MATHEMATICAL MODELING OF DRYING PATTERN AND THERMAL PROPERTIES OF OGI PRODUCED FROM FOUR MAIZE VARIETIES

Bolaji, Olusola Timothy, Akindele, Abimbola Dolapo and Aina, Oluwaseunfunmi Damola
Department of food Technology, Lagos state Polytechnic Ikorodu Lagos
*E-mail: olusholat@yahoo.com

Abstract
Subsequent processing of Ogi Slurry into various products often requires heat application. Drying pattern and thermo physical properties of Ogi slurry produced from four maize varieties were therefore investigated at soaking period of 24, 48, 72 and 96 hours. The drained Ogi slurries from all the maize varieties were oven dried at temperature (65±3ºC). Moisture content (%), Moisture ratio, drying rate (kg/min.), thermal conductivity (Wm^{-1} K^{-1}), specific heat capacity ($kJkg^{-1}$ºC) and thermal diffusivity(m^2/s) were determined. Initial moisture content was in the range 44.0-48.2% for C3Y, 42.0-51.8% for B2Y, 42.0-49.8% for A4W and 45.0-50.2% E9W. Drying rate decreased from 4.48 to 0.041667 kg/minutes, 4.18 to 0.02416 kg/min, 4.48 to 0.062 and 0.027 kg/minutes for Ogi produced from maize varieties E9W with increase in drying time. Similar trend were observed for Ogi Slurries produced from other maize varieties. The values obtained for specific heat of Ogi slurries were in the range of 1.7-2.38 kJ/kgºC, 1.4-2.95, 2.21-3.51 kJ/kgºC and 1.68-2.34 kJ/kgºC for C3Y, B2, A4W and E9W, respectively. The values for thermal diffusivity ranged from 1.67-2.20 x $10^{-7)}$, 1.11 -2.2.14 x 10^{-7}, 1.59-2.67x10^{-7}, 1.78-2.73 x 10^{-7} for C3Y, B2, A4W and E9W, respectively. Soaking period had no significant effect (p>0.05) on the drying pattern and thermal properties of Ogi.

Keywords: Ogi slurry, moisture, drying, thermal properties, drying rate

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1. INTRODUCTION

Drying of agricultural produce is a complex process involving transient transfer of heat and mass (Tang *et al*, 1991; Rahman, 1995; Sakamon, 2000; Bart-Plange *et al.*, 2012). Drying aids longer shelf-life, product diversity, volume reduction and ease of transportation (Bart-Plange *et al.*, 2012). Heat application is very necessary in achieving removal of moisture and could be a complex process depending on the nature of materials and prevailing conditions. This may result in physical changes, chemical reactions and may affect the sensory characteristics, such as colour, flavour and texture (Fontana *et al.*, 1999; Ansari *et al.*, *2004*).
A necessary analysis and prediction of behavior of heat application to a food material cannot be independent of it thermal properties. It has been established that all thermal processes in food process involve three distinct periods: a heating period, holding period and cooling period (Mohsenin, 1980; Tang *et al*, 1991) and all these periods are prevalent in drying process. Specific heat, thermal conductivity and thermal diffusivity which are greatly influenced by moisture are used in the engineering design calculations involving thermal processing of agricultural products and food materials (Fontana *et al.*, 1999 ; Constenla *et al.*, 1989).Thermal conductivity is useful in predicting the heat flux in food during processes where heat application is relevant (Hsu and Heldman, 2004). Thermal diffusivity is a very important thermal property since it is a factor dependent on mass density, thermal conductivity and specific heat capacity (Fontana *et al*., 1999; Morley and Miles, 1997**;** Ansari *et al., 2004)*. According to some researchers, food composition and temperature are the most important factors affecting thermal properties (Mohsenin, 1980; Sweat, 1995; Rahman, 1995; Saravacos and Maroulis, 2001). Choi and Okos, (1986) developed general models for the prediction of thermal properties of food products as functions of contents of basic food components (fat, protein, moisture, carbohydrate, fiber, and ash).

Waananen *et al*., (1993) provided an extensive bibliography of over 200 references dealing with models for drying based on prevalent factors. Yang *et al*., (2002) determined the specific heat of borage seeds in the moisture contents of 1.2 to 30.3% (w.b.) and temperatures of 6, 10 and 20ºC. The specific heat of minor millet grains and flours was reported to increase from 1.33 to 2.40 kJ /kg ºC with moisture content in the range of 10 to 30% (w.b.) (Subramanian and Viswanathan, 2003). The specific heat of berberis increased linearly from 1.9653 to 3.2811 kJ/ kg ºC at temperatures of 50, 60 and 70ºC and moisture contents of 19.3, 38.5, 55.4, and 74.3% (w.b.) (Aghbashlo *et al*., 2008). Generally, the specific heat is expressed as a function of moisture content using linear relations (Mohsenin, 1980). Some works have been done on thermal properties of starches (Wang and Hayakawa 1993; Hsu and Heldman, 2004).The drying pattern of Ogi has not been explored while the ever increasing population in the cities directly or indirectly crave for ease to store and process food materials, thus the need to produce dried Ogi. This definitely will extend the shelf life and meet the needs of increasing population in the industrialise environment who still crave for this fermented product. However, the drying process and behavior of Ogi cannot be independent of its thermal properties. The information on thermal properties of Ogi has not been reported Ikegwu and Ekwu, (2009) reported that little published information is available for the thermal properties of tropical fruits and food product, fermented food materials were not inclusive. The processing of Ogi to weaning foods, pap and Agidi definitely require heat application of varying degrees which are dependent on the thermal properties, however, these are scanty in the literature even though very important. This is the thrust of this research work.

2. MATERIALS AND METHODS

The maize used for this research work C3Y; B2Y; A4W and E9W were obtained from International Institute of Tropical Agriculture, Ibadan, and Oyo State. Ogi paste was produced from maize grain subjected to soaking period of 24, 48, 72 and 96 hours. This was subsequently milled, sieved and drained. The Drying process was carried out with the aid of oven at temperature (65±3^{0}C) considering the pasting temperature (74-80^{0}C) (Bolaji *et al*., 2011a ; Bolaji, *et al*., 2011b) and the moisture content (%), Moisture ratio, drying rate (kg/min.), thermal conductivity (Wm^{-1} K^{-1}), specific heat capacity (kJkg^{-1} K^{-1})and thermal diffusivity(m^2/s) were determined. These all were replicated before statistical analysis.

ACR-9931DMR-SR-Y	C3Y
BR-9928-DMRSRY	B2Y
ACR-97T2L-COMP4 C2	A4W
ACR-97T2L-COMP1-W	E9W

Moisture Content

The moisture content of the paste (Ogi) was determined by the method of ASAE (2002) whereby, a known mass (2g)of the paste was placed in an oven at 110^{0}C for 3 hours. The final weight was taken when the product cooled down inside a dessicator and the moisture content determined as a ratio of weight of water to weight of wet paste expressed in percentage as shown in equation (1). Initial moisture content (wet basis) was used as it was the optimum for the experiment. Using the electric oven, the moisture contents of the paste was monitored at an interval of 20 minutes from the beginning of drying till the end of drying, until equilibrium moisture content was reached.

$$Moisture\ content = \frac{weight\ of\ sample - weight\ after\ drying}{weight\ of\ sample} \times 100 \qquad (i)$$

Moisture Ratio (MR)

Moisture ratio is the ratio of the moisture content at any given time to the initial moisture content (both relative to the equilibrium moisture content). It can be calculated as shown in equation (1)

$$MR = \frac{M - M_e}{M_0 - M_e} \qquad (ii)$$

The drying rate can be expressed as in equation 3 (Doymaz, 2007):

$$DR = \frac{M_{t+dt} - M_t}{dt} \qquad (iii)$$

Specific Heat Capacity
This is the amount of heat required to raise the temperature of a unit mass of a substance through 1°C. The specific heat capacity of the paste in a unit time and dried Ogi was determined by calorimetric (Shukla *et al.*, 1985). Whereby a 20g (volume) of Ogi paste was heated at a specified temperature (75±3^{0}C) in an electric oven after 10 minutes, it was taken out into a copper calorimeter with water and stirred until an equilibrium temperature was attained and the values of the heat gained and heat loss were recorded using stop watches to monitor the time and steel thermometer for temperature. This process was replicated. The specific heat capacity was calculated using the mathematical expression in equation (iv)

$$C_p = \frac{Q}{M\Delta T} \left(\frac{kj}{kg^{\circ}C}\right) \qquad (iv)$$

where, Q is heat gained or loss (kJ), M is mass of the product (kg),ΔT is temperature change in the material (°C) and C_p is specific heat (kJ/kg°C).

Thermal Conductivity
The thermal conductivity was determined for the Ogi using modified method of (Kreith and Bohn, 1986). Instead of the heating plate, a heating mantle was used. A transparent laboratory glass conical flask of thickness 0.385 mm and of known length and diameter was filled with Ogi sample and placed on a heating mantle with the output energy 1000 watts. The heating mantle and the change in temperature at interval of three (3) minutes monitored using thermometer. The value obtained was used to calculate thermal conductivity and these were replicated. The equation v was used to compute the thermal conductivity, where k is the thermal conductivity Q is the heat energy applied (watts), ln (t_2/t_1), is the logarithm of the corresponding time ratio, and T_2-T_1 temperature difference at the intervals considered in the experiment.

$$k = \frac{Q\ln(\frac{t_2}{t_1})}{4\pi(T_2 - T_1)} \qquad (v)$$

Thermal Diffusivity
The Thermal 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 indicates the speed at which temperature equilibrium will be reached. The thermal diffusivity was determined from the values of the thermal conductivity, specific heat capacity and the bulk density of Ogi using the empirical equation given (6).

$$\alpha = \frac{k}{\rho_b C_{ps}}, \qquad (vi)$$

Where: ∝ is the thermal diffusivity (m^2/s), ρ_b is the bulk density of the paste (kg/m^3), C_{ps} is the specific heat capacity of the sample (kJ/ kgK)

BULK DENSITY
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 50ml measuring cylinder and electric weighing balance.
The measurements were taken from the electronic weighing balance (0.001)

$$\rho = \frac{Mass}{volume} \qquad (vii)$$

ρ is the density (kg./m^3), mass (kg),V is volume (m^3)

3. RESULT AND DISCUSSION

The moisture content is as shown in Figure 1 were in the range 44.0-48.2% for C3Y, 42.0-51.8% for B2Y, 42.0-49.8 for A4W and 45.0-50.2% for E9W.The variation in moisture content values were as a result of varying pressure applied since it was manual and not quantified. As the drying progresses, the moisture content decreased for Ogi produced from these four varieties of maize. The moisture decline pattern and drying rate versus drying time is as shown in the Figure 1 and 2. The moisture decline by 240 minutes for Ogi produced from maize for 24,48 72 and 96 hours from 48.6 to 10.2, 44-9.5,51-2 to 11.3 and 48.4 to8.8% (24 hours), 48 to 8.6%,42 to 8.12%,42 to 7.6 and 48 to 6.8%(48 hours), 51.2 to 8%, 48 to 13%,49.87.6% and 49.6 to 6.4%(72 hours) and 48.4 to 13%, 45.4 to 13.8, 49.8 to 13 , 49.6 to 10(96 hours) for all the C3Y,B2Y, E9W andA4W, respectively. This depends on the quantity and spread of the product in the drying equipment. The drying rate decreased from 4.48 to 0.041667 kg/minutes, 4.18 to 0.02416 kg/min,4.48 to 0.062 and 0.027 kg/minutes (24 hour soaking), 3.4 to 0.0175, 4 to 0.033, 4 to 0.032 and 4.25 to 0.02 kg/min (48 hours of soaking),4.92 to 0.033 kg/min, 4.54 to 0.054kg/minutes,4.3 to 0.03kg/minutes and 4.46 to 0.027(72 hours of soaking) and 4.66 to 0.057 kg/min., 4.2 to 0.057 kg/min., 4.42 to 0.054 kg/min and 4/72 to 0.042 kg/min. This may have been due to the free moisture near the surface of the product being removed early in the process.

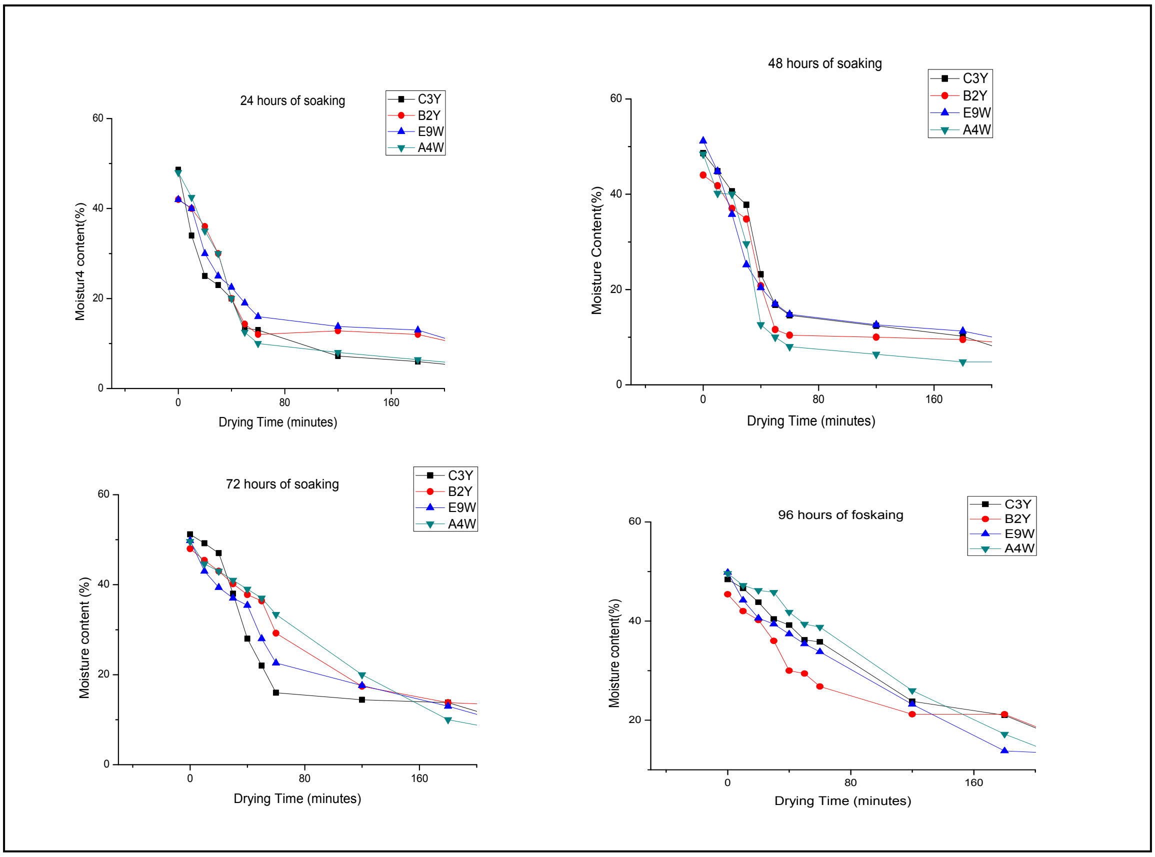

Figure 1: Moisture Content of Ogi produced at varying soaking period and Drying Time

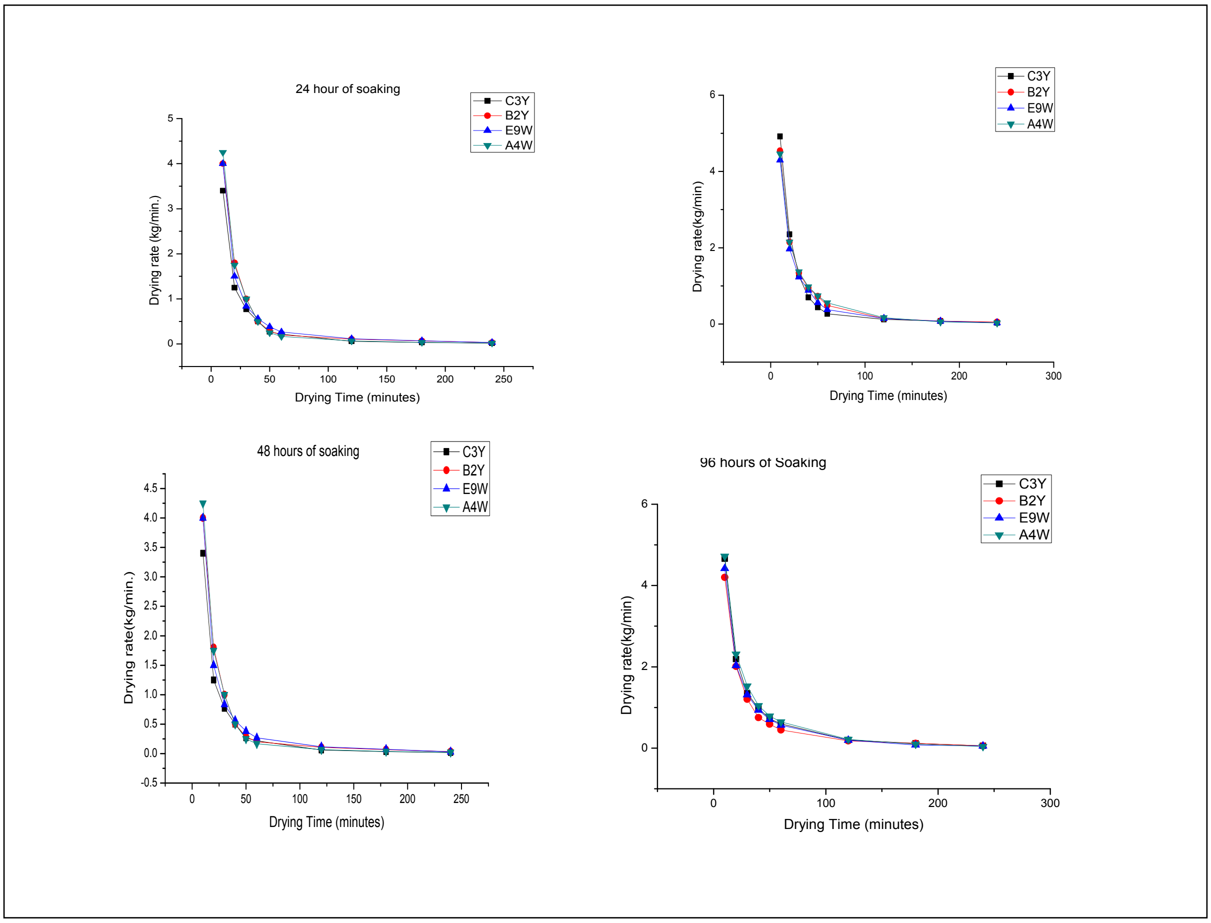

Figure 2: The drying rate (kg/minutes) at varying drying time

This was consistent with observation of some researchers (Xiong, *et al.*, **1991**; Dandamrongrak *et al.*, 2003). According to Saravacos *et al.*, 2005).The porous structures of dehydrated could affect the transport properties and may have affected the heat transfer process and subsequently determined the moisture removal pattern.

The bulk density and Thermal Conductivity

The bulk density, thermal conductivity, specific heat capacity and thermal diffusivity is as shown in Table 1. The values obtained for density were. C3Y (0.93-1.16), B2Y (0.99-1.07), A4W (0.91-1.01), A4W 0.96-1.09. This variation cannot but be connected to the variation that exited in the amount of moisture in the Ogi paste. The result of the thermal conductivity revealed that Significant difference existed ($p<0.05$). The values ranged from 4.20-4.80 x 10^{-1}wm/k (C3Y), 3.50-4.20 10^{-1} wm/k (B2Y), 3.84-5.40 x 10^{-1}wm/k (A4W) and 3.60-6.10 x 10^{-1} wm/k (E9W). The values obtained in these experiment for the wet Ogi were higher than the values obtained for some thermal conductivity of gram (Dutta, 1988), Arabica and Robusta coffee (Chandrasekar and Viswanathan, 1999). This may be connected to the high moisture of the paste, the surface area and the degree of pore spaces within the paste. The values were higher the bulk thermal conductivity of whole rapeseed (0·118–0·138 Wm^{-1} K^{-1}) and the thermal conductivity of ground rapeseed (0·0625–0·0881 Wm^{-1} K^{-1}) at 6·3–13·2% moisture content and 4–32°C temperature (Bilanski and Fisher, 1976).

The values obtained for specific heat of Ogi paste revealed that they were in the range of 1.7-2.38 (24 hours soaking), 1.4-2.95 (48 hours Soaking), 2.21-3.51(72 hours soaking) and

1.68-2.34(96 hours Soaking) for maize varieties C3Y, B2Y, E9W and A4W, respectively. These were within the range of values obtained for spring wheat which increased from 1.054 to 2.521 kJ kg^{-1} $^{o}C^{-1}$ at temperature range of -33.5 to 21.8°C and moisture content of 1 to 23% dry base (d.b.) (Njie *et al.*, 1998).The specific heat obtained in this research were also close to the value obtained for millet grains and flours which increased from 1.33 to 2.40 kJ kg^{-1} $^{o}C^{-1}$ with moisture content in the range of 10 to 30% (Subramanian and Viswanathan, 2003), Berberis which increased linearly from 1.9653 to 3.2811 kJ kg^{-1} $^{o}C^{-1}$ at temperatures of 50, 60 and 70 ºC and moisture contents of 19.3, 38.5, 55.4, and 74.3%(Aghbashlo *et al*., 2008), soya bean, ranging from 1·584 to 2·353 $kJkg^{-1}$ K^{-1} the moisture content range of 9·5–38% (Alam and Shove, 1973).
The specific heat capacity increased with increase in moisture content but not as linearly as reported by some other research workers (Dutta *et al*, 1988; Hsu *et al*, 1991). The rate of increase in specific heat capacity was higher at lower moisture content
Than at higher values. Similar findings have been reported for other agricultural materials by Tang *et al.*, (1991) and Wang and Brennan (1993) for potato.

Thermal Diffusivity

The thermal diffusivity of wet Ogi for variety E9W. the moisture content, varieties C3Y, B2Y and E9W with moisture content above 50% displayed a less thermal diffusivity. Kazarian and Hall, (1965) reported a decrease in thermal diffusivity of wheat and corn with increase in moisture content. The value range C3Y (1.41-2.59 x 10^{-7}), B2Y (1.04 -2.25 x 10^{-5}), A4W (1.61-2.67 x 10^{-7}), and E9W (1.46-2.26 x 10^{-7}). According to Tansakul and Chaisawang, (2006) Thermal diffusivity of coconut milk 1.325–1.634 · 10^{-7} m^2/s.

Table 1: Thermal properties of Ogi produced at different soaking period

	24 (hour)	48 (hour)	72 (hour)	96 (hour)	Mean value
	BULK **DENSITY OGI. (KG/M^3)X 10^3**				
C3Y	1.12^{a}	1.16^{a}	0.93^{ab}	1.02^{ab}	1057.5
B2Y	1.07^{a}	1.07^{a}	0.99^{ab}	0.93^{ab}	1015
A4W	1.01^{a}	1.01^{a}	0.91^{ab}	1.05^{a}	1010
E9W	0.98^{ab}	1.00^{ab}	0.96	1.09^{a}	1032.5
	THERMAL CONDUCTIVITY (X 10^{-1})				
C3Y	4.40^{b}	4.20^{b}	4.60^{b}	4.80^{b}	4.50
B2Y	4.08^{bc}	3.50	4.20^{b}	4.20^{b}	3.995
A4W	3.84^{bc}	3.90^{ab}	5.40^{a}	4.40^{b}	4.385
E9W	4.08^{bc}	3.60^{bc}	6.10^{a}	4.10^{b}	
	SPECIFIC HEAT CAPACITY(kj/kg/^{0}C)				
C3Y	2.34^{a}	2.4^{a}	2.51^{a}	2.13	2.345
B2Y	1.9	2.95^{a}	2.34^{a}	2.1	2.3225
A4W	2.38^{a}	1.91^{ab}	2.21^{a}	2.34^{a}	2.11
E9W	2.34^{a}	1.68^{b}	2.33^{a}	1.68^{b}	2.0075
	THERMAL DIFFUSIVITY OF OGI (M^2/S) X 10^{-7}				
C3Y	1.778	1.65^{b}	1.73^{b}	2.14^{a}	1.82
B2Y	2.12^{a}	1.17^{b}	1.77^{b}	1.97^{ab}	1.76
A4W	1.59^{bc}	2.56^{a}	2.42^{a}	1.86^{b}	2.11^{a}
E9W	1.69^{b}	2.08^{a}	2.54^{a}	2.36^{a}	2.17

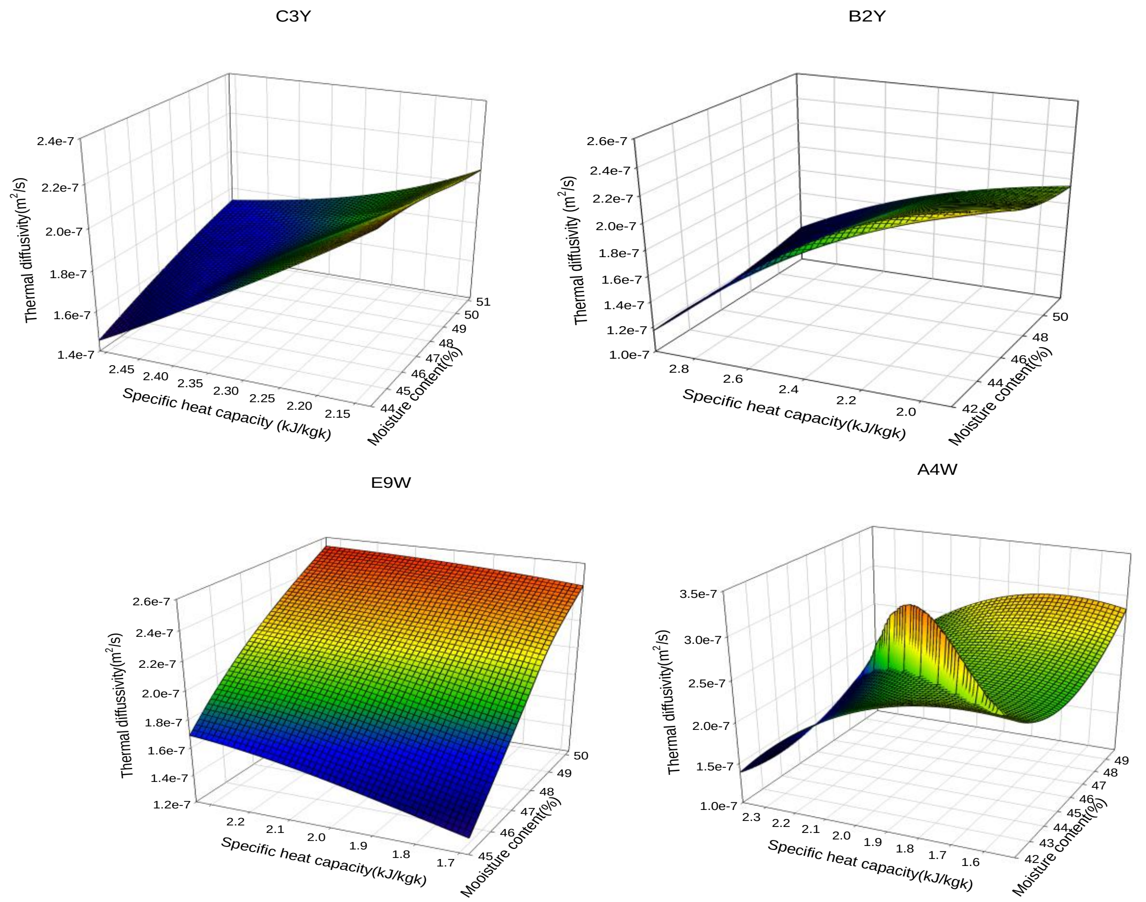

Figure 3. The interaction effect of thermal diffusivity, moisture content and the soaking time

The result obtained in this work were in the range of the values reported by Wang and Hayakawa, (1993) for thermal conductivity of starch gels (0.4770 to 0.5667 W/m·K) at 80 to 120^{0}C with varied moisture content from 39.6 to 75% wet basis. This was also similar to the observation of Morley and Miles, (1997) for starch. The interaction effect of thermal diffusivity, moisture content and the soaking time is as shown figure 3. The mathematical model fit followed a pattern of Gaussian functions as shown in equation. Where a, b, c and d are constant. These constants may be related to the intrinsic properties having effect on the thermal properties. The R^2 ranged from 0.999999-0.99999999, sum square (SS) 1.33-6.20 x 10-^{11} and Mean square (MS) 1.37-3.33x 10-^{11}, Where α is the thermal diffusivity, Δm and ΔS are changes in moisture content and specific heat capacity, respectively.

$$\propto = ae^{0.5\left[\left(\frac{\Delta m}{b}\right)^2+\left(\frac{\Delta S}{c}\right)^2\right]}$$

4. CONCLUSIONS

The thermo physical properties of Ogi seem to be affected by the composition of the Ogi rather than the length of soaking. The initial moisture content of each of the Ogi produced from these varieties determines the drying pattern and not the soaking period. Also, soaking period may have effect on the degree of nutrient leaching, which may subsequently affect the thermo physical properties of this important product.

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