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Thermal properties of soursop seeds and kernels

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Abstract

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The thermal properties of soursop seeds and kernels were determined as a function of moisture content, ranged from 8.0 to 32.5% (d.b.). Three primary thermal properties: specific heat capacity, thermal conductivity and thermal diffusivity were determined using Dual-Needle SH-1 sensors in KD2-PRO thermal analyser. The obtained results shown that specific heat capacity of seeds and kernels increased linearly from 768 to 2,131 J/kg/K and from 1,137 to 1,438 J/kg/K, respectively. Seed thermal conductivity increased linearly from 0.075 to 0.550 W/m/K while it increased polynomially from 0.153 to 0.245 W/m/K for kernel. Thermal diffusivity of both seeds and kernels increased linearly from 0.119 to 0.262 m^2/s and 0.120 to 0.256 m^2/s, respectively. Analysis of variance results showed that the moisture content has a significant effect on thermal properties ($p \leq 0.05$). These values indicated the ability of the material to retain heat which enhances oil recovery and can be used in the design of machine and selection of suitable methods for their handling and processing.

Keywords: specific heat capacity; thermal conductivity; thermal diffusivity; SH-1 sensors; moisture content

Soursop seed (*Annona muricata* L.) is economically important oil seeds source in the world and produces about 10 t/ha in Nigeria (Oyenuga 1978). It is rich in protein (21.43% per 100 g), carbohydrate (29.05% per 100 g) and contains about 40.0% pale yellow oil. The oil possesses an average saponification value of 227.48, a iodine value of 111.07, 28.07% saturated and 71.93% unsaturated fatty acids; and can be classified in the oleic-linoleic acid group which is one of the most important polyunsaturated fatty acid in human food because of its prevention of distinct heart vascular diseases (Boelhouwer 1983; Onimawo 2002; Fasakin et al. 2008; Kimbonguila et al. 2010).

The oil is extracted using the method and processes that involve size reduction and heat transfer operation, therefore, information on the thermal properties of seed and kernel is essential in the development of the processes and equipment needed in its thermal processing operations as well as in drying and storage (Aviara et al. 2008). Specific heat capacity, thermal conductivity and thermal diffusivity are three important engineering properties of biomaterials related to heat transfer characteristics (Yang et al. 2002). Thermal conductivity and diffusivity are involved in the determination of the rate of heat transfer for efficient process and equipment design while specific heat capacity is needed in the estimation of the amount of energy required to change the temperature of biomaterials (Aviara et al. 2008).

Therefore, from the point of view of optimization of a technological procedure, the thermal behaviour of agricultural products and moisture content are of the crucial importance. They present the most important parameters having clear relation to the character of physical, chemical and physiological processes in biological agricultural materials (Jiříčková et al. 2006).

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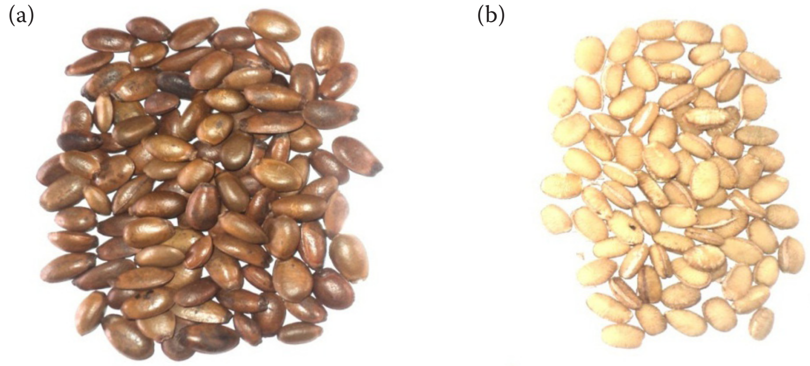

Fig. 1. Soursop seeds (a) and soursop kernels (b)

A number of researchers determined the thermal properties of several grains, seeds and kernels; Jiříčková et al. (2006) for soybean, Aviara et al. (2008) for guna seed, Ato et al. (2012) for cashew kernel, Kara et al. (2011) for safflower seeds, Sadeghi (2012) for feed pellets, Bamgboye and Adejumo (2010) for roselle seeds. The method of mixture was used in determining specific heat capacity; thermal conductivity was determined using steady state and transient heat flow methods while thermal diffusivity was mostly determined from experimental values of bulk density and thermal conductivity of bio-materials.

However, Murlidahar and Goswami (2011) determined thermal properties of black pepper using thermal analyser (DSC 204 *phoenix*) for specific heat capacity and thermal conductivity meter (QTM-D3) was used to determine thermal conductivity of black pepper. Data on the thermal properties of soursop seeds and kernels do not appear to be available in the literature. The objective of this study was, therefore, to determine the thermal properties of soursop seeds and kernels as a function of moisture contents using a Dual-Needle *SH-1* sensors in KD2- Pro thermal analyser. Fig. 1 shows soursop seeds and kernels.

MATERIALS AND METHOD

A bulk quantity of soursop seeds at safe storage condition (between 9–10% (w.b.) moisture content) was obtained from Ogbomosho, Nigeria. The seeds were manually cleaned and stored at room temperature (23–32°C), then divided into two portions. One portion was left as unshelled seeds while the other was manually shelled to obtain the kernels. The initial moisture contents of both seeds and kernels were determined using oven drying method at 103 ± 2°C as described by ASABE S352.2 (2001) and applied by Okoro and Osunde (2013), Oloyede et al. (2015) and Oniya et al. (2016) for soursop seeds. 5.0 g of each sample were weighed and put in three separate cans of known weights. The weights of the samples and the cans were taken using an electronic digital weighing balance (MP 1001) with an accuracy of 0.1 g. The can containing each sample was placed in a laboratory oven (TT-9083; Gallenkamp Devices, UK). The weights of the samples were taken at an hourly interval until a constant weight was obtained. The mean value for the initial moisture content was calculated based on dry basis (d.b.).

Samples of desired moisture contents were prepared by adding calculated amount of water, thoroughly mixing and then sealed in a separate polythene bags. The samples were kept in a refrigerator (HR-170T; Haier thermocool, China) for at least seven days at temperature of 5 ± 2°C to enable uniform distribution of moisture throughout the samples. Required quantity of seeds and kernels were allowed to warm to room temperature prior to each test as reported by Calisir et al. (2005), Isik (2007) and Simoyan et al. (2008). The quantity of water added was estimated from equation 1 used by (Hojat et al. 2009):

$$Q = \frac{W(M_f - M_i)}{100 - M_f} \quad (1)$$

where: Q – quantity of water added (g), W – the initial weight of the sample (g), M_i – the initial moisture content of the sample (%, d.b.); M_f – desired moisture content of the sample (%, d.b.)

The specific heat capacity, thermal conductivity and thermal diffusivity of seeds and kernels were

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Fig. 2. Thermal properties analyser (KD2-PRO, Decagon devises)

determined using Dual-Needle *SH-1* sensors in KD2-Pro thermal analyser (Decagon devices, USA) (Fig. 2) following the procedure according to Fontana et al. (1999) and Oladunjoye and Sanuade (2012). KD2-Pro thermal analyser is a portable field and laboratory thermal properties analyser, consists of Dual-Needle *SH-1* sensor among other sensors. The Dual-Needle *SH-1* sensor consists of two parallel stainless steel needles of 1.3 mm diameter, 30 mm long needles with 6 mm space in between. One needle contains a line heat source and the other is a thermocouple. It uses transient line heat source method to measure the thermal diffusivity, specific heat capacity, thermal conductivity and thermal resistivity simultaneously, and is compatible with both solid and granular materials (Decagon Devices 2008–2011; Oladunjoye, Sanuade 2012).

Thermal properties of soursop seeds and kernels were measured in laboratory conditions at the average temperature of 25.5°C. To determine the three primary thermal properties, *SH-1* Dual-Needle sensors was connected to KD2 Pro meter (Decagon devices, USA). 100 ml cylinder was filled with seeds and kernels sample separately. The *SH-1* Dual-Needle sensor was properly inserted into the sample at the centre of the cylinder to avoid boundary effect of the cylinder. After a time interval of 180 s, the measured values of specific heat capacity, thermal conductivity and thermal diffusivity were displayed via screen on the KD2 Pro meter and recorded. The experiment was replicated three times for each moisture level for both seeds and kernels and the mean value was calculated.

Data Analysis. Data obtained were analysed using the analysis of variance (ANOVA) in SPSS (IBM, Version 20) with three replications at 0.05 significant level (95% confidence level) to study the effect of moisture content on thermal properties of soursop seeds and kernels while the Duncan's multiple range test in SPSS (IBM, Version 20) was used to show if there are significant differences between the mean values. Graphs were plotted using Microsoft Excel (2010).

RESULTS AND DISCUSSION

Moisture content of soursop seed and kernel

The mean initial moisture contents for the samples were found to be 11.9% (d.b.) for seeds and 7.9% (d.b.) for kernels. The five moisture levels obtained after conditioning the samples were 8, 11.9, 15.4, 22.6 and 32.5% (d.b.). The thermal properties in this study were determined at the stated moisture levels.

Specific heat capacity of soursop seed and kernel

The mean values for the specific heat capacity of soursop seed and kernel increased from 768 to 2,131 J/kg/K and 1,137 to 1,438 J/kg/K, respectively. Thus, it was shown that at the moisture level of 8.0% and 11.9% (d.b.), the specific heat capacity of kernel is higher than that of the seed. This is due to the low surface area of kernel compared with the seed. This implies that the amount of heat energy required to change the temperature of 0.047 kg of kernel at 8.0% (d.b.) is higher than that of the seed at the same moisture level except at the moisture content range of 15.4–32.5% (d.b.) where seed showed higher values of specific heat capacity than that of kernel. This may be a result of an increase

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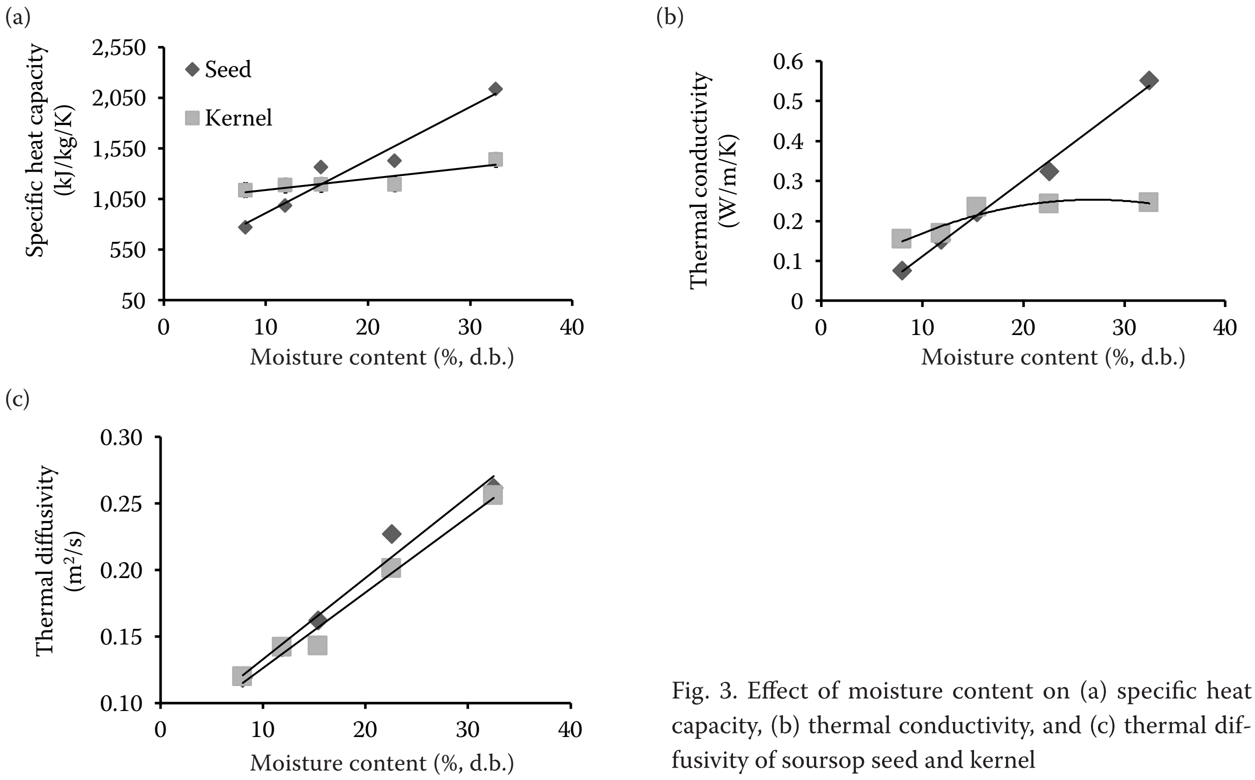

Fig. 3. Effect of moisture content on (a) specific heat capacity, (b) thermal conductivity, and (c) thermal diffusivity of soursop seed and kernel

in the mass of seed sample due to its higher moisture content level. A similar trend was observed for the specific heat capacity of borage seeds (Yang et al. 2002), guna seeds and kernels (Aviara et al. 2008), black pepper seeds (Murlidahar, Goswami 2011), cashew kernels (Ato et al. 2012), black sunflower seeds (Hosain et al. 2012) and coriander seeds (Vijay 2013).

The change in the specific heat capacity of seed and kernel of soursop with moisture content is presented in Fig. 3a; it depicts that the specific heat capacity of both seeds and kernels increased linearly with increasing moisture content from 8.0–32.5% (d.b.). Also, at the moisture content level of 11.9 to 22.6% (d.b.), there were no significant ($p \leq 0.05$) differences between the mean data of specific heat capacity of soursop kernels while the differences between the mean data of specific heat capacity of soursop seeds at all experimental moisture level were significantly different. This also is shown in Table 1 for soursop seeds and kernels as analysed using Duncan multiple range test at $p \leq 0.05$.

The differences between the mean data of specific heat capacity at varying moisture were significant ($p \leq 0.05$) as shown in Table 1. Similarly, the effect of moisture content on specific heat capacity of both seeds and kernels was significant. The relationship between specific heat capacity (*SCH*) and moisture content (*Mc*) of seed and the kernel are presented in equation 2 and 3, respectively, with high correlation coefficient. Information on the specific heat capacity of soursop seeds and kernels will be useful in the design of soursop kernel expeller heating compartment, in drying of the seed and kernel and selection of suitable method for their handling and processing.

$$SHC = 5.25Mc + 38.45 \quad (R^2 = 0.953) \quad (2)$$

$$SHC = 1.108Mc + 102.8 \quad (R^2 = 0.811) \quad (3)$$

where: *SHC* – specific heat capacity; *Mc* – moister content (%, d.b.)

Thermal conductivity of soursop seed and kernel

The mean values for the thermal conductivities of soursop seeds and kernels were found to increase from 0.075 to 0.550 W/m/K and 0.153 to 0.245 W/m/K, respectively, as the moisture content increased from 8.0 to 32.5% (d.b.). Fig. 3b shows a linear increasing trend of thermal conductivity of soursop seeds with moisture content and increased with a polynomial of second order for kernels. It is

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Table 1. Thermal properties of soursop seeds and kernels at different moisture content

Thermal properties	Moisture content (%, d.b.)				
	8	11.9	15.4	22.6	32.5
Soursop seeds					
Spec heat capacity (J/kg/K)	768 ± 1.7[a]	985 ± 2.3[b]	1360 ± 1.2[c]	1429 ± 3.2[d]	2131 ± 1.5[e]
Thermal cond. (W/m/K)	0.075 ± 0.02[a]	0.153 ± 0.02[b]	0.221 ± 0.01[c]	0.324 ± 0.02[d]	0.55 ± 0.01[e]
Thermal diffusivity (m^2/s)	0.119 ± 0.03[a]	0.142 ± 0.01[b]	0.162 ± 0.01[c]	0.227 ± 0.05[d]	0.262 ± 0.03[e]
Soursop kernels					
Spec heat capacity (J/kg/K)	1137 ± 4.04[a]	1185 ± 2.89[b]	1190 ± 1.73[b]	1194 ± 2.31[b]	1438 ± 2.31[c]
Thermal cond. (W/m/K)	0.153 ± 0.0[a]	0.168 ± 0.0.3[b]	0.234 ± 0.02[c]	0.241 ± 0.02[d]	0.256 ± 0.03[d]
Thermal diffusivity (m^2/s)	0.12 ± 0.02[a]	0.142 ± 0.01[b]	0.143 ± 0.01[b]	0.201 ± 0.01[c]	0.256 ± 0.02[d]

[a–e]values with the superscript in the same row differ significantly ($p \leq 0.05$)

depicted from the figure that there was a significant difference between the mean data obtained for the thermal conductivity of kernel at moisture level range of 8.0 to 15.4% (d.b.) while at moisture level of 22.6 and 32.5% (d.b.), the mean data obtained showed no significant difference. This implies that at higher moisture content, soursop kernel has similar rate of heat conduction. The thermal conductivity of the seed is higher than that of the kernel except at 8% (d.b.) moisture content which shows higher value of the thermal conductivity of kernel compared with seed. This may be due to the size and low water content of the kernel at that moisture level. The increase in thermal conductivity with increasing moisture content of the sample could be due to higher thermal conductivity of water compared to the dry material of samples associated with air-filled pores.

Differences between the mean values of the thermal conductivities of seeds and kernels observed at different moisture content were significantly ($p \leq 0.05$) different (Table 1 for seed and Table 2 for kernel). Also, moisture content had a significant effect on thermal conductivity of both seeds and kernels. The obtained results will be found useful in the design and development of agricultural equipment and selection of suitable method for processing of soursop seeds and kernels. Similar trend was observed by Kara et al. (2011) for safflower seeds, Hosain et al. (2012) for black sunflower seeds, Aviara et al. (2008) for guna seeds and Vijay (2013) for coriander seeds. The relationship between moisture content and thermal conductivity (*TCD*) of the seed and kernel can be expressed with regression equations in 4 and 5, respectively.

$$TCD = 0.0189Mc - 0.078 \quad (R^2 = 0.993) \tag{4}$$

$$TCD = -0.0003Mc^2 - 0.015Mc + 0.0403 \quad (R^2 = 0.894) \tag{5}$$

where: TCD – thermal conductivity; *Mc* – moisture content (%, d.b.)

Thermal diffusivity of soursop seed and kernel

The mean values for the thermal diffusivity ranged from 0.119 to 0.262 m^2/s for seed and 0.120 to 0.256 m^2/s for kernel. The seed thermal diffusivity showed not much difference to that of kernel. This shows that both soursop seeds and kernels have higher possibility to transmit heat at similar rates. This information will be useful when designing expeller heating compartment for heat transfer rate within the compartment, for drying and processing of seeds and kernel and in qualified assessment of optimal modes for technological processes. Fig. 3c shows the existence of a linear relationship between thermal diffusivity and moisture content for both seed and kernel. It was observed that thermal diffusivity increased with an increase in moisture content. This shows that moisture content has a significant effect on thermal diffusivity of both seed and kernel. An increase in thermal diffusivity with moisture content may be due to the increase in pore of the sample as a result of increase in seed or kernel size.

Similar trend was observed for thermal diffusivity of roselle seed by Bamgboye and Adejumo (2010), guna seed by Aviara et al. (2008), corian-

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der seed by Vijay (2013). However, it was different to reported results on thermal diffusivity of black sunflower seeds by Hosain et al. (2012) which decreases with increased moisture content. Differences between the mean data for thermal diffusivity as analysed using the Duncan's multiple range test were significant ($P \leq 0.05$) (Table 1).

The relationship between moisture (*mc*) content of seed and kernel are expressed using regression Eqs (6 and 7).

$$\alpha = 0.061Mc - 0.072 \quad (R^2 = 0.973) \qquad (6)$$

$$\alpha = 0.057Mc + 0.00698 \quad (R^2 = 0.811) \qquad (7)$$

where: α – thermal diffusivity (m^2/s); *Mc* – moisture content (%, d.b.)

CONCLUSION

The investigation on the thermal properties of soursop seed and kernel at different moisture contents revealed that within moisture content range of 8.0 to 32.5% (d.b.):

- the mean values of specific heat capacity increased linearly from 768 to 2131 J/kg/K for seeds and from 1,137 to 1,438 J/kg/K, for kernels. Seed thermal conductivity increased linearly from 0.075 to 0.550 W/m/K but increased with polynomial of second order from 0.153 to 0.245 W/m/K for kernel, while the thermal diffusivity of both seed and kernel increased linearly from 0.119 to 0.262 m^2/s and 0.120 to 0.256 m^2/s, respectively.
- the analysis of variance (ANOVA) results showed that moisture content has a significant ($p \leq 0.05$) effect on the thermal properties of soursop seeds and kernels.

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