Experimental Study of Drying Parameters of Ginger at Different Temperature and Moisture Content

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Abstract—Drying provides extended shelf life to agricultural crops in general and thus proper design of dryer will assist in drying them to acceptable level and quality. To design adequate dryer, necessary drying parameters of drying materials is necessary. This work involves experimental determination of effective drying parameters such as moisture content, moisture diffusion coefficient, density (true and bulk), specific heat, thermal conductivity and thermal diffusivity of ginger and to analyze these parameters in relation to each other. Fresh ginger rhizomes were washed to remove soil from the field, peeled and washed again in clean water and sliced into thin pieces. The sliced ginger was heat-treated by adding 200ml of clean water and steaming for 5–8 minutes in an aluminum pot, to a temperature of 85–90 °C, and a light brown colour. Microwave oven, calorimeter, desiccators, thermometers, triple beams balance, micrometer screw gauge were used to determine the drying parameters of ginger. Effect of temperature and moisture content on some thermal properties was determined. The results of the experiments show that average initial moisture content for the ginger samples was 72.31%, the true and bulk densities of the sample increased linearly from 0.5809 to 0.6338g/cm³ and 0.7405 to 0.7972 g/cm³ respectively between the temperatures of 45 – 75 °C. The specific heat capacity of ginger varied from a minimum of 1.568kJkg⁻¹K⁻¹ to a maximum of 2.026kJ kg⁻¹K⁻¹, with temperature in the range of 45°C to 75°C and moisture content in the range of 24.43 to 46.19 % (d.b). The thermal conductivity of ginger samples varied from 0.316×10⁻³ to 9.763×10⁻⁴ Jm⁻¹S⁻¹ °C; as the moisture content and temperature increased. Thermal diffusivity of the ginger increased linearly from 3.149×10⁻⁸ to 4.438×10⁻⁸ m²s⁻¹ with increase in moisture content and temperature. Conclusively, the experimental study analysis show that specific heat of ginger varies with temperature. Also, there is variation in length, breadth and thickness of ginger when subjected to temperature. Therefore, it can be said that ginger do shrinks when it is subjected to heat.

Index Terms—Dryer; Drying; Ginger; Moisture Content; Temperature; Thermal Conductivity.

I. INTRODUCTION

The ginger plant (*Zingiber Officinale* Roscoe) is a member of the *Zingiberaceae* family. It is a perennial, slender plant that grows to a height of 2 to 3 feet, from underground rhizomes in tropical and subtropical climates of Asia, Africa, India, Jamaica, Mexico, China, Australia and Haiti. It has grass-like leaves that may grow up to a foot in length. The flowers are white or yellowish-green. Ginger grows well where the soil is not waterlogged and the annual rainfall exceeds 1500mm. It requires rich soils and both

natural and artificial fertilizers may be added to obtain a good harvest. The rhizome that grows elongated underground is the useful part of the plant for human consumption. Ginger is used worldwide as a cooking Spice. It is an important spice used as a condiment in vegetable preparations. It is also an important ingredient in herbal medicines for the treatment of rheumatism, nervous diseases, gingivitis, toothache, asthma, stroke, constipation and diabetes [1]–[3]. The oil and oleoresins obtained from ginger are also used in many food items, soft drinks and beverages [4].

Fresh ginger is sold commercially without processing in the local market. Ginger that is freshly harvested has high moisture content of about 83% and this makes it susceptible to deterioration during transportation and therefore, there is need for a means of reducing the moisture contentment for its preservation [5]. Food preservation has been of tremendous help in agricultural industry because of its great importance in provision of food all year round, minimization of wastage and increase the income of the farmers. While it is undeniably important to increase yield of major food crop in many developing countries, an even greater increase in the amount of food available for human consumption could be realized by using appropriate food preservation method [6].

Drying is an operation in which a liquid, usually water, is removed from a wet solid in equipment termed dryers. The use of heat to remove liquids distinguishes drying from mechanical dewatering methods. Drying of foodstuffs is an important method of preservation and it is applicable to a wide range of industrial and agricultural product [7]. The reduced weight and bulk of dehydrated product and their dry shelf stability reduce products storage and distribution cost [8]. Drying is an energy intensive process which involves the removal of moisture from a crop until the moisture content of the crop is in equilibrium with the surrounding air. Crops are usually dried to a moisture content that will allow safe storage and/or further processing for example, milling. The drying behavior of different crops depends to a large extent on the physical characteristics of the crop, for example particle size, internal structure and composition.

Appropriate dryer design will assist in moisture reduction to a safe level and improve the quality of the dry products. Determination of physical and thermal properties of food crops is essential for appropriate dryer design. Thermo-physical characteristics of fruits and vegetable tissues knowledge are very important for control and evaluation of the quality of foods during their storage and processing. Both theoretical and empirical relationship used when designing or operating heat processes require knowledge of the thermal properties of the food under consideration. Food

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thermal properties can be defined as those properties controlling the transfer of heat in a specified food. Heat transfer involves the transfer of heat into or out of a food. There are three ways that heat can be transferred: by radiation, conduction or convection. A better understanding of the way food materials respond to physical and chemical treatments allows for optimum design of food equipment and processes to insure food quality and safety. The main thermo-physical characteristics are thermal conductivity K, thermal diffusivity D and apparent specific heat C. These are interrelated [9].

Experimental study of drying parameter of various agricultural crops is widely used in agricultural engineering research. Several experiments have been proposed to describe the experimental study and parameters process involved in drying of agricultural product. Hence this project is to provide an experimental study of drying parameter of ginger.

II. MATERIALS AND METHODS

A. Sample Preparation

Fresh ginger (*Zingiber officinale*) was purchased at a local market in Ogbomoso, Nigeria. Ginger rhizomes were washed to remove soil from the field, peeled and washed again in clean water and sliced into thin pieces. Five hundred (500) grams of the sliced ginger was heat-treated by adding 200ml of clean water and steaming on the largest ring of a kitchen gas cooker for 5–8 minutes in an aluminum pot, to a temperature of 85–90 °C, and a light brown colour. Two hundred and fifty (250) grams of the heat-treated ginger were dried in an oven (Carbolite 22265, Fison Way, Thetford U.K.), at 56–60°C for 24–26 hours to a moisture content of 9.9–12.2%. The moisture content was determined in triplicates using a moisture balance (Adam Equipment AMB 310, U.K.). A few slices (16.7– 18.5g) of ginger were placed and spread evenly on the weighing pan of the balance, a drying temperature of 102°C was selected and the balance switched on. At steady conditions, the weight of the sample, drying time and moisture content in percentage were recorded. The other portion of 250g of heat-treated ginger slices were dried in the sun, on a solar tent, for 2–3 days in the dry season or 3–5 days in the rainy season to similar moisture content level as obtained when dried in the oven (9.9–12.2%). Two hundred and fifty (250) grams of raw sliced ginger were dried in the oven and another portion of 250 grams in the sun. The dried ginger was ground into powder using an electric kitchen blender (National MX-T2GN, China) and sieved through a metallic sieve of calculated pore-size of 0.39 mm². All equipment that came in contact with samples were steam sterilized or swabbed with 70 % alcohol before use.

B. Moisture Content Determination

The moisture content of the samples was determined using AOAC [10] method. The sample was weighed into already weighed clean drying cans. The cans and the sample was placed in a well ventilated oven (Fisser Scientific Isotemp. oven, by Fisser Scientific Co. USA, Model 655F) maintained at 103 °C for 48 hours. This was repeated five times to obtain five different moisture contents (dry basis).

The percentage moisture content was calculated using the relation in reference [11]:

$$\% \text{ moisture cont. (MC)} = \frac{W^1 - W^2}{S} \cdot 100 \quad (1)$$

where: W₁ is weight of the empty can with the sample before drying (g), W₂ is weight of the empty can with the sample after drying (g) and S is weight of the sample (g)

$$\% \text{ moisture cont. (d. b)} = \frac{\text{Weight of water in product}}{\text{Weight of the dry matter of the sample}} \cdot 100 \quad (2)$$

C. Bulk and True Density

The bulk density of the selected samples was determined using the method described by [11] in which a 250ml volumetric cylinder was filled with samples of cut ginger and the weight of the samples was weighed. Bulk density was calculated using the ratio of the weight and the volume of the cylinder. Bulk density was calculated at each moisture level. True density is the ratio of the ginger sample mass to volume of compact powder without voids.

$$\rho_b = \frac{\text{Weight of sample}}{\text{Volume of container}} \quad (3)$$

where ρ_b is bulk density (g/cm³)

D. Thermal Diffusivity

The thermal diffusivity of the selected samples was calculated using the experimental data of thermal conductivity, specific heat capacity and bulk densities of the samples [12].

$$\alpha = \frac{K}{\rho_b C_p} \quad (4)$$

where α is thermal diffusivity (m²s⁻¹), K is thermal conductivity (Jm⁻¹s⁻¹ °C), and ρ_b is bulk density (g/cm³).

E. Thermal Conductivity

The thermal conductivity of the samples was determined using method of poor conductors as cited by [12]. In this method, a carbon steel of a known thickness and area was heated by steam from boiling water in a conical flask. The temperature of the carbon steel (hot) was measured until the temperature was constant (T₁). The temperature of the samples (cold), T₂ was measured and the sample was placed on the carbon steel while the thermometer was placed on the sample. The increase in temperature of the sample was recorded at two minutes interval for ten minutes. The slope of the graph of temperature against time was used to determine the thermal conductivity using the relation:

$$K_s = \frac{XMC}{(T_1 - T_2)AS} \quad (5)$$

where K_s is thermal conductivity of the sample (Jm⁻¹s⁻¹ °C), X is thickness of the sample (m), M is mass of sample (g), C is specific heat capacity of sample (Jg⁻¹ °C⁻¹), Q₁ is temperature of carbon steel (hot) °C, Q₂ is temperature of sample (cold) °C, A is area of carbon steel (equal to area of sample) (m²), S is slope of graph of temperature against time and C_p is specific Heat Capacity (Jg⁻¹ °C⁻¹).

F. Specific Heat Capacity

The method of mixture as described by Anyakoha [13] was used to obtain the specific heat capacity of the selected samples. A sample of known mass, temperature and moisture content was dropped into the copper calorimeter of a known mass containing water of known mass and temperature. The mixture was gently stirred. At equilibrium, the final temperature of the mixture was noted and recorded. The experiments were performed at temperatures of 45, 55, 65, 70 and 75°C. The specific heat capacity was calculated at different moisture level using the equation [13].

$$C_s = \frac{McC_c(T_f - T_1) + MwC_w(T_f - T_1)}{Ms(T_2 - T_1)} \quad (6)$$

where C_s , C_c and C_w are the specific heats capacity of samples, calorimeter, and water respectively ($\text{kJ kg}^{-1} \text{K}^{-1}$), Mc , Ms and Mw is the masses of calorimeter, samples and water respectively (kg), T_1 is the initial temperature of water (K) and T_2 is the initial temperature of samples (K).

G. Volume and Density Determination

The volume of Ginger of a known weight was determined by putting the sample in the cuboids of a known volume and the cuboids was filled with the sorghum grain. The ginger was removed while the volume occupied by the grains was measured in volumetric cylinder and the difference in the volume was calculated as a measure of the volume of the sample. The experiment was replicated three times and density was calculated using the ratio of the weight and the volume of the samples at different moisture level [11].

$$V_s = V_c - V_g \quad (7)$$

where V_s is Volume of the sample (cm^3), V_c is Volume of cuboid (cm^3) and V_g is Volume occupied by the grains (cm^3).

$$\text{Density } \rho = \frac{M}{V} \quad (8)$$

where ρ is density (g/cm^3), M is mass of the samples (g) and V is volume of the samples (cm^3).

The volume used for the true density of the ginger was determined by multiplying the length, width and thickness of a slice, which equal the volume of the sample. The weight was divided by the volume of the sample which gave the true density of the sample at each moisture level.

III. RESULTS AND DISCUSSION

A. Physical Properties

1) Moisture Content

The average initial moisture content for the Ginger samples were 72.31% as shown in Table I.

TABLE I: OVERALL AVERAGE INITIAL MOISTURE CONTENT OF GINGER

Sample label	Moisture Content (%)
A	75.098
B	69.359
C	75.636
D	69.136
Overall average	72.31

2) True and Bulk Densities of Ginger

The true and bulk densities of the sample increased linearly from 0.5809 to 0.6338 g/cm^3 and 0.7405 to 0.7972 g/cm^3 respectively between the temperatures of 45 – 75 °C. Visranathan[14] reported similar increase with moisture content for linseed and Neemnut. The variations in true and bulk densities of ginger were best explained in Table II and Fig. 1 and 2.

TABLE II: RELATIONSHIP BETWEEN MOISTURE CONTENT TO TRUE DENSITY AND BULK DENSITY

	MOISTURE CONTENT (% d.b)	TRUE DENSITY (g/cm^3)	BULK DENSITY (g/cm^3)
1	24.43	0.5809	0.7405
2	28.78	0.5902	0.7505
3	37.49	0.6088	0.7704
4	41.84	0.6181	0.7804
5	46.19	0.6338	0.7972

Fig. 1. Effect of moisture content on true density of Ginger

Fig. 2. Effect of moisture content on bulk density of Ginger

The values of sample densities were very low which indicate that the samples will be less dense in water. The variation in True and bulk densities with moisture content can be expressed mathematically using the following regression equations:

$$\begin{aligned} \rho &= 0.522 + 0.002MC & r &= 0.995 \\ \rho_b &= 0.678 + 0.002MC & r &= 0.995 \end{aligned}$$

where, ρ is true density of Ginger sample (g/cm^3), ρ_b is bulk density (g/cm^3), and MC = Moisture content (% , d.b).

B. Thermal Properties

1) Specific Heat Capacity

The variations in specific heat capacity of ginger with moisture content and temperature were explained in Fig. 3

and 4 respectively. The specific heat capacity of ginger varied from a minimum of $1.568 \text{ kJ kg}^{-1} \text{ K}^{-1}$ to a maximum of $2.026 \text{ kJ kg}^{-1} \text{ K}^{-1}$, with temperature in the range of 45°C to 75°C and moisture content in the range of 24.43 to 46.19 % (d.b).

As depicted in Table III and Fig. 3 and 4, an increasing trend in the specific heat capacity of the two samples was observed with increase in both moisture content and temperature.

TABLE III: RELATIONSHIP BETWEEN SPECIFIC HEAT CAPACITY TO M.C AND TEMPERATURE

	SPECIFIC HEAT CAPACITY (kJ/kg $^\circ\text{C}$)	MOISTURE CONTENT (% d.b)	TEMPERATURE ($^\circ\text{C}$)
1	1.568	24.43	45
2	1.649	28.78	55
3	1.810	37.49	65
4	1.890	41.84	70
5	1.203	46.19	75

Fig.3. Effect of moisture content on specific heat capacity of Ginger

Fig. 4. Effect of temperature on specific heat capacity of Ginger

For Ginger:

$$C_p = 1.064 + 0.02MC \quad r = 0.993$$

$$C_p = 0.86 + 0.015T \quad r = 0.979$$

where C_p is Specific heat capacity ($\text{kJ kg}^{-1} \text{ K}^{-1}$), T is Temperature ($^\circ\text{C}$), r is Correlation coefficient and MC is Moisture content (% , d.b)

With the regression equations it was shown that there is a strong linear relationship between specific heat capacity, moisture content and temperature; and that, the specific heat capacity was dependent on moisture content and temperature of the samples.

The specific heat capacity of dairy cattle manure varied from 1.9925 to $3.606 \text{ kJ kg}^{-1} \text{ K}^{-1}$ at the temperature range of 40 to 60°C and moisture content ranged from 20 to 82%

(w.b), respectively [15]. Tansakul and Lumyong [16] research revealed that the specific heat capacity of mushroom varied from 2.284 to $4.008 \text{ kJ kg}^{-1} \text{ K}^{-1}$ at temperature range of 30 to 80°C and moisture content range of 30 to 90% (w.b) respectively.

2) Thermal Conductivity

The thermal conductivity of ginger samples varied from 0.316×10^{-3} to $9.763 \times 10^{-4} \text{ J m}^{-1} \text{ S}^{-1} \text{ }^\circ\text{C}$; as the moisture content and temperature increased. Similar trend was observed in the investigations of Oluka and Bardey [12] in which the thermal conductivity of pigeon pea flour paste varied from 0.566 to $0.800 \text{ J m}^{-1} \text{ S}^{-1} \text{ }^\circ\text{C}$. Aviara and Haque [17] investigation showed that the thermal conductivity of whole and ground seed kernel of guna seed increased from 0.0711 to 0.1282 and from 0.087 to $0.1260 \text{ W m}^{-1} \text{ S}^{-1}$, as the moisture content and temperature increase.

The changes in the thermal conductivity of the ginger with moisture content at different temperatures are presented in Table IV and Fig. 5 and 6; it was shown that the thermal conductivities increased with increasing moisture content and temperature.

TABLE IV: RELATIONSHIP BETWEEN THERMAL CONDUCTIVITY, MOISTURE CONTENT AND TEMPERATURE

	THERMAL CONDUCTIVITY (J/m/s $^\circ\text{C}$) $\times 10^{-3}$	MOISTURE CONTENT (% d.b)	TEMPERATURE ($^\circ\text{C}$)
1	0.316	24.43	45
2	0.432	28.78	55
3	0.664	37.49	65
4	0.780	41.84	70
5	0.976	46.19	75

Fig. 5. Effect of moisture content on thermal conductivity of Ginger

Fig. 6. Effect of temperature on thermal conductivity of Ginger

The relationship existing between thermal conductivity of the two residues with moisture content and temperature can be expressed mathematically using the following regression

equations:

For Ginger:

$$K = 0.410 + 0.029MC \quad r = 0.994$$

$$K = 0.705 + 0.021T \quad r = 0.980$$

Where is C_p is Specific heat capacity ($\text{kJ kg}^{-1}\text{C}^{-1}$), T is Temperature ($^{\circ}\text{C}$), r is Correlation coefficient and MC is Moisture content (% d.b).

The simple regression analysis showed that there is a linear relationship between thermal conductivity, temperature and moisture content of the ginger and that the thermal conductivity was dependent on moisture content and temperature.

3) Thermal Diffusivity

The change of thermal diffusivity of ginger with moisture content and temperature presented in Table V and Fig. 7 and 8; shows that the thermal diffusivity of the ginger increased linearly from 3.149×10^{-8} to $4.438 \times 10^{-8} \text{ m}^2\text{s}^{-1}$ for ginger with increase in moisture content and temperature. Similar trend was reported for the thermal diffusivity of borage seeds in [18].

TABLE V: RELATIONSHIP BETWEEN THERMAL DIFFUSIVITY TO M.C AND TEMPERATURE

	THERMAL DIFFUSIVITY ($\text{m}^2/\text{s}) \times 10^{-8}$	MOISTURE CONTENT (% d.b)	TEMPERATURE ($^{\circ}\text{C}$)
1	3.149	24.43	45
2	3.376	28.78	55
3	3.829	37.49	65
4	4.055	41.84	70
5	4.438	46.19	75

Fig. 7. Effect of thermal diffusivity on moisture content of Ginger

Fig. 8. Effect of temperature on thermal diffusivity of Ginger

The relationship existing between thermal diffusivity of the two residues with moisture content and temperature can be expressed mathematically using the following regression equations:

For ginger:

$$\alpha = 1.711 + 0.057MC \quad r = 0.994$$

$$\alpha = 1.155 + 0.642T \quad r = 0.980$$

where α is Thermal diffusivity (m^2s^{-1}), T is Temperature ($^{\circ}\text{C}$), r is Correlation coefficient and MC is Moisture content (% d.b)

The regression equations showed that there is a linear relationship between thermal diffusivity, temperature and moisture content of the ginger.

Determination of Shrinkage

Sample A -Weight of can = 19.47

Sample B - weight of can = 19.45

TABLE VI: RESULT OF INITIAL VALUE (WEIGHT, LENGTH, BREADTH AND THICKNESS)

	Sample A	Sample B
Initial Weight (W_o) (g)	33.10	27.13
Initial Length (L_o) (mm)	53.00	32.00
Initial Breadth (B_o) (mm)	30.25	12.15
Initial Thickness (T_o) (mm)	13.16	16.17

There is variation in l , b , t , of gingers when subjected to heat, therefore, it can be said that ginger do shrinks when subject to heat. This is necessary when designing and modelling the drying process of ginger.

TABLE VII: RESULT OF WEIGHT, LENGTH, BREATH AND THICKNESS AFTER THREE HOURS

	D_b after 1 hour				D_b after 2 hours				D_b after 3 hours			
	W1	L1	B1	T1	W2	L2	B2	T2	W3	L3	B3	T3
Sample A	30.89	5200	25.23	12.14	28.42	50.5	25.21	11.13	28.30	50.00	25.10	11.08
Sample B	25.39	31.00	10.13	15.16	23.86	30.00	9.11	15.13	23.52	30.00	9.06	15.10

IV. CONCLUSIONS

An evaluation has been carried out on determination of physical and thermal properties of ginger. The varied moisture contents for the samples were varied between 24.43 to 46.19 % (d.b) of temperature between 45 to 75°C respectively.

It was observed that the true and bulk densities for the ginger were dependent on moisture content. An increase in

the moisture content led to increase in true and bulk densities of the samples. This shows that there is a positive correlation between density (true and bulk) and moisture content of the samples. Also, the values obtained for the bulk densities of the ginger were greater than their true densities which imply that more of this sample can be transported in bulk or packed when they are to be consumed or used for manufacturing purposes.

The thermal properties of ginger samples were strongly

dependent on moisture content and temperature. The specific heat capacity of the ginger increased with both moisture content and temperature between $1.568 \text{ kJ kg}^{-1} \text{ K}^{-1}$ to $2.026 \text{ kJ kg}^{-1} \text{ K}^{-1}$.

The value of the thermal conductivity lies between 0.316×10^{-3} to $9.763 \times 10^{-4} \text{ J m}^{-1} \text{ s}^{-1} \text{ }^{\circ}\text{C}$ for ginger between the temperature range of $45 - 75 \text{ }^{\circ}\text{C}$. The values obtained for the thermal conductivity of the sample were very low which indicates that the samples were poor heat conductors.

An increasing trend in the thermal diffusivity of the sample were observed with increase from 3.149×10^{-8} to $4.438 \times 10^{-8} \text{ m}^2 \text{ s}^{-1}$ between the temperature of $45 - 75 \text{ }^{\circ}\text{C}$ which implies that there is a linear relationship between temperature, moisture content and thermal diffusivity of the sample. The simple regression equations show that there is a positive correlation between thermal properties of the sample and moisture content and temperature.

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