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SPECIFIC HEAT OF SELECTED LEGUMES AND CEREAL GRAINS GROWN IN NORTH EASTERN NIGERIA

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Abstract
Thermal properties of agricultural materials are important parameters in the design and operation of thermal processing machines. This study focuses on the determination of specific heat of some staple crops at different moisture contents and temperatures, using the method of mixtures. The crops included maize, rice, millet, sorghum, groundnut, cowpea, locust bean and sesame seed. The temperature levels were 50°C, 60°C, 70°C and 80°C, while the four moisture levels employed ranged from 1.96-15.89% (maize), 2.79-13.58% (rice), 2.27-23.55% (millet), 2.89-25.42% (sorghum), 1.57-29.02% (groundnut), 2.38%-30.70% (cowpea), 1.80%-12.20% (locust bean) and 2.37-21.5% (sesame). Results showed that the specific heat varied with grain and increased with increase in moisture content but decreased with respect to temperature increase. It ranged from 1689.1 to 3224.7J/kgK (maize), 1527.5 to 2661.4J/kgK (rice), 1689 to 3224.7J/kgK (millet), 1689 to 3224.7J/kgK (sorghum), 1689 to 3157.5J/kgK (groundnut), 1852 to 3224.7J/kgK (cowpea), 2523.7 to 3224.7J/kgK (locust bean) and 1689 – 3224.7J/kgK (sesame). Regression equations that could be used to express the relationship existing between the specific heat and moisture content of the different crops were established.

Keywords: Specific heat, cereal grains, thermal properties, legumes, moisture content, regression models

1. Introduction

Maize is a cereal crop that is grown widely throughout the world. About 50 species of the cereal exist and consist of different colours, textures, grain shape and size with white, yellow and red types being most common. The grains are rich in vitamins A, C and E, carbohydrates, essential minerals, and protein. They are also rich in dietary fiber and calories which are a good source of energy. Maize is the most important cereal crop in sub-Saharan African and an important staple food for north eastern Nigeria. All part of the crop can be used for food and non-food products. In industrialized countries, maize is largely used as livestock feed and as a raw material for industrial products. The grains are normally processed and prepared in various forms depending on the region and some of these are as ground maize flour prepared into porridge in West Africa and 'tuwo' in Northern Nigeria. It can be boiled or roasted on it cob and served as a snack. It is called 'oka' in Igbo, 'masara' in Hausa and 'agbado' in Yoruba.

Rice is the seed of monocot plant *oryza sativa* (Asian rice) or *oryza glaberrima* (African rice). As a cereal grain it is the most important staple food for large part of the human population. There are many varieties of rice and culinary preferences tend to vary regionally. It is normally grown as an annual plant. Rice cultivation is well suited to countries and regions with low labour cost and high rainfall as it is labour-intensive to cultivate and requires ample water. In Nigeria it is called 'shinkafa' in Hausa and 'osikapa' in Igbo.

The millets include species in the subfamily *panicoideae* of the grass family *poaceae*. The exception is the finger millet that is of the subfamily *chloridoidaee*. The most widely cultivated species in order of worldwide production are pearl millet (*pennisetum glaucum*) and foxtail millet (*setaria italica*).

The millet varieties are widely grown around the world for both human and animal consumption. They do well in the semi-arid tropics of Asia and Africa.

Sorghum is in the subfamily *panicoideae* and the tribe *Andropogoneae*. One of the species, sorghum bicolor is an important crop used for food, fodder and the production of alcoholic beverages and bio fuel.

Groundnut belongs to the bean or legume plant family (*Leguminosae*). It has a vine like growth form that twines upon and through the shrubbery beneath the forest. Ground nuts once-pinnately compound leaves have 5-7 leaflets. The flower occurs in clusters and are brownish-red, the tubers are high in starch are protein. On a dry weight basis, groundnut has three times the protein as potatoes. Groundnut is a wide plant with a great potential as a future food source.

Cowpea is one of the several species of the widely cultivated genus *vigna*. It is one of the most important food legumes crops in the semi-arid tropics covering Asia, Africa, southern Europe central, South America. It is a drought-tolerant and warm weather crop. Cowpea is also well-adapted to the drier regions of the tropics, where other foods legumes do not perform well. It also has the useful ability to fix atmospheric nitrogen through its root nodules and it grows well in poor soils with more than 85% sand and with less than 0.02% organic matter and low levels of phosphorus. It is called 'ewa' in Yoruba, 'wake' in Hausa, and 'alasande' in Hindi. It is one the many staple crops in North-Eastern Nigeria.

Locus bean (*parkia fillicaidea*) is a savannah land tree crop whose seed is processed into local condiment 'iru', 'dadawa' or 'ogili', in the Western, Northern and Eastern Nigeria, respectively. The locust bean fruit consist of bunches of pods which form the edible part of the plant. The brownish-black seeds in each pod are edible, and contain a high percent of sucrose. After the shelling of the pod by cracking and tearing, the peel is washed off and the seed dried. The seed coat is tightly attached to the cotyledon that it encloses, but it is the cotyledon or kernel that is processed into local condiment. As a result the seed is normally dehulled to remove the coat.

Sesame is a flowering plant in the genus *sesamum* with numerous wild relatives occuring in Africa and a small number in India. It is widely naturalized in tropical regions around the world and is cultivated for its edible seeds which grow in pods. Sesame seed is considered to be the oldest oilseed crop known to man and the crop is drought-tolerant. It is called survivor crop which is an indication of its ability to grow where most crops fail. It is a common ingredient in cuisines of many parts of the world. The seeds are small in size.

To get these grains and seeds processed into food requires the subjection of them to thermal operations. Such operations require knowledge of the thermal properties of the crops in order to produce good quality products. One of the important thermal properties needed is the specific heat. Many investigators have studied the specific heat of agricultural grains and seeds. Aviara *et al.* (2011) reported that the specific heat of soya bean variety TGX 1440 – 1E, moringa oleifera seed, moringa oleifera kernel and mucuna flagellipes nut were evaluated and their variations with moisture content and temperature investigated using the method of mixtures. The specific heat increased with increase in moisture content. 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. The specific heat of lentil was determined using differential scanning calorimeter (Tang *et al*., 1991) and reported to range from 0.81 to 2.2 KJ/kg K, and that the specific heat increased quadratically with moisture content over the range from 2.1 to 25.8% but linearly with temperature varying from 10 to 80^{o}C. They also stated that the classical compartment model was modified to accommodate the variation of specific heat with temperature and moisture content.

Singh and Goswami (2000) reported that the specific heat of cumin seed increased with increase in temperature in the range of -70 to 50^{o}C and moisture content from 1.8 to 20.5% (db). The specific heat of minor millet grains and flours increased from 1.33 to 2.40 KJ/kg^{o}C with moisture content in the range of 10 to 30% as reported by Subramanian and Viswanathan (2003). While the specific heat of four varieties of Iranian pistachio nut as affected by moisture content and temperature was studied by Razavi and Taghizadeh (2007).

Aviara and Haque (2001) determined the specific heat of shea-nut kernel as a function of moisture content and temperature, and reported that the specific heat of the kernel lies between 1792 and 3172 J/kg K at four moisture levels in the range of 3.32-20.70% (db) and five temperature ranges 303-363K, 303.4-333K, 303-343K, 305-353K and 306.5-363K. Ogunjimi *et al.* (2001) reported that at the moisture level of 10.25% (db) the specific heat of locust bean was 1415.3 J/kgK. The specific heat of banana ranged from 1574.0 - 2506.8J/kg^{o}C in the moisture range of 18.5-50.0% (Bart–Plange *et al.*, 2012).

The most common method used in determining the specific heat of agricultural and food products is the method of mixtures. This method has been used by such researchers as Aghbashlo *et al.* (2008) for berberis fruits, Aviara and Haque (2001) for shea nut kernel, Tansakul and Lumyong (2008) for straw mushroom and Aviara *et al.* (2008) for guna seeds. It has also been noted that the specific heat of food products according to Tansakul and Lumyong (2008) is a function of the moisture content in the product.

The main aim of this study was to determine the moisture dependence of the specific heat of several cereal grains and legumes grown in North eastern Nigeria.

2. Materials and method

The cereals (maize, rice, millet and sorghum), and legumes (groundnut, sesame, locus bean and cowpea) used in this study were obtained from Monday Market in Maiduguri, Borno State, Nigeria. The seeds were cleaned and sorted so that foreign matter, broken and immature seeds were removed. The moisture contents were determined using the method described by Aviara *et al.* (1999), which involved drying samples in a laboratory oven set at 105^{o}C for 4 hours. During this drying process, the weight of sample was recorded at interval of 1 hr until there was no change in weight of samples. Finally the moisture content was calculated on wet basis using the following equation.

$$MC = \frac{W_i - W_f}{W_i} \quad (1)$$

where:

MC = Moisture content, (%), W_i = initial mass of sample, (g), W_f = final mass of sample, (g).

To determine the specific heat of each crop sample, four moisture levels were used. The samples at desired moisture levels were prepared by conditioning them using the method of Ezeike, (1986) as described by Aviara *et al.*, (2003). This involved the soaking of sample in clean water for a period of 30, 90, 120, and 180 min, respectively. This was followed by spreading the sample out in thin layer to dry in natural air for eight hours. After this, the samples were sealed in polythene bags and stored in that condition for a period of 24 hrs. This is to allow stable and uniform moisture content of the sample to be achieved.

The specific heat of samples was determined using a copper calorimeter placed inside a flask in the method of mixtures as described by Ogunjimi *et al.* (2002). A sample of known weight and temperature was poured into the calorimeter containing water of known weight and temperature. The mixture was stirred with a copper stirrer until equilibrium was attained. The final temperature was noted and the specific heat of the sample crops was calculated using the equation.

$$C_S = \frac{(M_c C_c + M_w C_w)(T_w - T_e)}{M_s (T_e - T_s)} \qquad (2)$$

where:

C_s = specific heat of sample (J/kgK), M_c = mass of calorimeter (kg), C_c = specific heat of calorimeter (J/kgK), M_w = mass of water (kg), C_w = specific heat of water (J/kgK), T_w = temperature of water (K), T_e = equilibrium temperature of water-sample mixture (K), M_s = mass of sample (kg) and T_s = temperature of sample (K).

In this method, the following assumptions were made:

a. Heat loss as a result of transfer of product from the heating chamber to the calorimeter is negligible.

b. Loss due to evaporation during equilibration period is negligible.

Measurements were replicated three times at each moisture level for the different crops. Sample temperatures used were 50, 60, 70 and 80^{o}C respectively. The water temperature was the room temperature. The relationship existing between specific heat with moisture content and temperature was expressed using regression equations. Also the variations of specific heat with moisture content at different temperatures were plotted.

3. Results and discussion

The initial moisture content of maize, rice, sorghum and millet was found to be 1.96%, 2.79%, 2.89%, 2.27%, respectively, and for groundnut, cowpea, locus bean and sesame it was found to be 1.57%, 2.38%, 1.80%, 2.37% all in wet basis. The other moisture levels obtained after conditioning the samples were for maize (6.60%, 12.99% and15.89%), rice (9.72%, 11.47% and 13.58%), sorghum (12.37%, 16.36% and 25.42%) and millet (9.79%, 13.75% and 23.55%). For groundnut, they were (15.04%, 24.61%, 29.02%), cowpea (5.896%, 15.44%, 30.70%), locust bean (5.36%, 9.79%, 12.20%) and (5.15%, 10.43%, 21.50%) for sesame respectively.

The specific heat of the cereal and legume crops increased with increase in moisture level. The specific heat of maize, rice, sorghum, millet, groundnut, cowpea, and locust bean and sesame seeds were as follows:

For maize, the specific heat ranged from 1689.1 – 3404.8J/kgK at 50^{o}C, 1420.7 – 3224.7J/kgK at 60^{o}C, 1130.7 – 3224.7J/kgK at 70^{o}C and 1209.3 – 3224.7J/kgK at 80^{o}C, increasing as the moisture content increased in the range of 1.96 – 15.89%. The trend of specific heat of maize with moisture content at the different initial temperature of the grain is presented in Figure 1. From this figure, it can be seen that the specific heat of the grain increased linearly with moisture content and decreased with increase in temperature.

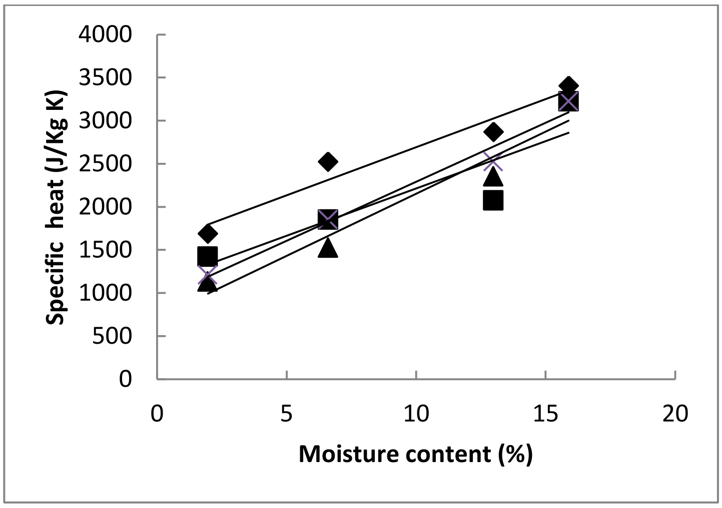

Figure 1: Variation of specific heat of maize grains with moisture content at different temperature, -♦-50°C, -■-60°C, -x-70°C, -▲-80°C

The relationships existing between the specific heat of maize grain and its moisture content at different temperatures can be expressed with the following equations

50°C: $Cs = 111.5M + 1577$, $R^2 = 0.946$ (3)

60°C: $Cs = 109.6M + 1116$, $R^2 = 0.797$ (4)

70°C: $Cs = 143.9M + 711.4$, $R^2 = 0.946$ (5)

80°C: $Cs = 136.6M + 923.0$, $R^2 = 0.978$ (6)

The specific heat of rice was found to range from 1527.5-2870.3 J/kgK at 50°C, 1511.6-2523.7 J/kgK at 60°C, 1367.5-2353.1 J/kgK at 70°C and 1335.7-2661.4 J/kgK at 80°C as the moisture content increased from 2.79 to 13.58%. The variation of the specific heat of rice with moisture content presented in Figure 2 shows that in the studied temperature range, the specific heat of the grains had polynomial of the second order relationship with moisture content. The relationship can be expressed with the following equations

50°C: $Cs = 13.91M^2 - 103.3M + 1707$, $R^2 = 1.000$ (7)

60°C: $Cs = 15.27M^2 - 155.3M + 1825$, $R^2 = 0.998$ (8)

70°C: $Cs = 10.87M^2 - 85.01M + 1517$, $R^2 = 0.994$ (9)

80°C: $Cs= 12.10M^2 - 113.8M + 1556$, $R^2 = 0.987$ (10)

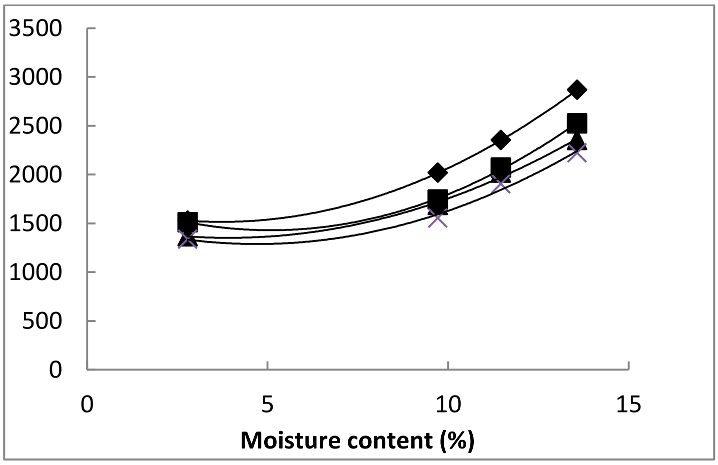

Figure 2: Variation of specific heat of rice grains with moisture content at different temperature, -♦-50°C, -■-60°C, -▲-70°C, -x-80°C

Similar trend of specific heat with moisture content was exhibited by mucuna flagellipes (Aviara et al., 2011).

Similar results were obtained for sorghum at 50°C (1689-3224.7J/kgK), 60°C (1314.6-2073J/kgK), 70°C (1288.2-3046.5J/kgK) and at 80 °C (1272.4-3224.7J/kgK) with moisture content increasing from 2.89%-25.42%. The trend of specific heat with moisture content is shown in Figure 3 for sorghum grains. This figure shows that the specific heat of the grain increased linearly with moisture and decreased with increase in temperature. The relationship existing between the specific heat of sorghum grains and moisture content can be represented by the following equations:

50°C: $C_s = 67.36M + 1487$, $R^2 = 0.994$ (11)

60°C: $C_s = 91.42M + 833.3$, $R^2 = 0.892$ (12)

70°C: $C_s = 81.76M + 887.8$, $R^2 = 0.903$ (13)

80°C: $C_s = 34.13M + 1124$, $R^2 = 0.902$ (14)

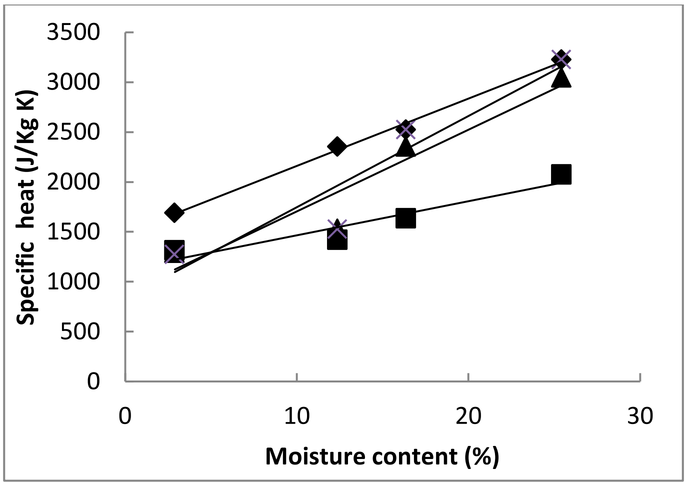

Figure 3: Variation of specific heat of sorghum grains with moisture content at different temperature, -♦-50°C, -▲-60°C, -x-70°C, -■-80°C

The specific heat of millet ranged from 1689-3586.9J/kgK at 50°C, 1209.3-2073J/kgK at 60°C, at 70°C, it ranged from 1699-3224J/kgK and at 80°C, it was from 1209.3-3224.7J/kgK as the moisture content increased from 2.27-23.55%. Figure 4 shows that the specific heat of millet grains increased linearly with moisture and decreased with increase in temperature. The specific heat-moisture content relationship of the grain can be expressed using the following equations:

50°C: $C_s = 91.25M + 1542$, $R^2 = 0.959$ (15)

60°C: $C_s = 74.27M + 1457$, $R^2 = 0.970$ (16)

70°C: $C_s = 41.86M + 1014$, $R^2 = 0.929$ (17)

80°C: $C_s = 96.86M + 1009$, $R^2 = 0.976$ (18)

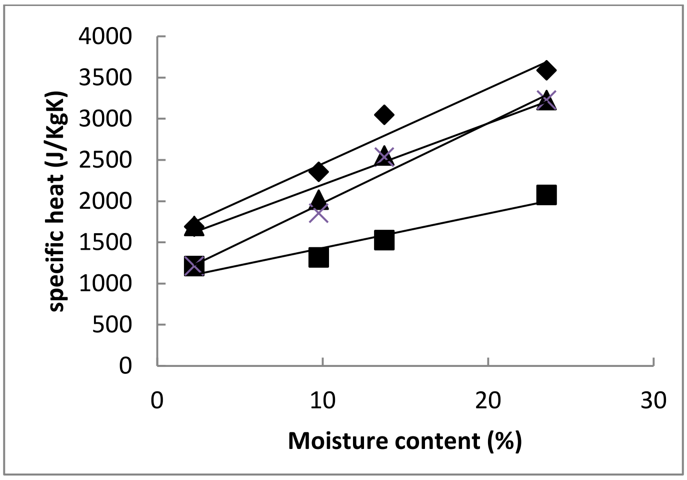

Figure 4: Variation of specific heat of millet grains with moisture content at different temperature, -♦-50°C, -▲-60°C, -x-70°C, -■-80°C

Also the specific heat of groundnut was obtained at 50°C (1689-3404J/kgK), 60°C (1583-2638.4J/kgK), 70°C (1570.8-2870J/kgK) and 80°C (1892.7-3157.5J/kgK) showing linear increase with moisture content (Figure 5) in the moisture range of 1.57%-29.02%. The specific heat-moisture content relationships of groundnut can be represented by the following equations:

50°C: $Cs = 41.35M + 1832$, $R^2 = 0.931$ (19)

60°C: $Cs = 61.23M + 1590$, $R^2 = 0.997$ (20)

70°C: $Cs = 42.95M + 1553$, $R^2 = 0.930$ (21)

80°C: $Cs = 37.66M + 1514$, $R^2 = 0.996$ (22)

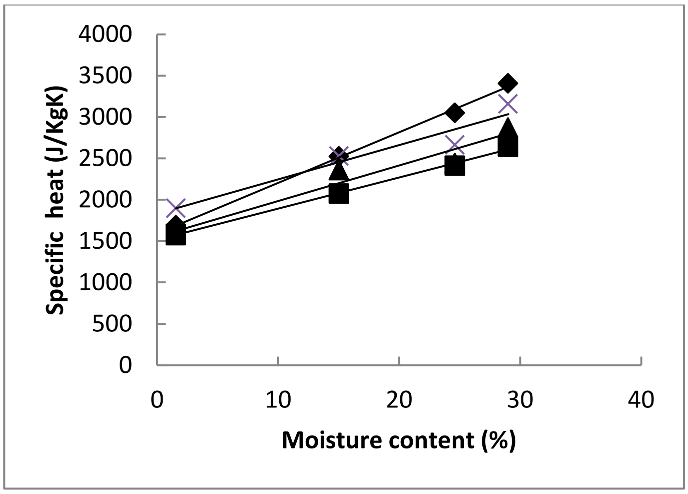

Figure 5: Variation of specific heat of groundnuts with moisture content at different temperature, -♦-50°C, -x-60°C, -▲-70°C, -■-80°C

For cowpea, the specific heat ranged from 1852.5-3587J/kgK at 50°C, 1743.4-3224.7J/kgK at 60°C, 1130.7-2523.7J/kgK at 70°C and 1656.6-3224.7J/kgK at 80°C in the moisture range of 2.38-30.70%. The variation of specific heat with moisture content is shown in Figure 6. The figure shows that the specific heat of cowpea increased linearly with moisture and decreased with increase in temperature. The relationship existing between the specific heat and moisture content can be expressed with the following equations:

50°C: $Cs = 51.00M + 1596$, $R^2 = 0.975$ (23)

60°C: $Cs = 55.90M + 1553$, $R^2 = 0.989$ (24)

70°C: $Cs = 50.37M + 1158$, $R^2 = 0.838$ (25)

80^oC: Cs = 32.81M + 1729, $R^2 = 0.821$ (26)

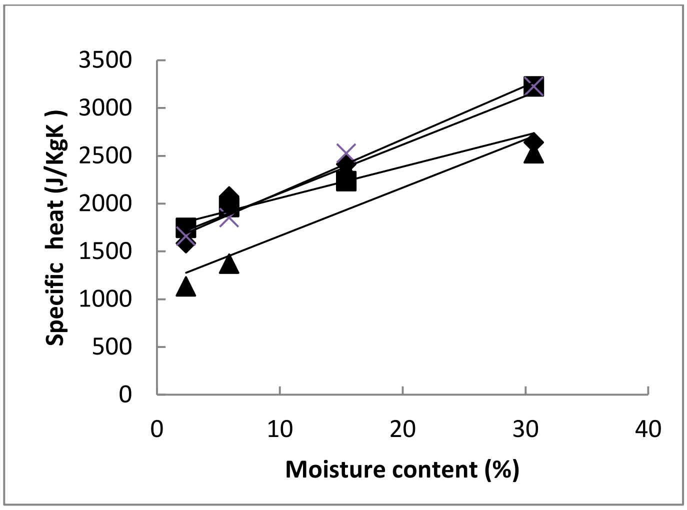

Figure 6: Variation of specific heat of cowpea with moisture content at different temperature, -■-50^oC, -x-60^oC, -♦-70^oC, -▲-80^oC

The specific heat of sesame seed at 50^oC ranged from 1689-3422.9J/kgK, 60^oC (1209.3-3833.1J/kgK), 70^oC (1608.1-3864.1J/kgK) and 80^oC (1463.3-3224.7J/kgK) in the moisture range of 2.37-21.5%. The trend of specific heat with the moisture content of sesame seed is presented in Figure 7. The figure shows that specific heat increased linearly with moisture content and decreased with increase in temperature. The relationship existing between specific heat and moisture content can be represented with the following equations:

50^oC: Cs = 114.7M + 1634, $R^2 = 0.855$ (27)

60^oC: Cs = 131.3M + 1261, $R^2 = 0.870$ (28)

70^oC: Cs = 83.22M + 1807, $R^2 = 0.840$ (29)

80^oC: Cs = 89.96M + 1379, $R^2 = 0.962$ (30)

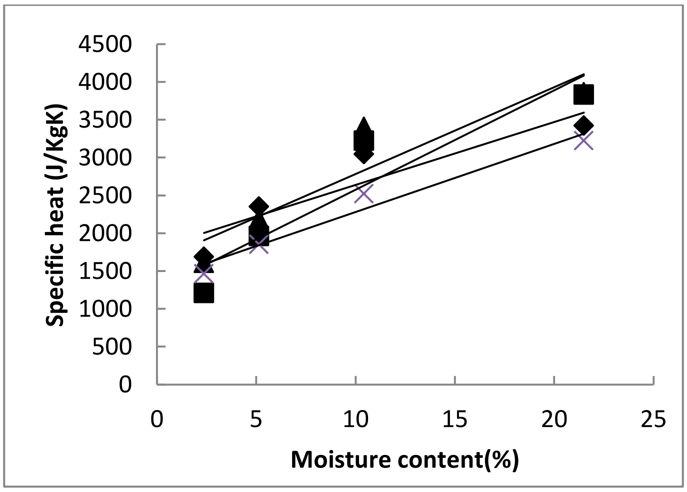

Figure 7: Variation of specific heat of sesame seed with moisture content at different temperature,
-▲-50^oC, -■-60^oC, -♦-70^oC, -x-80^oC

The specific heat of locust bean at 50^oC ranged from 2523.7-3587J/kgK, 1743.4-3224.7J/kgK at 60^oC, 1689-3224.7 J/kgK at 70^oC and at 80^oC, 959.4-3224.7J/kgK with increase in moisture range of 1.80-12.20%.The variation of specific heat with moisture content for locust bean is presented in Figure 8. This figure shows that the specific heat increased linearly with moisture content and decreased with increase in temperature. The relationship existing between specific heat and moisture content can be expressed using the following equations:

50^oC: Cs = 124.4M + 1424, $R^2 = 0.833$ (31)

60^oC: Cs = 102.2M + 2264, $R^2 = 0.969$ (32)

70^oC: Cs = 129.6M + 1351, $R^2 = 0.837$ (33)

80^oC: Cs = 199.7M + 351.1, $R^2 = 0.842$ (34)

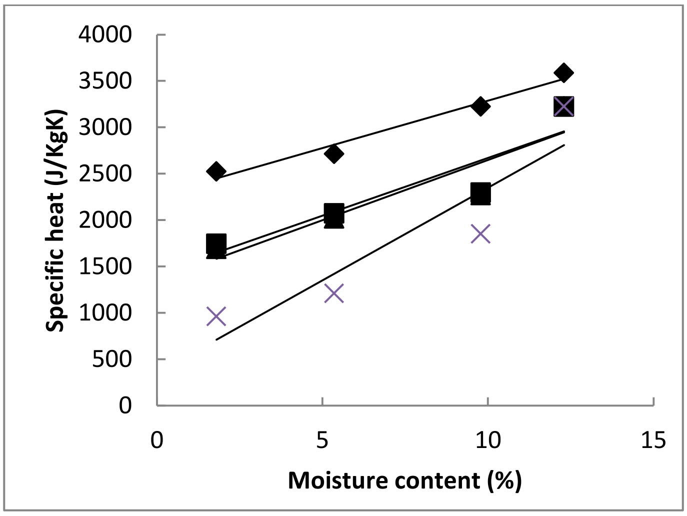

Figure 8: Variation of specific heat of locust bean with moisture content at different temperature, -♦-50^oC, -■-60^oC, -▲-70^oC, -x-80^oC

The increase of specific heat linearly with increase in moisture content at each temperature studied was similar to the results reported for gram (Dutta et al., 1988), shea nut kernel (Aviara and Haque, 2001), guna seed (Aviara et al., 2008), soya bean (Deshpande and Bal, 1999), cumin seed (Singh and Goswami, 2000) and moringa oleifera seed (Aviara et al., 2011).

Conclusions

The specific heat increased with increase in moisture content and decreased with increase in temperature in ranges of 1.96-15.89%, 1.79-13.58%, 2.38-30.70%, 1.80-12.20% and 2.37-21.5% and $50\text{-}80^oC$, respectively for maize, rice, millet, sorghum, groundnut, cowpea, locus bean and sesame. The specific heat for maize increased from 1689.1 – 3224.7J/kgK as moisture content increased from1.96 – 15.89%, for rice, specific heat increased from 1527.5-3224.7 J/kgK as moisture content increased from 2.79 – 13.58%. For millet, the specific heat increased from 1689-3224.7 J/kgK as moisture content increased from 2.27 – 23.55%, and for sorghum, the specific heat increased from 1689-3224.7 J/kgK as moisture content increased from 2.89 – 25.42%. For Groundnut, the specific heat increased from 1689 – 3157.5J/KgK as moisture content increased from 1.57 – 29.02%, and for cowpea, the specific heat increased from heat increased from 1852.5 – 3224.7J/KgK as moisture content increased from 2.38 – 30.70%. For locust bean, the specific heat increased from 2523.7 – 3224.7J/KgK as moisture content increased from 1.80 – 12.20%, and the specific heat of sesame increased from 1689 – 3224.7J/KgK as moisture content increased from 2.37 – 21.5%.

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