THERMAL PROPERTIES OF SELECTED SPECIES OF BANANA GROWN IN GHANA

by

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DECLARATION

I hereby declare that this submission is my own work towards the Masters of Science and that, to the best of my knowledge, it contains no material previously published by another person nor material which has been accepted for the award of any other degree of the University, except where due acknowledgement has been made in the text.

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DEDICATION

This project work is dedicated to my lovely sons, Daniel and Newton.

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Finally, it is needless to say however, that any inadequacies or errors substantially or marginally that may be detected in this write-up all remains my responsibility.

ABSTRACT

Banana (*Musa acuminata*) is an important fruit eaten by most Ghanaians in raw state. The fruit has a very short life span after ripening, hence most are discarded during bumper harvest. Processing will increase its shelf-life and also add value to the product. In order to design equipment, facilities and determine the amount of heat to be added or removed from banana during processing, knowledge of thermal properties of these locally grown bananas of which specific heat, thermal conductivity and thermal diffusivity are vital. The selected varieties for the study were dried to moisture content (MC) ranging from 18.5 – 50.0%wb for gros michel and 34.4 – 65.9 %wb for the medium cavendish. Specific heat was measured by the method of mixtures while the thermal conductivity was measured by the line heat source probe method. Thermal diffusivity was then calculated from the experimental results obtained from specific heat, thermal conductivity and bulk density. Bulk density was measured by the mass per unit change in volume of the sample. The bulk densities for both varieties of banana were found to be in a range of 1376.2 – 1130.0 kg. m^{-3} and 1233.5 -1065.3 kg. m^{-3} for the gros michel and medium cavendish varieties respectively, which was found to decrease in with increasing MC. The coefficients of determination were 94.1% and 96.4% respectively for the gros michel and medium cavendish. The specific heat for gros michel variety ranged from 1574 – 2506.8 $Jkg^{-1}\ ^oC^{-1}$ and that of the medium cavendish variety was 1982.9 – 2970.6 J $kg^{-1}\ ^oC^{-1}$. The coefficients of determination were 95.4% and 99.9% for the gros michel and medium cavendish varieties of banana respectively. The thermal conductivity of gros michel varied from 0.249 – 0.458$Wm^{-1}\ ^oC^{-1}$ and that of the medium cavendish also varied from 0.317 – 0.543 $Wm^{-1}\ ^oC^{-1}$.

The LSD and coefficient of determination were 0.0091 and 0.0084; and 98.1% and 97.2% for gros michel and medium cavendish respectively. The thermal diffusivity range for gros michel was 1.15 $x10^{-7}$–1.62 $x10^{-7} m^2 s^{-1}$ and that of the medium cavendish also ranged from 1.29 $x10^{-7}$-1.7$x10^{-7} m^2 s^{-1}$. Specific heat, thermal conductivity and thermal diffusivity were found to increase with increasing MC for both varieties. The effects of MC on all parameters studied were significant at $p \geq 0.05$. Regression equations of second order of polynomials were established which could be used to reasonably estimate the values of bulk density, specific heat, thermal conductivity and thermal diffusivity respectively.

Keywords: Gros michel 'asante kwadu', Medium cavendish 'broni kwadu', thermal conductivity, specific heat, thermal diffusivity, bulk density, and moisture content.

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NOTATIONS

AOAC	Association of Official Analytical Chemists
C_b	Specific heat of banana (J/kg ^oC)
C_c	Specific heat of calorimeter (J/kg ^oC)
C_f	Specific heat of aluminium foil (J/kg ^oC)
C_p	Specific heat (J/kg ^oC)
C_{gm}	Specific heat gros michel (J/kg ^oC)
C_{mc}	Specific of medium cavendish (J/kg ^oC)
C_w	Specific heat of water (J/kg ^oC)
db	Dry basis
K	Thermal conductivity (W/ m ^oC)
K_{gm}	Thermal conductivity of gros Michel (W/ m ^oC)
K_{mc}	Thermal conductivity of medium Cavendish (W/ m ^oC)
M_b	Mass of banana (kg)
M_{cw}	Mass of calorimeter and water (kg)
M_{hw}	Mass of hot water (kg)
M_f	Mass of aluminium foil (kg)
M_w	Mass of water (kg)
T_e	Equilibrium temperature (^oC)
T_f	Final temperature (^oC)
T_i	Initial temperature (^oC)
a	Thermal diffusivity (m^2/s)
a_{gm}	Thermal diffusivity of gros michel (m^2/s)
a_{mc}	Thermal diffusivity medium canvendish (m^2/s)
ρ_{gm}	Density of gros michel (kg/m^3)
ρ_{mc}	Density of medium cavendish (kg/m^3)
wb	Wet basis

APPENDIX

Table 2. Variation in bulk density of gros michel banana at different moisture content levels.

Replication / Treatment (MC % wb)	Bulk Density (kg/m^{-3})					
	I	II	III	IV	Total	Mean
50.0	1129.5	1132.5	1128.0	1130.0	4520.0	1130.0
39.7	1194.2	1195.8	1195.0	1192.6	4777.6	1194.4
24.5	1255.4	1260.0	1257.0	1256.4	5028.8	1257.2
18.5	1377.5	1372.4	1378.0	1377.2	5504.8	1376.2

Anova: Single Factor

SUMMARY

Groups	*Count*	*Sum*	*Average*	*Variance*
Row 1	4	4520	1130	3.5
Row 2	4	4777.6	1194.4	1.866667
Row 3	4	5028.8	1257.2	3.92
Row 4	4	5505.1	1376.275	6.7825

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Treatment	132179.8	3	44059.93	10967.57**	6.89E-21	3.490295
Error	48.2075	12	4.017292			
Total	132228	15				

Table 3. Statistical analysis (ANOVA) of bulk density for gros michel banana

** Highly significant at P ≥0.05 LSD (3.09)

Table 4. Variation in bulk density of medium cavendish banana at different moisture content levels.

Replication / Treatment (MC %wb)	Bulk Density (kg/m^{-3}) I	II	III	IV	Total	Mean
65.9	1068.0	1066.2	1062.4	1064.6	4261.3	1065.3
59.3	1152.4	1155.9	1158.8	1155.3	4622.4	1155.6
45.3	1190.0	1194.0	1197.0	1199.0	4780.0	1195.0
34.4	1229.5	1240.0	1234.0	1230.5	4934.0	1233.5

Anova: Single Factor

SUMMARY

Groups	*Count*	*Sum*	*Average*	*Variance*
Row 1	4	4261.2	1065.3	5.666667
Row 2	4	4622.4	1155.6	6.886667
Row 3	4	4780	1195	15.33333
Row 4	4	4934	1233.5	22.5

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Treatment	62370.44	3	20790.15	1650.448**	5.85E-16	3.490295
Error	151.16	12	12.59667			
Total	62521.6	15				

Table 5. Statistical analysis (ANOVA) of bulk density for medium cavendish banana

** Highly significant at $P \geq 0.05$ LSD (5.47)

Table 6. Variation in specific heat of gros michel banana at different moisture content levels.

Replication / Treatment (MC %wb)	Specific Heat (J/kg ^{o}C)					
	I	II	III	IV	Total	Mean
50.0	2510.0	2525.0	2493.1	2499.1	10027.2	2506.8
39.7	2158.0	2149.5	2150.5	2146.8	8604.8	2151.2
24.5	1698.0	1750.0	1786.0	1782.0	1754.0	1754.0
18.5	1582.0	1566.0	1572.0	1576.0	1574.0	1574.0

Anova: Single Factor

SUMMARY

Groups	*Count*	*Sum*	*Average*	*Variance*
Row 1	4	10027.2	2506.8	196.1533
Row 2	4	8604.8	2151.2	22.99333
Row 3	4	7016	1754	1653.333
Row 4	4	6296	1574	45.33333

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Treatment	2086603	3	695534.2	1450.682**	1.27E-15	3.490295
Error	5753.44	12	479.4533			
Total	2092356	15				

Table 7. Statistical analysis (ANOVA) of specific heat for gros michel banana

** Highly significant at P ≥0.05 LSD (33.74)

Table 8. Variation in specific heat of medium cavendish banana at different moisture content levels.

Replication / Treatment (MC %wb)	Specific Heat (J/kg ^{o}C)					
	I	II	III	IV	Total	Mean
65.9	2950.9	2965.7	3002.0	2963.8	11882.4	2970.6
59.3	2801.2	2805.8	2850.0	2785.0	11242.0	2810.5
45.3	2345.3	2300.5	2360.0	2375.0	9380.8	2345.2
34.4	1980.1	2001.0	1975.0	1975.5	7931.6	1982.9

Anova: Single Factor

SUMMARY

Groups	*Count*	*Sum*	*Average*	*Variance*
Row 1	4	11882.4	2970.6	481.4333
Row 2	4	11242	2810.5	773.0267
Row 3	4	9380.8	2345.2	1035.06
Row 4	4	7931.6	1982.9	150.8733

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Treatment	2424996	3	808331.9	1324.921**	2.18E-15	3.490295
Error	7321.18	12	610.0983			
Total	2432317	15				

Table 9. Statistical analysis (ANOVA) of specific heat for medium cavendish banana

** Highly significant at P ≥0.05 LSD (38.06)

Table 10. Variation in thermal conductivity of gros michel banana at different moisture content levels.

Replication / Treatment (MC %wb)	Thermal conductivity (W/m ^{o}C)					
	I	II	III	IV	Total	Mean
50.0	0.465	0.448	0.461	0.458	1.832	0.458
39.7	0.366	0.368	0.358	0.356	1.448	0.362
24.5	0.277	0.279	0.275	0.277	1.108	0.277
18.5	0.240	0.248	0.251	0.257	0.996	0.249

Anova: Single Factor

SUMMARY

Groups	*Count*	*Sum*	*Average*	*Variance*
Row 1	4	1.832	0.458	5.27E-05
Row 2	4	1.448	0.362	3.47E-05
Row 3	4	1.108	0.277	2.67E-06
Row 4	4	0.996	0.249	5E-05

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Treatment	0.106436	3	0.035479	1013.676**	1.08E-14	3.490295
Error	0.00042	12	3.5E-05			
Total	0.106856	15				

Table 11. Statistical analysis (ANOVA) of thermal conductivity for gros michel banana

** Highly significant at P ≥0.05 LSD (0.0091)

Table 12. Variation in thermal conductivity of medium cavendish banana at different moisture content levels.

Replication / Treatment (MC %wb)	Thermal conductivity (W/m ^{o}C)					
	I	II	III	IV	Total	Mean
65.9	0.535	0.539	0.546	0.552	2.172	0.543
59.3	0.457	0.458	0.460	0.465	1.840	0.460
45.3	0.380	0.382	0.374	0.376	1.512	0.378
34.4	0.314	0.324	0.320	0.310	1.268	0.317

Anova: Single Factor

SUMMARY

Groups	*Count*	*Sum*	*Average*	*Variance*
Row 1	4	2.172	0.543	5.67E-05
Row 2	4	1.84	0.460	1.27E-05
Row 3	4	1.512	0.378	1.33E-05
Row 4	4	1.268	0.317	3.87E-05

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Treatment	0.116084	3	0.038695	1275.648**	2.73E-15	3.490295
Error	0.000364	12	3.03E-05			
Total	0.116448	15				

Table 13. Statistical analysis (ANOVA) of thermal conductivity for medium cavendish banana

** Highly significant at P ≥0.05 LSD (0.0084)

Table 14. Variation in thermal diffusivity of gros michel banana at different moisture content levels.

Replication / Treatment (MC %wb)	Thermal Diffusivity ($m^2 s^{-1}$)					
	I	II	III	IV	Total	Mean
50.0	1.64×10^{-7}	1.57×10^{-7}	1.64×10^{-7}	1.62×10^{-7}	6.47×10^{-7}	1.62×10^{-7}
39.7	1.30×10^{-7}	1.32×10^{-7}	1.34×10^{-7}	1.32×10^{-7}	5.28×10^{-7}	1.32×10^{-7}
24.5	1.30×10^{-7}	1.27×10^{-7}	1.22×10^{-7}	1.26×10^{-7}	5.05×10^{-7}	1.26×10^{-7}
18.5	1.10×10^{-7}	1.15×10^{-7}	1.16×10^{-7}	1.18×10^{-7}	4.59×10^{-7}	1.15×10^{-7}

Anova: Single Factor

SUMMARY

Groups	*Count*	*Sum*	*Average*	*Variance*
Row 1	4	6.47	1.6175	0.001092
Row 2	4	5.28	1.32	0.000267
Row 3	4	5.05	1.2625	0.001092
Row 4	4	4.59	1.1475	0.001158

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Treatment	0.481719	3	0.160573	178.0023**	3.27E-10	3.490295
Error	0.010825	12	0.000902			
Total	0.492544	15				

Table 15. Statistical analysis (ANOVA) of thermal diffusivity for gros michel banana

** Highly significant at $P \geq 0.05$ LSD = 0.0463

Table 16. Variation in thermal diffusivity at of medium cavendish banana at different moisture content levels.

Replication / Treatment (MC %wb)	Thermal Diffusivity ($m^2 s^{-1}$)					
	I	II	III	IV	Total	Mean
65.9	1.70×10^{-7}	1.71×10^{-7}	1.70×10^{-7}	1.75×10^{-7}	6.86×10^{-7}	1.70×10^{-7}
59.3	1.42×10^{-7}	1.41×10^{-7}	1.39×10^{-7}	1.44×10^{-7}	5.66×10^{-7}	1.42×10^{-7}
45.3	1.36×10^{-7}	1.39×10^{-7}	1.32×10^{-7}	1.32×10^{-7}	5.32×10^{-7}	1.35×10^{-7}
34.4	1.29×10^{-7}	1.29×10^{-7}	1.29×10^{-7}	1.29×10^{-7}	5.18×10^{-7}	1.29×10^{-7}

Anova: Single Factor

SUMMARY

Groups	*Count*	*Sum*	*Average*	*Variance*
Row 1	4	6.85	1.7125	0.000625
Row 2	4	5.66	1.415	0.000433
Row 3	4	5.39	1.3475	0.001158
Row 4	4	5.16	1.29	0

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Treatment	0.423725	3	0.141242	254.8722**	3.96E-11	3.490295
Error	0.00665	12	0.000554			
Total	0.430375	15				

Table 17. Statistical analysis (ANOVA) of thermal diffusivity for medium cavendish banana

** Highly significant at P≥0.05 LSD = (0.0363)

Table 18. Values of Specific Heat

ITEM	Specific heat (J kg^{-1} $^{o}C^{-1}$)
Water	4200.0
Aluminium fold	898.6
Copper calorimeter	389.7