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Thermal Properties and Energy Utilization of Cassava Meal in Conductive Rotary Drying

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Abstract In this study the thermal properties and drying behaviour of cassava meal in a conductive rotary dryer was investigated. Cassava flour and gelatinized *gari* were produced at drying temperatures of 70°C and 90°C, respectively. The activation energy of cassava meal was 49.52 kJ/mol, and the effective moisture diffusivity, thermal conductivity and heat capacity increased with temperature from 1.74×10^{-10} to 4.51×10^{-10} m^2/s, 0.329 to 0.344 W/m°C and 1.804 to 1.901 kJ/kg°C, respectively. With increase in bulk density of cassava meal from 379.50±2.55 to 464.79±30.38 kg/m^3, thermal diffusivity and specific energy consumption decreased from 4.81×10^{-7} to 3.89×10^{-7} m^2/s and 618.88 to 456 kJ/kg, respectively. The thermal efficiency of the dryer was greater than 31% for both cassava flour and *gari*. Compared with previous works, performance of the conductive rotary dryer was satisfactory and upgrade of its design will make it suitable for application in the cassava processing industry.

Keywords: *thermal properties, energy consumption, cassava meal, conductive rotary dryer*

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1. Introduction

Drying is one of the many food processing and preservation activities involving heat transfer. Food properties such as thermal conductivity, specific heat capacity and thermal diffusivity affect the thermal efficiency of food drying equipment. Understanding the thermal properties and behaviour of foods during drying is therefore important for optimum design and application of dryers [1]. Thermal conductivity (k) is the ability of a material to conduct heat. In porous food materials thermal conductivity depends mostly on proximate composition but other factors such as void ratio, shape and size, and moisture content also affect the property. Thermal conductivity of food materials vary between that of water (0.614 W/m°C at 27°C) and that of air (0.026 W/m°C at 27°C). Models have been developed to predict the thermal conductivity of food materials but product specific factors must be considered in their application [2,3,4]. Specific heat (C_p) is the amount of heat required to increase the temperature of a unit mass of material by one degree (J/kg°C) and therefore depends largely on the process of heating (either by constant pressure or constant volume). However because pressure changes in heat transfer processes of agricultural materials are small, the specific heat at constant pressure is assumed [5]. Like thermal conductivity, specific heat of food materials depend on their composition and therefore knowing the specific heat of each component is sufficient to predict the specific heat of the composite food material [6]. The predictive models for specific heat are generally valid if there is no phase change during the heat transfer process [4]. Thermal diffusivity (α) is more of a physical property of foods which is associated with heat flow, and it measures the ability of a material to conduct heat relative to its ability to store thermal energy. Materials with large thermal diffusivity will respond more quickly to changes in ambient temperature and vice versa. Thermal diffusivity can be calculated indirectly from thermal conductivity, density and specific heat of a food material [1].

Cassava (*Manihot esculenta* Crantz.) is a root crop that is popular for its rich source of carbohydrate. The crop is widely grown in tropical countries of Africa and Nigeria is the largest producer of cassava in the world with an estimated annual production of 40 million metric tonnes [7]. The utilization of cassava includes domestic and industrial applications. *Gari* a toasted granular meal is the most popular foodstuff produced from fermented cassava and unfermented cassava flour is a versatile raw material widely utilized in the textile, pharmaceutical and confectionary industries [8,9]. Processing of fresh cassava tubers into *gari* and cassava flour are similar [10]. At the final stage of processing, dewatered and pulverized meal of cassava with moisture content of 40 – 50 % (wet basis) is heated up and dried to produce *gari* or cassava flour respectively [11,12].

Drying of cassava meal is a challenge among many cassava producing countries where the tubers are processed manually by drudgery-laden traditional methods. Thin layer sun-drying and direct roasting of cassava meal in hot frying pan are common practices among cassava processors [13]. However the demand for *gari* and cassava flour is increasing worldwide and the need for industrial processing of cassava at commercial scale requires the development of cost-effective technologies which are capable of increasing production capacities and quality of the cassava products [14]. Convective rotary dryers have been developed for drying various agricultural and non-agricultural materials and their application in the drying industry have been widely studied [15]. The use of conductive rotary dryer for drying cassava is feasible [16], but its application in the cassava processing industry is yet to be fully exploited.

A conductive rotary dryer was developed for drying pulverized cassava meal in the Department of Agricultural and Environmental Engineering, Obafemi Awolowo University, Ile-Ife, Nigeria [14]. The dryer's operational parameters such as drum temperature and vapour extraction rate (air flow rate) can be regulated. Its performance evaluation showed that good quality cassava flour and *gari* were produced at specific levels of the dryer parameters [12,17]. However, the thermal properties, thermal behaviour of the cassava meal and thermal efficiency of the dryer were yet to be investigated. This work aims at determining the thermal properties and behaviour of cassava meal under different operational settings of the conductive rotary dryer. The energy utilization and thermal efficiency of the dryer were also determined.

2. Materials and Methods

2.1. Operation of Conductive Rotary Dryer

A conductive rotary dryer described by Sanni *et al.* [17] was used for drying cassava meal from its initial moisture content (M_i) to final moisture content (M_f). Rotation of the stainless drum made the internal flights to continuously lift up the wet cassava meal and the particles were dispersed in a cascading motion throughout the drying time (*t*). The surface of the drum was maintained at constant temperature (T_d) and the activation energy (E_a) required for vaporization of moisture was absorbed by contact between the cassava and heated surface of the drum. Vapour from the cassava meal was continuously expelled by suction through a central duct covered with filter cloth. The continuous extraction of vapour from the drying chamber created a vapour pressure gradient which aided the effective moisture diffusivity (D_{eff}) in the cassava granules. The system compared well with thin-layer drying [18] and the thermal conductivity was predicted using the parallel model as described by Maroulis *et al.* [19].

2.2. Sample Preparation and Drying Experiments

Cassava meal used for the drying experiments was prepared using the method similar to that of Nwabanne [20] and Ademiluyi and Puyate [13], but with slight modification. Fresh cassava tubers (TMS 30572 variety) were peeled, washed and grated to produce a watery mash which was pressed to extract the free water content. The compressed cake was pulverized and sieved in a 3 mm aperture screen to remove the fibrous content. The initial moisture content of the granular cassava meal was determined using oven-drying method [21]. Six drying experiments were performed under different dryer parameters as shown in Table 1 and used to study the drying kinetics of cassava meal in the conductive rotary dryer.

Table 1. Drying experiments using conductive rotary dryer

Experiment	Dryer parameters				
	No. of flights	Drum speed (rpm)	Batch quantity, Q_b (kg)	Vapour extraction rate, R_v (m^3/s)	Drum temp., T_d (^0C)
1	2	20	5	0.0075	140
2	2	20	5	0.03	200
3	2	20	8	0.03	140
4	2	20	8	0.0075	200
5	2	20	8	0.03	200
6	2	20	5	0.0075	200

Each of the drying experiments was run for 60 minutes to allow for bone drying, and small samples of cassava meal were collected at 5 minutes interval for moisture content determination using oven drying method. Experiments 3 and 6 were repeated and run for 45 and 25 minutes to produce cassava flour and *gari*, respectively. The temperature of the two products was determined towards the end of drying, using a digital temperature meter (MASTECH MS6500; -50°C – 750°C measuring range). Bulk density of the dried cassava meals was determined using the method described by [22] and samples from the two products were taken to the Chemical Analysis laboratory of Faculty of Agriculture where their proximate compositions were determined using the method described by AOAC [21].

2.3. Evaluation of Effective Diffusivity and Activation Energy

The moisture ratio, MR was calculated from the expression M_t/M_i, where M_t was the moisture content of cassava meal during drying and M_i was the initial moisture content [23]. The moisture contents and moisture ratios were plotted against drying time (t) to generate drying curves. Because the drying of cassava meal was in the falling rate period [13, 22] the effective moisture diffusivity (D_{eff}) of the cassava meal was determined from Fick's diffusion law of Eq. (1) according to the method used by Radhika *et al.* [24].

$$MR = \frac{6}{\pi^2}\sum_{n}^{\infty}\frac{1}{n^2}\exp\left(\frac{-n^2 D_{eff}\pi^2 t}{r^2}\right) \quad (1)$$

where, MR is dimensionless moisture ratio, D_{eff} is the effective moisture diffusivity (m^2/s), r is the average grain radius of the cassava granules (0.0015m) and t is the drying time. According to [25] for relatively long drying time Eq. (1) was simplified to Eq. (2).

$$\ln MR = \ln\frac{6}{\pi^2} - \left(\frac{\pi^2}{r^2}\right) D_{eff}\, t \quad (2)$$

lnMR was plotted against drying time and effective moisture diffusivity, D_{eff} at each temperature was calculated from the slope [26] using Eq. (3).

$$D_{eff} = S_d\left(\frac{r^2}{\pi^2}\right) \quad (3)$$

where, S_d is the slope of the straight line plot of D_{eff} against time. The temperature dependence of effective moisture diffusivity was described by the Arrhenius type relationship as shown in Eq. (4).

$$D_{eff} = D_o \exp\left(-\frac{E_a}{RT}\right) \quad (4)$$

where, D_o is the pre-exponential Arrhenius diffusivity (m^2/s), E_a is the activation energy (kJ/mol), R is the universal gas constant (8.314 J/mol.K) and T is the absolute temperature of the cassava meal taken as its final drying temperature. Using the method of Khawas *et al.* [27], $\ln D_{eff}$ was plotted against 1/T and the activation energy, E_a was derived from the slope, S_e, as presented in Eq. (5).

$$E_a = S_e R. \quad (5)$$

2.4. Thermal Properties of Cassava Meal

The thermal conductivity (k) and specific heat capacity (C_p) of cassava meal were estimated from predictive empirical models based on proximate composition. The thermal conductivities of water, carbohydrate, protein, fat and ash were empirically predicted as functions of temperature [2]. According to Sanni *et al.* *[18]*, drying of cassava granules in the conductive rotary dryer obeyed the Logarithmic thin-layer drying model and because of the isotropic physical structure of the cassava granules, the parallel energy flow model was used to determine their effective thermal conductivity [1] as presented in Eq. (6) and Eq. (7).

$$k = \sum_{i}^{n} k_i X_i^v \quad (6)$$

$$X_i^v = \frac{\left(\frac{X_i^w}{\rho_i}\right)}{\sum_{i=1}^{n}\left(\frac{X_i^w}{\rho_i}\right)} \quad (7)$$

where, k is the effective thermal conductivity of cassava meal, X_i^v and X_i^w are volume fractions and mass fractions of the *i*th component respectively, n is the number of components and k_i is the thermal conductivity of the *i*th component, ρ_i is the density (kg/m^3) of the *i*th component.

The specific heat capacity (C_p) of cassava meal was estimated using the model of Choi and Okos [2] as presented in Eq. (8). Thermal diffusivity (α) of the cassava meal was calculated using Eq. (9) as reported by Nwabanne [20].

$$C_p = \sum_{i}^{n} X_i^w C_{pi} \quad (8)$$

$$\alpha = \frac{k}{\rho C_p} \quad (9)$$

where, C_{pi} is the specific heat of the *i*th component (J/kg°C); ρ is the density of dried cassava meal (kg/m^3), k and C_p are thermal conductivity and specific heat of cassava meal, respectively.

2.5. Energy Consumption and Thermal Efficiency of Dryer

Thermal efficiency is one of the most important performance indicators of a dryer and it was determined from the method used by Moreno *et al.* *[28]* but modified for the batch dryer used in this work. The useful heat energy (Q_u) consumed in the drying process was calculated as the energy required to raise the temperature of cassava meal plus the energy required for vaporization and drying. The useful energy consumed for drying is expressed in Eq. (10).

$$Q_u = W_c C_c (T_f - T_i) + W_d h_{fg} (M_i - M_f) \quad (10)$$

where, W_c is mass of wet cassava meal introduced in the dryer (kg), C_c is the specific heat capacity of wet cassava meal (kJ/kg°C) which was derived from the model of Choi and Okos [2], T_f is the final drying temperature of cassava meal (°C), T_i is the initial temperature of cassava meal which was 25°C, W_d is the mass of dry matter content of cassava meal (kg), h_{fg} is the heat of vaporization of water at the drying temperature (kJ/kg), M_i and M_f are initial and final moisture contents of the cassava meal (% wet basis). Data from repeated experiments 3 and 6 which produced un-gelatinized flour and gelatinized *gari* were used.

The thermal efficiency (η_t) of the conductive rotary dryer was calculated from the ratio of useful energy consumed to the actual energy dissipated by the heat source of the dryer [28]. The heat source of the dryer comprised of six electrical heating elements of 1,800 W each. The actual heat dissipated during each drying process was separated into two parts namely, the time taken for the stainless drum to heat up from room temperature to the desired temperature level and the time for drying the cassava meal from its initial moisture content to the final moisture content. The actual heat dissipated was estimated by recording the time fraction of each heat transfer period during which the heating elements were powered. According to Sanni [14], it took 4.5 minutes and 2 minutes for the drum to reach 200°C and 140°C respectively. Experiments in which the vapour extraction rate was 0.03 m^3/s, the heating elements were on for approximately 45% of the drying time, and 25% for experiments with 0.0075 m^3/s vapour extraction rate. For each drying experiment therefore, Eq. (11) and Eq. (12) were used to estimate the actual heat energy dissipated.

$$Q_a = (2.92 + 0.162t) \times 10^3 \quad (11)$$

for experiments using 0.0075 m^3/s

$$Q_a = (1.30 + 0.292t) \times 10^3 \quad (12)$$

for experiments using 0.03 m^3/s

where Q_a is the actual heat dissipated by the heating elements (kJ) and t is the drying time (minutes) taken for the cassava to reach the desired final moisture content. The thermal efficiency (η_t) of the dryer for each drying process was calculated using Eq. (13).

$$\eta_t(\%) = \frac{Q_u}{Q_a} \times 100. \quad (13)$$

3. Results and Discussions

The drying curves of the six drying experiments are presented in Figure 1 and the respective time taken for each batch of cassava meal to reach 10% moisture were read off as 44, 19, 47, 40, 32 and 24 minutes. The final drying temperature of cassava meal at drum temperature of 140°C and 200°C were approximately 70°C and 90°C, respectively. Sanni *et al.* [12,17] showed that drum temperature of the dryer had the greatest effect on the drying process and this explains why experiments 1, 3 and 4 took longer drying times and produced un-gelatinized, white and bland cassava flour with swelling index below 2.0. Experiments 2, 5 and 6 which were run at 200°C drum temperature had shorter drying times and produced gelatinized cassava flour known as *gari*.

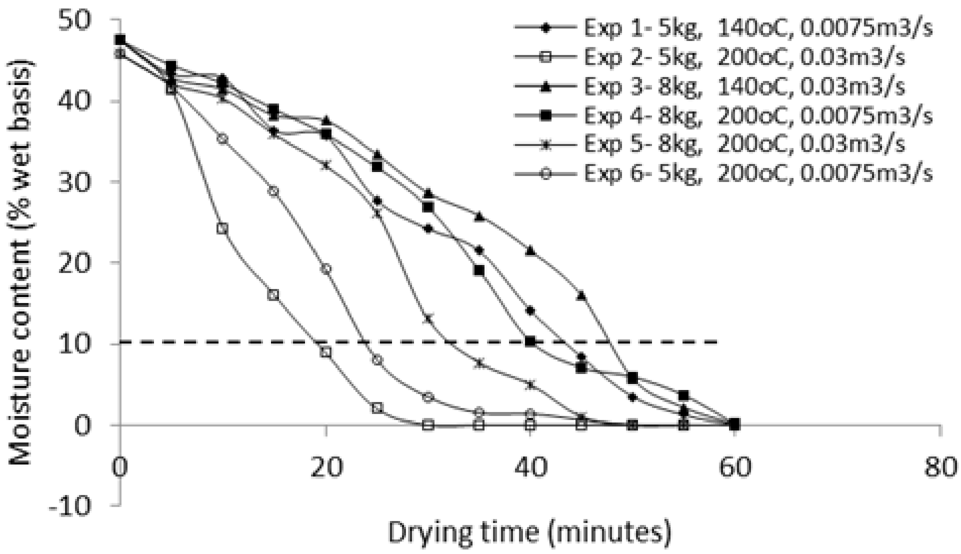

Figure 1. Drying curves of cassava meal under different drying conditions

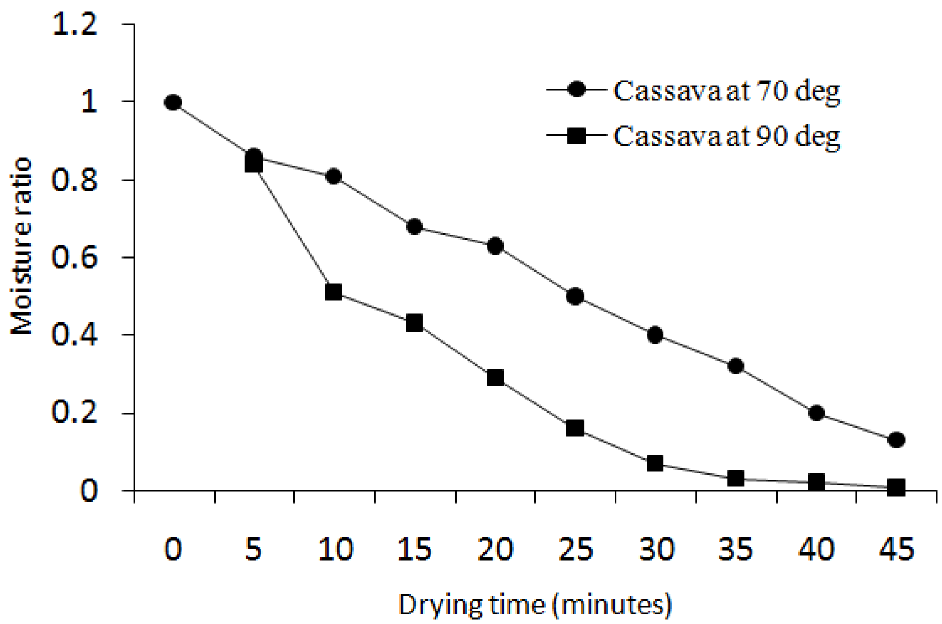

Figure 2. Averaged moisture ratio curves for cassava meal

The averages of moisture contents of cassava meal dried at drum temperatures of 140°C (cassava temperature of 70°C) and 200°C (cassava temperature of 90°C), were used to calculate moisture ratios which were plotted against drying time as presented in Figure 2. The drying curves represented un-gelatinized cassava flour and gelatinized *gari*, respectively. The categorization of the drying curves into two distinct products was to take care of the combined effects of drum temperature, batch quantity and vapour extraction rate on drying kinetics.

The two drying curves exhibited the falling rate drying period which is characteristic of agricultural and food materials [23,29]. At higher temperature, drying of cassava at temperature above its gelatinization point was observed to exhibit double falling rate period. The plots of lnMR against drying time, for both cassava flour and *gari* are shown in Figure 3.

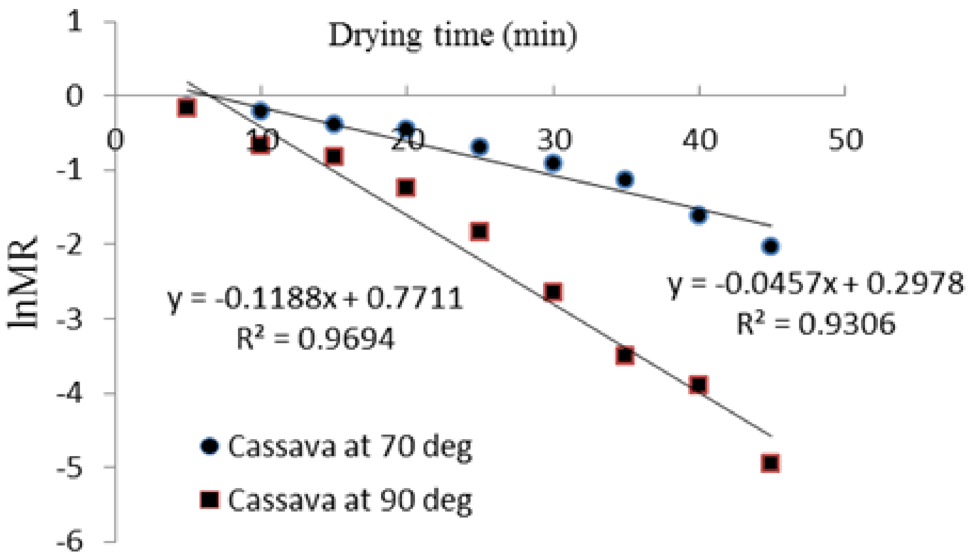

Figure 3. Graphs of lnMR versus drying time

From the slopes of the linear regression lines (0.0457 and 0.1188), the effective moisture diffusivities for cassava flour and *gari* were calculated to be 1.74 x 10^{-10} m^2/s and 4.51 x 10^{-10} m^2/s, respectively. In convective drying of the same variety of cassava meal (TMS 30572), Ademiluyi and Puyate [13] reported values of $1.32x10^{-9}$ to $3.52x10^{-9}$ m^2/s at air temperature range of 115°C to 230°C. This further confirmed that effective diffusivity of biological materials increases with temperature [25,30]. The values also fell within the range 10^{-9} m^2/s and 10^{-11} m^2/s reported for food materials [26]. Ajala *et al.* [31] reported lower diffusivity values of $2.43x10^{-11}$, $3.45x10^{-11}$, and $4.52x10^{-11}$ m^2/s for cassava chips dried at 60, 70 and 80°C, respectively.

The Arrhenius relationship of Eq. (4) was used to plot lnD_{eff} of the cassava meal diffusion kinetics against 1/T as presented in Figure 4. The slope of the line (5956.2) was inserted into Eq. (5) and the activation energy of cassava meal was 49.52 kJ/mol. This value compares favourably with activation energies of other agricultural materials reported in literature. Ajala *et al.* [31] reported 30.30 kJ/mol for cassava chips and Chayjan *et al.* [23] reported values ranging between 18.57 to 50.74 kJ/mol for corn dried at 50 to 95°C.

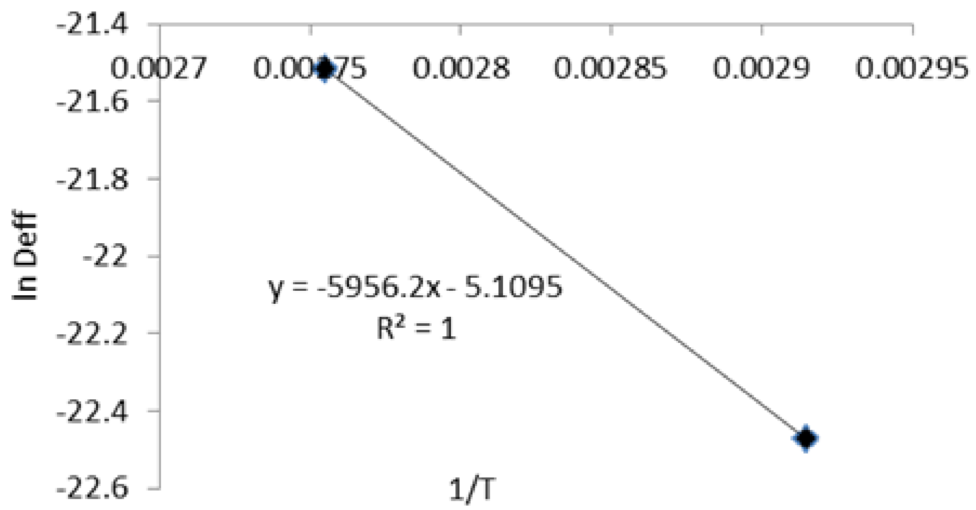

Figure 4. Linear graph of lnD_{eff} against 1/T

The thermal conductivities of cassava meal at 70°C and 90°C were derived from predictive models [2,32] as presented in Table 2 and Table 3 respectively. Un-gelatinized cassava flour which was dried at a lower temperature of 70°C had a thermal conductivity of 0.329 W/m°C and the gelatinized *gari* that was dried at a higher temperature of 90°C had a higher thermal conductivity of 0.344 W/m°C. The values fall within the range of 0.614 W/m°C for water and 0.026 W/m°C for air as expected for food materials [1]. The higher value of thermal conductivity for *gari* can be attributed to the slightly higher moisture content of 8.96 % and the higher drying temperature of 90°C, as corroborated in literature. Nwabanne [20] used the predicted model proposed by Sweat [33] where the average value was 0.24 W/m°C for three varieties of cassava meal.

Table 2. Component-based properties of cassava meal at 70°C

Component	Mass fraction (%)	[a]Density (kg/m^3)	Specific volume (m^3/kg)	Volume fraction	[b]Thermal conductivity (W/m °C)	$\mathbf{k_i X_i^v}$ (W/m °C)
Water	8.78	978.99	8.97x10^{-5}	0.14	0.6616	0.093
Carbohydrate	82.37	1577.37	5.2x10^{-4}	0.82	0.2773	0.227
Protein	1.97	1293.71	1.52x10^{-5}	0.02	0.2492	0.005
Fat	0.67	896.36	7.47x10^{-6}	0.01	0.0134	0.0001
Ash	1.29	2404.16	5.37x10^{-6}	0.01	0.4134	0.0041
Total:			**6.38x10^{-4}**	**1.0**		**0.329**

[a]Choi and Okos (1985); [b]Choi and Okos (1986).

Table 3. Component-based properties of cassava meal at 90°C

Component	Mass fraction (%)	[a]Density (kg/m^3)	Specific volume (m^3/kg)	Volume fraction	[b]Thermal conductivity (W/m °C)	$\mathbf{k_i X_i^v}$ (W/m °C)
Water	8.96	967.03	9.27x10^{-5}	0.14	0.6754	0.095
Carbohydrate	86.80	1571.16	5.52x10^{-4}	0.82	0.2913	0.239
Protein	1.88	1283.34	1.47x10^{-5}	0.02	0.2644	0.005
Fat	0.33	888.01	3.72x10^{-6}	0.01	0.0692	0.0007
Ash	1.69	2398.54	7.05x10^{-6}	0.01	0.4322	0.0043
Total			**6.70x10^{-4}**	**1.0**		**0.344**

[a]Choi and Okos (1985); [b]Choi and Okos (1986).

Table 4 shows the temperature dependence of specific heat values for cassava meal which were derived from the predictive model of Choi and Okos [2]. Specific heat for cassava meal at drying temperatures of 70°C and 90°C were 1.804 kJ/kg°C and 1.901 kJ/kg°C, respectively. Nwabanne [20] reported values of 1.40 to 1.45 kJ/kgK for bone dry cassava meal from three cultivars and Ademiluyi *et al.* [34] obtained values of 1.085 to 1.284 kJ/kgK for bone dry cassava meal. The higher values of specific heat in this study can be attributed to the higher moisture content of the cassava meal.

Table 4. Specific heat of cassava meal in indirect rotary drying

Food component	Cassava flour at 70°C			*Gari* at 90°C		
	Mass fraction	*Specific heat (J/kg°C)	$C_{pi}X_i^w$ (J/kg°C)	Mass fraction	Specific heat (J/kg°C)	$C_{pi}X_i^w$ (J/kg°C)
Water	0.0878	4196.66	368.47	0.0896	4212.35	377.43
Carbohydrate	0.8237	1657.07	1364.93	0.8680	1677.31	1455.91
Protein	0.0197	2086.39	41.10	0.0188	2106.37	39.60
Fat	0.0067	2061.29	13.81	0.0033	2074.67	6.85
Ash	0.0129	1206.83	15.57	0.0169	1232.84	20.83
Total			**1803.88**			**1900.62**

*Choi and Okos (1986).

The bulk density of cassava meal from experiments 3 and 6 which produced flour and *gari* was 379.50±2.55 kg/m^3 and 464.79±30.38 kg/m^3 respectively. The values were substituted in Eq. (9) to get thermal diffusivity of 4.81x10^{-7} m^2/s for cassava meal dried at 70°C and 3.89x10^{-7} m^2/s for cassava meal dried at 90°C. Thermal diffusivity of the cassava meal decreased with increase in bulk density despite the increase in drying temperature. This shows that density had a significant effect on the diffusion of energy during contact or indirect drying of cassava meal. Moisture diffusivity in the cassava meal (1.74x10^{-10} m^2/s and 4.51x10^{-10} m^2/s) was lower than thermal diffusivity but directly proportional to bulk density. This indicates that in conductive or contact drying, less bulky cassava meal will diffuse heat faster, but more bulky cassava meal will diffuse moisture faster. Temperature gradient had greater effect on moisture diffusivity than thermal diffusivity.

The specific energy consumption and thermal efficiency of the conductive rotary dryer were calculated from the data in Table 5. The specific energy consumption for producing un-gelatinized cassava flour and gelatinized *gari* was 618.88 kJ/kg and 456 kJ/kg, respectively. Thermal efficiency of the conductive rotary dryer was 31.17% when used to dry 8kg of cassava meal at drum temperature of 140°C and vapour extraction rate of 0.03 m^3/s. At drum temperature of 200°C, vapour extraction rate of 0.0075 m^3/s and 5 kg of cassava meal, the dryer operated at a thermal efficiency of 32.71% to produce *gari*. The performance of the conductive rotary dryer falls within the range of 25 to 70% recommended for rotary dryers [15].

Table 5. Drying parameters of cassava meal in conductive rotary dryer

Parameters	Experiment 3: Cassava flour	Experiment 6: *Gari*
Drum temperature (°C)	140	200
Vapour extraction rate (m^3/s)	0.03	0.0075
Quantity of cassava (kg)	8	5
Drying time (min)	50	25
Specific heat (kJ/kg°C)	3.15	3.29
Drying temperature (°C)	70	90
Initial temperature (°C)	25	25
Initial moisture content (%)	47.48	45.79
Final moisture content (%)	8.78	8.96
Dry matter content (kg)	4.16	2.71
Heat of vaporization (J/g)	2,333.6 at 70°C	2,283.4 at 90°C
Useful energy consumed (kJ)	$4.951x10^3$	$2.280x10^3$
Actual energy dissipated (kJ)	$15.88x10^3$	$6.97x10^3$

4. Conclusion

The study shows that the conductive rotary dryer was suitable for drying fresh cassava meal at different operational parameters. The drying behaviour and thermal properties of cassava flour and *gari* which were dried at 70°C and 90°C respectively compared well with similar works in literature. Though most of other drying experiments were designed to investigate the effect of convective or hot air drying, this work specifically investigated the application and efficacy of indirect or contact drying principle in the technology of rotary drying with particular application to the cassava processing industry. The findings will be useful in upgrading the design of the dryer and make it more cost-effective for commercialization. When fully upgraded the conductive rotary dryer promises to find good application in cassava producing countries like Nigeria that are focusing on agro-industrial growth of their economies.

Statement of Competing Interests

The authors have no competing interests.

References

[1] Serpil, S and Servet, G. S, *Physical Properties of Foods*. Springer Science and Business Media, LLC, New York. 2006.

[2] Choi, Y. and Okos, M.R., “Effects of temperature and composition on thermal properties of foods,” *Journal of Food Process and Applications*, 1(1). 93-101. 1986.

[3] Murakami, E.G., and Okos, M.R., *Measurement and prediction of thermal properties of foods*. In: Food Properties and Computer-Aided Engineering of Food Processing Systems, (R.P. Singh and A.G. Medina, Eds.). Kluwer Academic, Dordrecht. 1989. 3-48.

[4] Rahman, M.S., *Food Properties Handbook*. New York: CRC Press. 1995.

[5] Mohsenin, N.N., *Physical properties of plant and agricultural materials*. Gordon and Breach Science Publishers, New York. 1980.

[6] Sweat, V.E, *Thermal properties of foods*. In: Engineering Properties of Foods, (M.A. Rao and S.S.H. Rizvi, Eds). 2nd Ed, Marcel Dekker, New York. 1995.

[7] Babatunde, J., *Reviving Nigeria’s economy through cassava plan*. Newspaper report attributed to Minister for Agriculture. Vanguard Newspaper, January 6, 2012.

[8] Irtwange, S.V and Achimba, O, “Effect of the Duration of Fermentation on the Quality of Gari,” *Current Research Journal of Biological Science*, 1(3). 150-154. 2009.

[9] Dziedzoave, N.T., Abass, A.B., Amao-Awua, W.K.S., Sablah, M, *Quality management manual for production of high quality cassava flour*, International Institute of Tropical Agriculture, Ibadan, Nigeria. 2006.

[10] Nweke, F.I., Spencer, D.S.C., Lynam, J.K., *The cassava transformation: Africa’s best kept secret*, Michigan State University Press, East Lansing, USA. 2002.

[11] CIGR, *Handbook of Agro-processing Engineering*. Volume IV. American Society for Agricultural Engineers. USA. 1999.

[12] Sanni L.A., Odukogbe O.O., Faborode M.O. and Ibrahim R.O, “Optimization of process parameters of a conductive rotary dryer for gari production,” *Journal of Emerging Trends in Engineering and Applied Science*, 6(7). 255-261. 2015.

[13] Ademiluyi, F.T. and Puyate, Y.T, “Modeling drying kinetics of fermented ground cassava in a rotary drye,” *Transnational Journal of Science and Technology*, 3(5). 76-85. 2013.

[14] Sanni, L.A, *Studies on conductive rotary drying for industrial cassava processing*. Unpublished Ph.D. Thesis. Department of Agricultural and Environmental Engineering. Obafemi Awolowo University, Il-Ife, Nigeria. 2014.

[15] Taylor, R and Francis, W., *Handbook of Industrial Drying*. Taylor and Francis Group. LLC. 2006.

[16] Ademiluyi, F.T, *Development of predictive models for drying fermented ground cassava in a rotary dryer*. Unpublished PhD Thesis., Department of Chemical Engineering, Rivers State University of Science and Technology, Port Harcourt, Nigeria. 2009.

[17] Sanni, L.A., Ugoso, E.S., Faborode, M.O, “Effect of dryer parameters on drying characteristics and quality of cassava flour,” *African Journal of Food Science and Technology*, 6(7). 185-193. 2015.

[18] Sanni, L.A., Odukogbe, O.O., Faborode, M.O., Ibrahim, R.O, “Optimization of Process Parameters of a Conductive Rotary Dryer for *Gari* Production,” *Journal of Emerging Trends in Engineering and Applied Science*, 6(7). 255-259. 2015.

[19] Maroulis, Z.B., Saravacos, G.D., Krokida, M.K., Panagiotou, N.M, “Thermal conductivity prediction for foodstuffs: Effects of moisture content and temperature,” *International Journal of Food Properties*, 5. 231-245. 2002.

[20] Nwabanne, J.T, “Drying characteristics and engineering properties of fermented ground cassava,” *African Journal of Biotechnology*, 5(8). 873-876. 2009.

[21] AOAC, *Official methods of analysis of the Association of Official Analytical Chemists International*. 19th Edition, Washington D.C. P1094. USA. 2012.

[22] Owuamanam, C.I Ogueke, C.C, Achinewhu, S.C and Barimalaa, I.S, “Quality Characteristics of Gari as Affected by Preferment Liquor, Temperature and Duration of Fermentation,” *American Journal of Food Technology*, 6. 374-384. 2010.

[23] Chayjan, R.A., Parian, J.A., Esna-Ashari, M, “Modeling of moisture diffusivity, activation energy and specific energy consumption of high moisture content corn in a fixed bed and fluidized bed convective dryer,” *Spanish Journal of Agricultural Research*, 9(1). 28-40. 2011.

[24] Radhika, G.B., Satyanarayana, S.V. and Rao, D.G, “Mathematical Modelling on Thin Layer Drying of Finger Millet (*Eluesine coracana*),” *Advance Journal of Food Science and Technology*. 3(2). 127-131. 2011.

[25] Flores, M.J.P., Febles, V.G., Perez, J.J.C., Dominguez, G., Mendez, J.V.M., Gonzalez. E.P., Lopez, G.F.G., “Mathematical modelling of castor oil seeds (*Ricinus Communis*) drying kinetics in fluidized bed at high temperatures,” *Ind. Crop. Prod*, 38. 64-71. 2012.

[26] Bassene, P.T., Gaye, S., Talla, A., Sambou, V., Azilinon, D., “Experimental and modelling study of thin layer drying kinetics of pellets millet flour,” *African Journal of Agricultural Research*. 8(28). 3806-3813. 2013.

[27] Khawas, P., Das, A.J., Dash, K.K., Deka, S.C., “Thin-layer drying characteristics of *Kachkal* banana peel (*Musa* ABB) of Assam,” *India International Food Research Journal*, 21(3). 1011-1018. 2014.

[28] Moreno, R.M., Antolin, G., Reyes, A., “Thermal behaviour of forest biomass drying in a mechanically agitated fluidized bed,” *Latin American Applied Research*, 37. 105-113. 2007.

[29] Ademiluyi, F.T, Abowei, M.F.N., Puyate, Y.T. and Achinewhu, S.C., “Effects of Drying Parameters on Heat Transfer during Drying of Fermented Ground Cassava in a Rotary Dryer,” Drying Technology, 28(4). 550-561. 2010.

[30] Doymaz, I., “Convective drying kinetics of strawberry”. *Chem. Eng. Process.* 47. 914-919. 2008.

[31] Ajala, A.S., Ajala, F.A., Tunde-Akintunde, T.Y., “Study on drying kinetics of fermented corn grains,” *Food Science and Quality Management Journal*, 5. 10-17. 2011.

[32] Choi, Y. and Okos, M.R. *Effects of temperature and composition on thermal properties of foods*. Paper No. 9, Proceedings of the Fourth International Congress on Engineering and Food, Etnisnton, Alberta, Canada, July 7-10. 1985.

[33] Sweat, V.E., *Thermal properties of foods*. Macel Dekker Inc., New York, 1986.

[34] Ademiluyi, T., Abowei, M.F., Achinewhu, S.C., Fubara, T.T., “Effect of variety on the drying and engineering properties of fermented ground cassava,” *NEAM*, 1(1). 80-96. 2006.