Effects of moisture content and temperature on the specific heat of soya bean, *Moringa oleifera* seed and *Mucuna flagellipes* nut

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Abstract: The specific heat of soya bean variety TGX 1,440–1E, *moringa oleifera* seed, *moringa oleifera* kernel and *mucuna flagellipes* nut were evaluated and their variations with moisture content and temperature were investigated, using the method of mixture. The specific heat of soya bean, *moringa oleifera* seed, *moringa oleifera* kernel and *mucuna flagellipes* nut increased linearly from 1 780 to 2 646 J/(kg·K), 1 520 to 2 516.121 J/(kg·K), 1 625.24 to 2 458.214 J/(kg·K) and 2 080 to 4 586 J/(kg·K) in the moisture content and temperature ranges of 6.16%–51.52% (d.b.) and 305.8–363 K, 8.43%–31.66% (d.b.) and 300–341.88 K, 6.75%–31.5% (d.b.) and 300–344.38 K, and 3.38%–10.7% (d.b.) and 300–330.75 K, respectively. While the specific heat of soya bean increased with increase in temperature up to a certain point and decreased with further increase in temperature, the specific heat of *moringa oleifera* seed and kernel increased linearly, and *mucuna flagellipes* nut exhibited a second order polynomial relationship between its specific heat and average temperature. Regression models, which could be used to reasonably predict the specific heat of these products at specified moisture content and average temperature, were established.

Key words: soya bean var. TGX 1,440-1E, *moringa oleifera, mucuna flagellipes*, specific heat, moisture content, temperature
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1 Introduction

Soya bean (Glycine max), *moringa oleifera* seed and *Mucuna flagellipes* nut are highly nutritious, and provide both oil and protein in the diet of people all over the world. Oil and protein contents of soya bean have been reported as 13.5%–24.2% and 29.6%–50.3%, respectively[1]. The soya bean variety TGX 1,440–1E seed contains about 17.5% of oil by weight, 37.8% protein, 32% carbohydrate, 9.57% fiber and 5.6% ash[2]. *Moringa oleifera* is grown mainly in the semi-arid, tropical and sub-tropical regions. Its seed contains 35% – 40% oil by weight[3], and can be processed to yield edible vegetable oil, which is high in oleic acid[4] and resistant to rancidity[5]. *Mucuna flagellipes* is found worldwide in the woodlands of tropical regions and grown as food crop by many tribal and ethnic groups in Asia and Africa[6,7]. The tree is mainly important for its nut which contains a kernel with approximately 20% protein and 70% carbohydrate[8], and an oil content of (3.77±0.21)100/g[9]. The composition of the oil compares well with those of rape seed, sesame, sunflower and groundnut seed oil and its seed gum functions well as thickening agent in food[10].

The processing of soya bean, *moringa oleifera* seed and *mucuna flagellipes* nut into various forms of food and the extraction of oil from the seed and nut usually involved such thermal treatments as roasting, parboiling,

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cooking, drying and cooling. The specific heat of these crops and its variation with moisture content and temperature is essential in the design and evaluation of thermal process systems that are required to handle them.

Most of the methods described by Mohsenin N N[11] have been employed by investigators in determining the specific heat of food and agricultural materials. Suter D A et al.[12], Moysey E B et al.[13] and Fasina O O and Sokhansanj S[14] determined the specific heat of peanut, rape seed and alfalfa pellets respectively, by calculating it from measured thermal conductivity, thermal diffusivity and bulk density. Choi Y and Okos M R[15] and Yang W et al.[16] employed the methods of mixture in determining the specific heat of major food components and borage seed using the differential scanning calorimeter. Ezeike G O I[17] used a modified adiabatic bomb calorimeter in determining the specific heat of tropical food crops, while Shepherd H and Bhardwaj R K[18], Dutta S K et al.[19] and Aviara N A and Haque M A[20] used calibrated aluminium and copper calorimeters placed inside insulated vacuum flasks in measuring the specific heat of pigeon pea, gram and shea nut kernel respectively. The method of mixtures has also been used in determining the specific heat of wheat[21], faba beans[22], oil bean seed[23], ground and hydrated cowpea[24], cumin seed[25], locust bean seed[26] and millet grains and flours[27]. Muir W E and Viravanichai S[21] found that the specific heat of hard red spring wheat was a linear function of both moisture content and temperature within the range of 1.00%–9.00% (w.b.) and –33.5–21.8℃. They further noted that at moisture content above 23.4% (w.b.), the specific heat of wheat was not a linear function of moisture content and/or temperature. Fraser B M et al.[22], Dutta S K et al.[19], Telis-Romero et al.[28], Singh K K and Goswami T K[25] and Aviara N A and Haque M A[20] reported that the specific heat of fababean, gram, Brazilian orange juice, cumin seed and shea nut kernel respectively, increased with increase in moisture content, while Taiwo K A et al.[24] noted that that of ground cowpea increased with moisture content and temperature up to a certain level and decreased with further increase in temperature. Fasina O O and Sokhansanj S[14] noted that a polynomial relationship of the second existed between the specific heat of alfalfa pellets and moisture content. Deshpande S D and Bal S[29] investigated the moisture dependence of the specific heat of soybean variety Cv JS–7244 at a mean temperature of 315 K and moisture range of 8.1% to 25% (d.b.), and presented a regression model, that could be used to express the relationship between the specific heat and moisture content. The effect of temperature on the specific heat was not investigated. A comparison of their results with those of Alam A and Shove G C[30] showed that variety had significant effect on the specific heat of soya bean.

The objective of this study was to investigate the moisture and temperature dependence of the specific heat of soya bean var. TGX 1440-1E, *moringa oleifera* seed and kernel and *mucuna flagellipes* nut.

2 Materials and methods

2.1 Material preparation

Bulk samples of dry soya bean var. TGX 1440-1E were obtained from the International Institute of Tropical Agriculture, Ibadan, and seeds and kernels of *moringa oleifera*, and *Mucuna flagellipes* nut were purchased at Monday main market in Maiduguri, Nigeria. The samples were cleaned and conditioned to different moisture levels in the range of 6.16% to 51.52% (d.b.), 8.43% to 31.66% (d.b.), 6.75% to 31.5% (d.b.) and 3.38% to 10.7% (d.b.), for soya bean, *moringa oleifera* and *mucuna flagellipes*, respectively, using the method of Ezeike G O I[31]. This method involved soaking the samples in clean water for a period of time ranging between one to six hours for soya bean, *moringa oleifera* seed and kernel, and between 16 and 48 h for *mucuna flagellipes* nuts. The soaked samples were then spread out in thin layer to dry in natural air for about eight hours. After this, the samples were sealed in polythene bags and stored in that condition for further 24 h. This enabled the samples to attain uniform and stable moisture levels. The moisture contents of the samples were determined using the oven method. Samples were dried in an oven set at 105℃ for seven hours with weight loss monitored on hourly basis to determine the time at which the weight began to remain constant.

2.2 Specific heat determination

The specific heat of soya bean var. TGX 1440-1E, seed and kernel of *moringa oleifera*, and *mucuna flagellipes* nut was determined using a calibrated copper calorimeter placed inside a flask, using the method of mixture as described by Ogunjimi L A O et al[26]. The calorimeter was calibrated following the procedure described by Aviara N A and Haque M A[20]. To determine the specific heat of any of the products, a sample of known weight, temperature and moisture content was dropped into the calorimeter containing water of known weight and temperature. The mixture was stirred with a copper stirrer and the temperature was recorded at an interval of two seconds. At equilibrium, the final temperature was noted and the specific heat was calculated using the following equation:

$$c_s = \frac{(m_c c_c + m_w c_w)\{T_w - (T_e - t'R')\}}{m_s\{(T_e + t'R') - T_s\}} \qquad (1)$$

Where, C_c specific heat of calorimeter, J/(kg·K); C_s specific heat of sample, J/(kg·K); C_w specific heat of water, J/(kg·K); m_c mass of calorimeter, kg; m_s mass of sample, kg; m_w mass of water, kg; T_e equilibrium temperature of sample and water mixture, K; T_s initial temperature of sample, K; T_w initial temperature of water, K; R' rate of temperature fall after equilibrium, K/s; t' time taken for seed and water to come equilibrium, s.

The $t'R'$ term accounted for the heat of hydration and heat exchange with the surrounding. Samples at different moisture levels, different temperature ranges between sample initial temperature and final temperature of water – sample mixture, and the average temperatures obtained, were used to investigate the effect of moisture content and temperature on the specific heat of the crops. The experiment was replicated three times at each moisture level and temperature range, and the average values of the specific heat were recorded and used in regression analysis.

3 Results and discussion

The specific heat of soya bean var. TGX 1440–1E in the moisture and temperature ranges of 6.16%–51.52% (d.b.) and 305.8–363 K (between the initial temperature of the seed and final temperature of the water-seed mixture) was found to lie between 1 780–2 646 J/(kg·K). In the moisture and temperature ranges of 8.43%–31.66% (d.b.), 6.75%–31.5% (d.b.) and 300–341.88 K, 300–344.38 K, the specific heat of *moringa oleifera* seed and kernel ranged from 1 520 to 2 516.121 J/(kg·K), and from 1 625.24 to 2 458.214 J/(kg·K), respectively. The specific heat of *mucuna flagellipes* nut in the moisture range of 3.38%–10.7% (d.b.) and temperature range (300–330.75 K) was found to lie between 2 080 and 4 586 J/(kg·K).

The variations of the specific heat of soya bean, *moringa oleifera* seed, *moringa oleifera* kernel and *mucuna flagellipes* nut with moisture content are presented in Figures 1, 2, 3 and 4, respectively. From these figures, it can be seen that the specific heat of the products increased linearly with the increase in moisture content within the specified temperature ranges. This was similar to the trend of specific heat with moisture content observed for cumin seed[25], shea nut kernel[20], guna seed and kernel[32] and other varieties of soya bean[33].

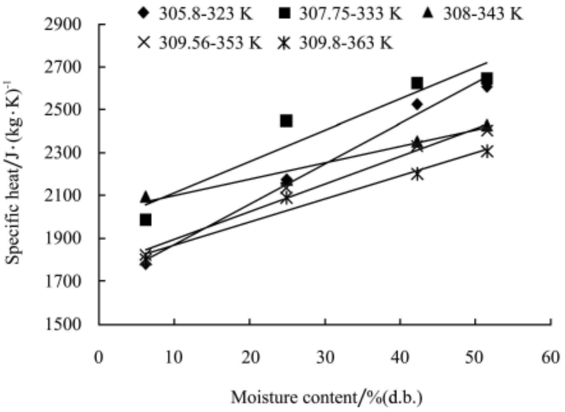

Figure 1 Variations of the specific heat of soya bean var. TGX 1440 – 1E with moisture content at different temperature ranges

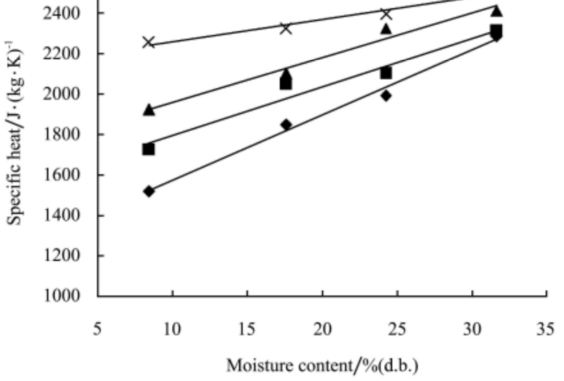

Figure 2 Variations of the specific heat of *moringa oleifera* seed with moisture content at different temperature ranges

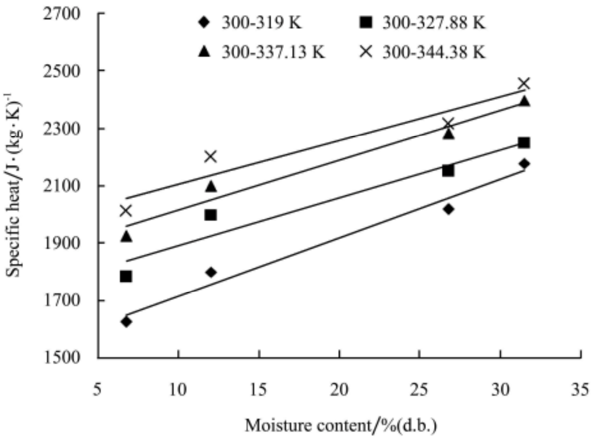

Figure 3 Variations of the specific heat of *moringa oleifera* kernel with moisture content at different temperature ranges

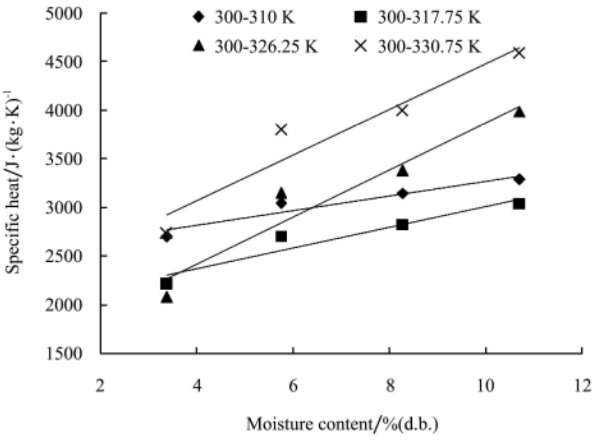

Figure 4 Variations of the specific heat of *mucuna flagellipes* nut with moisture content at different temperature ranges

At a similar moisture level and average temperature, the specific heat of *moringa oleifera* seed was higher than that of the kernel and lower than soya bean. The specific heat of *mucuna flagellipes* nut was significantly higher than *moringa oleifera* seed. The differences in the specific heat of these products may be due to their composition.

The effects of temperature on the specific heat of soya bean, moringa oleifera seed, *moringa oleifera* kernel and *mucuna flagellipes* nut are respectively presented in Figures 5, 6, 7 and 8. These figures show that the specific heat of soya bean increased with the increase in average temperature up to a certain point and decreased with further increase in temperature, while the specific heat of *moringa oleifera* seed and kernel increased linearly with the increase in temperature, and that of *mucuna flagellipes* nut exhibited a second order polynomial relationship with temperature at all the moisture levels within which the study was carried out.

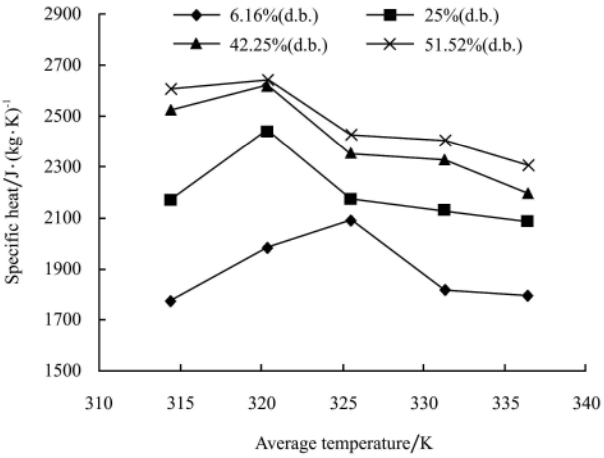

Figure 5 Variations of the specific heat of Soya bean TGX 1440 – 1E with average temperature at different moisture content levels

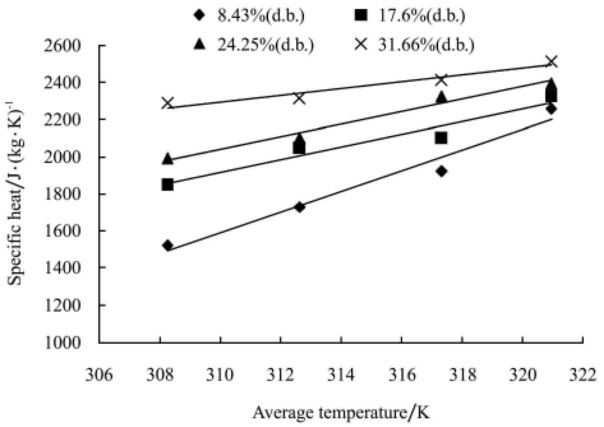

Figure 6 Variations of the specific heat of moringa oleifera seed with average temperature at different moisture levels

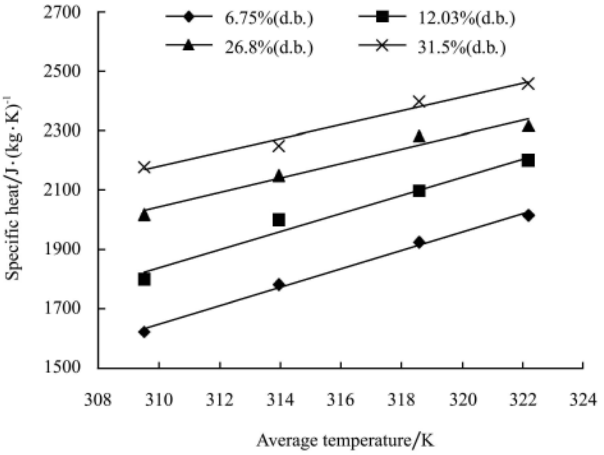

Figure 7 Variations of the specific heat of moringa oleifera kernel with average temperature at different moisture levels
6.75%(d.b.) 26.8%(d.b.)

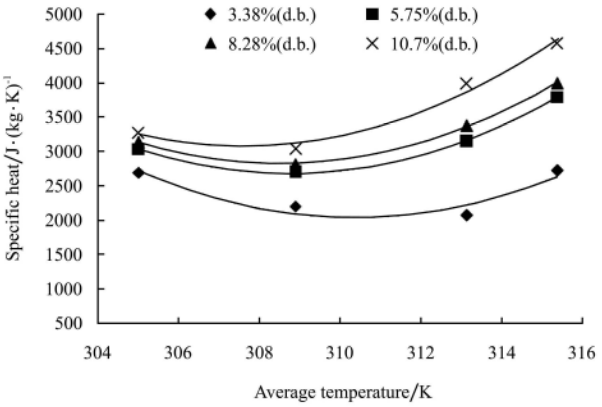

Figure 8 Variations of the specific heat of mucuna flagellipes nut with average temperature at different moisture levels

Multiple regression models with the specific heat of soya bean, *moringa oleifera* seed, *moringa oleifera* kernel and *mucuna flagellipes* nut as a function of moisture content, M and average temperature, Ta were fitted to the experimental data. These yielded the following equations:

Soya bean:

$$C_{sb} = -101190.128 + 125.437M - 0.132M^2 + 633.862Ta - 0.975Ta^2 - 0.322MTa \quad R^2=0.91 \tag{2}$$

Moringa seed:

$$C_{ms} = -8783.162 + 496.818M - 0.29M^2 + 0.105a^2 - 1.504\,MTa \quad R^2=0.98 \tag{3}$$

Moringa kernel:

$$C_{mk} = -3637.578 + 134.363M - 0.285M^2 - 0.053Ta^2 - 0.336MTa \quad R^2=0.98 \tag{4}$$

Mucuna nut:

$$C_{fn} = 7571.95 - 2806.629M - 16.067M^2 - 19.983Ta^2 + 10.241MTa \quad R^2=0.85 \tag{5}$$

A t-test of the coefficients of terms in the model for soya bean (Equation 2) showed that the M^2 term did not make statistically significant contribution to the function, while the other terms made significant contributions at 1% level. A similar test showed that for *moringa oleifera* seed (Equation 3), the M, Ta^2 and MTa terms had significant effect on the function at 1% level, while the other terms did not make significant contributions. For *moringa oleifera* kernel (Equation 4), the M and T^2 a terms made significant contribution to the function at 5% level, while the other terms did not make significant contributions. In the model for *mucuna flagellipes* nut (Equation 5), the M and MTa terms were found to have made significant contribution to the function at 1% level, while the other terms did not make significant contributions. The overall assessment of these equations depicted by coefficient of determination (R^2) showed that they could be used to reasonably predict the moisture and temperature dependence of the specific heat of the crops.

4 Conclusions

From the investigations on the effects of moisture content and temperature on the specific heat of soya bean var. TGX 1440-1E, *moringa oleifera* seed, *moringa oleifera* kernel and *mucuna flagellipes* nut, the following conclusions could be drawn:

1) The specific heat of the products increased linearly with moisture content.

2) Specific heat of soya bean increased with the increase in temperature up to a certain point and decreased with further increase in temperature.

3) The specific heat of *moringa oleifera* seed and kernel increased linearly with increase in temperature.

4) Specific heat of *mucuna flagellipes* nut had a parabolic relationship with temperature.

[References]

[1] Weiss E A. Oil seed crops. London: Longman Ltd, 1983.

[2] IITA. International Institute of Tropical Agriculture. Personal Communication, Ibadan, 2001.

[3] Levicki K. A catchment to consumer approach to rural water resource assessment Baseline Study and Safe Drinking Water Supply Strategy for Orongo Village, Lake Victoria Basin, Kenya. Royal Institute of Technology. Stockholm, Sweden. 2005.

[4] Sutherland J P, Folkard G K, Mtawah M A, Grant W D. *Moringa oleifera* as a natural coagulant. Affordable Water Supply and Sanitation. In: Proceedings of the 20th WEDC Conference, Colombo, Sri Lanka, 1994.

[5] Fahey J W. *Moringa oleifera*: A review of the medical evidence for its nutritional, therapeutic, and prophylactic properties. Part 1. Journal of Phytochemistry, 2005; 47: 122–157.

[6] Dako D Y, Hill D C. Chemical and biological evaluation of *Mucuna pruriens* (*Utilis*) beans. Nutrition Report International, 1977; 15: 239–244.

[7] Iyayi E A, Egharevba J I. Biochemical evaluation of seeds of an underutilized legume (*Mucuna utilis*). Nigerian Journal of Animal Production, 1998; 25: 40–45.

[8] Jansen P C M. *Mucuna flagellipes*. 2005. Available: www.database.prota.org/PROTAhtml/*Mucuna flagellipes*-Eu.htm, Accessed on [2009–11].

[9] Ajayi I A, Oderinde R A, Kajogbola D O, Uponi J I. Oil content and fatty acid composition of some under-utilized legumes from Nigeria. Food Chemistry, 2006; 99(1): 115–120.

[10] Nwokocha L M, Williams P A. Isolation and rheological characterization of mucuna flagellipes seed gum. Food Hydrocolloids, 2009; 23: 1394–1397.

[11] Mohsenin N N. Thermal Properties of Food and Agricultural Materials. New York: Gordon and Breach Science, 1980.

[12] Suter D A, Agarwal K K, Clary B L. Thermal properties of peanut pods, hulls and kernels. Transactions of the ASAE, 1975; 18: 370–375.

[13] Moysey E B, Shaw J T, Lampman W P. The effect of temperature and moisture on the thermal properties of rapeseed. Transactions of the ASAE, 1977; 20(3): 461–464.

[14] Fasina O O, Sokhansanj S. Bulk thermal properties of alfalfa pellets. Canadian Agricultural Engineering, 1995; 37(2): 91–95.

[15] Choi Y, Okos M R. Effect of Temperature and Composition on the Thermal Properties of Food. In: M. Le Maguer & P. Jelen, Food Engineering and Process Applications, Volume 1: Transport Phenomena. Essex: Elsevier Applied Science (Chapter 9). 1986.

[16] Yang W, Sokhansanj S, Tang J, Winter P. Determination of the thermal conductivity, specific heat and thermal diffusivity of borage seeds. Biosystems Engineering, 2002; 82: 169–176.

[17] Ezeike G O I. A Modified Adiabatic Bomb Calorimeter for Specific Heat Capacity Measurements. In: Proceedings of the Nigerian Society of Agricultural Engineers, 1987; 11: 222–245.

[18] Shepherd H, Bwardwaj R K. Thermal properties of pigeon pea. Cereal Foods World, 1986; 31: 466–470.

[19] Dutta S K, Nema V K, Bhardwaj R K. Thermal properties of gram. Journal of Agricultural Engineering Research, 1988; 39: 269–275.

[20] Aviara N A, Haque M A. Moisture dependence of thermal properties of shea nut kernel. Journal of Food Engineering, 2001: 47(2): 109–113.

[21] Muir W E, Viravanichai S. Specific heat of wheat. Journal of Agricultural Engineering Research, 1972; 17: 338–342.

[22] Fraser B M, Verma S S, Muir W E. Some physical properties of fababeans. Journal of Agricultural Engineering Research, 1978; 23: 53–57.

[23] Oje K, Ugbor E C. Some physical properties of oil bean seed. Journal of Agricultural Engineering Research, 1991; 50: 305–313.

[24] Taiwo K A, Akanbi C T, Ajibola O O. Thermal properties of ground and hydrated cowpea. Journal of Food Engineering, 1995; 29: 249 – 256.

[25] Singh K K, Goswami T K. Thermal properties of cumin seed. Journal of Food Engineering, 2000; 45: 181–187.

[26] Ogunjimi L A O, Aviara N A, Aregbesola O A. Some engineering properties of locust bean seed. Journal of Food Engineering, 2002; 55(2): 95–99.

[27] Subramanian S, Viswanathan R. Thermal properties of minor millet grains and flours. Biosystems Engineering, 2003; 84: 289–296.

[28] Telis-Romero J, Telis V R N, Gabas A L, Yamashita F. Thermophysical properties of Brazilian orange juice as affected by temperature and moisture content. Journal of Food Engineering, 1998; 38: 27–40.

[29] Deshpande S D, Bal S. Specific heat of soyabean. Journal of Food Process Engineering, 1999; 22: 469–477.

[30] Alam A, Shove G C. Hygroscopicity and thermal properties of soybean. Transactions of the ASAE, 1973; 16(4): 707–709.

[31] Ezeike G O I. Quasi-static hardness and elastic properties of some tropical seed grains and tomato fruit. International Agrophysics, 1986; 2: 15–29.

[32] Aviara N A, Haque M A, Ogunjimi L A O. Thermal properties of guna seed. International Agrophysics, 2008; 22: 291–297.

[33] Deshpande S D, Bal S, Ojha T P. Bulk thermal conductivity and diffusivity of soy bean. Journal of Food Processing and Preservation, 1996; 20: 177–189.