Effect of physical properties on the specific heat preserved ground sheanut kernel *(BUTYROSPERNUMPARADOXUM)*

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Abstract: Most agricultural materials undergo various forms of preservation in order to enhance shelf life. Sheanut is usually preserved by heating the kernels over fire in a pot for a time period. This affects its properties especially during heat processing. It is expected that this work will provide information that would help optimize such processing. Preserved sheanut kernel samples sourced locally were prepared by manually cleaning, sorting, grinding and sieving to obtain desired particle sizes. The specific heat of the samples were evaluated as a function of particle size (2.36 mm), (1.18 mm and 1.00 mm), moisture content (initial moisture content, 10%, 20%, 30% and 40% db) and temperature (50oC, 60oC, 70oC, 80oC, and 90oC). The specific heat of each particle size increased with increase in moisture content and varied with temperature with values in the range of 2674 to 4114.67, 1952.08 to 4401.82, and 2429.05 to 4343.87 J/kgoC for P1, P2 and P3 respectively. It was observed that the effect of moisture content was greater than both particle size and temperature. The relationships that existed between specific heat and the observed variables were best described by trinomial model equations with attendant (R2) values. Application of these equations will aid in predicting the specific heat of ground preserved sheanut samples as a function of the observed variables.

Keywords: specific heat, particle size, moisture content, temperature, sheanut

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1 Introduction

Vitellaraparadoxa, the Shea butter tree, grows throughout Sahelian Africa, from Senegal to Ethiopia. The trees are multi-purpose and are highly valued not only for the economic and dietary value of the cooking oil, but also for the fruit pulp, bark, roots and leaves, which are used in traditional medicines, for the wood and charcoal as cooking fuel, and also for building. Shea nut (*vitellariaparadoxa*) is of a botanical family *sapoteceae* and has a botanical name *Butryospermumparkli* with other names such as Karite (French), Nku(Ghana) and Ese (Yoruba). European explorers first recorded Shea in the early 18th century and by the 1920s, a flourishing trade was developing between West Africa and Europe. The oldest known botanical specimen of *Vitellaria*was apparently collected by Mungo Park, and is currently held in the Natural History Museum in London (Hallet al, 1996). The shea-butter grows everywhere in West and West-Central Africa, where the oil palm does not. In Northern Nigeria especially, it flourishes over large areas. It has fleshy fruits which grow in bunches, are ovoid in shape like an avocado with deep green or brown colour. The sweet pulp is edible and inside the fruit is a nut surrounded by a thin shell containing a hard kernel and a whitish almond-like nut that contains fat equal to about 50% of its weight, called shea butter. Despite its various uses, there is no known plantation of sheanut and little information is available on the existence of commercial plants for the purpose of processing the oil (Oluwole, 2004).

When shea fruits are harvested, they undergo traditional methods of extraction mostly performed by

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women and children (Adgidziet al. 2003). These traditional methods comprise activities such as collection and cleaning of nuts by removal of unwanted materials which include stones, grass and dirt. They are usually eaten to de-pulp them and the resulting nuts are boiled and then cracked to give the kernels. These kernels are sun dried to a safe storage moisture content of about 10%-15% before oil extraction (Wiemer and Korthals, 1989).

Researchers have investigated specific heat as a function of process conditions and physico-chemical properties of the biomaterials and their findings are reported in literature. The specific heat of rice bran in the moisture and temperature ranges of 4.3%-18% and 38 ℃-63 ℃ respectively was reported by Sreenarayanan and Chattopadhyay, (1986), while the specific heat of cumin seed was observed to increase with increase in temperature from -70 ℃ to 50 ℃ and moisture content from 1.8%-20.5% (d.b) as reported by Singh and Goswami (2000). The specific heat of minor millet grains and flours increased from 1.33 to 2.40 kJ/kg ℃ with moisture content in the range of 10%-30% (w.b) as reported by Subramanian and Viswana than (2003). Opokuet al., (2006) using the method of indirect mixtures studied the specific heat of timothy hay, while the specific heat of four varieties of Iranian pistachio nuts as affected by moisture content and temperature was studied by Razavi and Taghizadeh (2007.)

Aviara and Haque (2001) while investigating the moisture dependent thermal properties of sheanut kernels reported thatits specific heat, 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). Aremu and Nwannewuihe (2011) reported that the specific heat of ground fresh sheanut kernels were 2679.75 to 4230.17, 1952.08 to 4401.82 and 1716.84 to 4353.03 J/kg^{o}Cfor selected particle sizes of 1.00 mm, 1.18 mm and 2.36 mm. This study was aimed at determining the specific heat of ground preserved sheanut kernels for the same particle size range. With the challenge of deforestation and due to the seasonal nature of sheanut, it is usually roasted over fire to preserve it. Hence it is expected that the results of this research would provide information on the effects of this method of preservation on the specific heat of the crop. It is also expected to help in the design of process equipment and process optimization especially during the extraction of its oil (shea butter) since sheanut undergoes a lot of heat processing in its ground form.

2 Materials and methods

2.1 Sample preparation

The shea kernels were obtained locally from Doko village in Lavun L.G.A Niger state, Nigeria. The samples, already roasted for preservation using local methods were cleaned to remove dust, particles and other unwanted debris. Sorting was done to separate broken kernels from whole kernels which were selected for the experiment. The selected kernels were ground and sieved to get the desired particle sizes 2.36 mm (P_1), 1.18 mm (P_2) and 1.00 mm (P_3) respectively. See Figure 1 please.

P_1

P_2 P_3

Figure 1 Particle sizes of sample.

(Source; Nwannewuihe, 2010)

2.2 Moisture content determination

The hot air oven method (AOAC, 2002) was used to determine the moisture content of the samples. Thirty g of the sample was placed in a container of known weight and dried in an oven at 105°C to constant weight. The moisture content in % dry basis was found by applying Equation 1 below as reported by Bup et al 2008.

$$M_c(\%db) = \left(\frac{M_i - M_f}{M_f}\right) x100\% \quad (1)$$

Where M_c is the moisture content, M_i is the initial mass of sample and container (g),$M_f$is the final mass of sample and container (g) at constant weight. This was replicated six times and the average value taken as the initial moisture content of the samples. The initial moisture content of the samples was 3.26% (db). The ground samples were conditioned to 10%, 20%, 30% and 40% (db) by adding 7.5, 20.9, 38.2 and 54.5 g of water Q as calculated from the following Equation 2 to 100 g of sample:

$$Q = A(b - a)/ (100 - b) \quad (2)$$

Where:

A = the initial mass of the sample in g

a =the initial moisture content of sample (% dry basis)

b = is the desired or final moisture content of the sample (Balasubramanian, 2001).

2.3 Determination of specific heat of ground sheanutkernel

The most common technique for measuring the specific heat of biomaterials from literature is the method of mixtures as reported by Mohsenin (1980) and Tabil (1999). The specific heat of the samples was determined with the aid of a calibrated copper calorimeter placed inside a flask, using the method of mixtures. The calorimeter was calibrated by pouring a measured quantity of cold water, $\boldsymbol{M_{cw}}$, into it. The temperature of the cold water was allowed to stabilize at $\boldsymbol{Tc}$**,** and a measured quantity of hot water $\boldsymbol{M_{hw}}$ at a known temperature $\boldsymbol{T_h}$, was added. The equilibrium temperature $\boldsymbol{T_e}$ of the mixture of hot and cold water was recorded. The respective quantities of hot and cold water were adjusted until a final temperature of the mixture that is close to the room temperature was obtained. The equation for the heat capacity $\boldsymbol{C}$ of the calorimeter was obtained from the energy balance as shown as Equation 3 below (Aviara and Haque, 2001; Razavi and Taghizadeh, 2007)

$$C = \frac{M_{hw}C_w(T_h - T_e)}{(T_e - T_c)} - M_{cw}C_w \quad (3)$$

Where $\boldsymbol{C}$ is specific heat of the calorimeter (J/kg°C), $\boldsymbol{M_{cw}}$ is the mass of cold water (g), $\boldsymbol{C_w}$is the specific heat of water (J/kg°C), $\boldsymbol{M_{hw}}$is the mass of hot water (g), $\boldsymbol{T_h}$ is the temperature of hot water (°C), $\boldsymbol{T_e}$is the equilibrium temperature while $\boldsymbol{T_c}$ is the temperature of cold water (°C). The calibration was replicated five times while adjusting the quantities of hot and cold water. The average value of the specific heat of the calorimeter was found to be 395.2 J/kg°C with standard deviation of 5.14 J/kg°C.

The specific heats of the samples were obtained by adding a sample of known weight, temperature and moisture content was into the calorimeter containing water of known weight and temperature. The mixture was stirred continuously with the aid of a copper stirrer. The temperature was recorded at an interval of 10s using a K-type thermocouple. At equilibrium, the final temperature was noted and the specific heat was calculated using Equation 4 (Aviara and Haque, 2001).

$$C_s = \frac{(M_cC_c + M_wC_w)[T_w - (T_e + t'R')]}{M_s[(T_e + t'R') - T_s]} \quad (4)$$

Where C_s= Specific heat of sample (J/kg °C); M_c= Mass of calorimeter (kg); C_c= Specific heat of calorimeter (J/kg °C); M_s= Mass of sample (kg); M_w= Mass of water (kg); C_w= Specific heat of water (J/kg °C); T_w, $T_s$andT_e = temperatures of water, sample and at equilibrium respectively.

$R'$is the rate of temperature fall of the mixture after equilibrium (°C) and t' is the time taken for the sample and water mixture to come to equilibrium (s). The term $t'R'$ accounts for the heat of hydration and heat exchange with the surroundings. The experiment was repeated 3 times at each moisture level, and the average values of specific heat are reported.

3 Results and discussion

Table 1, Table 2 and Table 3 below give the full results of the experiments. They showed the values obtained experimentally for the specified moisture content and temperature ranges. The analysis of variance (ANOVA) was performed on the results to get a better understanding of the effect of the variables on specific heat of the samples. The result of this analysis showed that the influence of these variables on the specific heat of preserved ground sheanut was significant.

Table 1 Specific heat values of P_1(2.36 mm) at temperatures range 50°C – 90°C and moisture content 3.26% - 40% d.b.

Temp.,°C	Moisture content,% d.b.				
	3.26	10	20	30	40
	Specific heat, J/kg °C				
50	2914.47	2927.20	3722.76	3100.59	4114.67
60	2674.53	3340.95	3226.87	3283.22	3579.76
70	3230.98	3209.00	3412.81	3314.21	3847.72
80	2715.62	2847.27	3480.78	3566.50	4014.27
90	3446.39	3783.93	3392.04	3585.95	4007.75

Note: Source; Nwannewuihe, 2010

Table 2 Specific heat values of P_2(1.18 mm) at temperatures range 50°C – 90°C and moisture content 3.26%- 40% d.b.

Temp.,°C	Moisture content, % d.b				
	3.26	10	20	30	40
	Specific Heat, J/kg °C				
50	1952.08	3613.43	3740.86	3943.29	4056.35
60	2021.26	3442.28	3826.37	3650.99	3863.84
70	2545.14	3530.96	3692.41	3882.36	4189.82
80	2636.14	3555.07	3654.73	4129.45	4156.26
90	2944.72	3251.35	3774.34	4151.56	4401.82

Note: Source; Nwannewuihe, 2010

Table 3 Specific heat values of P_3 (1.00 mm) at temperatures range 50°C – 90°C and moisture content 3.26%- 40% d.b.

Temp.,°C	Moisture content, % d.b				
	3.26	10	20	30	40
	Specific heat, J/kg °C				
50	2429.05	3385.58	3896.47	3957.56	4343.87
60	2704.46	3325.16	3589.20	3735.89	3649.28
70	2765.46	3532.00	3675.24	4102.32	3962.74
80	2718.87	3364.63	3606.61	4214.75	3710.06
90	2836.73	3412.22	3637.23	3969.03	3969.95

Note: Source; Nwannewuihe, 2010

3.1 Effect of moisture content

From the data obtained it was observed that specific heat value increased with increase in moisture content of the samples. For particle size P_1, values of specific heat varied between 2674.53 and 4114.67 J/kg°C with increasing moisture content of the range 5%–40% db. P_2 and P_3 also varied between 1952.08 to 4401.82 and 2429.05 to 4343.87 J/kg°C respectively. This showed lower values at initial moisture content and relatively higher values at other moisture contents. See Figure 2 to Figure 6.

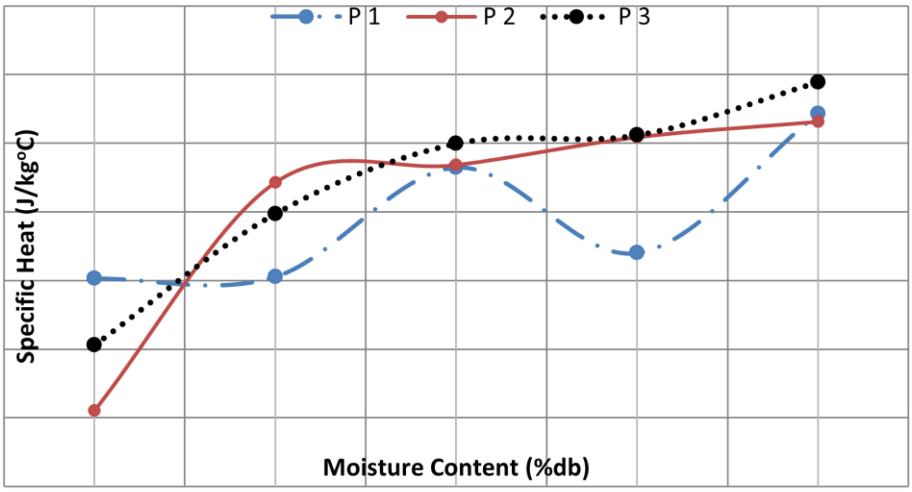

Figure 2 Effect of particle size and moisture content on specific heat of fresh ground sheanut kernel at 50°C.
Source; Nwannewuihe, 2010

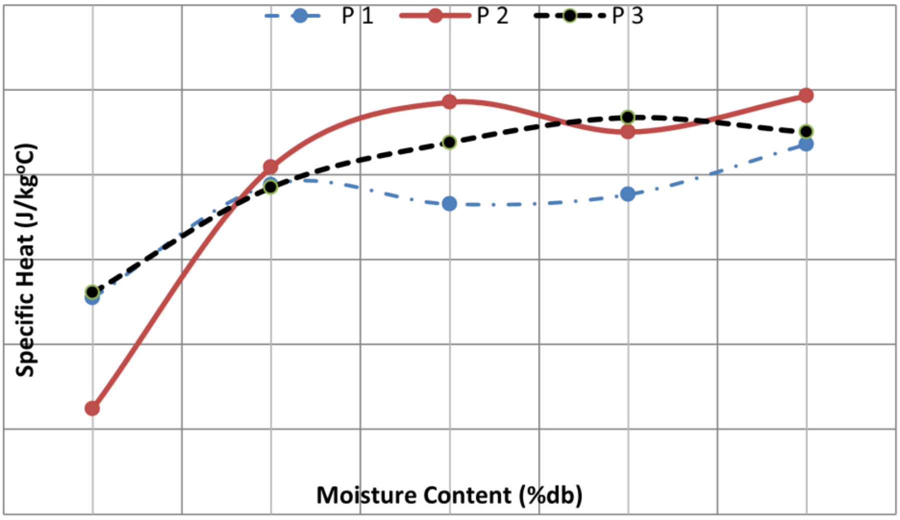

Figure 3 Effect of particle size and moisture content on specific heat of fresh ground sheanut kernel at 60°C.Source; Nwannewuihe, 2010

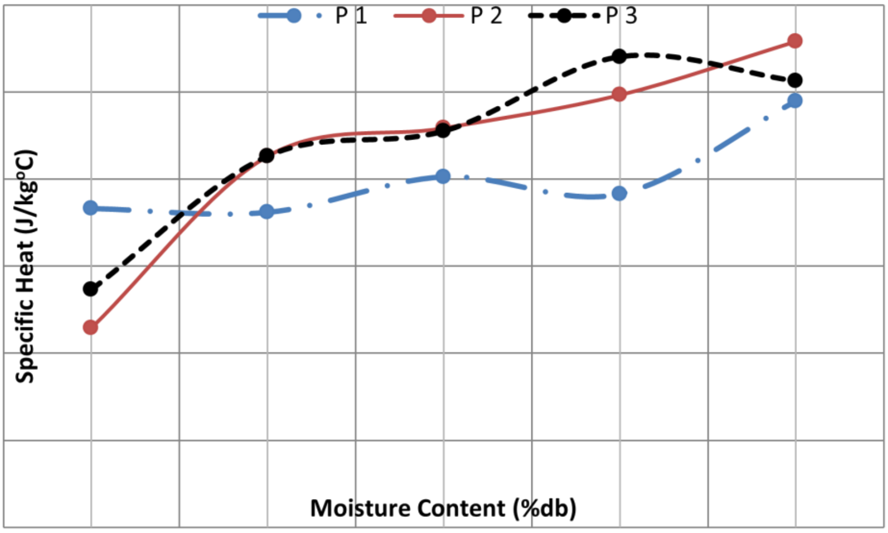

Figure 4 Effect of particle size and moisture content on specific heat of fresh ground sheanut kernel at 70°C. Source; Nwannewuihe, 2010

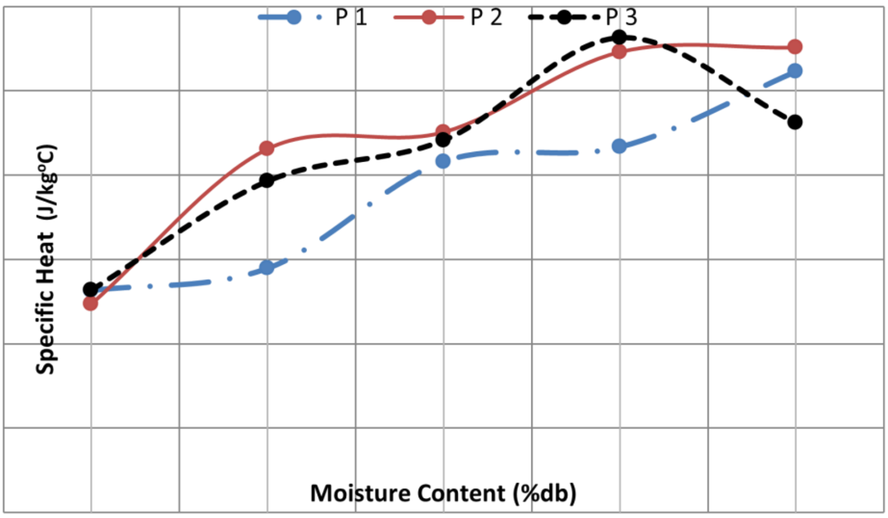

Figure 5 Effect of particle size and moisture content on specific heat of fresh ground sheanut kernel at 80°C. Source; Nwannewuihe, 2010

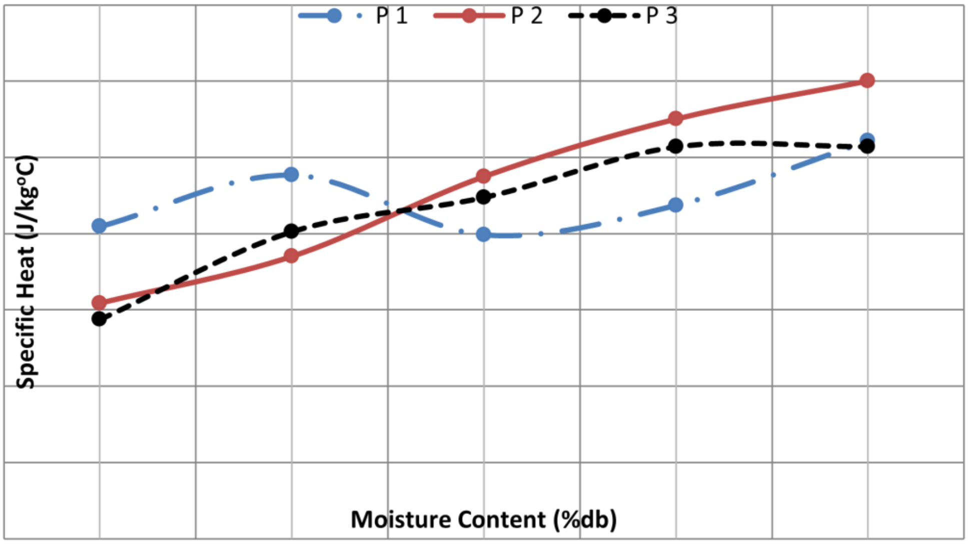

Figure 6 Effect of particle size and moisture content on specific heat of fresh ground sheanut kernel at 90°C.
Source; Nwannewuihe, 2010

The relationship between the specific heat and moisture content for each particle size can be best expressed by the following regression Equations (from Equation 5 to Equation 19):

(50°C)

P_1 $C_s = 2375.27 + 152.82M – 7.74M^2 + 0.12M^3$ $R^2 = 0.897$ (5)

P_2 $C_s = 920.79 + 387.28M – 15.76M^2 + 0.20M^3$ $R^2 = 0.903$ (6)

P_3 $C_s = 1701.44 + 252.998M – 9.67M^2 + 0.13M^3$ $R^2 = 0.955$ (7)

(60°C)

P_1 $C_s = 2229.01 + 172.57M – 8.25M^2 + 0.12M^3$ $R^2 = 0.903$ (8)

P_2 $C_s = 0.21M^3 – 16.14M^2 + 386.57M + 940.78$ $R^2 = 0.896$ (9)

P_3 $C_s = 0.04M^3 – 3.97M^2 + 129.11M + 2342.52$ $R^2 = 0.914$ (10)

(70°C)

P_1 $C_s = 0.05M^3 – 2.50M^2 + 41.43M + 3087.5$ $R^2 = 0.912$ (11)

P_2 $C_s = 0.13M^3 – 9.62M^2 + 235.69M + 1909.82$ $R^2 = 0.936$ (12)

P_3 $C_s = 0.03M^3 – 3.22M^2 + 123.48M + 2448.6$ $R^2 = 0.925$ (13)

(80°C)

P_1 $C_s = 0.01M^3 – 0.74M^2 + 52.59M + 2507.51$ $R^2 = 0.982$ (14)

P_2 $C_s = 0.06M^3 – 5.34M^2 + 164.15M + 2217.09$ $R^2 = 0.938$ (15)

P_3 $C_s = – 0.05M^3 + 1.64M^2 + 48.62M + 2604.43$ $R^2 = 0.903$ (16)

(90°C)

P_1 $C_s = 0.09M^3 – 5.12M^2 + 79.35M + 3285.27$ $R^2 = 0.886$ (17)

P_2 $C_s = – 0.02M^3 + 0.52M^2 + 43.97M + 2790.7$ $R^2 = 0.992$ (18)

P_3 $C_s = 0.02M^3 – 2.45M^2 + 98.48M + 2570.28$ $R^2 = 0.950$ (19)

From the above, it can be observed that a trinomial relationship exists between the specific heat of ground preserved sheanut kernel and moisture content with the above Equations their best fit mathematical models. This was similar to what was reported by Dattaet al., 1988 (gram), Razavi and Taghizadeh (2007) for four varieties of Iranian pistachio nutsAremu and Nwannewuihe (2011) for fresh ground sheanut kernel.

However, researchers such as Singh and Goswami, 2000 (cuming seed), Aviara and Haque 2001 (whole sheanut kernel), Yang et al., 2002 (borage seeds), Subramanian and Viswanathan, 2003 (minor millet grains and flours) showed that linear relationships existed between the specific heat of the crops studied and moisture content.

3.2 Effect of temperature

The results of the values of specific heat of the selected particle sizes at various temperatures are presented in from Figure 7 to Figure 11. It can be observed from the values obtained that the specific heats of the samples increased as temperature increased. It was also observed to decrease with decrease in particle size at storage content (3.26% db). Particle size 1.18 mm (P_2) had the highest specific heat value across the temperature range selected. Though variation with temperature was observed, its effects on specific heat were minimal as values were slightly close to one another for all three-particle sizes. Generally, the specific heats of all the particle sizes were in the range of 1952.08 to 4401.82 J/kg^{o}C. The relationship between the specific heat and temperature was also non-linear and their best fit mathematical models were third order polynomial Equations given in from Equation 20 to Equation 34 below.

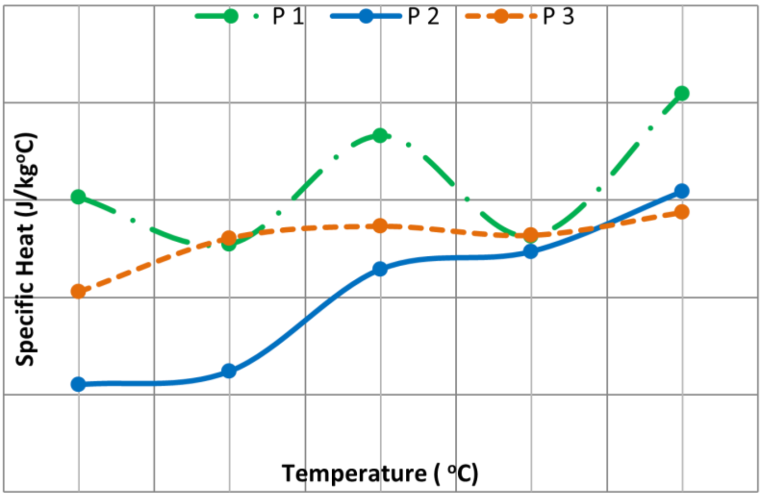

Figure 7 Effect of particle size and temperature on specific heat of ground sheanut kernel samples at initial moisture content. Source; Nwannewuihe, 2010

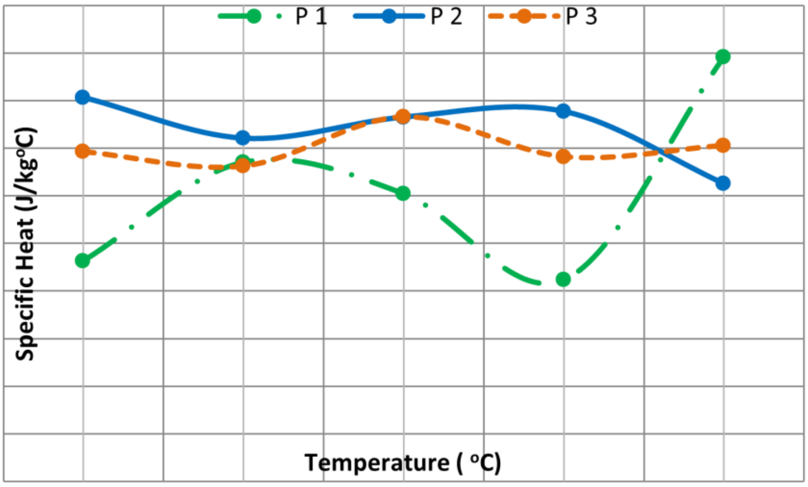

Figure 8 Effect of particle size and temperature on specific heat of ground sheanut kernel samples at 10% moisture content. Source; Nwannewuihe, 2010

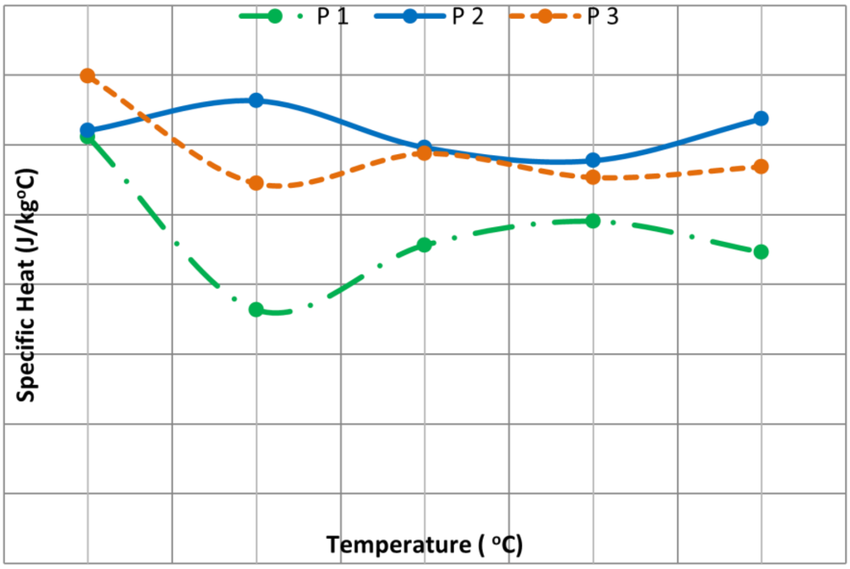

Figure 9 Effect of particle size and temperature on specific heat of ground sheanut kernel samples at 20% moisture content. Source; Nwannewuihe, 2010

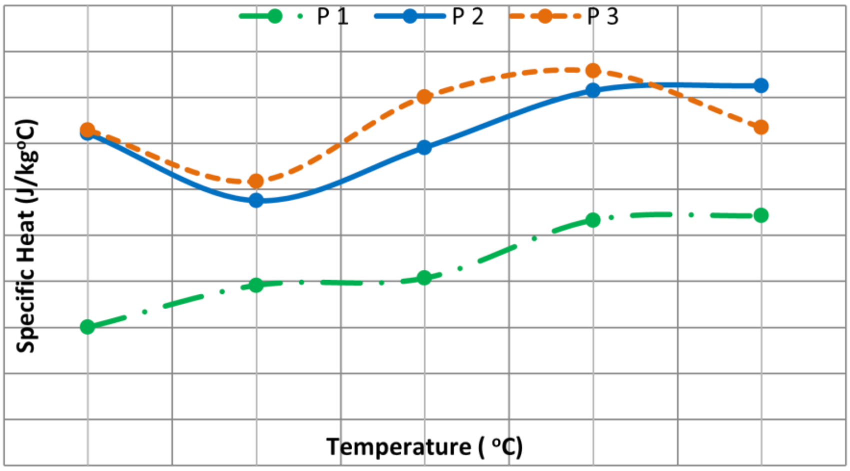

Figure 10 Effect of particle size and temperature on specific heat of ground sheanut kernel samples at 30% moisture content. Source; Nwannewuihe, 2010

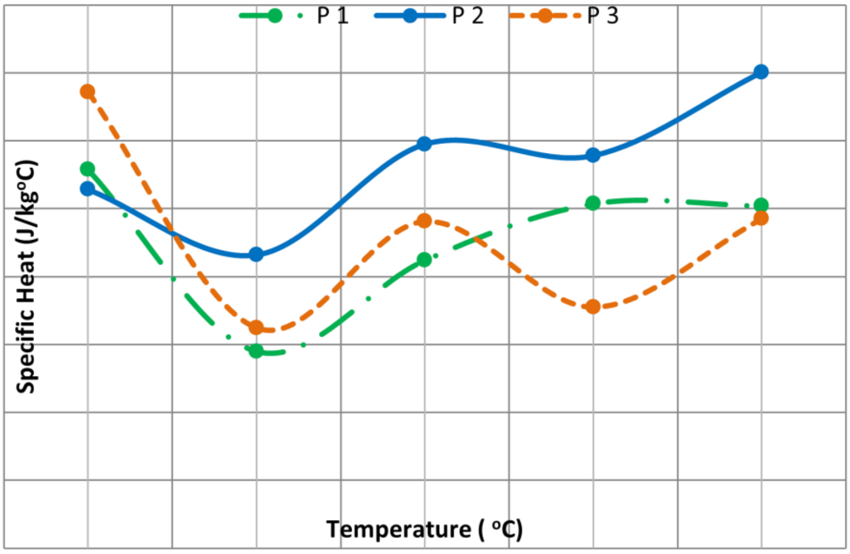

Figure 11 Effect of particle size and temperature on specific heat of ground sheanut kernel samples at 40% moisture content. Source; Nwannewuihe, 2010

The following regression Equations express their relationship where 1-5 represent the moisture content range of 3.26% -40 % db.

P_1 (1) $Cs= 0.04T^3 - 7.25T^2 + 462.28T - 6820.73$ ($R^2 = 0.888$) (20)

P_2 (1) $Cs = -0.02T^3 + 4.18T^2 - 262.34T + 7061.3$ ($R^2 = 0.978$) (21)

P_3 (1) $C_s = 0.32T^3 - 6.93T^2 + 503.94T - 9386.63$ ($R^2 = 0.917$) (22)

P_1 (2) $Cs= 0.15T^3 - 31.69T^2 + 2137.36T - 43945.4$ ($R^2 = 0.889$) (23)

P_2 (2) $Cs= - 0.05T^3 + 10.05T^2 - 676.38T + 18431.5$ ($R^2 = 0.887$) (24)

P_3 (2) $Cs = - 0.004T^3 + 0.80T^2 - 45.84T + 4199.11$ ($R^2 = 0.950$) (25)

P_1 (3) $Cs= -0.07T^3 + 15.17T^2 - 1077.16T + 28375.2$ ($R^2 = 0.912$) (26)

P_2 (3) $Cs= 0.03T^3 - 6.48T^2 + 433.36T - 5658.62$ ($R^2 = 0.936$) (27)

P_3 (3) $Cs = - 0.03T^3 + 5.52T^2 - 409.01T + 13603.1$ ($R^2 = 0.885$) (28)

P_1(4) $Cs = -0.01T^3 + 1.35T^2 - 74.12T + 4299.51$ ($R^2 = 0.974$) (29)

P_2 (4) $Cs= -0.06T^3 + 13.56T^2 - 951.39T + 25402.9$ ($R^2 = 0.888$) (30)

P_3(4) $Cs= - 0.08T^3 + 16.34T^2 - 1097.12T + 27800.7$ ($R^2 = 0.898$) (31)

P_1 (5) $Cs = -0.08T^3 + 17.76T^2 - 1261.21T + 32925.7$ ($R^2 = 0.955$) (32)

P_2 (5) $Cs= -0.02T^3 + 4.56T^2 - 328.27T + 11546.81$ ($R^2 = 0.902$) (33)

P_3 (5) $Cs= - 0.04T^3 + 9.63T^2 - 734.17T + 22098.9$ ($R^2 = 0.905$) (34)

The analysis of variance (ANOVA) done showed that calculated F-values of P_1, P_2 and P_3 were 4.29, 4.45 and 4.51 respectively. This is higher than the tabulated F-value of 2.87 and indicates that at 5% level of significance the observed differences were statistically significant. It was also observed that these calculated F-values increased with increase in particle size.

4 Conclusions

From the above results and analysis it can be concluded that of the three variables investigated (particle size, moisture content and temperature), moisture content had the most direct effect on the specific heat of the preserved ground sheanut kernels. The specific heat increased with increase in moisture content and varied with both particle size and temperature. Particle size P_2 (1.18mm) showed greater variation than P_1 and P_3 and while the effect of temperature was minimal within the range studied. The developed models can be used to estimate the specific heat of preserved ground sheanut kernels satisfactorily under similar conditions.

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