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Specific Heat and Thermal Diffusivity of Okra as Affected by Moisture Content and Bulk Density

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Abstract: The objectives of this study, were to investigate the effect of moisture content and bulk density on specific heat and thermal diffusivity of okra. The study was conducted on okra in the market as at when the experiment was conducted for thermal properties of the sample (okra: chopped, ground (dry) and fresh whole). The chopped okra experiment was conducted in the moisture content range of 10-80% (wb). The bulk density of okra sample was determined following the AOAC recommended method. The experiments at each moisture levels and bulk density were replicated 3 times. The results obtained show that specific heat capacity varied between 7.3069-19.8864 J/mKg°C and has no significant difference at 5% level of significance; thermal diffusivity values varied in range of $0.5736\text{-}3.0919\times10^{-8}$ m^2 s^{-1} has significant difference at 5% level of significance. For the ground okra, the parameters have significant difference at 5% level of significance. Same procedure applies to fresh okra; the parameters have significantly difference at 5% level of significance. For bulk density in the range of 170-280 Kg m^{-3}, the specific heat varied in the range of 9.5628-19.8864 J/mKg°C and is not significantly affected at 5% level of significance while thermal diffusivity varied from $1.3685\text{-}5.7360\times10^{-8}$ m^2 s^{-1} and is significantly affected at 5% level of significance.

Key words: Okra (*Abelmuschus* sp.), specific heat, thermal diffusivity, moisture content, bulk density

INTRODUCTION

Okra is a powerhouse of valuable nutrients. Nearly half of which is soluble fiber in the form of gum and pectins. Soluble fibre helps to lower serum cholesterol, reducing the risk of heart disease. The other half is insoluble which helps to keep the intestinal tracts healthy, decreasing the risk of some forms of cancer, especially colorectal cancer. Nearly 10% of recommended levels of vitamin B6 and folic acid are also present in a half-cup of cooked okra. Appreciable research has been carried out on thermal properties of grains and seeds. However, there is not much research on the thermal properties of okra. Their importance hence need to be investigated and exploited especially in okra that is known to be consumed in most part of the world especially in India and West Africa as is seen from literature. The vegetable is well known and enjoys a wide popularity and importance but the thermal properties are undermined.

Specific heat has often been measured with calorimeters of one form or another using the method of mixture while Timbers (1975) and Drusas *et al.* (1986), measured thermal diffusivity using the Dickerson (1965) apparatus, while Kazarian and Hall (1965), Shepherd and Bhardwaj (1986) and Dutta *et al.* (1988), determined it from the measured values of specific heat, thermal conductivity and bulk density. Hwang and Hayakawa (1979) reported the use of a vacuum bottle calorimeter in measuring the specific heat of food and Mohsenin (1980) and Lund (1983) described the Differential Scanning Calorimeter (DSC). Shepherd and Bhardwaj (1986) and Dutta *et al.* (1988) used an aluminum calorimeter placed inside an insulated vacuum flask to measure the specific heat of pigeon pea and gram, respectively. Otten and Ezeike (1976) developed a continuous adiabatic calorimeter and Ezeike (1987) presented a technique for measuring the specific heat of agricultural products with a modified adiabatic drop calorimeter.

Some investigators have calculated the specific heat of seeds and grains from other thermal properties such as thermal conductivity and thermal diffusivity while others made direct measurement of the specific heat. Tang and Sokhansanj (1990) carried out a study to determine the specific heat of Laird lentil seed as affected by moisture content and temperature using differential scanning calorimeter. Specific heat value ranged from 0.8-2.2 KJ Kg^{-1} K increasing with increase in moisture content over the range from 2.1-25.8% (wb) and with temperature varying from 10-80°C. Information on the

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thermal properties of lentils is valuable for drying and storage. Tang *et al*. (1991) used the Differential Scanning Calorimeter (DSC) to determine the specific heat of lentil seed. The values of lentil seeds ranged from 0.81-2.2KJ Kg^{-1} K specific heat increased quadratically with increase in moisture content over the range from 2.1-25.8% (wb).

Jekendra *et al*. (1995) conducted an experiment to determine the thermal diffusivity of wheat, maize, sorghum, black grain and Sesa num using standard methods. The thermal diffusivity of grain decreased as moisture content increase. Fasina and Sokhansanj (1995) used the line heat source method to obtain bulk thermal conductivity and thermal diffusivity of Lucerne pellets with moisture contents in the range 7.5-18.0% (wet basis).

MATERIALS AND METHODS

The study was conducted on the variety which was in the market as the study was conducted for okra pods (fresh) chopped and ground (dry). The chopped okra experiment was conducted using 10 through 80% moisture content wet basis and current input (0.5-1.5A). The variety in stock is called 'ila Oyo', by the market women which is the long, dented okra at the base. Because of very high moisture content of okra, the sample was gotten from market according to the quantity needed to perform the experiment at a time.

The Plate 1 and 2 show the type of okra from the market and that at 20% (wb) used for the experiment. The moisture content was determined by oven dry method using the weighing balance.

The bulk density of chopped (sliced) okra was determined following the AOAC (1980) recommended method. It involves the filling of a 100 mL cylinder with chopped okra from a height of 15 cm and then weighing the content on a weighing balance to determine the mass of the sample. The ratio of the weighed mass of the sample in 100 mL cylinder to the bulk volume was taken which is the bulk density.

The specific heat capacity of okra was calculated for each moisture content of 10 through 80% wet basis from heat generated from thermal conductivity experiment, each calculated value of specific heat of moisture content was done at a replication of 3. The calculated specific heat capacity was gotten after passing current in the ranges of 0.5, 1.0, 1.5 A through each moisture content.

Using $Q = I^2 R$ for the heat generated in the chamber at a resistance of the wire of 6Ω, which is constant.

Hence,

$$Q = I^2 R = MCp\Delta t \quad (1)$$

Plate 1: Sample of the okra bought from the market

Plate 2: Okra at 20% wet basis moisture content

$$Cp = \frac{Q}{Mx\Delta t} = \frac{I^2 R}{Mx\Delta t} \quad (2)$$

Where,

Q = Heat input (J/m)
M = Mass of sample in chamber (Kg)
Δt (T_2-T_1) = Change in temperature (°C)
I = Current input (A)
R = Resistance (Ω)

The thermal diffusivity was determined from the calculation using the calculated values of specific heat, experimental values of thermal conductivity and the bulk density from the equation given below:

$$Di = \frac{K}{P_b.C_p} \quad (3)$$

Where,

Di = Thermal diffusivity ($m^2 s^{-1}$).
K = Thermal conductivity (W/m°C).
P_b = Bulk density (Kg m^{-3}).
C_p = Specific heat capacity (J/mKg°C).

Thermal diffusivity is determined for the moisture content of 10, 20, 30, 40, 50, 60, 75, 80% wet basis and it covers the diffusivity of fresh (whole) okra at 87.2% (wb) and that of dry ground okra at 12% (wb).

RESULTS AND DISCUSSION

The results obtained in respect of the thermal conductivity, K, thermal diffusivity, Di and the specific heat capacity, Cp, at various moisture content, MC, are presented in this study.

The ANOVA tables as well as different graphs are also given in the appendices.

Specific heat: The results of specific heat measurement for okra when chopped with moisture content, when chopped with current input, when dry ground with current input, when fresh (whole) okra with current input and when chopped with bulk density are summarised and presented in Table 1-5 and in Fig. 1-5.

The cubic equation is the equation that correctly fit for the specific heat variation at various moisture content is given as:

Table 1: Specific heat of chopped okra as affected by moisture content

MC (%)	Specific heat (J/mKg°C)
10	9.5628
20	13.7255
30	18.0412
40	17.7665
50	13.1579
60	7.3069
75	19.8864
80	10.4790

Table 2: Specific heat capacity of chopped okra as affected by current input

Current input (A)	Specific heat (J/mKg°C)
0.5	2.9445
1.0	11.7778
1.5	26.5001

Table 3: Specific heat of ground okra as affected by current input

Current input (A)	Specific heat (J/mKg°C)
0.5	1.0232
1.0	4.0928
1.5	9.2087

Table 4: Specific heat of fresh okra as affected by current input

Current input (A)	Specific heat (J/mKg°C)
0.5	1.2417
1.0	4.9669
1.5	11.1755

Table 5: Specific heat capacity of chopped okra as affected by bulk density

Bulk density (Kg m^{-3})	Specific heat (J/mKg°C)
170	9.5628
180	13.7255
220	18.0412
230	12.7437
240	19.8864
280	10.4790

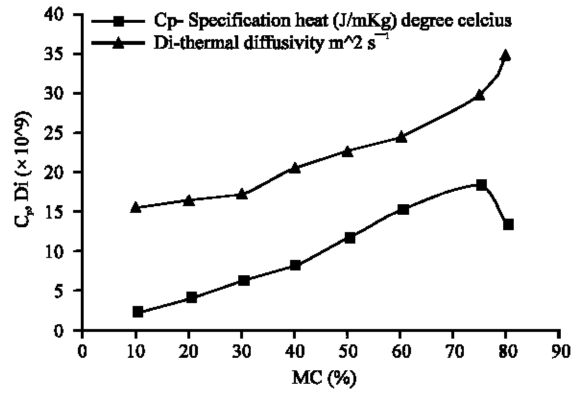

Fig. 1: Thermal properties of chopped okra against misture content, at 0.5A contant current

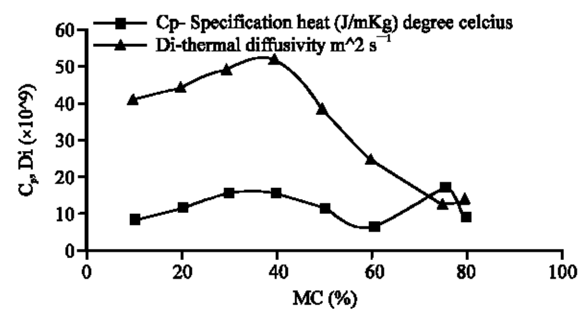

Fig. 2: Thermal properties of chopped okra against Moisture Content, MC (%) at 1.0A constant current

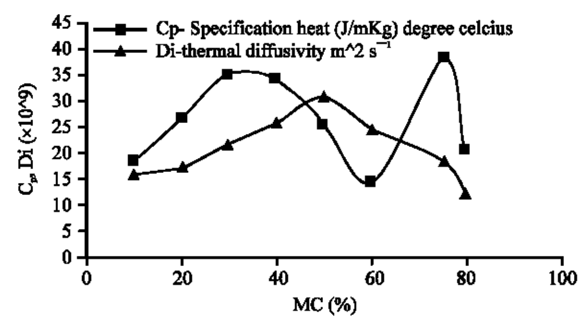

Fig. 3: Thermal properties of chopped okra against Moisture Content, MC (%) at 1.5A constant current

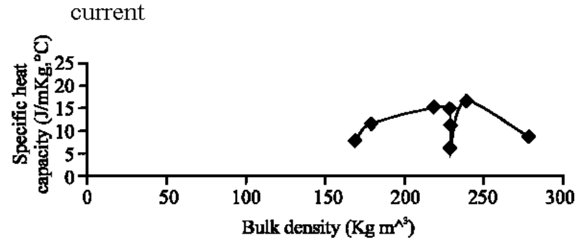

Fig. 4: Specific heat capacity against bulk density

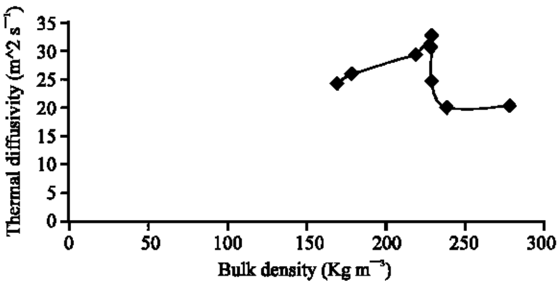

Fig. 5: Thermal diffusivity against bulk density

$$Cp = -2.7663+1.5448M -0.0374M^2+0.0003M^3 \quad (R^2 = 0.317) \qquad (4)$$

Where,

Cp = Specific heat capacity (J/mKg°C).

M = Moisture content at wet basis (%).

The specific heat increased with increase in moisture content of 10-30% wet basis from 9.5628-18.0412 J/mKg°C while at moisture content increase of 40 through 60% wet basis, the specific heat decreases from 17.7665-7.3069 J/mKg°C. It (specific heat) increased again at 75% to 19.8864 J/mKg°C before it then reduces to 10.4790 J/mKg°C at 80% wet basis. The specific heat increased, as the current input increased from 0.5-1.5A, from 2.9445-26.5001 J/mKg°C, for chopped or sliced okra. For dry ground okra, the specific heat increased with current input of 0.5-1.5A from 1.0232-9.2087J/mKg°C. For fresh okra, the specific heat increased, with current input of 0.5-1.5A, from 1.2417-11.1755 J/mKg°C. The specific heat of chopped okra, with bulk density of 170-220 Kg m^{-3}, was seen to increase from 9.5628-18.0412 J/mKg°C. The specific heat, with bulk density 230 Kg m^{-3}, reduces to 12.7438 J/mKg°C. The specific heat at bulk density of 240 Kg m^{-3} rose to 19.8864 J/mKg°C for that of bulk density of 230 Kg m^{-3} which then reduces to 10.4790 J/mKg°C for the bulk density of 280 Kg m^{-3}.

The analysis of variance of the specific heat with moisture content shows no significantly difference ($p \leq 0.05$), but the specific heat with current input shows high significant difference ($p \geq 0.05$). The specific heat with current input for fresh (whole) okra shows significant difference ($p \geq 0.05$). For dry ground okra, the specific heat shows significant difference ($p \geq 0.05$) with current input. Finally, the specific heat was found or seen not to be significantly different ($p \geq 0.05$) with bulk density.

The specific heat capacity varied from 7.3069-19.8864 J/mKg°C in this study, looking at it in the light of other studies carried out by other researchers like Tang and Sokhansanj (1990) using Laird lentil seed in the range of 0.8-2.2 kJ/KgK with moisture content range of 2.1-25.8%, is different since their percentage difference is high.

Table 6: Thermal diffusivity of chopped okra as affected by moisture content

MC (%)	Thermal diffusivity (m^2 s^{-1}) ($\times 10^{-8}$)
10	3.0919
20	1.3685
30	0.5736
40	0.9904
50	1.4417
60	3.9138
75	2.0189
80	2.9761

Table 7: Thermal diffusivity of chopped okra as affected by current input

Current input (A)	Thermal diffusivity (m^2 s^{-1}) ($\times 10^{-8}$)
0.5	1.2735
1.0	1.9581
1.5	2.9090

Table 8: Thermal diffusivity of grinded okra as affected by current input

Current input (A)	Thermal diffusivity (m^2 s^{-1}) ($\times 10^{-8}$)
0.5	1.2162
1.0	1.6612
1.5	2.4302

Table 9: Thermal diffusivity of fresh okra as affected by current input

Current input (A)	Thermal diffusivity (m^2 s^{-1}) ($\times 10^{-8}$)
0.5	1.2892
1.0	2.2321
1.5	2.7932

Table 10: Thermal diffusivity of chopped okra as affected by bulk density

Bulk density (Kg m^{-3})	Thermal diffusivity (m^2 s^{-1}) ($\times 10^{-8}$)
170	3.0919
180	1.3685
220	5.7360
230	2.1153
240	2.0189
280	2.9761

Specific heat, which is the amount of heat required to raise the temperature of a unit mass of grain by 1°C is important in aeration, drying, milling, etc. of food crops. It has to do with variation of temperature with amount of heat store within the substance and as such finds application in cooling operations. The limited capacity of commercial or on the farm driers often necessitates cooling of stored grains to dissipate the heat build up due to respiration and keep the grains at temperature close to ambient temperature until drying.

Thermal diffusivity: The results of thermal diffusivity measurement for okra when chopped with moisture content, when chopped with current input, when dry ground with current input, when fresh (whole) okra with current input and when chopped with bulk density are summarised and presented in Table 6-10 and in Fig. 1-5.

Thermal diffusivity decreases with increase in moisture content (10-30%) from 3.0919×10^{-8} m^2 s^{-1} to 0.5736×10^{-8} m^2 s^{-1}.

The cubic and quadratic regression equations are shown below,

$$Di = 7.2\times10^{-8}-5.0\times10^{-9}M+1.3\times10^{-10}M^2-9.0\times10^{-13}M^3 \quad (R^2 = 0.721) \qquad (5)$$

$$Di = 2.4\times10^{-7}-2\times10^{-9}P_b + 4.7\times10^{-12}P_b^2 \quad (R^2 = 0.524) \qquad (6)$$

Where,

M = Moisture content (wet basis) (%).

Di = Thermal diffusivity ($m^2 s^{-1}$).

P_b = Bulk density (Kg m^{-3}).

While the thermal diffusivity with moisture content of 40-60% wet basis increased from 0.9904×10^{-8} to 3.9138×10^{-8} $m^2 s^{-1}$, thermal diffusivity with moisture content of 60-75% wet basis decreased from 3.9138×10^{-8} $m^2 s^{-1}$ to 2.0189×10^{-8} $m^2 s^{-1}$, the thermal diffusivity with moisture content of 75-80% wet basis increases from 2.0789×10^{-8} to 2.9761×10^{-8} $m^2 s^{-1}$. The effect of current input on thermal diffusivity when the current input was 0.5A through 1.5A, the thermal diffusivity increased from 1.2735×10^{-8} to 2.9090×10^{-8} $m^2 s^{-1}$ for chopped okra. For ground dry okra, the thermal diffusivity, when the current input was from 0.5-1.5A for moisture content of 12% wet basis, was from 1.2162×10^{-8} to 2.4302×10^{-8} $m^2 s^{-1}$. For fresh whole okra, the thermal diffusivity when the current input was 0.5-1.5A at moisture content of 87.2% wet basis increased from 1.2892×10^{-8} through 2.7932×10^{-8} $m^2 s^{-1}$. Thermal diffusivity of okra decreased from 3.6919×10^{-8} to 0.5736×10^{-8} $m^2 s^{-1}$ at bulk density of 170-220 Kg m^{-3}. The thermal diffusivity, at 230 Kg m^{-3} bulk density, increased to 2.1153×10^{-8} $m^2 s^{-1}$, finally, thermal diffusivity increased for bulk density of 240-280 Kg m^{-3} from 2.0189×10^{-8} to 2.9761×10^{-8} $m^2 s^{-1}$.

The Analysis of Variance (ANOVA) for thermal diffusivity shows that there is significant difference since ($p\geq0.05$). Duncan Multiple Range test was used to find how much difference is gotten. The effect of current input on thermal diffusivity is significantly different ($p\geq0.05$) F cal is greater than F tab for chopped okra. For dry ground okra, the analysis of variance of the effect of current input on thermal diffusivity is significantly different ($p\geq0.05$), it shows that F tab is less than F cal. The analysis of variance for fresh okra shows that the thermal diffusivity is significantly different since F cal is greater than F tab. The effect of bulk density on thermal diffusivity shows that it is significantly different. The level of significance is also carried out by the use of Duncan Multiple Range Test.

Other researchers reported studies on the thermal diffusivity (Screenarayanan and Chattopadlyay, 1986) are in the range of 1.08×10^{-7} to 9.95×10^{-8} $m^2 s^{-1}$ on rice bran with moisture range of 7-15% (wet 1basis). The percentage difference shown compare to this work is 94.27% which is significantly different and also for high range of value, the percentage is 74.52% which is also significantly different, due to the high moisture content of okra.

CONCLUSION

The following conclusions could be drawn from this study:

- Specific heat of chopped okra with moisture content in the range of 10-80 %, varied from 7.3069-19.8864 J/kg°C, while with bulk density of 170 through 280 Kg m^{-3}, it varied from 9.5628-19.8864 J/kg°C.
- Thermal diffusivity of chopped okra with moisture content of 10-80 % varied from $0.5736\text{-}3.0919\times10^{-8}$ $m^2 s^{-1}$, with bulk density range from 170-280 Kg m^{-3}, it varied from $1.3685\text{-}3.0919\times10^{8}$ $m^2 s^{-1}$.
- All the two parameters increased at fresh and ground state with current input with values of 1.0232-9.2087 J/mKg°C for ground, 1.2417-11.1755 J/mKg°C for fresh okra of specific heat; $1.2162\text{-}2.4302\times10^{-8}$ $m^2 s^{-1}$ for ground, $1.2892\text{-}2.7932\times10^{-8}$ $m^2 s^{-1}$ for fresh okra of thermal diffusivity.

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