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EFFECT OF DRYING RATE AND MOISTURE REMOVAL ON THE DRYING PROPERTIES OF GROUND AND FERMENTED CASSAVA MASH ("GARI")

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ABSTRACT

Drying characteristics of ground and fermented cassava mash called "gari" (a carbohydrate and staple food in Nigeria) were studied. Several properties such as drying rate, thermal conductivity, thermal diffusivity, specific heat capacity, and bulk density were investigated during the roasting of the mash. These properties were discovered to be influenced by the removal of moisture as the mash dries. The optimum initial moisture content was 46 % wb at 60 % Rh. The roasting chamber reaches a steady state temperature of 160 oC in 12 minutes before roasting while 5 kg of the wet cassava mash dried to a final moisture content of 9.8 % wb in 21 minutes. It was observed that as the moisture content reduces from 46 % to 9.8 %, the bulk density increased from 441.32 kg/m3 to 507.91 kg/m3, drying rate reduces from 2.64 to 0.54 kg/min and specific heat capacity reduces from 4.14 to 2.01 kJ/(kgK). The effects of the moisture removal on the studied parameters were thus discussed as the mash dries along the length of the dryer.

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1.0 INTRODUCTION

Drying properties are such that could be monitored or measured while a particular product undergoes drying, such includes moisture content, bulk density, thermal conductivity (k), specific heat capacity (c), thermal diffusivity (α), thermal emmissivity (β) and others. These properties are important when dealing with food processing equipment either in design or their usage. The ability of a food industry to provide a continuous supply of nutritious and healthy food to their consumer is highly dependent on the process and equipment used throughout all stages of handling, processing and distribution (Hall, 1980). The knowledge of the drying properties helps the engineer to formulate drying equations and select materials for the design of dryers and other heat related equipment. It also helps to solve various problems on heat transfer operations always encountered in bulk storage or drying of grains.

Drying is the removal of moisture from a certain material by evaporation as a result of heat applied to it. The intention is to reduce the moisture of materials to a pre-determined level through the application of heat under controlled conditions which may be of

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temperature, humidity and air flow rate. This converts a solid, semi-solid or liquid feedstock into a solid product by evaporation of the liquid into a vapour phase via application of heat. It is a preservation technique and as such, must maintain the quality of the product (Mujumdar, 2000). The process of making "gari" involves roasting, alternate cooking and drying of fermented cassava mash causing the starch in it to gelatinize. Heat is supplied at the boundary of the drying object so that the heat can diffuse into the solid primarily by conduction. The liquid must travel to the boundary of the material before it is transported away by the carrier gas as water vapour. When cassava mash is roasted at high temperature, moisture is removed and gelatinization of the starch granules occur giving a dry, free flowing granular product called "gari" (Babalola, 2014).

The amount of moisture that is present in a material affects its drying properties due to the fact that drying is a function of moisture content (Oyerinde, 1998; Obadina *et al*., 2008). The drying of the cassava mash is characterized by a short constant rate drying regime followed by a falling rate regime which is largely aided by a diffusion mechanism of internal moisture movement (Akeredolu *et al*., 2003). Hygroscopic materials are known to lose most of their internal moisture during the falling rate period (Jackson and Lamb, 1981). The initial moisture content of the mash is an important factor that must be determined before the roasting to ensure proper gelatinization of the mash. Scala and Crapiste, (2008) posited that moisture removal causes solid shrinkage and product quality change during red pepper drying.

Traditionally, "gari" is made at home using cassava tubers which had been peeled and washed. It is then grated and the resulting mass is packed into sacks topped with weights to squeeze off the water and allowed to partially dry and ferment for 2 to 3 days to add the "gari" characteristics aroma and flavour (Onwuka, 2003). Fermentation enhances the nutrient content of foods through the biosynthesis of vitamins, essential fatty acids, essential amino acids, and proteins and by improving protein quality and fibre digestibility (Etsuyankpa *et al*., 2016; Oluwafemi and Udeh, 2016). The lumps were broken and allowed to pass through sieves and then ready for roasting (Ogunlowo and Oyerinde, 2000) which could be done in shallow pans, pots or roasting trough until it is completely cooked and free of moisture. The resulting "gari" could be stored until it is needed.

"Gari" is a popular food in Africa where cassava is grown widely. It is a starchy carbohydrate used in the same manner as rice, although, "gari" requires no additional cooking when it is eaten, it only needs to be moistened (Nweke *et al*., 2002). Heat treatment of the mash breaks down residual unreacted cyanide and drives off lingering hydrogen which gradually reduces the total amount of cyanide in cassava roots, thus making consumption of "gari" safe (Cooke, 1978; Williams, 1979; Vasconcelos *et al*. 1990; Babalola, 2014). Equally, prolonging the fermentation time of the cassava mash had been found to reduce the cyanide content (Owuamanam et al. 2010). Wesby, 2002 reported that drying of fermented cassava mash is that of thermal gelatinization in a limited water environment and that is why

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"gari" behaves differently in cold and hot water environment. It is insoluble in cold water but solubilizes in hot water to form a viscous paste that has adhesive properties (Osoka and Okpala, 2006; Sobowale *et al*., 2016). If gelatinization does not occur, the drying material will not have the properties of "gari". The objective of this work therefore was to evaluate the effect of drying rate and moisture removal on the drying properties of ground and fermented cassava mash.

2.0 METHODOLOGY

The material used for this work was the ground, fermented and sieved cassava mash which was obtained after matured cassava tuber has undergone several processes such as peeling, grating, pressing, fermenting and sieving. Five drying parameters were investigated and the effect of moisture removal was observed on them while drying. The product was dried using an experimental roasting trough fabricated for the purpose in the Agricultural Engineering Department of the Federal University of Technology, Akure, Nigeria, and various drying parameters were determined as follows:

Moisture Content

The moisture content of the mash was determined by the method of ASAE (ASAE, 1990) whereby, a known mass of the mash was placed in an oven at 110 °C for 8 hours. The final weight was taken when the product had cooled down inside a desiccator and the moisture content determined as a ratio of weight of water to weight of wet mash expressed in percentage. Initial moisture content of 46 % (wet basis) was used as it was the optimum for the experiment. Using both the electrical oven and electrical moisture meter the moisture contents of the mash was monitored at intervals of 3 minutes from the beginning of drying till the end of drying.

Thermal Conductivity (k)

This is the ability of the mash to allow heat to pass through it measured in W/(mK) i.e. the amount of heat flow through a unit thickness of material over a unit area per unit time for unit temperature difference. The thermal conductivity was determined for the "gari" mash using the flat plate method (Kreith and Bohn, 1986). A cylindrical plate of known length and diameter was filled with "gari" sample and was placed on a hot plate and the change in temperature with time was monitored using constantan thermocouples. The values obtained were later used to calculate thermal conductivity. This was done at interval of 3 minutes as the sample dries and the amount of moisture reduces. k was determined using equations (1) to (3):

where,

T_1, T_2 are initial and final temperatures of the sample (°C).

$$k = \frac{q \ln\left(\frac{t_2}{t_1}\right)}{4\pi\left(T_2 - T_1\right)} \quad (1)$$

t_1, t_2 are initial and final time (mins).

q is heat input (J).

k is thermal conductivity [J/(kgK)].

whereas,

Where,

Q is heat flow rate, J/hr

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q is heat flux, J/hr

$$Q = kA\frac{dT}{dX} \quad (2)$$

and

$$\frac{Q}{A} = q = k\frac{dT}{dX} \quad (3)$$

dT is temperature difference

dX is sample thickness, m

A is sample area, m^2

Specific heat capacity ©

Specific heat capacity is the amount of heat required to raise the temperature of a unit mass of a substance through 1oC. The specific heat capacity of the mash in a unit time and the drying "gari" was determined by the calorimetry method (Shukla et. al., 1985), whereby a known mass (5 g) of the mash was heated at a specified temperature in an electric oven, after some time, it was taken out into a copper calorimeter that has been set up for the purpose. The content was poured into the calorimeter with water, it was covered and stirred until an equilibrium temperature was attained and the values of the heat gained and heat loss were recorded using stopwatches to monitor the time and steel thermometers for the temperature. This was done at intervals of 3 minutes when the moisture content of the mash changes. The relationship is shown in equation (4):

$$c = \frac{(m_2c_1 + m_3c_2)(\Delta T_2 - \theta)}{m_1(\Delta T_1 + \theta)} \quad (4)$$

Where,

m_1 is mass of the sample, g

m_2 is mass of the calorimeter cup, g

m_3 is mass of water, g

c_1 is specific heat of calorimeter cup, J/(gK)

c_2 is specific heat of water, J/(gK)

ΔT_1 is temperature change of the sample, K

ΔT_2 is temperature change of the calorimeter cup and water, K

θ is temperature corrections, K.

Thermal Diffusivity (α)

The molecular diffusivity of heat is a measure of the ratio of heat transmission and energy storage capacities (Kreith and Bohn, 1986). The thermal diffusivity is a quantity which measures the rate of temperature changes and indicate the speed at which temperature equilibrium will be reached, that is, how fast heat goes through a material. The thermal conductivity experiment was used to determine diffusivity since it's a function of conductivity, specific heat capacity and bulk density of the material (Hall, 1980), which is related as shown in equation (5) as:

$$\alpha = \frac{\kappa}{\rho c} \quad (5)$$

Where:

is the thermal diffusivity, m^2/s;

k, the thermal conductivity, W/(mK);

is the bulk density, kg/ m^2 and

c is the specific heat capacity, kJ/(kgK).

This was calculated as the moisture content of the mash changes along the length of the roasting chamber.

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Bulk density (ρ)

This is the ratio of mass to the volume of a material measured in kg/m^3. It explains how loose or tightly packed a material is. This was measured using a 50 ml measuring cylinder and electric weighing balance the measurements were taken at intervals of 3 minutes as the moisture content of the mash reduces along the length of the dryer.

The drying rate

This is the measure of how drying was obtained with respect to time. It describes the amount of water removed with time in kg/(m^{2}min). The moisture–time graph (drying curve) of the drying mash was differentiated and the rate of drying was obtained based on the moisture removal from the mash.

3.0 RESULTS AND DISCUSSIONS

At 46% (wb) initial moisture content, 5 kg of the cassava mash dried to 9.2 % at an average time of 21 minutes when the relative humidity was 60 % as shown in Figure 1. Values of the "gari" drying properties were as shown in Table 1. Batches were run on the dryer in triplicates and average values of the parameters were recorded. The steady state temperature of the roasting trough (fryer) was found to be 160°C, which was reached in 12 minutes before roasting. As the drying progresses, the bulk density reduces and suddenly around 12 minutes into the drying when the critical moisture content of 17 % wb was attained, it began to increase until the end of roasting showing a relationship that is not linear. This phenomenon had earlier been reported by Singh and Heldman, 1993 that materials with more compact molecular arrangement have higher densities.

The drying rate reduces from an all-high value of 2.86 kg/min at the beginning of drying to 0.54 kg/min when the drying ends. The thermal conductivity equally reduces from 0.24 to 0.06 (W/mK) as the drying progresses. The specific heat capacity and the thermal diffusivity all reduces as the moisture content of the mash reduces while the roasting progresses and the drying time increases one minute to 21 minutes attesting that they are all functions of moisture content. The moisture content of the mash was monitored along the length of the roasting chamber and regression

Table 1. The Cassava Mash properties during drying

Drying time, t (min)	Trough temperature, *TT* (°C)	Trough/ Distance (cm)	Moisture content, MC_{wb} (%)	Drying rate, R [kg/min]	Bulk density, ρ (kg/m^3)	Thermal conductivity, k [W/(mK)]	Specific heat capacity, c [kJ/(kgK)]	Thermal diffusivity, α (m2/s) x 10-7
0	27	0	46	2.64	441.32	0.24	4.14	1.31
3	60	30	38.5	2.86	437.21	0.19	3.94	1.1
6	93	60	30	2.81	433.9	0.15	3.52	0.98
9	120	90	21.5	2.25	430.12	0.14	2.76	1.18
12	160	120	17	1.56	426.81	0.12	2.61	1.08
15	160	150	12.5	1.11	491.3	0.1	2.34	0.87
18	160	180	10.9	0.63	499.62	0.08	2.16	0.74
21	160	210	9.2	0.54	507.91	0.06	2.01	0.59

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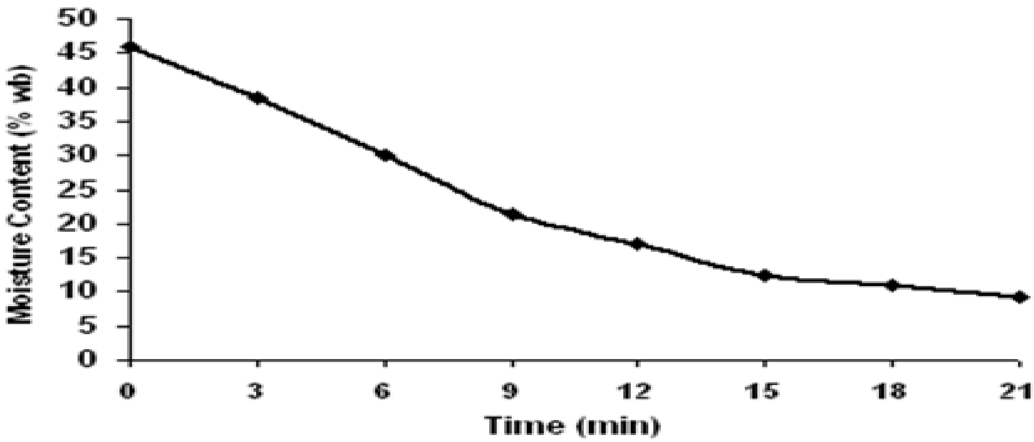

Figure 1. Cassava Mash drying curve

relationships with other properties were obtained. Moisture removal and the roasting chamber's length were related, and equation (6) was obtained as:

$$mc = 47.57 - 0.58L + 0.0023L^2 \quad (6)$$

Where mc is the moisture content, %, L is the roasting chamber's length, m.

The bulk density ρ, was found as an exponential function of the moisture content and was described by equation (7):

$$\rho = e^{-140.4486mc} \quad (7)$$

The thermal conductivity, k, and specific heat capacity, c, were also related to the moisture content according to equations (8) and (9).

$$k = 0.074 + 0.204mc - 0.00658mc^2 + 7.8435X10^{-6}mc^3 \quad (8)$$

$$c = 1.2049 + 0.0937mc - 0.006378mc^2 \quad (9)$$

It was noted that freshly sieved cassava mash is usually bulky and heavy as it contains about 46 % moisture. As the mash dried it lost moisture and became less heavy, but further drying of the mash tends to break all bonds between the mash particles thus reducing the pore spaces within the mash and consequently increasing the bulk density at lower moisture level, a situation similar to one reported by Faborode and others (Faborode *et al*., 1992). As the moisture content of the mash reduces all other properties were reducing in value as well until the product reaches the final moisture content of 9.2 % at 21 minutes. It was also reported (Onwuka, 2003) that high moisture foods with low initial drying rates tend to shrink inwards to yield products of high bulk density. Figures 2 and 3 shows the drying rate with moisture content and drying time, here, it was noted that the drying mash has a short constant drying rate as most of the drying occurred at the falling rate portion. The drying rate also reduces as the mash loses moisture.

CONCLUSION

Based on the results obtained in this study, it was generally observed that as the time of roasting of the mash increases, the moisture content decreases and causes the "gari" particulates to dry thereby reduces every other

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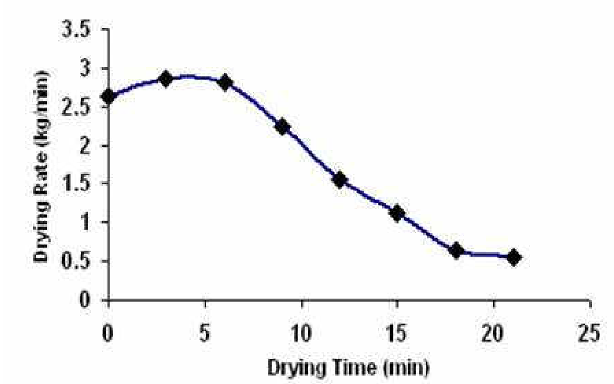

Figure 2: Mash drying rate with drying time

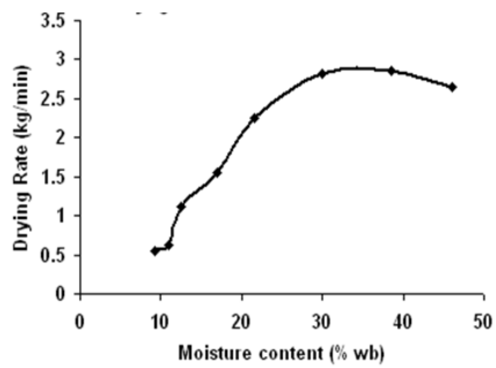

Figure 3: Mash drying rate with moisture content

factor except the bulk density, this helps the material to store well and for a long period of time. Thus, the less the materials contain moisture, the more loosely it becomes thus, increases the bulk density. It could then be said that smaller mash particles dried faster and well than bigger particles as it absorbs heat easily to evaporate its moisture through the pores of the granules, indicating that the smaller the mash particulates obtained from the grating machine the faster the mash dries.

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