ARID ZONE JOURNAL OF ENGINEERING, TECHNOLOGY & ENVIRONMENT

AZOJETE, March, 2019. Vol. 15(1):17-24

Published by the Faculty of Engineering, University of Maiduguri, Maiduguri, Nigeria.

Print ISSN: 1596-2490, Electronic ISSN: 2545-5818

www.azojete.com.ng

ORIGINAL RESEARCH ARTICLE

MOISTURE-DEPENDENT THERMAL PROPERTIES OF COCOYAM CORMELS

B. O. Oyefeso[1*] and A. O. Raji

([1]Department of Agricultural and Environmental Engineering, University of Ibadan, Ibadan, Nigeria.)

**Corresponding Author: oyefesobabatunde@gmail.com*

ARTICLE INFORMATION

Submitted 28 March, 2018

Revised 15 December, 2018

Accepted 19 December, 2018

Keywords:
Cocoyam cormels
thermal conductivity
thermal diffusivity
specific heat
moisture content

ABSTRACT

Cocoyam (*Xanthosoma sagittifolium*) has served as a cheap carbohydrate source for many people in the developing countries with prospects in the production of animal feed, lager beer, and its starch as binding agent in drug formulation. Drying is an important unit operation in cocoyam processing and there appears to be lack of information on the thermal properties which are significant in designing heat treatment systems such as dryers for the cormels. This study therefore, investigated some thermal properties of *X. sagittifolium* cormels as affected by moisture content. Thermal properties namely thermal conductivity, diffusivity and specific heat of white- and pink-fleshed cocoyam cormels were investigated at moisture contents within the ranges of 130 to 395% and 85 to 200% (dry basis), respectively. The selected thermal properties of the cormels were determined with the aid of a thermal properties analyser which has a dual needle probe and uses transient line heat source method. Thermal conductivity, diffusivity and specific heat were within the ranges of 0.454 to 0.562 $Wm^{-1}K^{-1}$, 1.62×10^{-7} to 2.32×10^{-7} m^2s^{-1}, 1.836to 4.029 $kJkg^{-1}K^{-1}$, respectively for white-fleshed cocoyam and 0.489 to 0.601 $Wm^{-1}K^{-1}$, 1.79×10^{-7} to 2.65×10^{-7} m^2s^{-1}, 1.615 to 2.991 $kJkg^{-1}K^{-1}$, respectively for pink-fleshed cormels. Analysis of variance showed that there were significant differences between the measured properties at different moisture content levels. Regression models were established between the investigated thermal properties and moisture content.

1.0 Introduction

Cocoyam, *Xanthosoma sagittifolium*, is cultivated for various applications. It ranks third in importance after cassava and yam although it is superior to them in terms of the nutritional value (Onyeka, 2014). The cormel has a lot of potentials which include its utilization for production of lager beer (Onwuka and Eneh, 1998)), as binding agents in paracetamol tablet formulation (Odeku *et al.*, 2005) and as carbohydrate source of juvenile African catfish (Aderolu *et al.*, 2009). Itis also used traditionally as soup thickeners (Enwere, 1998).

It is processed before consumption and used essentially in the same way as yam (Odebunmi *et al.*, 2007). It undergoes several heat treatment processes such as boiling (cooking), drying, frying, smoking and refrigeration to produce its various end products such as chips, flakes, flour and fufu. The knowledge of its thermal properties, such as thermal conductivity, thermal diffusivity and specific heat, is necessary in designing heat treatment systems for processing of the cormels;

to foster a sound understanding of the behaviour of the crop when exposed to heat treatments such as cooling, drying, freezing, frying and smoking (Yang *et al*., 2002); in modelling of heat transfer and temperature distribution during processing (Zhu *et al*., 2007); in the simulation of heat treatment processes involved in the conversion of cocoyam cormels into cocoyam flour which is one of its important final products.

Thermal conductivity, thermal diffusivity and specific heat have been determined for cassava root, yam tuber and plantain fruit (Njie *et al*., 1998), cumin seed (Singh and Goswami, 2000), shea nut kernel (Aviara and Haque, 2001), borage seeds (Yang *et al*., 2002), berberis fruit (Aghbashlo *et al*., 2008), guna seed (Aviara *et al*., 2008), roselle seeds (Bamgboye and Adejumo, 2010) and doum palm fruit (Aremu and Fadele, 2010). However, there appears to be scarcity of information on the thermal properties of cocoyam. The objectives of this study include the determination of thermal conductivity, thermal diffusivity and specific heat of white- and pink-fleshed cocoyam (*Xanthosoma sagittifolium (L.) Schott*) cormels and the investigation of the effect of moisture content on the selected thermal properties.

2. Materials and Methods

Fresh white- and pink-fleshed cormels were obtained from Ogunmakin market near Ibadan city, Ogunmakin town, Ogun State, South Western Nigeria. Fresh agricultural products are usually brought in large quantities to the market from neighbouring farms. The cormels were cleaned, peeled manually and cut into the cylindrical shape of 22 mm diameter and 33 mm height with the aid of a cylindrical borer for uniformity and reduce the probable effect of variation in shape and size. The dimensions of the samples were similar to that of a standard verification block provided with the equipment used in determining the thermal properties. The initial average moisture content of the cocoyam cormels was determined by the air oven method as described by Aghbashlo *et al.* (2008). This involved keeping cocoyam sample of known weight in an oven maintained at a temperature of 105±2°C until the differences between three consecutive weights were within 0.05g. The quantities of moisture removed from the samples were obtained and the moisture contents obtained according to Equations 1 and 2.

$$MC_{wb} = \frac{M_w}{M_{wp}} \times 100 \quad (1)$$

$$MC_{db} = \frac{MC_{wb}}{100 - MC_{wb}} \times 100 \quad (2)$$

where:

MC_{db} = % moisture content (dry basis)

MC_{wb} = % moisture content (wet basis)

M_w = mass of moisture removed from the cormel (kg)

M_{dp} = mass of fresh cocoyam cormel (kg)

The thermal properties of white-fleshed cocoyam cormels were investigated at 130, 180, 250, 320 and 395% average moisture content levels (db) and pink-fleshed cocoyam cormels at 85, 105, 125, 150 and 200% average moisture content levels (db). The desired moisture contents were obtained by conditioning the samples as described by Olaniyan and Oje (2002). Selected thermal properties of the cocoyam cormels namely thermal conductivity, thermal diffusivity and specific heat, were determined with the aid of KD2 Pro Thermal Properties Analyser (Decagon Devices Inc., USA) which has a dual needle probe and uses the transient line heat source method in its operation. One of the needles has a heater while the second one has a temperature sensor.

The dual needles (30mm long, 1.3 mm in diameter and spaced at 6mm apart) were inserted into the cocoyam sample. Pilot holes were made near the centre of the sample to ensure that the needles have correct spacing. The needles were allowed to equilibrate to the surrounding before beginning a reading and good thermal contact was ensured between the sensors and the cocoyam sample by fitting the sample tightly into the hole to ensure accurate measurements. After inserting the needles into the cocoyam sample, both the needles and sample were allowed to attain temperature equilibrium before starting the measurements. Current was passed through the needle with a heater and the heat was applied for a minute and 30 seconds were allowed for temperature equilibration before heating starts. Sixty temperature readings were taken at 15 seconds intervals. Analysis of the probe temperature was used to determine the thermal conductivity of the cocoyam samples (Njie *et al.*, 1998) while the volumetric specific heat was obtained from an algorithm developed based on relationships established between thermal conductivity and specific heat. Thermal diffusivity was determined according to Equation 3. The measured thermal conductivity, diffusivity and specific heat were read directly from the menu display and properly documented for further analysis. The measurements were taken by allowing 15 minutes interval between readings to allow the temperatures to re-equilibrate. All the measurements were carried out in triplicates and the average values were recorded. The experimental set up for thermal properties measurement was as presented in Figure 1.

$$\mu = \frac{k}{\rho C_p} \tag{3}$$

where: μ = thermal diffusivity $\left(m^2 s^{-1}\right)$
k = thermal conductivity $\left(Wm^{-1}K^{-1}\right)$
ρ = density of cormel (kgm^{-3})
C_p = specific heat $(kJkg^{-1}K^{-1})$
Analysis of variance (ANOVA) was carried out to determine the effect of moisture content on the measured thermal properties.

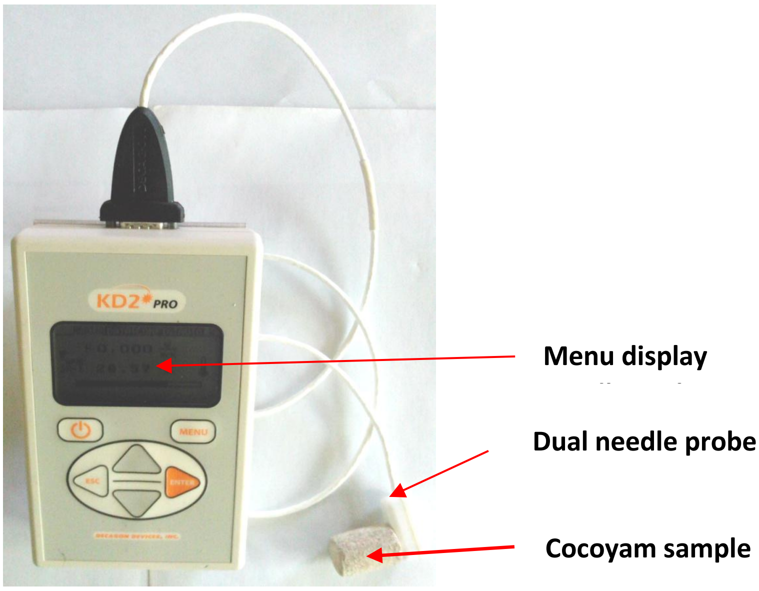

Figure 1: Experimental set up for thermal properties measurement

Corresponding author's e-mail address: gbengailori@unilag.edu.ng

3. Results and Discussion

The thermal conductivity, specific heat and thermal diffusivity of the white- and pink-fleshed cocoyam cormels are as presented in Figures 2 to 4.

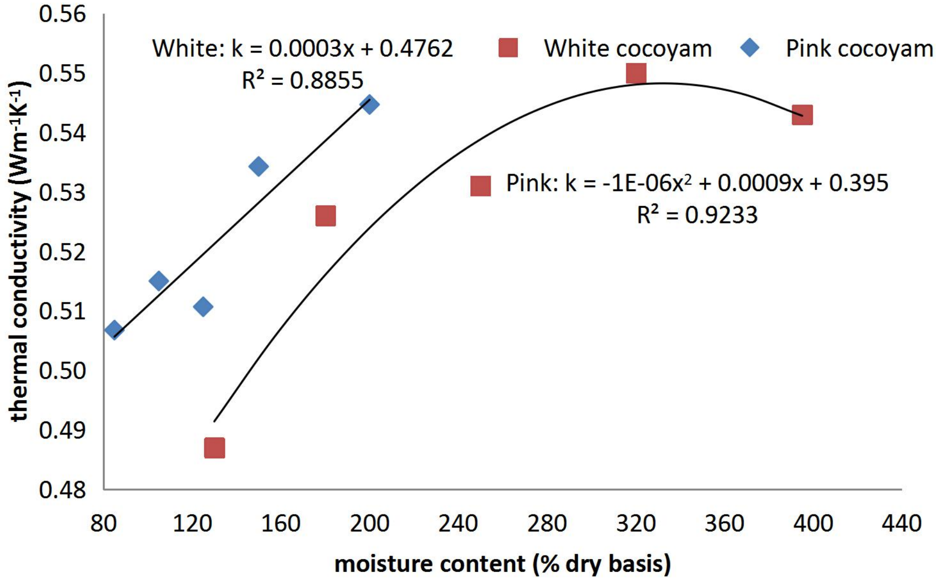

Figure 2: Thermal conductivity of cocoyam cormels

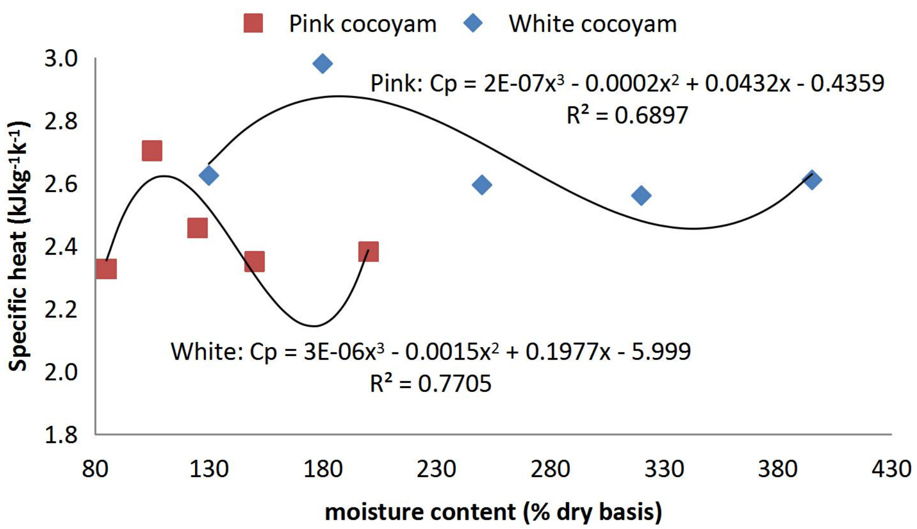

Figure 3: Specific heat of cocoyam cormels

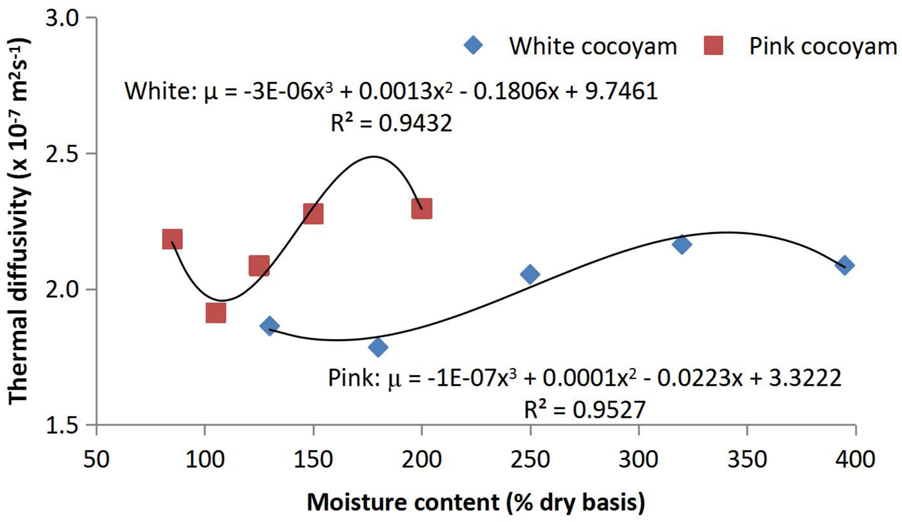

Figure 4: Thermal diffusivity of cocoyam cormels

Thermal conductivities of white-f and pink-fleshed cocoyam cormels increased with increasing moisture content (Figure 2). A similar trend has been reported for potato (Donsi *et al.,* 1996) and cassava root and yam tuber (Njie *et al.,* 1998).The thermal conductivity of the white-fleshed cormels were within the ranges of 0.454 to 0.562 $Wm^{-1}K^{-1}$ while that of the pink-fleshed cormels were within the ranges of 0.489 to 0.601 $Wm^{-1}K^{-1}$ for the range of moisture content considered. The relationships between the thermal conductivity of the cormels and moisture content could be represented by Equations 4 and 5.

White: $k = 0.0003M + 0.4762$ ($R^2 = 0.886$) (4)

Pink: $k = -1E\text{-}06M^2 + 0.0009M + 0.395$ ($R^2 = 0.923$) (5)

The increase in thermal conductivity with increasing moisture content could be attributed to the high thermal conductivity of water in the cormel which made it possible for heat energy to be easily conducted through its tissues. This implies that low heat energy input will be required to uniformly distribute heat (as in drying) through the cocoyam cormels at high moisture content (Taiwo *et al*., 1996; Cansee *et al*., 2008). Similar trends were observed for shea nut kernel (Aviara and Haque, 2001) and borage seeds (Yang *et al*., 2002).

The relationships between specific heat and thermal diffusivity of white-f and pink-fleshed cocoyam cormels and moisture content could be represented by Equations 6 to 9.

Pink: $Cp = 3E\text{-}06M^3 - 0.0015M^2 + 0.1977M - 5.999$ ($R^2 = 0.771$) (6)

White: $Cp = 2E\text{-}07M^3 - 0.0002M^2 + 0.0432M - 0.4359$ ($R^2 = 0.670$) (7)

White: $\mu = -3E\text{-}06M^3 + 0.0013M^2 - 0.1806M + 9.7461$ ($R^2 = 0.943$) (8)

Pink: $\mu = -1.35E\text{-}07M^3 + 1.02E\text{-}04M^2 - 2.23E\text{-}02M + 3.32E{+}00$ ($R^2 = 0.953$) (9)

The relationships were non-linear and sinusoidal in nature since the specific heat and thermal diffusivity increased and decreased within the range of moisture content considered for both varieties. This sinusoidal variation in specific heat and thermal diffusivity of the white-fleshed and pink-fleshed cocoyam could be attributed to the non-homogeneous nature of the cormel as a bio-material and structural arrangement of its tissues (Aremu and Fadele, 2010). Similar sinusoidal trend was observed for the thermal diffusivity of doum palm fruit (Aremu and Fadele, 2010) while a linear decreasing trend was observed for whole guna seed and kernel (Aviara et al.,

Corresponding author's e-mail address: gbengailori@unilag.edu.ng

2008). Taiwo *et al.,* (1996) observed an increase in specific heat of ground and hydrated cowpea up to a point followed by a decrease with subsequent increase in moisture content while only a linear decreasing trend was observed for roselle seed (Bamgboye and Adejumo, 2010).The specific heat and thermal diffusivity of the white-fleshed cormels were found to be within the ranges of 1.836 to 4.029 $kJkg^{-1}K^{-1}$ and 1.62×10^{-7} to $2.32 \times 10^{-7} m^2s^{-1}$, respectively while those of the pink-fleshed cormels were within the ranges of 1.615 to 2.991 $kJkg^{-1}K^{-1}$ and 1.79×10^{-7} to $2.65 \times 10^{-7} m^2s^{-1}$, respectively. The thermal conductivity and specific heat of the cormels compared well with the range of values obtained for other agricultural materials such as doum palm fruit, berberis fruit, plantain, cassava root and yam tuber (Aremu and Fadele, 2010; Aghbashlo *et al.*, 2008; Njie *et al.*, 1998).

The ANOVA results of the effect of moisture content on the selected thermal properties are as presented in Tables 1 and 2. The statistical analysis showed that the effect of variation in moisture content was significant ($p<0.05$) on all the measured thermal properties. This clearly indicated that the response of the cocoyam cormels as biological materials to heat treatments is dependent on the amount of moisture present in the cormels. This could serve as a guide in determining the amount of energy required to properly condition cocoyam cormels at a given moisture content during heat treatments and in storage. Therefore, knowledge of thermal properties investigated with respect to moisture content is applicable in the optimization of thermal processing systems and serve as an essential guide in the design of heat treatment equipment such as a dryer for cocoyam cormels.

Table 1: Effect of moisture content on thermal properties of white-fleshed cocoyam cormels

Source	Model	Sum of Squares	Degree of freedom (Df)	Mean Square	F-value	Level of Significance
Thermal conductivity	Regression	0.002	1	0.002	10.014	0.051
	Residual	0.001	3	0.000		
	Total	0.002	4			
Thermal diffusivity	Regression	0.000	1	0.000	6.360	0.086
	Residual	0.000	3	0.000		
	Total	0.000	4			
Specific heat	Regression	0.173	1	0.173	0.829	0.430
	Residual	0.627	3	0.209		
	Total	0.800	4			

Table 2: Effect of moisture content on thermal properties of pink-fleshed cocoyam cormels

Source	Model	Sum of Squares	Degree of freedom (Df)	Mean Square	F-value	Level of Significance
Thermal conductivity	Regression	0.000	1	0.000	7.737	0.069
	Residual	0.000	3	0.000		
	Total	0.001	4			
Thermal diffusivity	Regression	0.000	1	0.000	1.551	0.301
	Residual	0.000	3	0.000		
	Total	0.000	4			
Specific heat	Regression	0.317	1	0.317	5.910	0.093
	Residual	0.161	3	0.054		
	Total	0.478	4			

4. Conclusions

Thermal properties of white- and pink-fleshed cocoyam (*X. sagittifolium*) cormels were examined in the study. The results showed that:

Thermal conductivity of the cormels increased with increasing moisture content and the values were within the ranges of 0.454 to 0.562 $Wm^{-1}K^{-1}$ and 0.489 to 0.601 $Wm^{-1}K^{-1}$, for white- and pink-fleshed cormels respectively; Thermal diffusivity of white-f and pink-fleshed cormels were within the ranges of 1.62×10^{-7} to 2.32×10^{-7} m^2s^{-1} and 1.79×10^{-7} to 2.65×10^{-7} m^2s^{-1}, respectively; Specific heat of white-f and pink-fleshed cormels were within the ranges of1.836 to 4.029 $kJkg^{-1}K^{-1}$ and 1.615 to 2.991 $kJkg^{-1}K^{-1}$, respectively; All the investigated properties were dependent on the level of moisture present in the cormel. Data on the thermal properties investigated with respect to variation in moisture content is applicable in the optimization of thermal processing systems and as an essential guide in the design of heat treatment equipment for cocoyam cormels.

References

Aderolu, AZ. 2009. Processed cocoyam tuber as carbohydrate source in the diet of juvenile African catfish (*Clarias gariepinus*). European Journal of Scientific Research, 35(3): 453-460.

Aghbashlo, M., Kianmehr, MH., Hassan-Beygi, SR. 2008. Specific heat and thermal conductivity of berberis fruit (*Berberis vulgaris*). American Journal of Agricultural and Biological Sciences, 3(1): 330-336.

Aremu, AK. and Fadele, OK. 2010. Moisture dependent thermal properties of doum palm fruit (*Hyphaene thebaica*). Journal of Emerging Trends in Engineering and Applied Sciences (JETEAS), 1(2): 199-204.

Aviara, NA. and Haque, MA. 2001. Moisture dependence of thermal properties of sheanut kernel. Journal of Food Engineering, 47: 109-113.

Aviara, NA., Haque, MA. and Ogunjimi, LAO. 2008. Thermal properties of guna seed. International Agrophysics, 22: 291-297.

Corresponding author's e-mail address: gbengailori@unilag.edu.ng

Bamgboye, AI. and Adejumo, OI. 2010. Thermal properties of roselle seeds. International Agrophysics, 24: 85-87.

Cansee, S., Watyotha, C., Thivavarnvongs, T., Uriyapongson, J. and Varith, J. 2008. Effect of temperature and concentration on thermal properties of cassava starch solutions. Songklanakarin Journal of Science and Technology, 30(3): 405 - 411.

Donsi, G., Ferrari, G and Nigro, R. 1996. Experimental determination of thermal conductivity of apple and potato at different moisture contents. Journal of Food Engineering, 30: 263-268.

Enwere, JN. 1998. Foods of plant origin. Afro-Orbis Publications, Nsukka, Nigeria. 64-124.

Njie, DN., Rumsey, TR. and Singh, RP. 1998. Thermal properties of cassava, yam and plantain. Journal of Food Engineering, 37(1): 63-76.

Odebunmi, EO., Oluwaniyi, OO., Sanda, AM. and Kolade, BO. 2007. Nutritional compositions of selected tubers and root crops used in Nigerian food preparations. International Journal of Chemistry, 17(1): 37-43.

Odeku, OA., Awe, OO., Popoola, B., Odeniyi, MA. and Itiola, OA. 2005. Compression and mechanical properties of tablet formulations containing corn, sweet potato, and cocoyam starches as binders. Pharmaceutical Technology, 29(4): 82-90.

Onwuka, NO. and Eneh, OC. 1998. The potentials of cocoyam (Colocasia) in stout beer brewing. Journal of Science and Technology, 4: 78-80.

Onyeka, J. 2014. Status of cocoyam (*Colocasia esculenta* and *Xanthosoma spp*) in West and Central Africa: Production, household importance and the threat from leaf blight, Lima (Peru). CGIAR Program on Roots, Tubers and Bananas (RTB). www.rtb.cgiar.org

Singh, KK. and Goswami, TK. 2000. Thermal properties of cumin seed. Journal of Food Engineering, 45:181-187.

Taiwo, KA., Akanbi, CT. and Ajibola,OO. 1996 Thermal Properties of Ground and Hydrated Cowpea. Journal of Food Engineering 29: 249-256

Yang, W., Sokhansanj, S., Tang, J. and Winter, P. 2002. Determination of thermal conductivity, specific heat and thermal diffusivity of borage seeds. Biosystems Engineering, 82(2): 169–176.

Zhu, S., Ramaswamy, HS., Marcotte, M., Chen, C., Shao, Y. and Le Bail, A. 2007. Evaluation of thermal properties of food materials at high pressures using a dual-needle line-heat-source method. Journal of Food Science, 72: 49–56.