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Investigation of the thermal properties of selected fruits and vegetables

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Abstract
Thermal Properties of different fruits and vegetables such as Orange, Lime, Onion, Okra, Pepper and Tomatoes were investigated. The properties determined were density, moisture content, thermal conductivity, specific heat capacity and thermal diffusivity at varying temperatures 35^{o}C, 45^{o}C and 55^{o}C. The results obtained showed that the thermal conductivity is directly proportional to thermal diffusivity while specific heat capacity was observed to be indirectly proportional to thermal diffusivity. The results were low compared to pure water due to the total solid content of the fruits and vegetables. Hence they are poor conductors of heat, consequently, the heat energy diffusion or transfer through these fruits during drying, refrigeration, freezing and evaporation are likely to be slow.

1. Introduction

Heating and cooling of food is one of the earliest methods of applying science to foods. The primary goal of the food processing industry is to supply the markets (consumers) with safe products. One common means of attaining this, is food preservation by means of thermal processing. The application of heat can induce favorably product changes, deactivate enzymes and kill microorganisms. The result is a product, hopefully of appetizing quality with extended shell-life and safe to consumers. Unfortunately, side effects of product heating involve nutritional and textural losses (Qashou *et. al.*, 1972). Friuts are natures's wonderful gift to mankind, indeed, medicine packed with vitamins, minerals, antioxidants and many phyto-nutrients. They are absolute feast to sight, not just because of their color and flavor but for their unique nutritional values that protect the human body against diseases in order to stat healthy. Vegetables provide an abundant and inexpensive source of energy, body building nutrients, vitamins and minerals. They are an important part of world agricultural food production, even though their production volumes are small compared with grains. As in fruits, vegetables too are home of many antioxidants that, firstly, help protect the human body from oxidant stress, diseases and cancers and secondly; help the body develop the capacity to fight against these by boosting immunity (Studman, 1999). These fruits and vegetables are perishable crops which deteriorate few days after harvest. This is mainly due to their high moisture contents and inability to maintain physiological constancy (Ikegwu and Ekwu, 2009). Therefore, they need special attention to prevent all those losses taking place. Reasonable percentages of harvest usually go into waste annually. As such, this has led to various processing works and practices carried out by researchers with a view to minimizing wastages of these crops (Kordylas, 1990).

Thermal properties of foods are those properties that control the transfer and storage of heat in a particular food (Lozano, 2006). Thermal properties of most fruits and vegetables are significantly influenced by their moisture content and it is also affected by temperature, the chemical composition and physical structure of the fruits and vegetables. Besides processing and preservation, thermal properties also affect the sensory quality of foods as well as energy saving from processing. The thermal properties that are generally considered in this research are density, moisture content, specific heat capacity, thermal conductivity and thermal diffusivity.

Knowledge of these properties is very necessary for modeling, simulation and optimization of process operations which involves heat transfer.

The structure and properties of fruits and vegetables as well as their biological and microbiological characteristics and importance create the need for unique consideration of their thermal properties, hence the need to experimentally determine the thermal properties of fruits and vegetables such as density, moisture content, specific heat capacity, thermal conductivity and diffusivity at various temperatures.

2. Experimental

2.1. Experimental Procedure

2.1.1. Sample collection and Preparation

The fruits and vegetables that were studied in this research include lime, onion, orange, okra, pepper and tomato. All the fruits and vegetables used in this research were undamaged, fresh, mature and ripe. They were purchased from the Orie market in Emene, Enugu State, Nigeria. They were properly adapted (washed and dried).

2.1.2. Methods of Analysis

i) Moisture Content Determination

Oven-dry method was used for the moisture content determination. The electric oven was switched on and allowed to run for 30 minutes at a temperature of 35^0c. The samples were individually weighed and their respective masses were recorded as M_b (mass of the sample before drying). The weighed sample was placed in a sauce pan and was put inside the oven and allowed to dry for 60mins at 35^0c. At the expiration of 60minutes, the sample was recovered from the oven and was re-weighed and recorded as M_a (mass of sample after drying). The moisture loss was determined by subtracting the mass of sample after drying (M_a) from mass of sample before drying (M_b).

$$\text{Moisture loss } (M_L) = M_b - M_a$$

Percentage moisture loss was determined using this equation

$$\text{Moisture loss (ML)\%} = \frac{\text{Mb} - \text{Ma}}{\text{Mb}} \times 100$$

Then, the percentage moisture content at 35^0c was calculated by subtracting the percentage moisture loss from the total percentage moisture content.

$$\%\text{ moisture content } (M_c) = 100\% - M_L\ (\%) \text{ at } 35^0\text{C}.$$

These steps were repeated for the various fruit samples at 45^0C and 55^0C and their respective percentage moisture content was calculated and recorded.

ii) Density Determination

All the samples were weighed using the digital weighing scale and their respective weight were recorded in grams. The volumes of the fruits were determined by displacement method (Archimedes principle). The conical flask was kept inside the bowel and filled to the brim with water using siphon bottle. Then the weighed sample was wholly immersed into the water-filled beaker so as to displace its equivalent volume of water. The displaced volume of water in the bowel was collected and measured using the measuring cylinder.

This procedure was repeated for all the various samples and their corresponding volumes were recorded.

The density of each sample was calculated using the mass – volume ratio by dividing the mass of each sample by its volume.

$$\text{P} = \frac{\text{M}}{\text{V}}$$

Where p = density in g/cm^3

M = mass of sample in grams (g)

V= volume of the sample in Cm^3

iii) Thermal Conductivity Determination

The Apparatus for the test was set up accordingly.

The initial temperature of each of the samples was determined with the aid of the thermo-couple and was recorded as T_1.

The sample was placed in a container and was lowered into a lagged cylindrical container to avoid heat loss due to conduction.

The set – up above was put into a thermo statically controlled oven and (was) powered to the mains.

The maximum operating temperatures was taken as the final temperature, T_2. Where

$T_2 = 35^0$C for thermal conductivity at 35^0C

$T_2 = 45^0$C for thermal conductivity at 45^0C

$T_2 = 55^0$C for thermal conductivity at 55^0C

Therefore the oven was set at these temperatures and controlled with a thermo-couple.

The closed system was allowed to run until it reaches the final time for each of the test

The Quantity of Energy supplied (Q) from the A.C was measured with the aid of a suitable wattmeter connected to the plug of the oven at the mains.

These procedures were repeated for all the samples and data got were recorded for their thermal conductivity determination.

iv) Specific Heat Capacity Determination

The various samples and empty calorimeter were weighed with the aid of the digital weighing scale and their masses were recorded. The mass of the calorimeter and water was also weighed and recorded. The electric oven was switched on and set at 35^0C then the sample was placed in the cylindrical metallic beaker and was put inside the electric oven and left for 60minnutes. 100ml of water was filled in the calorimeter at room temperature. At the elapse of the 60mins, the cylindrical metallic beaker containing the sample was removed from the oven and quickly transferred into the calorimeter. The equilibrium temperature between the sample and water inside the calorimeter was determined and recorded, the mass of the sample at equilibrium temperature was also determined

Then the specific heat capacity (c_p) of the sample was calculated thus:

$$C_p \text{ sample } = \frac{(\text{HC} + \text{M}_{\text{cw}} \text{ Cw})(\text{Te} - \text{ Tcw}) - \text{Hc}(\text{T}_\text{f} - \text{Te})}{\text{Mf } (\text{T}_\text{f} - \text{Te})}$$

Where
HC = Heat capacity of calorimeter
H_c = Heat capacity of cylinder
Mcw = Mass of cold water
Cw = Specific capacity of water
Te = Temperature equilibrium of cold water
Tcw = Temperature of cold water
T_f = Temperature of fruit
M_f = Mass of Fruit

This experiment was also repeated for all the various samples at 45^0C and 55^0C for the same period of time (60mins).

3. Results and Discussion

3.1. Moisture Content

Table 1. *Average Moisture Content of the samples at temperatures of 35^0C, 45^0C and 55^0C*

Sample	Ave. % Moisture C. at 35ºC	Ave. % Moisture C. at 45ºC	Ave. % Moisture C. at 55ºC
Orange	99.70	99.25	98.60
Lime	99.25	97.90	96.40
Onion	99.70	99.60	99.50
Okra	98.30	93.70	88.20
Pepper	100.00	98.10	99.40
Tomato	99.70	99.40	99.40

The table above shows that the moisture content of orange, lime onion, okra, pepper and tomato at 35^0C, 45^0C and 55^0C respectively. The moisture content were observed to be decreasing as the temperature increased. The figures revealed that the percentage moisture content of the fruits examined at these range of temperatures were very high. Knowledge of moisture content of food is important to manufacturers for a variety of reasons, for example, it is an important factor in food quality, preservation and resistance to deterioration (Kaymak, 2002). Moisture content also increases the weight of food hence the food will be affected by additional weight differences in conductivity or quality and on turn affects the storage ability of the food. Consequently, the moisture content of the fruits makes them suitable for spoilage organisms and agents to grow and multiply. Consumption of natural vegetables rich in flavonoids helps to protect lung and oral cavity cancers (Daunthy, 1995). Vegetables on the other hand undergo tremendous chemical changes once separated from the parent plant until finally spoilage sets in as a result of attack from bacteria, yeast and fungi. This problem of storage may arise from the texture of the food, color, flavour, respiratory activities and moisture content. Modification of temperature can be used to increase storage life of the vegetables. High moisture content also contributes to the quality of deterioration and indirectly to a decrease in quantity (Musa-Makama *et. al.*, 2005). Thus the way out of this problem is converting the fresh produce to suitable forms so that the shelf lives can be extended. Therefore all the samples are classified as highly perishable and cannot be preserved or stored at these temperatures for a very long time. In order to preserve these fruits, their moisture content has to be reduced to the level that will make moisture unavailable for microbial growths. Drying is one of such techniques. The effect of temperature and the duration of the drying are essential factors that require intense investigation.(Daunthy, 1995) Other ways of preservation include refrigerating or freezing which require transfer of heat to achieve them.

3.2. Density

Table 2. *Average Density of the samples*

Sample	Average Density (g/cm^3)
Lime	3170.3
Okra	1714.9
Orange	1157.3
Onion	1180.7
Pepper	705.0
Tomato	1727.8

The density of the samples examined as presented in the table above shows that lime has the highest density of 3190.3g/cm^3 while pepper has the least density value of 705.0g/cm^3.

The quality of a particular fruit is influenced by its density. This implies that the lower the density, the higher the flotation of the fruit samples on top of water. And as a result may not be of a high quality and may in truth be rejected by consumers. Density as an engineering property is usually used for quality assessment especially during separation of intact quality fruits and vegetables from damaged or rotten ones (Krokida and Maroulis, 2000; Nwanekezi and Ukagu., 1999).)

3.3. Specific Heat

Table 3. *The specific heat capacity of the samples at 35^{0}C, 450C and 55^{0}C*

Sample	Cp at 35^{0}C (kjkg^{-1} ^{0}C)	Cp at 45^{0}C (kjkg^{-1} ^{0}C)	Cp at 55^{0}C (kjkg^{-1} ^{0}C)
Orange	1.683	1.694	1.709
Lime	1.694	1.729	1.766
Onion	1.682	1.684	1.687
Okra	1.717	1.843	1.846
Pepper	1.675	1.723	1.846
Tomato	1.690	1.690	1.697

From the data above, it could be discovered that the specific heat capacity of the samples were found to be high running into thousands of joule per kilogram for a unit change in temperature T. This translates that lot of energy will be required to heat or cool these fruits and once heated or cooled, they retain their temperatures for a very long time. This is as a result of their high moisture content and specific heat capacity value. Heat capacity is directly linked with temperature and for vegetables, are essential for rigorous control of processes. Realistic designs of processes in industry (Morad *et. al.*, 2004). It also useful in determining the behaviour during different technological processes as they vary with chemical composition (Ngadi *et. al.*, 2003). Apart from moisture content, specific heat capacity is also influenced by the composition of fruits and vegetables such as protein and fat (Wang and Brenner, 1993).

3.4. Thermal Conductivity

Table 4. *Average Thermal Conductivity of the samples at various temperature*

Sample	K at35^{o}C (Jsm^{-1o}C)	K at 45 ^{o}C (Jsm^{-1o}C)	K at 55 ^{o}C (Jsm^{-1o}C)
Orange	0.149	0.151	0.155
Lime	0.152	0.159	0.166
Onion	0.149	0.150	0.151
Okra	0.156	0.181	0.214
Pepper	0.148	0.158	0.182
Tomato	0.151	0.151	0.152

The importance of thermal of foods is to predict or control the heat flux in food during processes such as cooking, frying, freezing, drying or pasteurization. It is also dependent on composition which is often considered as porosity and moisture content, transient techniques are of high importnace during measurements (Sweat, 2006). The result shows that the thermal conductivity of the fruits is very low compared to pure water; this may be due to the presence of other solids in the fruit bulk. This implies that they are poor conductors of heat. Moreover, the heat energy diffusion or transfer through these fruits during heat processes like drying, refrigeration and evaporation are likely to be very show.

3.5. Thermal Diffusivity

The thermal diffusivity of a material being a measure of how quickly a body can change its temperature can be calculated when all other parameters such as density, specific heat and Thermal conductivity are known. The relationship between these parameters is given as

$$\propto = K/\rho \text{ X } C_P$$

Where $\propto$ = Thermal diffusivity
K = Thermal conductivity
ρ = Density
C_P = Specific heat capacity

The thermal diffusivity of the fruits where calculated at 35^{0}C, 45^{0}C and 55^{0}C as shown on the table below.

Table 5. *Thermal Diffusivity of samples at various temp.*

Sample	Diffusivity at 35^{o}C (m^{2}s^{-1})	Diffusivity at 45^{o}C (m^{2}s^{-1})	Diffusivity at 55^{o}C (m^{2}s^{-1})
Orange	7.65 X 10^{-5}	7.7.70 X 10^{-5}	7.84 X 10^{-5}
Onion	7.50 X 10^{-5}	7.54 X 10^{-5}	7.60 X 10^{-5}
Lime	2.80 X 10^{-5}	2.88 X 10^{-5}	2.95 X 10^{-5}
Okra	5.25 X 10^{-5}	5.68 X 10^{-5}	6.15 X 10^{-5}
Tomato	5.17 X 10^{-5}	5.17 X 10^{-5}	5.17 X 10^{-5}
Pepper	1.25 X10^{-5}	1.30 X 10^{-5}	1.39 X 10^{-5}

4. Conclusion

The thermal properties of orange, onion, lime, okra, pepper and tomato were investigated at varying temperatures of 35^{0}c, 45^{0}c and 55^{0}c. The investigation indicated that the moisture content composition of the fruits and vegetables decreases with increasing temperature. The thermal conductivity of fruits and vegetables showed an increment with increasing temperature. Moreover, the result of specific heat capacity of the samples revealed that different samples have different ability to store heat. It also indicates that as the temperature increases, the specific heat capacity (C_p) increases, therefore, specific heat capacity is directly proportional to temperature of a material. The thermal diffusivity values of the fruits showed increment with an increase in temperature. It was also observed that the diffusivity values were very low compared to pure water. This may be due to the total solid content of the fruit, hence they are poor conductors of heat, consequently the heat energy diffusion or transfer through these fruits during drying, refrigeration, freezing and evaporation are likely to be very slow. Therefore, movement or diffusion of heat energy from one point to another in these samples would generally be very low during thermal processing.

Thus, it is recommended that the moisture content of the samples studied in this work be reduced to the level that will make moisture unavailable for microbial growth in order to preserve them. Other suggested or recommended ways of preservation includes, extracting their juice and canning them so as to reduce microbial actions, drying the bulk mass, refrigerating or freezing which require transfer of heat to achieve them.

References

[1] Qashou, M.S., Vachon, R.I. and Toulokian, Y.S. 1972. Thermal conductivity of foods. ASHRAE Transactions. Feb. 29.

[2] Lozano, J.E. (2006), Thermal Properties of food, Journal of Food Engineering Vol. 1.28.

[3] Studman, C.J. 1999. Fruit and vegetables: Fruit and vegetable quality. CIGR handbook of agricultural engineering: Agro processing engineering. International Commission of Agricultral and Biosystem Engineering (CIGR), Sapporo, Hokkaido, Japan, 4: 243-72.

[4] Ikegwu, O.J and Ekwu, F.C (2009), Thermal and physical properties of some tropical fruits and their juices in Nigeria; Journal of food technology, vol. 7, (2), pp. 38-42.

[5] Kordylas, J.M. 1990. Processing and preservation of tropical and subtropical foods. Macmillan Publishers Ltd., London, UK. Kaymak, (2002)

[6] Daunthy, M.. E. (1995) Fruit and vegetable processing, FAO agricultural services bulletin No. 119. Food Agriculture Organisation (FAO) of the United Nations (UN), Rome, Italy.

[7] Krokida M.K, and Maroulis (2000). Quality changes during drying of food materials. In: Mujumdar A.S. (ed). Drying Technology in Agriculture and Food Science, Enfiled, N.H. Science, 313.

[8] Sweat, V.E (2006) Thermal Properties of food, in Engineering properties of foods, Springer, New York, 105 – 155.

[9] Morad N, Idrees M, and Hasan A. (1995). Improved conditions for measurement of specific heat capacities of pure triglycerides by differential scanning calorimeter. Journal of Thermal Analysis, 44: 823 – 835.

[10] Musa-Makama A.L., Sobowale M.S. And Afolabi A.C. (2005). Post-harvest technology: A pre-requisite for food security. Proceedings of Nigerian Institute of Agricultural Engineers, 27: 270-273.

[11] Ngadi M.O, Chinnan, and Mallikarjunan P. (2003). Specific heat capacity and heat capacity of fried shrimp at freezing and refrigeration temperatures. Lebensm. Wiss. U-Technology, 36: 75 – 81.

[12] Wang N. and Brennar J.G (1993). Influence of moisture content and Temperature on the Specific heat of Potato. Journal of Engineering, 49: 303 – 310.