JOURNAL OF ENGINEERING AND EARTH SCIENCES

JEES ISSN: 1897-8680
JEES 2022
VOLUME 15 ISSUE NO 1
PAGE 119 - 128

THERMAL PROPERTIES OF MORINGA *OLEIFERA* SEED AND KERNELS

*[1]Adebiyi, A. O., [2]Olaoye, J. O., [1]Ogunbiyi, A.O., & [1]Akomolafe, O.P.

[1]Postharvest Engineering Research Department, Nigerian Stored Products Research Institute, Ilorin, Kwara State
[2]Department of Agricultural and Biosystems Engineering, University of Ilorin, Kwara State
*Corresponding author email: adebiyioluwafemi@yahoo.com

ABSTRACT

Kernel recovery process from Moringa oleifera 'seed is susceptible to high degree of damages and ruptures; leading to kernel losses. This study investigates thermal properties of Moringa oleifera seed and kernel for optimum drying conditions. Seed and kernel samples were conditioned into four (4) levels of (6, 9, 12 and 15) % moisture content. A KD2-PRO thermal analyzer with density cup was used to measure the thermal properties. Average initial moisture content for seeds and kernels were 8.03% (d.b.) and 5.58% (d.b) respectively and density between 6.0 and 15% (d.b) were determined as 1.626 kg/m^3 and 1.340 kg/m^3 respectively at temperature ranges of 29.38 and 34.72°C. Thermal properties measured were Thermal conductivity, Specific Heat Capacity, Thermal diffusivity and Thermal Resistivity. Results showed that Thermal conductivity of seeds and kernel varies from 0.128 to 0.446 W/m-K; specific heat capacity were 0.407 and 1.985 kJ/kg/K respectively between 6 to 10 %. With increased moisture content between 12 and 15 %, thermal diffusivity of kernel and seed ranges between 0.225 to 0.355 m^2/s while thermal resistivity ranges from 224 to 812.5 m^{2}K/W respectively. The lower moisture content caused a steady increase of thermal conductivity and specific heat capacity, and a decrease in thermal resistivity for both seeds and kernels. Statistical analysis of properties mean values at $P \leq 0.05$ significant level, showed a mean deviation of ±0.133 with lower moisture content and temperature having significant effect on the thermal properties except thermal diffusivity of kernel. The result will aid optimization of drying and kernel recovery of Moringa oleifera seeds.

KEYWORDS: Thermal properties; KD2-Pro Thermal Analyser; Moisture content; Temperature; Moringa oleifera seed

INTRODUCTION

Moringa *oleifera* plant is a breed of *Moringaceae* family, domesticated in the tropical and subtropical climates as an herbs tree; the specie is widely cultivated and grown globally for production of oilseed and other acceptable edible products in the developing countries. It is a valuable tropical plant with multipurpose benefits (such as herb, supplement, vegetables etc.); (Reed et al., 2006; Mahmoud & Elkaoud, 2019).categorizes the seeds as a raw material for bio-oil production. The seed is composed of four different parts; the shell, hull, kernel (solid/semi – solid), oil and water (liquid) with numerous health benefits (Boukandoul et al., 2018). Utilization of the plant for different purposes had been explored by various studies with emphases on the usefulness of the leaf, stem, "tree bark" and the seeds for domestic herbs and medicinal use (Ndukwe et al., 2014). Nutritional composition of Moringa *oleifera* seed were reported by Kawo et al., (2009); Golestanbagh et al., (2011); Azeez et

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al., (2013) serving different benefits to human and animals health. The plant according to Warra (2014) is seasonal with potential to yield about 10 - 20 seeds per drumstick pod and up to 62-100 drumstick per tree to give about 2.5 t/ha twice annually. Ajav and Fakayode (2013) reported that the physical and mechanical (engineering) properties affecting oilseed in relation to oil extraction. Moringa *oleifera* seed have bio-oil yield of about 30 - 45% (Premi & Sharma, 2013; Ajav & Fakayode, 2013). Increased global demand for bio-oil as alternative to inorganic oil for industrial/commercial use has necessitates the study of Moringa *oleifera* seed thermal properties (Uzama et al., 2011). The seed was ranked among oilseeds with high domestic potentials and useful purposes (Adejumo & Abayomi, 2012). Enhancing the kernel recovery from the seed would optimize the oil yield of kernels when dried (Ogunsina & Bamgboye, 2014). Rheologically, there is need to establish the interactions of some engineering properties of the seed; such as moisture content and temperature of the seed with some physical characteristics by determination of its thermal properties. The sensitivity of bio-materials is one of the factor that informs the need for processing methods (Soltani et al., 2014). Biomaterial like Moringa *oleifera* are susceptible to kernel damages at processing, while locally existing shelling equipment does not perform effectively due to flexible nature of the seed (Mahmoud & Elkaoud, 2019). However, the quality of oil yield from extraction process relies on quality of oil-kernels, density and moisture content; hence, the study of thermal properties of Moringa *oleifera* seed will establish the optimum heat treatment conditions necessary for efficient oil yield of the seeds. Seed sizes, moisture level, density and degree of maturity according to (Golestanbagh et al., 2011) are other determinant of seed and kernel masses. Szczyglak and Żuk (2012) attributed possible seed damages to brokenness, excessive heating, discoloration and shrunken kernels etc. Navarro et al., (1989) and Yang et al., (2002) described physical damages caused by manual handling in soybeans and thermal properties of borage seeds respectively during drying to be in the form of indentations and cracks. For better understanding of intricacies of Moringa oilseeds handling, its behaviour when subjected to thermal treatment in relation to moisture content and temperature are important (Kocabiyik et al., 2009; Adejumo & Abayomi, 2012). Relatively, there is relationship between the physical, chemical, thermal and physiological properties of biological materials (Onimawo, 2002; Dobrzański & Stępniewski 2013; Ajav & Fakayode, 2013; Oloyede et al., 2013). No literature has shown the combined effect of moisture content and temperature in relation to the thermal properties and processing characteristics of Moringa *oleifera* seed with cognizance to varied seed density. Therefore, information about the thermal properties of this seed will be useful for efficient kernel drying, cracking and kernel oil extraction; which would influence the selection of appropriate threshing machine (Ajav et al., 2016). This study therefore investigates the thermal conductivity, specific heat capacity, thermal diffusivity and thermal resistivity of Moringa *oleifera* seed in relation to engineering properties using the dual-needle SH-1 sensors KD-2 Pro thermal analyzer at different moisture content (dry basis) and heating temperatures. This is expected to inform optimum kernel drying, oilseed recovery and promote bio-oil production for health benefits of the oilseed among processors and consumers.

MATERIALS AND METHODS

Materials

Materials employed for this study were; Moringa *oleifera* seed (dry), DHG – 9030 Laboratory oven HR-170T; Haier Thermocool fridge made from China, KD2-Pro Thermal Analyser manufactured by Decagon Devices USA with ±5 to 10% accuracy, Onset U14-002 HOBO temperature/humidity logger, and distilled water for sample moisture conditioning. Bulk dried seeds were obtained Moringa *oleifera* seed harvested from orchard at Nigerian Stored Products Research Institute Ilorin, Nigeria, located at 4° 32′ 31.70″ E and 80° 29′ 47.90″. The initial moisture content was determined following the AOAC (2007) method for oilseeds; by oven drying at 103°C ± 2 using the DHG – 9030 Laboratory oven.

Theoretical Analysis for Samples Moisture Conditioning

$$Q = \frac{W(Mf - Mi)}{100 - Mf} \qquad (i)$$

Source: (Hojat et al., 2009; Oniya et al., 2016).

Where,

Q is quantity of water added (g),

W is the initial weight of the sample (g),

Mi is the initial moisture content of the sample (%, d.b.)

Mf is the desired moisture content adjustment (%, d.b.) using equation ii to iv.

$$MC\ (db) = \frac{M_W}{M_D} \times 100\% \qquad (ii)$$

$$MC\ (db) = \frac{M_{W-}M_D}{M_D} \times 100\% \qquad (iii)$$

$$MC\ (Wb) = \frac{M_{W-}M_D}{M_W} \times 100\% \qquad (iv)$$

Where**,** *MC* is Moisture Content % (in d.b and w.b), M_W is Mass of water (g), M_D is Mass of dry sample (g).

Seed samples were separated into two portions to obtain unshelled seeds and kernels manually as shown in Figure 1; which were further subdivided into four (4) portions of 10 grams each, a calculated volume of distilled water (2.8, 3.2, 4.0, and 5.5) ml. was added to raise the moisture content of each 10 grams to (6, 9, 12 and 15) percent (%) each respectively using equation (i – iv). The moistened samples were packed inside a high density polythene bag and stored under a room temperature of 25 – 33 °C monitored using the onset Hobo meter. Samples were allowed to equilibrate inside the HR-170T; Haier Thermocool refrigerator at 5±1 °C adopting the (Ajav & Fakayode, 2013; Oniya et al., 2016) method for five (5) days. The quantity of water to raise moisture content was estimated by equation 1. Thermal conductivity, specific heat capacity, thermal diffusivity and thermal resistivity of unshelled seeds and kernels at four (4) varied moisture contents were measured under the laboratory room temperature conditions of ± 30.2°C, using the SH-1 sensor Dual-Needle KD2-Pro thermal analyser and density sampling can.

Description of Thermal Analyzer Instrument

KD2-Pro thermal analyser (Figure 2) is a portable laboratory thermal properties measuring equipment, consisting of Dual-Needle SH-1 sensor having two parallel stainless-steel needles of 1.3 mm diameter and 30 mm long with 6 mm space in-between the equal needles. It has a 25 ml cylindrical density-can for sampling filled with unshelled seeds and kernels samples separately.

The SH-1 Dual-Needle sensor was gently inserted into the sampling "can" directly from centre top with adequate precaution to avoid boundary effects. After 180 seconds interval the readings for four (4) thermal properties were displayed via the LED screen of the KD2-Pro analyser and recorded accordingly; they were measured in respect to the moisture content percentage at heating temperature of KD2 Pro analyser. The experiment was repeated three (3) times each for both unshelled seeds and kernels, and mean values for the properties were calculated.

Statistical Analysis

Analysis of variance (ANOVA) using SPSS (IBM, Version 20) was used to study the mean effect of moisture content and temperature on the thermal properties, while Duncan's multiple range test in SPSS (IBM, Version 20) was used to review the significance between the mean values at $p \leq 0.05$.

RESULTS AND DISCUSSION

Moisture Content of Unshelled Seed and Kernel

Average initial moisture contents for the fresh dried unshelled seed and kernel samples were determine to be 8.03% (d.b.) 5.58% (d.b.) respectively using the AOAC 2007 method.

Effects of Moisture Content and Heating Temperature on Thermal Properties

The average heating temperature recorded from the KD2 Pro thermal analyzer for thermal properties of both unshelled seeds and kernel at 6, 9, 12 and 15 % moisture levels were 33.40, 29.80, 29.30, 34.72 °C and 34.37, 34.57, 30.93 °C respectively, while mean standard error of ± 0.792 was recorded from the mean. The effect of moisture content on the thermal properties of seeds as shown on the curves plotted in (Figure 3 to 6); there is a linear increase in thermal properties for unshelled seeds at lower moisture content between 6 to 10 % and reduced as the moisture content increased beyond 10%. This could imply that unshelled seeds having tendency to absorb more heat at lower moisture which could enhance drying rate when compared with kernel without shell; this follows the same pattern described by Aviara et al., (2008) and Oniya et al., (2016) studies on guna seeds and soursop seeds respectively at lower moisture content.

Effect of Temperature on the Thermal Properties of Moringa Seed

From the table 1a and 1b the effect of heating temperature gradient of the KD2-Pro analyzer on the thermal properties of the unshelled seed and kernel were observed to be non-uniform in variation; this in reference to the ambient appears similar to Bart-Plange et al., (2012) observations for ground cocoa bean which are also oilseed. The result therefore indicates that a lower heating below ambient temperature from the analyzer, causes a reduction in the specific heat capacity, thermal diffusivity and thermal resistivity between 6 to 10 % moisture range. This also varied with increased level of moisture percentage at ratio of ± 0.2 for the unshelled seeds. A similar variation was also reported by Vijay (2013) for thermal properties of coriander seeds. In addition, while thermal conductivity and specific heat capacity for unshelled "Moringa *oleifera* seed" decreased at a higher temperature, thermal conductivity, thermal diffusivity and thermal resistivity for kernels at higher temperature above 10% moisture was vise-versa for seed.

Thermal Conductivity of Unshelled Seeds and Kernel

The values of thermal conductivity for unshelled seed and kernel were presented in Figure 3 giving a range from 0.128 to 0.446 W/m/K and 0.142 to 0.179 respectively; which occurs at the increased moisture content levels up to a peak of 12% and a steady drop of the conductivity property with further moisture increase. This could imply that higher moisture content beyond 15% may lead to decrease in the thermal conductivity causing a decrease in the oil yield of the kernel. Thermal conductivity of unshelled Moringa *oleifera* seed was found to be higher at lower moisture content than that of the 'kernel' with a minimum and maximum mean value of 0.133 and 0.333 W/m/K at 6.0 and 12.0 % (d.b) levels respectively; meanwhile, Oloyede et al., (2013) recorded a similar increase trend from 1.423 to 1.792 W/m/K at 8.0 to 32.5% (d.b) moisture level. The result for Moringa oleifera seeds appeared with average difference of 0.025 ratio. This aligns with Radhakrishnan et al., (1997) study for sea foods at 4.0 to 10 % moisture which recorded a minimum value of 0.502 W/m/K. This observation could be generalized to oilseeds with irregular seed and kernel sizes, pericarp shell with porosity of bulk sample.

Effect of Moisture and Heating Temperature on Specific Heat Capacity

Figure 4 shows the specific heat capacity of the unshelled seed and kernels with changes in moisture content ranging from 0.518 to 1.985 kJ/kg/K and 0.430 to 0.841 kJ/kg/K with mean temperature of 31.83 and 32.61 °C respectively; comparing this result with specific heat capacity of soursop seeds of 0.536 to 1.313 J/kg/K by Oniya et al., (2016). Variations in the specific heat capacity at different heating temperatures and moisture content can be inferred to differences in moisture levels and porosity of the seeds, this relates to Olajide et al., (2014) which report constant density with moisture changes for locust beans. Table 1a and 1b shows the reduction in specific heat capacity of the seed with variations introduced by heating temperature from the analyzer, this may be as a result of constant bulk density of the seeds in the "sampling can". Knowing that the kernel constitutes water and oil; there is tendency for the specific heat capacity to change by steady heating temperature under a constant volume as established by Yang et al., (2002) for borage seed. Mean values of the thermal properties with respect to moisture content and temperature is shown in Table 1a and 1b for seeds and kernels.

Effect of Moisture as Influenced Heating Temperature the Thermal Diffusivity

Thermal diffusivity was measure with varied moisture contents and average heating temperature of thermal analyzer ranging from 29.38 to 34.72 ˚C. The minimum and maximum thermal diffusivity recorded for the unshelled seeds were between 0.225 and 0.506 m^2/s and 0.146 and 0.324 m^2/s for kernels. Generally, there is linear change in the thermal diffusivity of Moringa *oleifera* compared to that of Corn, soybean and sunflower except for Oniya et al., (2016) which recorded otherwise. This study showed that, Moringa *oleifera* seed has the tendency to distribute heat capable of reducing the dry matter of the unshelled seeds and kernel with higher moisture content. Mean value of 0.383 m^2/s at 12% (d.b) moisture content and kernel having 0.2980 m^2/s at 15% (d.b) moisture content were the highest obtained. This showed that heating (drying) at higher moisture content, Moringa oleifera seed could be denatured.

Effect of Moisture as Influenced by Heating Temperature on Thermal Resistivity

Thermal Resistivity recorded as shown in figure 6 for both unshelled seed and kernel of Moringa oleifera ranges from 293.90 to 764.900 m^2K/W between heating temperature of 29.38 to 34.72 ˚C and 531.9 to 812.5 m^2K/W and heating temperature of 30.93 to 34.37 ˚C respectively at 6 to 15% moisture content. The mean thermal resistivity of unshelled seeds and kernels at higher moisture content increased from 313.866 m^2K/W at 12.0 % to 717.133 m^2K/W at 15.0 %; while for kernel increased from 569.80 m^2K/W at 9.0 % and 716.50 m^2K/W at 12.0 % respectively. Therefore, this show high thermal resistance of seed at higher moisture content.

Statistical analysis for the mean of thermal properties investigated was carried out, both the moisture content and heating temperature was found to have a significant effect on both unshelled seeds and kernels at higher moisture content and raised temperature within ambient heating temperature at probability ($p < 0.05$). However, the effects of moisture content on thermal diffusivity of both unshelled seeds and kernel shown in table 3 was not significant and there were no differences between the means when subjected to Duncan multiple ranged test. Moisture content has significant effect on the on the, thermal conductivity and thermal resistivity without significance on the specific heat capacity and thermal diffusivity of the kernels. When compared with unshelled seed, it was observed to loose heat at high degree of temperature.

CONCLUSIONS AND RECOMMENDATIONS

The investigation showed that initial moisture contents for freshly (dried) harvested Moringa *Oleifera* seed from pod significantly affects its thermal properties; while the bulk density of unshelled seeds and kernel between 6.0 and 15% (d.b) could vary between 1.626 kg/m^3 and 1.340 kg/m^3 respectively. Thermal properties measured were significantly affected by the moisture and drying temperature which was informed by heating temperature. Result showed significant linear increase of thermal conductivity, specific capacity at lower moisture content and decrease at higher moisture levels; while in thermal diffusivity and thermal resistivity a significant increase was recorded at higher moisture content for unshelled seeds and kernels. It can therefore be inferred that the amount of heat energy required to change the temperature of oil bearing kernel at higher moisture between 12 to 15.0% (d.b.) would be higher than that required for the unshelled Moringa seed at lower moisture. This result would be useful for optimization of seed drying, shelling and kernel recovery conditions of Moringa oleifera seed and also would be relevant for equipment design for the oilseed. Further investigation is recommended to determine engineering properties under a quasi-static compression loading of the seed, optimum energy required for efficient seed shelling conditions and effective kernel recovery for seed-shell cracking by mechanical process.

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Table 1a: Mean values of the thermal properties of unshelled seeds with moisture contents and heating temperature.

M.C	Temp °C	Thermal. Conductivity W/m/K.	S.H.Capacity J/kg/K	Thermal. Diffusivity m^2/s	Thermal. Resistivity m^2K/W
6	33.40	0.133	1.273	0.302	454.600
9	29.80	0.333	1.313	0.253	367.463
12	29.38	0.322	0.880	0.383	313.867
15	34.72	0.138	0.536	0.271	717.133

Table 1b: Mean values of the thermal properties of kernel with moisture contents and heating temperature.

M.C	Avg. Temp °C	Thermal. Conductivity W/m/K.	S.H.Capacity J/kg/K	Thermal. Diffusivity m^2/s	Thermal. Resistivity m^2K/W
6	34.38	0.144	0.663	0.228	704.500
9	34.57	0.179	0.611	0.282	569.800
12	30.55	0.142	0.459	0.295	716.233
15	30.93	0.160	0.552	0.298	625.700

* All values are average of replicates.
* Moisture percentage and temperature are in order of low and high values.

Table 2: ANOVA table for Unshelled Moringa *oleifera* Seeds

	M.C			
	6%	**9%**	**12%**	**15%**
Temperature	33.4 ± 0.64^{b}	29.8 ± 0.19^{a}	29.38 ± 1.69^{a}	34.72 ± 0.17^{b}
Thermal Conductivity	0.13 ± 0.005^{a}	0.33 ± 0.06^{b}	0.32 ± 0.019^{b}	0.14 ± 0.004^{a}
S.H. Capacity	1.27 ± 0.16^{b}	1.31 ± 0.34^{b}	0.88 ± 0.15^{ab}	0.54 ± 0.02^{a}
Thermal Diffusivity	0.30 ± 0.01^{ab}	0.25 ± 0.014^{a}	0.38 ± 0.06^{b}	0.27 ± 0.021^{ab}
Thermal Resistivity	454.6 ± 24.4^{b}	367.46 ± 21.7^{a}	313.87 ± 19.3^{a}	717.13 ± 24.4^{c}

Means with different superscripts on a row are significantly different at $P \leq 0.05$

Table 3: ANOVA table for Moringa *oleifera* Kernels

		M.C		
	6%	**9%**	**12%**	**15%**
Temperature	34.37 ± 0.44^{b}	34.57 ± 0.05^{b}	30.55 ± 0.13^{a}	30.93 ± 0.24^{a}
Thermal Conductivity	0.14 ± 0.01^{a}	0.18 ± 0.006^{b}	0.14 ± 0.003^{a}	0.16 ± 0.005^{ab}
S.H. Capacity	0.66 ± 0.09^{b}	0.61 ± 0.014^{ab}	0.46 ± 0.019^{a}	$0.55 \pm 0.0.05^{ab}$
Thermal Diffusivity	0.23 ± 0.042^{a}	0.28 ± 0.007^{a}	0.29 ± 0.009^{a}	0.29 ± 0.02^{a}
Thermal Resistivity	704.5 ± 55.8^{b}	569.8 ± 19.2^{a}	716.23 ± 2.86^{b}	625.69 ± 18.8^{ab}

Means with different superscripts on a row are significantly different at $P < 0.05$

(a) (b)

Figure 1: (a) Unshelled seeds and (b) Kernel of *Moringa oleifera* seed

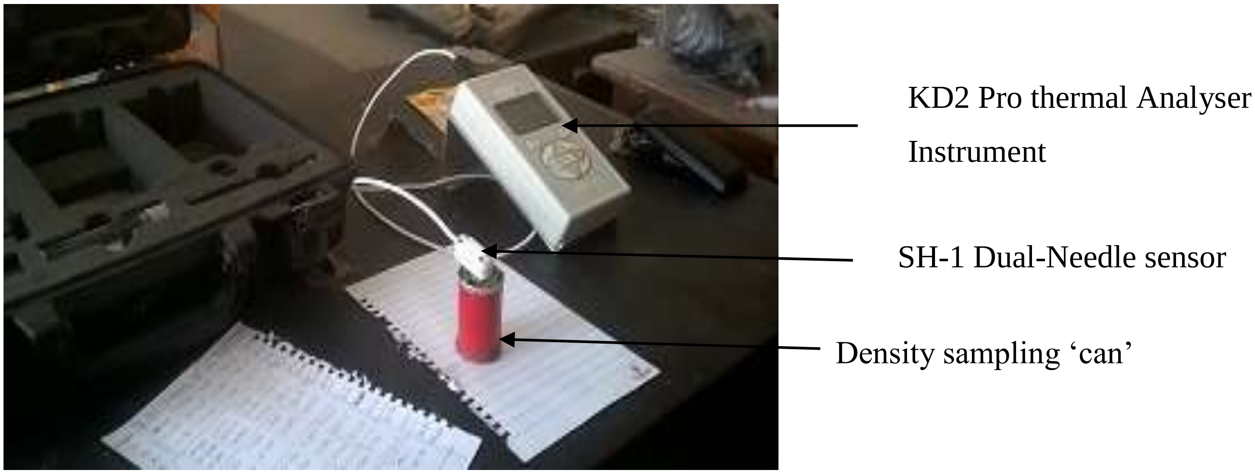

Figure 2: KD2 –Pro Thermal Analyzer

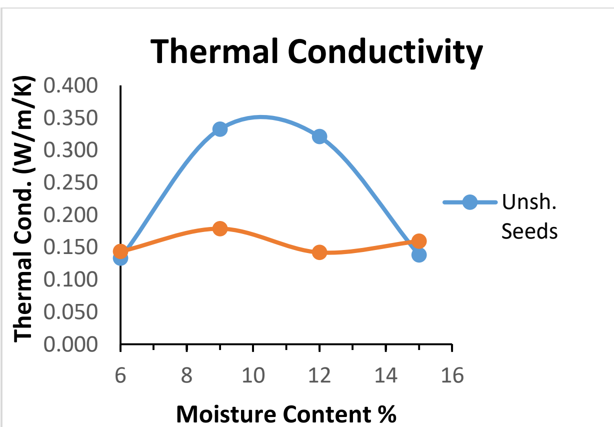

Figure 3: Thermal Conductivity

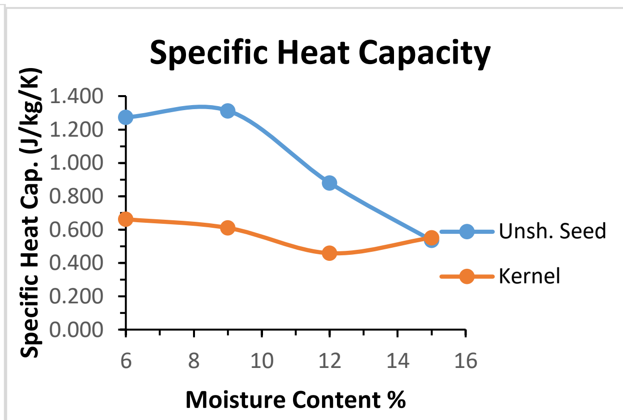

Figure 4: Specific heat capacity

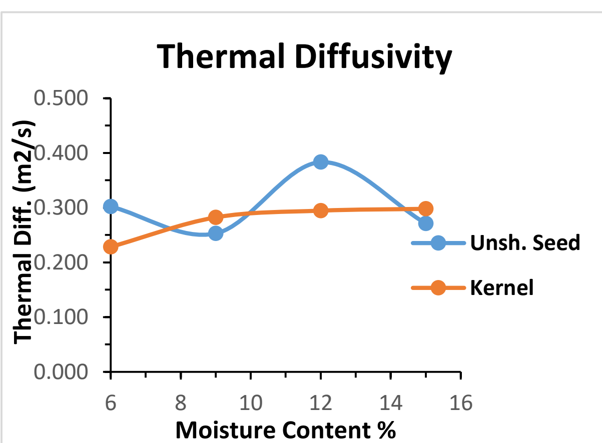

Figure 5: Thermal Diffusivity

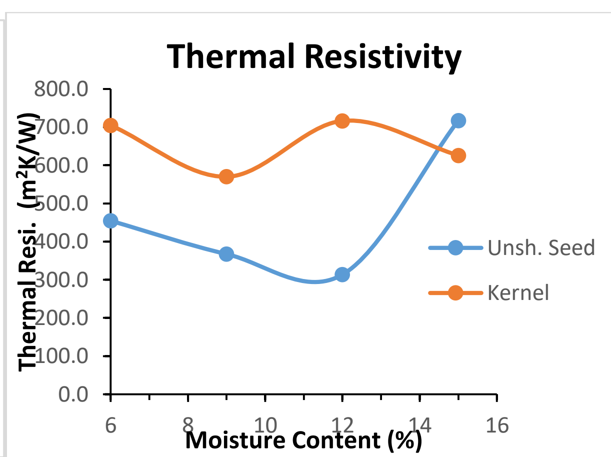

Figure 6: Thermal Resistivity