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Comparative Analysis of Thermal Properties of Two Varieties of Periwinkle Relevant to Its Processing Equipment Design

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Abstract This study was conducted to investigate and compare the thermal properties of two varieties: *Tympanotonus fuscatus* and *Pachymelania aurita* of Periwinkle in Nigeria. The thermal properties, namely; specific heat capacity,C_p, thermal conductivity, k, thermal diffusity, α, thermal absorptivity, γ and thermal effusivity, ϵ of Periwinkle samples were determined. The mean thermal conductivity of *T. fuscatus* was found to be 0.085 ± 0.00015 W/m.K at temperatures of 308 – 373 K, while that of *P. aurita* was 0.0952 ± 0.00056 W/m.K at the same temperature range.The average specific heat capacity value of *T. fuscatus* was found to be 2403.663 ± 3.4379 J/kg.K at temperature of 308 – 373 K lower than that of *P. aurita* having a mean value of 2832.314 ± 1.7385 J/kg.K at the same temperature. The mean thermal diffisivity of *T. fuscatus* was found to be 2.6553×10^{-8} m^2/s while that of *P. aurita* was found to be 5.6790×10^{-8} m^2/s. The average values for thermal absorptivity and effusivity of *T. fuscatus* and *P. aurita* were obtained as 81.085m^{-1}; 525.084 $W.s^{1/2}/m^2K$ and 55.441 m^{-1}; 396.952 $W.s^{1/2}/m^2K$, respectively. The results shown that average thermal absorptivity and effusivity values were higher in *T. fuscatus* than *P. aurita.* A Tukey pairwise comparison analysis carried out on the mean values of these thermal properties of *T. fuscatus* and *P. aurita* revealed that there is statistically significant difference at α<5% between the thermal properties of the two varieties of periwinkle samples. These data would help us in predicting and controlling the heat flux during the design of periwinkle processing equipment.

Keywords: *periwinkle varieties, T. fuscatus, P. aurita, specific heat capacity, thermal conductivity, thermal diffusivity, thermal properties*

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1. Introduction

Periwinkle meat is a potential source of good-quality proteins and minerals like calcium, potassium, iron and phosphorus and some vitamins. It contains most of the essential amino acids in adequate amount for human nutrition. They are used in the preparation of indigenous traditional dishes such as "edikang ikong", "ekpang nkukwo", "afia efere" and "afang" soup among others by the Efik and Ibibio ethnic groups in Nigeria. The periwinkle shells are potential sources of calcium for animal feeds. The powdered periwinkle shell with its high $CaCO_3$ content can be utilized as energizer during pack carburization of low carbon steel. The periwinkle shell strength and hardness makes it an excellent material for building construction and ornament decorations [1,2,3,4].

The thermo physical properties of foods, are important for modeling and optimization of processes involving heating and cooling. Thermal properties data are required in engineering and process design. The properties used in a mathematical model of heat transfer are usually thermal conductivity (k), specific heat (C_p), density (ρ) and diffusivity (α) [5,6], where k is in (W/mºC), C_p in (J/kg°C), ρ in (kg/m^3) and α in (m^2/s).Specific heat and thermal conductivity of foodstuff are essential in designing and operating thermal processing units [7].These properties are highly dependent on temperature, phase change during freezing, and composition, especially fat and moisture, thermal conductivity in particular has significant dependence on tissue structure [8,9,10]. According to [7] the thermal conductivity of shucked oyster increased from 0.577 to 0.677 W/mºC as temperature increased from 0 to 50°C measured by a line heat source thermal conductivity probe while its specific heat increased from 3.795 to

4.047kJ/kg°C when temperature was raised from 10 to 50°C. The objective of this work was to determine the thermal properties of two varieties of periwinkle (*Tympanotonus fuscatus* and *Pachymelania aurita*) relevant for the development of their processing equipment.

2. Materials and Methods

2.1. Sample Preparation

Fifteen kilogram (15kg) each of two varieties of periwinkle, namely *Tympanotonus fuscatus* and *Pachymelania aurita*, were purchased from the Itu waterfront market Akwa Ibom State, Nigeria. The periwinkle samples were washed, cleaned and graded and, then taken to the laboratory for analysis (Figure 1 and Figure 2).

Figure 1. Tympanotonus fuscatus

Figure 2. Pachymelania aurita

2.2. Determination of Thermal Properties of Periwinkle Meat

In determining the thermal properties of periwinkle meat for the two varieties, a substantial quantity of the sample each was de-shelled dried and blended into powder of particle size of 1.0 mm and was then compressed into a mould to form a cube of dimension 50mm × 50mm. This was carried out in triplicates (Figure 3 and Figure 4).

Figure 3. A de-shelled Periwinkle meat sample

Figure 4. A blended Periwinkle sample

2.3. Determination of Thermal Conductivity of Periwinkle Meat

The Guarded Hot Plate located in Department of Physics, Akwa State University, Ikot Akpaden Mkpat Enin, Nigeria, was used to determine the thermal conductivity of periwinkle in accordance with ASTM C177-13 and ASTM C1044-16.The standard guarded hot plate method is based on the steady-state longitudinal heat flow principle which determines the thermal conductivity of the material by applying Fourier's law. The experimental setup consisted of placing the sample material on one-sided mode to measure the heat flux for 48hrs and recorded.

The thermal conductivity (k) of the periwinkle samples was evaluated using the expression from ASTM C1044-16.

$$k = \left(P \times d \,/\, A \times \Delta T \right) \tag{1}$$

Where P is the heat flow = 1.4W, A is the cross sectional area perpendicular to the heat flow (m^2), d is distance between temperature sensors (m) and ΔT is the different between upper and lower temperature values (K).

2.4. Determination of Specific Heat Capacity of Periwinkle Meat

The experiment was conducted using the Differential Scanning Calorimeter (DSC 2 –Mettler Toledo) located in Department of Polymer Technology, Yaba College of Technology, Lagos, Nigeria, based on ASTM E1269-11. The sample was weighed into the sample pan and sapphire was measured into the reference pan. Aluminum standard 40µL was used. Heating was done from 35 to 100°C at 10K/min. Three scans were made: one for the sample, one for a standard (reference), and the third for the empty sample pan (holder).

The specific heat capacity of the periwinkle samples was determined using the expression from ASTM E1269-11.

$$C_{p(s)} = C_{p(st)} D_s W_{st} / D_{st} W_s \quad (2)$$

$C_{p(s)}$ is the specific heat capacity of the periwinkle samples, J/(g.K)

$C_{p(st)}$ is the specific heat capacity of the reference samples, J/(g.K)

D_s is the vertical displacement between the sample holder and the sample DSC thermograph at a given temperature, mW

D_{st} is the vertical displacement between the sample holder and the reference DSC thermograph at a given temperature, mW

W_s is the mass of periwinkle samples, mg. W_{st} is the mass of reference(sapphire) standard, mg.

2.2. Data Analysis

Statistical parameters such as standard deviation, coefficient of variance, mean, maximum and minimum values were used to analyze the thermal properties data of periwinkle samples.ANOVA was carried out to determine the significance and the effect among the two varieties of periwinkle. Turkey parwise comparison test was also used to check the difference in means of the responses for the two varieties of periwinkle using Minitab 17.0 software.

3. Results and Discussion

3.1. Thermal Properties of Periwinkle Meat

Table 1 and Table 2 present experimental and calculated values for the thermal properties of the two varieties of periwinkle meat samples which include specific heat capacity, C_p, thermal conductivity, k, thermal diffusity, α, thermal absorptivity, γ and thermal effusivity, ϵ. Comparatively, *T. fuscatus* with a mean bulk density value of 1338.045 ± 1.4052 kg/m^3 had a mean thermal conductivity of 0.085 ± 0.00015 W/m.K at temperatures of 308 – 373 K which is slightly lower than that of *P. aurita* at the same temperature range which was found to be 0.0952 ± 0.00056 W/m.K with a mean bulk density value of 588.09 ± 0.3134 kg/m^3. Thermal conductivity is dependent strongly on temperature, structure of the material and moisture content [9].

The average specific heat capacity value of *T. fuscatus* was found to be 2403.663 ± 3.4379 J/kg.K at temperature of 308 – 373 K lower than that of *P. aurita* having a mean value of 2832.314 ± 1.7385 J/kg.K at the same temperature. [7,9,11] reported the average specific heat capacity values of fresh *Loco* meat, Shrimp and Oyster meats to be 2.9613 ± 0.0887;3.630 ± 0.06 and 3.8343 KJ/kg°C at temperature of 0 – 30°C respectively. The mean thermal diffusivity of *T. fuscatus* was found to be 2.6553×10^{-8} m^2/s while that of *P. aurita* was found to be 5.6790×10^{-8} m^2/s. The average values for thermal absorptivity and effusivity of *T. fuscatus* and *P. aurita* were obtained as 81.085 m^{-1}; 525.084 W.s$^{1/2}$/m^{2}K and 55.441 m^{-1} ; 396.952 W.s$^{1/2}$/m^{2}K, respectively. The results shown that average thermal absorptivity and effusivity values were higher in *T. fuscatus* than *P. aurita*. Thermal conductivity is used to predict and control the heat flux during food processing such as cooking, frying, freezing, sterilization, drying or pasteurization, thermal diffusivity quantifies a material's ability to conduct heat relative to its ability to store heat transfer, thermal absorptivity entails the quantity of heat penetration to the periwinkle meat samples while effusivity measures the ability of periwinkle meat to exchange thermal energy [12,13]. Variation of thermal properties of *T. fuscatus* and *P. aurita* varieties of periwinkle showed *P. aurita* having a higher α than *T .fuscatus* while γ and ϵ were higher in *T. fuscatus* than *P. aurita* (Figure 5). The two periwinkle varieties showed no apparent transition peak, this could be possibly due to exothermic nature of periwinkle samples tested as presented by the DSC thermograph (Figure 6).

ANOVA carried out on the data reported for thermal properties of *T. fuscatus* and *P. aurita* varieties of periwinkle meat samples showed that mean values reported were significant ($p < 0.05$) (Supplementary Table 1), also a pairwise comparison analysis carried out on the mean values of the thermal properties of *T. fuscatus* and *P. aurita* revealed that there is statistically significant difference at α<5% between the thermal properties of the two varieties of periwinkle meat sample.

Table 1. Thermal Properties of *Tympanotonus Fascatus* Meat Samples

Thermal Properties	No of Observations	Unit of Measurements	Minimum Value	Maximum Value	Mean Value	Standard Deviation	Coefficient of Variation
C_p	3	J/Kg.K	2401.045	2407.860	2403.663	3.43785	13.48260
k	3	W/m.K	0.0853	0.0856	0.0854	0.00015	0.00000
α	3	10^{-8}.m^3/s	2.6537	2.6561	2.6553	0.0014	0.00000
γ	3	m^{-1}	81.083	81.085	81.084	0.001	0.00000
ϵ	3	Ws$^{1/2}$/m^{-2}.K	523.391	525.467	525.084	1.1974	1.4338
ρ_b	3	Kg/m^3	1336.970	1339.685	1338.045	0.8888	1.9745

Table 2. Thermal Properties of *Pachymelania Aurita* Meat Samples

Thermal Properties	No of Observations	Unit of Measurements	Minimum Value	Maximum Value	Mean Value	Standard Deviation	Coefficient of Variation
C_p	3	J/Kg.K	2830.676	2834.138	2832.314	1.7385	3.0223
k	3	W/m.K	0.0941	0.0952	0.0946	0.00056	0.0000003
α	3	$10^{-8}.m^3/s$	5.6439	5.7171	5.6794	0.0037	0.0000000
γ	3	m^{-1}	55.439	555.443	55.441	0.0021	0.000001
ϵ	3	$Ws^{1/2}/m^{-2}.K$	398.153	396.608	396.952	1.0713	1.14760
ρ_b	3	Kg/m^3	587.732	588.285	588.094	0.1840	0.09821

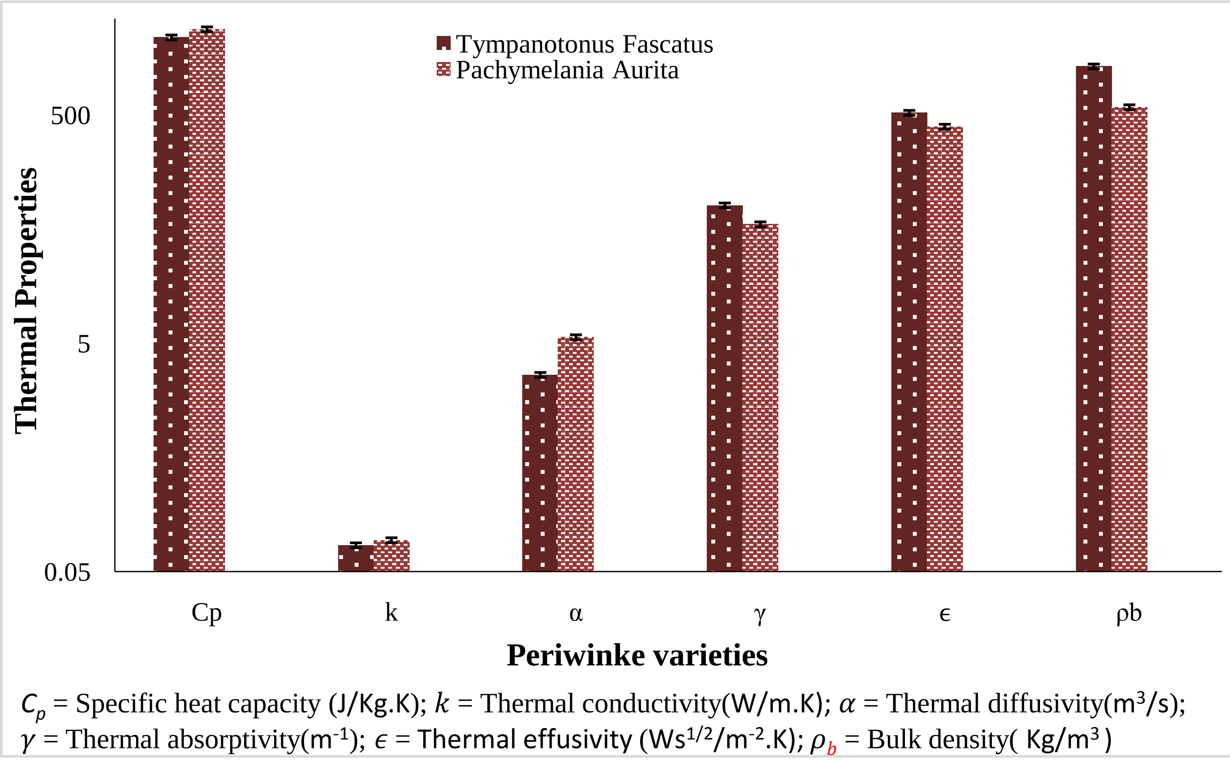

Figure 5. Variation of thermal properties of *T. fuscatus* and *P. aurita* varieties of Periwinkle. *Error bars* represent the standard deviation of the mean (*n=3*)

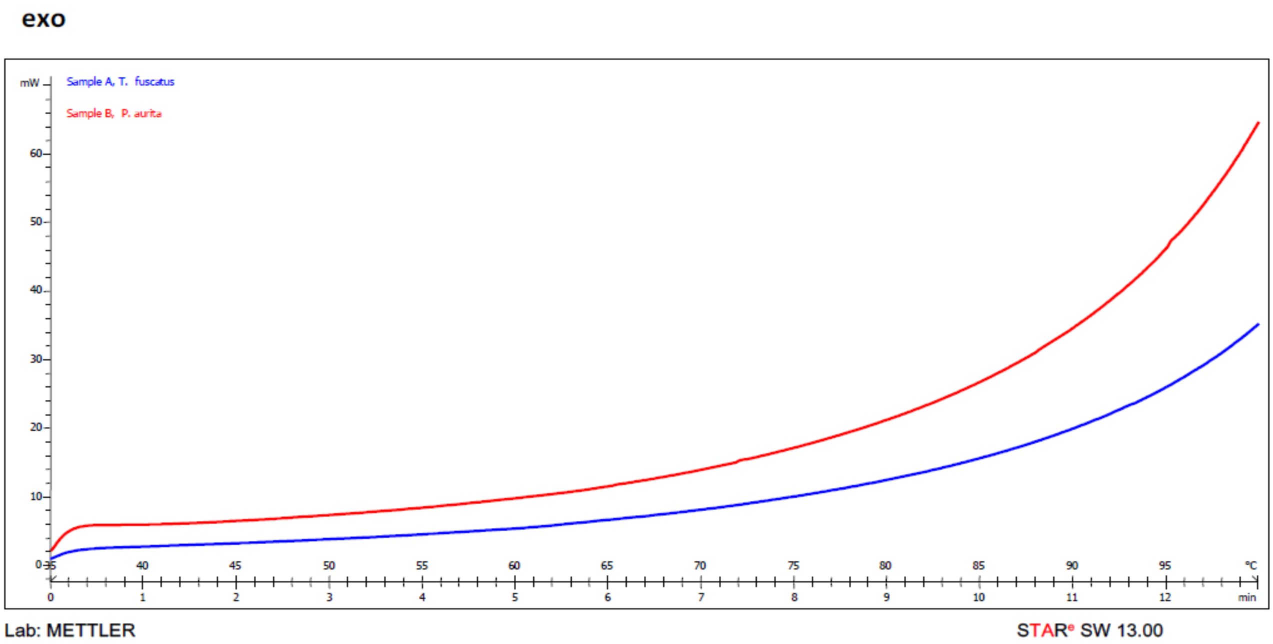

Figure 6. DSC curve for *T. fuscatus* (blue line) and *P.aurita* (red line)

4. Conclusion

This study investigated some thermal properties of two periwinkle varieties (*T. fuscatus* and *P. aurita*). The following conclusions were reached from the results of the study:

a) *P. aurita* had a slightly higher mean thermal conductivity value than *T. aurita* at the same temperature range.

b) The average specific heat capacity value of *P. aurita* was higher than that of *P. aurita*.

c) The results also shown that average thermal absorptivity and effusivity values were higher in *T. fuscatus* than *P. aurita*.

d) The two periwinkle varieties showed no apparent transition peak

e) The thermal properties of the two periwinkle varieties were significant on all the parameters investigated at $p< 0.05$.

References

[1] Kiin-kabari DB, Hart AD, Nyeche PT. Nutritional composition of selected shellfish consumed in River State, Nigeria. Amer. J. Food Nutr. 2017; 5(4):142-146.

[2] Ekanem AP, Job BE. Nutritional status of two periwinkle species from a tropical creek in Nigeria. African Journal of Environmental Pollution and Health 2010; 8(1): 41-44.

[3] Arularasan S, Lyla PS, Kesavan K, Khan SA. Recipes for the Mesogastropods – Strombus canavium. Adv. J. Food Sci. Technol. 2009; 2(1): 31-35.

[4] Ariahu CC, Ilori MO. Use of Periwinkles as sources of dietary protein: The Nutritional, Toxicological, Processing, And Policy Implications. Food Reviews International, 1992; 8: 2, 223-233.

[5] Rahma, MS. Food properties handbook.2nd edition. Taylor and Francis Group 2008; 534.

[6] Sahin S, Sumnu SG. Physical properties of foods. Sprinter science + Business Media. 2006; 107.

[7] Hu X, Mallikarjunan P. Thermal and dielectric properties of shuckedoysters.LWT- Food Science and Technology, 2005; 38: 489-494.

[8] Elansari AM, Hobani, AI. Effect of temperature and moisture content on thermal conductivity of four types of meat. International Journal of Food Properties, 2009; 12: 308-315.

[9] Karunakar B, Mishra SK, Bandyopadhyay S. Specific heat and thermal conductivity of shrimp meat. Journal of Food Engineering, 1998:37: 345-351.

[10] Wang JJ, Hayakawa KI. Maximum slope method for evaluating thermal conductivity probe data. Journal of Food Science, 1993; 58(6), 1340-1345.

[11] Reyes A, Pérez N, Mahn A. Determination of specific heat and thermal conductivity of “Loco” (Concholepas concholepas).Food Bioprocess Technology. 2013; 6: 1873-1877.

[12] Fontana JA, Varith J, Ikediala J, Reyes J, Weaker B. Thermal properties of selected foods using a dual needle heat – pulse sensor. Paper no. 996063. An ASAE meeting presentation. Institute of food technologist at Mc cornice place. USA, 1999.

[13] Stroshine R. Physical properties of agricultural materials and food products. Purdue University, west lafayatte, Indiana. U.S.A. 1998. http://www.purdue.ed/abe.

[14] ASTM E1269. Standard Test Method for Determining Specific Heat Capacity by Differential Scanning Calorimetry, ASTM International, West Conshohocken, PA. 2011. www.astm.org.

[15] ASTM, E177/C1044. Standard Test Method for Steady State Heat Flux Measurements and Thermal Transmission Properties by Means of Guarded Hot Plate Apparatus, ASTM International, West Conshohocken, PA. 2013 www.astm.org.

Supplementary data

Table 1s. Summary of One-way Analysis of Variance (ANOVA) for the Thermal Properties of the two varieties of Periwinkle

Source	Factor/ Type	Variety levels	DF	Adj SS	Adj MS	F-Value	P-Value
	Cp, J/Kg.K						
	Periwinkle Variety (Fixed)	2	1	183742	183742	2544.17	0.0005
	Error		2	0	0		
	Total		3	183742			
	k, W/m.K						
	Periwinkle Variety (Fixed)	2	1	0.000085	0.000085	16928.00	0.0005
	Error		2	0	0		
	Total		3	0.000085			
	α, m^3/s						
	Periwinkle Variety (Fixed)	2	1	9.13279	9.13279	313706.70	0.0005
	Error		2	0	0		
	Total		3	9.13284			
	γ, m^{-1}						
	Periwinkle Variety (Fixed)	2	1	657.487	657.487	8296359.90	0.0005
	Error		2	0	0		
	Total		3	657.487			
	ϵ,						
	Periwinkle Variety (Fixed)	2	1	16417.6	16417.6	1.93148E+08	0.0005
	Error		2	0	0		
	Total		3	16417.6			

Table 2s. Summary of Tukey Pairwise Comparisons for Thermal Properties of the two varieties of Periwinkle

Periwinkle Variety Levels	Difference of Means	SE of Difference	Simultaneous 95% CI	T-Value	P-Value
Cp, J/Kg.K					
T. fuscatus – P. aurita	-428.7	0.0	(-428.7,-428.7)	-115	0.0005
k, W/m.K					
T. fuscatus – P. aurita	-0.009200	0.000071	(-0.009504,-0.008896)	-130.1	0.0005
α, m^3/s					
T. fuscatus – P. aurita	-3.02205	0.00540	(-3.04527,-2.99883)	-560.1	0.0005
γ, m^{-1}					
T. fuscatus – P. aurita	25.6415	0.0089	(25.6032,25.6798)	2880.34	0.0005
$\boldsymbol{\epsilon}$, $Ws^{1/2}/m^{-2}.K$					
T. fuscatus – P. aurita	128.131	0.009	(128.091,128.171)	13897.8	0.0005