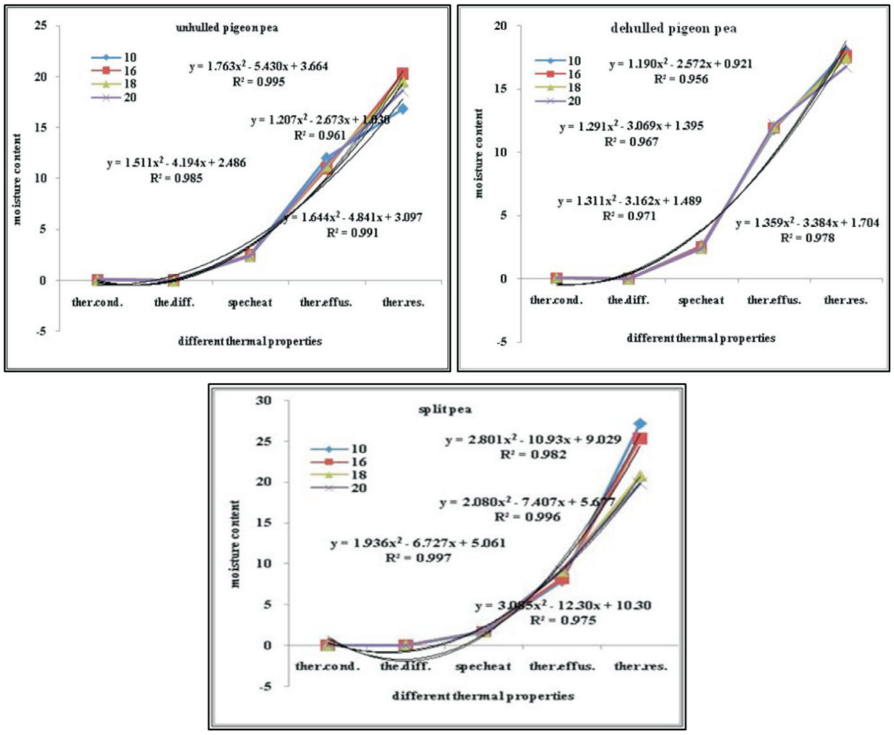

Fig. 4. Different thermal properties of different forms of pigeon pea

Specific heat capacity of agricultural flour determined the quantity of thermal energy a unit of the food flow retains at every unit increase in temperature (Sandra and Bernarda, 2015). Mean specific heat of unhulled was found to be 2.46kJ kg^{-1}K^{-1},in dehulled it was 2.51kJ kg^{-1}K^{-1} and in split form, it was 1.69 kJkg^{-1} K^{-1} and the range in three forms were 1.69-2.51kJ kg^{-1} K^{-1}. Specific heat for soybean was found to be both moisture and temperature dependent and increased from 1.33 to 3.09 kJ kg^{-1}K^{-1} with increase in temperature and moisture content (Singh and Goswami, 2000). Results of work on minor millet grains and flours showed that by increase in moisture from 10 to 30% (w.b.) specific heat and thermal conductivity increase from 1.33 to 2.4kJ.kg^{-1}°C^{-1} and 0.119 to 0.22 W.m^{-1} °K^{-1} respectively, but thermal diffusivity decrease from 0.73 to 0.55 m^2 h^{-1}.Oje and Ugbor (1991) observed that lighter seeds had higher specific heat capacity value than heavier seeds, indicating a decreasing linear trend of this parameter with increasing moisture content. The bulk density increases with increase in moisture content and this may be due to weight of water present in the sample. Fig. 6 shows the bulk density of different forms of pigeon pea at 4 different moisture contents. Thermal resistance is the resistance offered to the free flow of electricity in a food material and is more in harder materials than in softer grains. The thermal resistance is inversely proportional to the porosity of the material. Crude protein is more in grain thermal resistivity is more. The thermal properties of food products can be measured indirectly using mathematical calculations based on the chemical composition (water, protein, fat, carbohydrates, fibre and ash), temperature and structure of the analysed material (Carson, 2015).

Lower thermal resistivity, 793.3 °C cm W^{-1} was found to be in Warta variety of white mustard than Radena variety of white mustard and thermal resistivity was 820.5°C cm W^{-1} (Ewa Ropelewska *et al.,* 2018). Table (4.1) shows the split pigeon pea, dehulled pigeon pea and un-hulled pigeon pea regression equation, In unhusked form, thermal effusivity decreases with moisture content, but in dehusked and in split form, thermal effusivity increased with moisture content between the moisture content values of 10% to 20%. The mean thermal effusivity value was 11.45 W S1/2 m^{-2} K^{-}

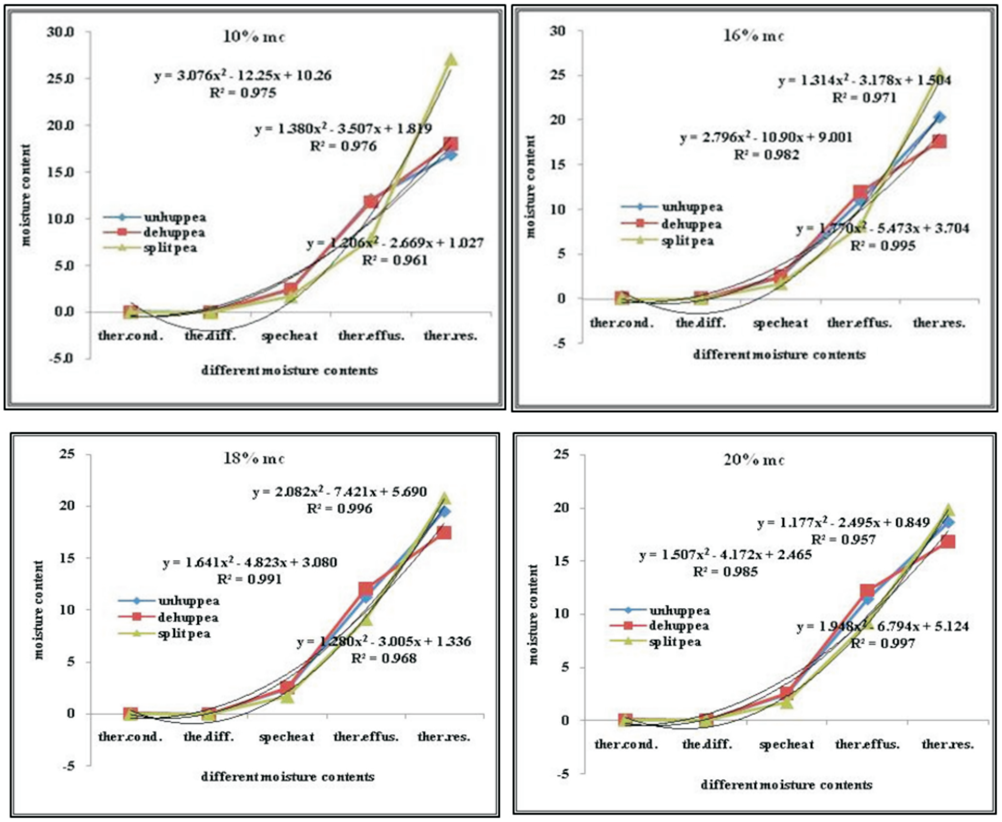

Fig.5. Different thermal properties of pigeon pea at 4 different moisture contents

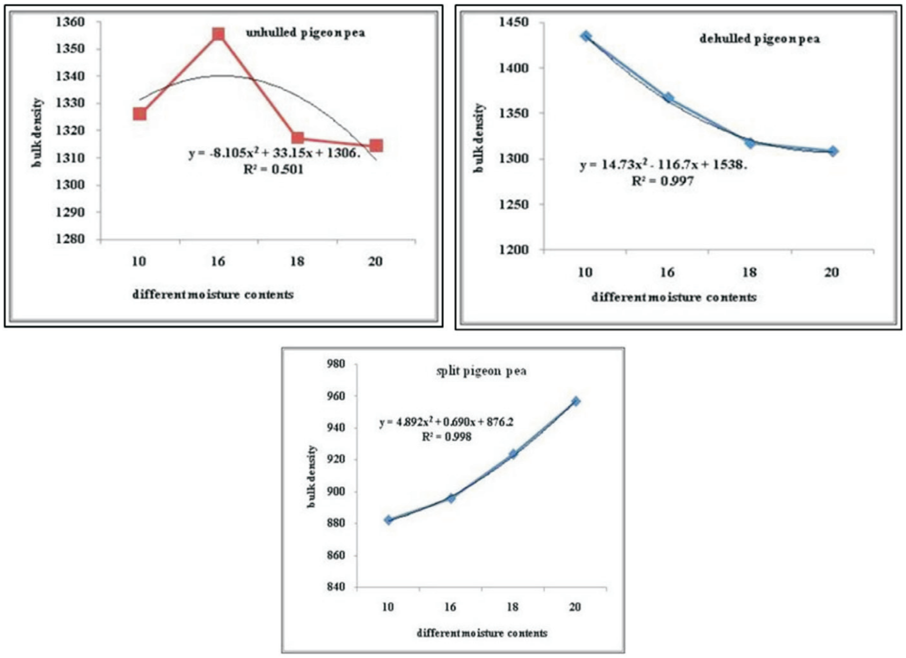

Fig. 6. Bulk density of different forms of pigeon pea at 4 different moisture contents

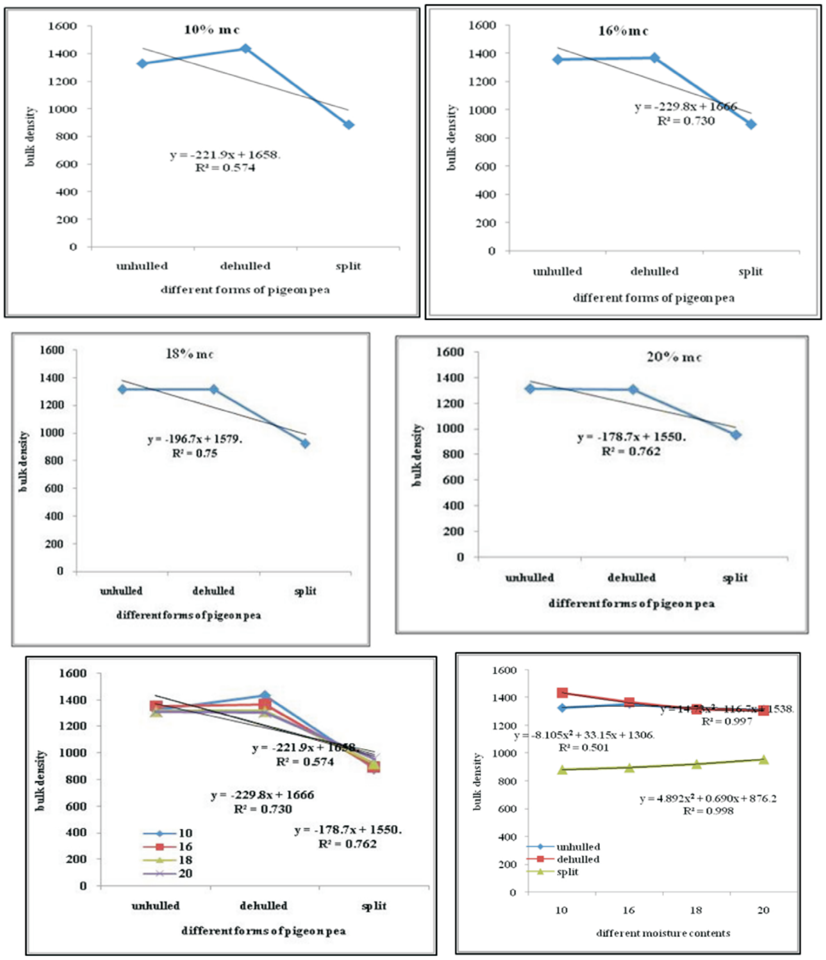

Fig.7. Bulk density of different forms of pigeon pea at 4 different moisture contents

^{1}±0.23 in unhusked form, 12 W S1/2m^{-2}K^{-1} ±0.09 in de-husked form and 8.61± 0.34 in split form of pigeon pea. The values of thermal effusivity of cocoyam ranged from 12.2 to 47.94W S1/2 m^{-2} K^{-1}. This range of values is higher than that given for agricultural soil, 1.38–4.01WS1/2m^{-2}K^{-1} and static air, 5.0 W S1/2 m^{-2} K^{-1}.(Oladunjoye and Sanuade, 2012). Fig. 2 shows the thermal conductivity, thermal effusivity, thermal diffusivity and thermal resistivity of three different forms of pigeon pea. Fig. 7 shows the bulk density of different forms of pigeon pea at 4 different moisture contents.

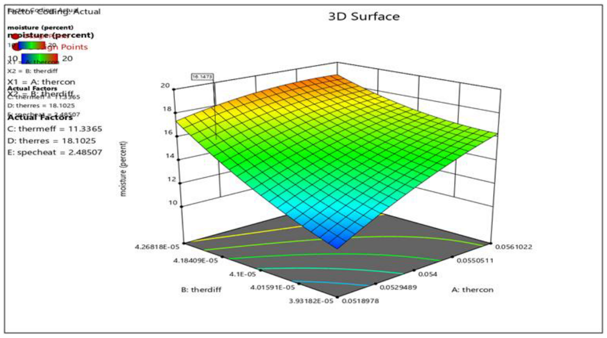

Fig. 8. Thermal diffusivity and thermal conductivity of unhulled pigeon pea sample at different moisture contents

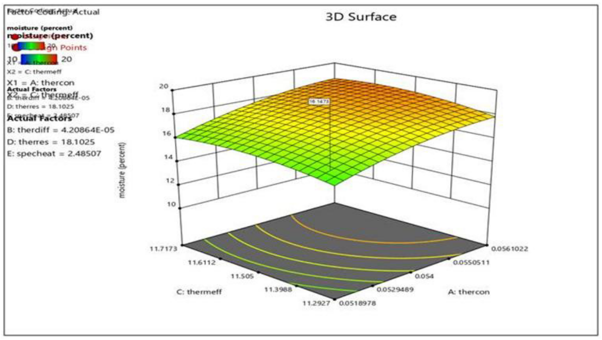

Fig.9. Thermal effusivity and thermal conductivity of unhulled pigeon pea sample at different moisture contents

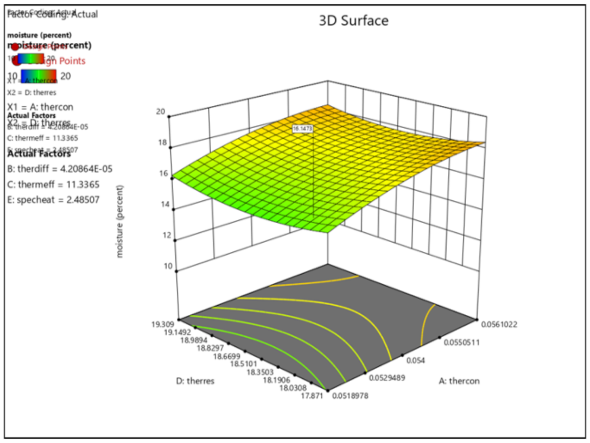

Fig. 10. Thermal resistivtiy and thermal conductivity of unhulled pigeon pea sample at different moisture contents

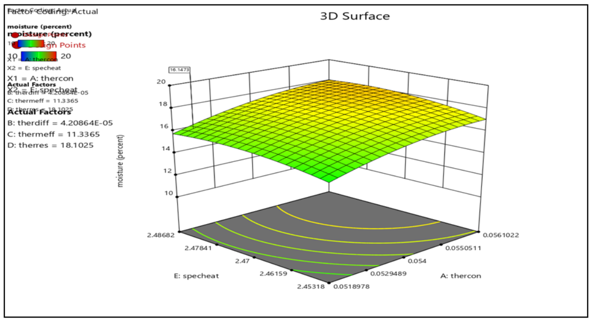

Fig.11. Specific heat and thermal conductivity of unhulled pigeon pea sample at different moisture contents

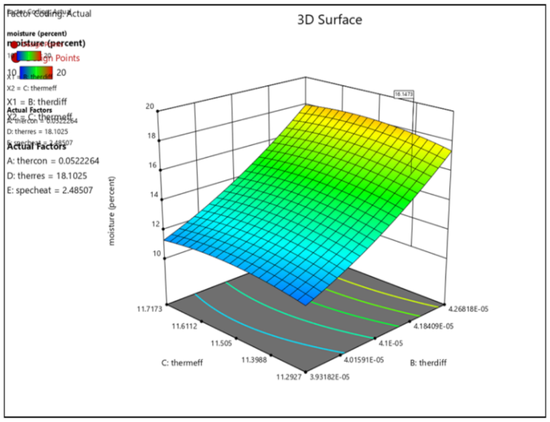

Fig.12. Thermal effusivity and thermal diffusivity of unhulled pigeon pea sample at different moisture contents

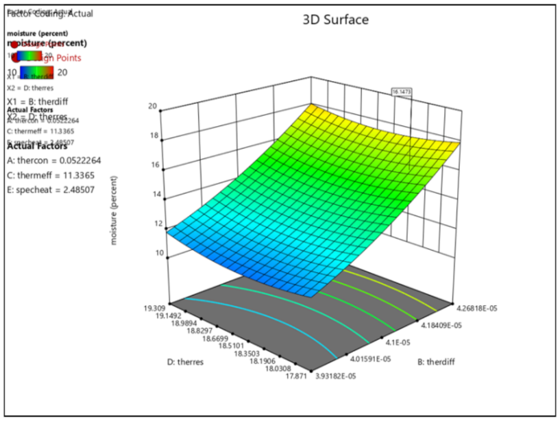

Fig.13. Thermal resistivity and thermal diffusivity of unhulled pigeon pea sample at different moisture contents

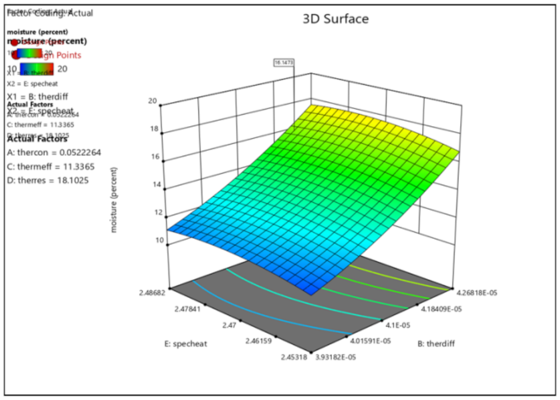

Fig. 14. Specific heat and thermal diffusivity of unhulled pigeon pea sample at different moisture contents

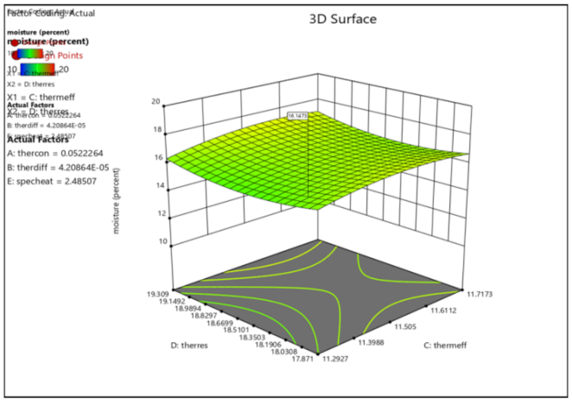

Fig. 15. Thermal resistivity and thermal effusivity of unhulled pigeon pea sample at different moisture contents

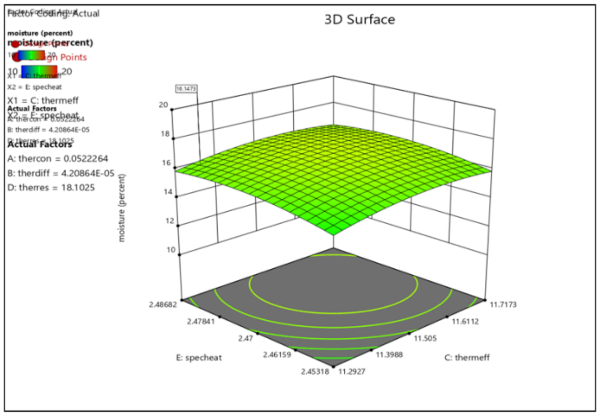

Fig. 16. Specific heat and thermal effusivity of unhulled pigeon pea sample at different moisture contents

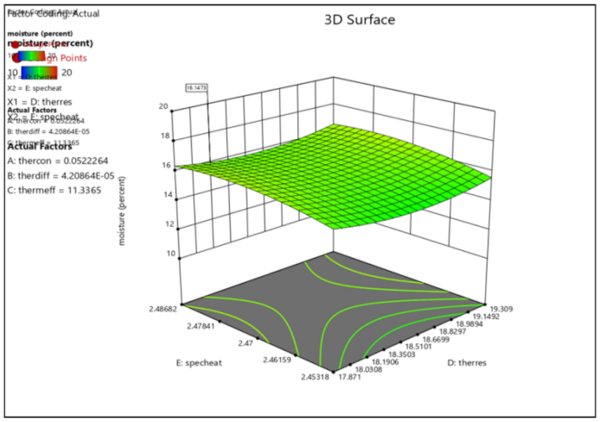

Fig. 17. Specific heat and thermal resistivity of unhulled pigeon pea sample at different moisture contents

CONCLUSION

It was determined that the thermal properties of dehulled pigeon pea depend on the moisture content. The specific heat and thermal conductivity of pigeon pea increases with increasing moisture content and thermal diffusivity decreases with increasing moisture content. The range of thermal conductivity at 4 different moisture contents in unhulled pigeon pea varied between 0.049-0.059Wm^{-1}°k±0.22, in dehulled pigeon pea it ranges between 0.056-0.060Wm^{-1}°k ± 0.001, in split pea at ranges between 0.020-0.040Wm^{-1}°k ±0.009. The range of thermal resistance at 4 different moisture content in unhulled pigeon pea is 16.89-20.31°C cm W^{-1}±0.74, in dehulled pigeon pea it is 16.81-18.02°C cm W^{-1}±0.25, in split pea it ranges between 19.90-27.14 °C cm W^{-1} ±1.74. The range of thermal effusivity at 4 different moisture contents in unhulled pigeon pea is 11.001-12.07 W S1/2m^{-2}K^{-1}±0.23, in dehulled pigeon pea is 11.80-12.22WS1/2 m^{-2} K^{-1} ± 0.08, in split pea it is 7.89-9.22 W S1/2 m^{-2} K^{-1}± 0.34. The range of thermal diffusivity in un - hulled pigeon pea is 3.7-4.5x10^{-5} m^{2}s^{-1}±1.7x10^{-6} at 4 different moisture contents, in dehulled pigeon pea, it varies between 4.1-4.4x10^{-5}m^{2}s^{-1}±6.0x10^{-6} and in split pigeon pea it varied between 4.0-5.5x10^{-5} m^{2}s^{-1}±3.9x10^{-6}. Specific heat of unhulled was found to be 2.46kJ kg^{-1}K^{-1}, in dehulled it was 2.51 kJ kg^{-1}K^{-1} and in split form, it was 1.69 kJkg^{-1} K^{-1}. The range of Specific heat in unhulled pigeon pea is 2.43-2.51 kJkg^{-1} K^{-1} at 4 different moisture contents, in dehulled pigeon pea, it varies between 2.42-2.7 kJkg^{-1} K^{-1} and in split pigeon pea it varied between 1.63-1.77 kJkg^{-1} K^{-1}. The range of bulk density for unhulled pigeon pea is 1314.33-1355.59kg/m^3±6.86 that of dehulled pigeon pea is 1308.44-1435.16±18.35 and split pigeon pea is 882.32-956.87 kg/m^3 ± 16.49.

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