# Convective Drying of Ginger Rhizomes

Gbasouzor Austin Ikechukwu, *Member IAENG*, Sam Nna Omenyi

**Abstract. This paper presents the results of convective drying of ginger rhizomes under blanched, unblanched, peeled and unpeeled conditions using the ars-0680 environmental chambers for the drying process and td1002a - linear heat conduction experimental equipment to measure the thermal conductivities of the ginger at six temperature levels ranging from 10°c - 60°c and drying times of 2 and 24 hours. The drying curves were drawn using the moisture and conductivity data. The drying rate at higher drying times (24 hours) was 0.889/°c and 0.4437/°c for 2 hours drying, giving 50% in moisture reduction rate. Whereas the initial moisture content was 95.12%, it reduced to 59.33% for the 24 hour-drying time. The result of this study shows that the lowest moisture content (5.98%) was obtained for unpeeled ginger while the highest was the blanched (9.04%) all for 24 hour-drying and at 60 °C. The average moisture content for 2 hours drying at 60°c was 70.6% while for 24 hours drying; it was an average of 7.55%. which is close to the target of 4 – 7% desired for this research. Though our results made our target, they are in line with the literature results that recommend moisture content of 7 – 12%. These show the superiority of higher temperature drying and the use of the convective drying method. The thermal conductivity for 24 hour-dried ginger at 60°C approximates to the thermal conductivity of dried ginger and it is 0.050 W/mK on the average. The unpeeled ginger gave the lowest value of 0.046 W/mK while the unblanched ginger gave the highest value of 0.055 W/mK. For 2 hours of drying, the average value was 0.079 W/mK while the unblancehd ginger gave the lowest (0.076 W/mK) while the blanched the highest (0.084 W/mK).**

***Keyword: Convective drying, ginger rhizomes, moisture content, thermal conductivity***

## I INTRODUCTION

Convective drying can be employed to remove volatile liquid from porous materials such as food stuffs, ceramic products, clay products, wood and so on. Porous materials have microscopic capillaries and pores which cause a mixture of transfer mechanisms to occur simultaneously when subjected to heating or cooling. The drying of moist porous solids involves simultaneous heat and mass transfer. Moisture is removed by evaporation into an unsaturated gas phase. Drying is essentially important for preservation of agricultural crops for future use. Crops are preserved by removing enough moisture from them to avoid decay and spoilage. For example, the principle of the drying process of ginger rhizomes involves decreasing the water content of the product to a lower level so that micro-organisms cannot decompose and multiply in the product. The drying process unfortunately can cause the enzymes present in ginger rhizomes to be killed.

Ginger is the rhizome of the plant *Zingiber officinale*. It is one of the most important and most widely used spices worldwide, consumed whole as a delicacy and medicine. It lends its name to its genus and family *zingiber aceae*. Other notable members of this plant family are turmeric, cardamom, and galangal. Ginger is distributed in tropical and subtropical Asia, Far East Asia and Africa.

**Fig. 1: Fresh Ginger Rhizomes**

Ginger is not known to occur in the truly wild state. It is believed to have originated from Southeast Asia, but was under cultivation from ancient times in India as well as in China. There is no definite information on the primary center of domestication. Because of the easiness with which ginger rhizomes can be transported long distances, it has spread throughout the tropical and subtropical regions in both hemispheres. Ginger is indeed, the most wildly cultivated spice (Lawrence, 1984). India with over 30% of the global share, now leads in the global production of ginger.

### Ginger Rhizomes in Nigeria

In Nigeria, large-scale cultivation of ginger began in 1927 in southern Zaria, especially within Jemima's federated districts as well as in the adjoining parts of the Plateau. Nigeria has tried to widen the genetic base of the crop through introduction of ginger cultivars, mainly from India. Currently, Nigeria is one of the largest producers and exporters of split-dried ginger. Ginger is readily available in the local Nigerian markets and is inexpensive. It is obtained in numerous forms in the market: fresh, dry and powdered ginger rhizomes (Omeni, 2015). Kaduna State is adjudged the largest producer of ginger whereas other states like Nassarawa, Gombe, Benue, Sokoto, Zamfara, Akwa Ibom, Oyo, Abia, Lagos and Bauchi are among the main producers of the farm produce. However Southern Kaduna still remains the largest producer of fresh ginger in Nigeria (KADP, 2000, 2004; Bernard, 2008).

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**Nigeria Ginger Rhizomes Research**

Studies conducted in the 1980s were focused on sun-drying and solar drying methods. Several studies conducted on ginger rhizomes were centered on effects of pricking, sun-drying and sieving on Ginger (*Zingiber officinale Roscoe*) colour and powder (Okafor and Okafor, 2007); composition of volatile oil (Ekundayo et al., 2006); Bio-chemical changes in ginger during storage (Oti et al., 1988); Development of ginger processing machines (Adeyemi and Onu, 1997; Nwandikom and Njoku, 1998; Onu and Okafor, 2003; Akomas and Oti, 1988; Onu, 1997; Egbuchuna and Enujeke, 2013); efficiency of ginger production in selected local government areas of Kaduna state, Nigeria (NdaNmadu, 2014); isolation and characterization studies of Ginger root starch as a potential industrial biomaterial (Afolayan et al., 2014) etc. In those periods, commercial ginger was exploited. The major difficulties encountered were on pests, diseases and pollutants. Extensive studies were done in the area of post-harvest chemical dips, improved and controlled air storage, spraying of fungicide, hot water treatment, cool storage, etc.

The moisture content of Ginger rhizomes has a major influence on the difficulties encountered in processing ginger rhizomes produced in Nigeria. Other difficulties include vulnerability to fungal rots and quality of dried ginger using open sun drying and/or solar drying. Ginger experiences moisture content loss either vigorously as a segment of the drying process or flaccidly under controlled storage of the farm produce which will not guarantee its' freshness thereafter and therefore will have to be dried to assured moisture content of about 20-35%.

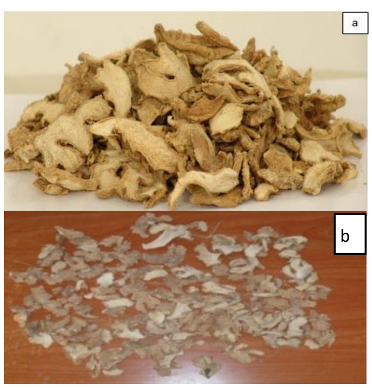


**Figure 2. Dried Split Ginger**

Although several studies have been conducted on drying of ginger rhizomes there are no published work on the convective drying of ginger rhizomes *(Zingiber Officinale)* to the knowledge of the authors. This work therefore is centered on the convective drying of ginger rhizomes. The hitherto assumed principal processing of ginger rhizomes involves sorting, washing, soaking, splitting or peeling and drying it to moisture content 7-12% (Eze and Agbo, 2011). In this work, the target using the convective drying methodology would be 4-7% from initial moisture content of 87-90% (wb).

## II THEORETICAL ASPECTS

Drying is a very complex process which involves simultaneous heat and mass transfer. Drying is one of the least understood processes at the microscopic level, because of the complexities and deficiencies in mathematical formulations. It is a form of unit operation that converts a liquid, solid or semi-solid feed material into a solid product of very low moisture content (Erbay & Icier, 2009). Ginger drying is very complicated because of the differential structure of products. The mechanisms used for drying are surface diffusion or liquid diffusion on the pore surfaces, liquid or vapor diffusion due to moisture concentration differences, and capillary action in granular and porous foods due to surface forces (Strumillo & Kundra, 1986; Ozilgen & Ozdemir, 2001).

Drying processes are categorized into two major models:

**Distributed model: T**his model considers simultaneous heat and mass transfer. It takes into account both the internal and external heat and mass transfers. It predicts the temperature and moisture gradients in the product better. The distributed model depends on the Luikov equations that were derived from Fick's second law of diffusion as shown in equation 1 (Luikov, 1975; Erbay & Icier, 2009).

$$\frac{\partial M}{\partial t} = \nabla^2 K_{11} M + \nabla^2 K_{12} T + \nabla^2 K_{13} P$$
$$\frac{\partial T}{\partial t} = \nabla^2 K_{21} M + \nabla^2 K_{22} T + \nabla^2 K_{23} P$$
$$\frac{\partial P}{\partial t} = \nabla^2 K_{31} M + \nabla^2 K_{32} T + \nabla^2 K_{33} P \qquad (1)$$

Where $K_{11}$, $K_{22}$,$K_{33}$ are the phenomenological coefficients while $K_{12}$,$K_{13}$, $K_{21}$,$K_{23}$,$K_{31}$,$K_{32}$ are the coupling coefficients (Booker, et al., 1974).

In most of the drying processes, the effects of pressure are negligible compared with the temperature and moisture effect. Hence, Luikov equations reduce to (Booker, et al., 1974; Erbay & Icier, 2009):

$$\frac{\partial M}{\partial t} = \nabla^2 K_{11} M + \nabla^2 K_{12} T$$
$$\frac{\partial T}{\partial t} = \nabla^2 K_{21} M + \nabla^2 K_{22} T \qquad (2)$$

Equation 2 is the modified form of Luikov equations and may not be solved using analytical methods due to the complexities of real drying mechanisms. However, the modified form can be solved with the Finite Element Method (Ozilgen & Ozdemir, 2001).

**Lumped parameter model:** This model does not consider the temperature gradient in the product but assumes a uniform temperature distribution that is equal to the drying air temperature in the product. This assumption reduces the Luikov equation to:

$$\frac{\partial M}{\partial t} = \nabla^2 K_{11} M \qquad (3)$$

$$\frac{\partial T}{\partial t} = \nabla^2 K_{22} T \qquad (4)$$

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The phenomenological coefficient $K_{11}$ is known as effective moisture diffusivity ($D_{eff}$) and $K_{22}$ is known as thermal diffusivity (α). For constant values of $D_{eff}$ and α, Equations 3 and 4 can be rearranged as:

$$\frac{\partial M}{\partial t} = D_{eff}\left[\frac{\partial^2 M}{\partial x^2} + \frac{a_1}{x}\frac{\partial M}{\partial x}\right] \quad (5)$$

$$\frac{\partial T}{\partial t} = \alpha\left[\frac{\partial^2 T}{\partial x^2} + \frac{a_1}{x}\frac{\partial T}{\partial x}\right] \quad (6)$$

Where parameter $a_1 = 0$ for planar geometries, $a_1 = 1$ for cylindrical shapes and $a_1 = 2$ for spherical geometries (Ekechukwu, 1999).
Assumptions resembling the uniform temperature distribution and temperature equivalent of the ambient air and product were found to cause errors (Erbay and Icier, 2010). Henderson & Pabis (1961) reported that this error can be reduced to acceptable values with reduction in the thickness of the product. This necessitates the derivation of the thin layer drying equations. In this report, the mathematical expressions were not solved but have been presented to alert on the existence of such equations. The work presented here is purely experimental.

## III METHODOLOGY

**Materials**

The Ginger rhizomes used in this study were purchased from the popular Eke Awka market in Awka, Anambra State and stored at room temperature before being used for the experimentations. The drying experiments were carried out at the Electronic Manufacturing Engineering Laboratory (ERMERG) Hawkes building, University of Greenwich
The ginger rhizomes used for the experiment were classified under: (a) Blanched (b) Unblanched (c) Peeled (d) Unpeeled

**Sample Preparation**

*(a) Blanched*

- Fill a large pot with water until half full. Put the pot on a stovetop, and turn the burner to high heat. Add several shakes of salt to the water.
- Strip the ginger of its outer peel by running a knife vertically and horizontally.
- Put the ginger into the boiling pot of water. Set the stove timer for 3 minutes.
- Remove blanched ginger and drop it into ice cold water. This will suddenly put a stop to the cooking process.
- Wait for another 3 minutes for the ginger to complete the blanching process. Remove the ginger and place on a paper towel linen plate to dry.

*(b) Unblanched*

- Freshly unwashed ginger with water

*(c) Peeled*

- Wash the ginger with water and peel
- Hold a piece of ginger and scrap the edge of ginger with a spoon to peel off the skin

*(d) Unpeeled*

- Wash ginger with water and then keep unpeeled


**Fig.3: (a) Raw materials for the experiments (Ginger Rhizomes) (b) Device designed for the chopping of ginger rhizomes to the required sizes (18x30mm diameter) for the drying and heat conduction experiments**

Raw ginger and the device used to chop the ginger rhizomes to size are shown in figure 3.

**Methods**

ESPEC's ARS-0680 Environmental Humidity and Temperature Chamber as shown in fig.4 was used for heating the specimen at low or high temperature with controlled humidity. The ESPEC's ARS-0680 Environmental Humidity and Temperature chamber has the following features:

- Internal dimension of W850 x H1000 x D800 and an External dimension of W1050 x H1955 x D1805
- Operating temperature ranging from $-73℃$ **to** $+180℃$ ($-103℉$ **to** $+356℉$)
- Temperature function of 0.3K
- Temperature deviation in space of±1.5K
- Temperature gradient of 3.0K
- Rate of temperature change 6.0K/min or more while heating and
- Rate of temperature of change 4.2/min or more while cooling.

ESPEC's Environmental Stress Chambers can withstand heat loads produced by the specimen, improve temperature change rates, and provide expanded ranges for temperature and humidity. Each chamber is also equipped with a specimen temperature control function to meet stringent testing demands typically required for automotive parts and mobile products (ESPEC, 2015).

The ginger used was cut into slices of 30mm diameter and 18mm thickness by scoopers designed for this purpose and prepared as Blanched, Unblanched, Peeled and Unpeeled as previously described. at temperatures of 10°C - 60°C for drying times of 2 and 24 hours and the Linear Heat Conduction Experiment was used to measure the thermal conductivity of the sample.

The temperature and humidity chamber installed at the Hawke building, University of Greenwich was used for the drying of the ginger rhizomes at a minimum temperature of $10^0$C; maximum temperature of $60^0$C and resident time of 10 minutes starting at a room temperature (RT) of $24^0$C in the environmental chamber. A total of 16 samples were placed in the environmental chamber which was programmed to run for 2 or 24 hours initially. However, at the end of every cycle, a sample would be retrieved from the environmental chamber for analysis and measurement to evaluate the percentage moisture content and its thermal conductivity using the TD1002A - Linear Heat Conduction Experiment Unit shown in figure 5a. Humidity test was totally ignored in

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**Fig.4: ARS – 0680 Temperature and Humidity Chamber**

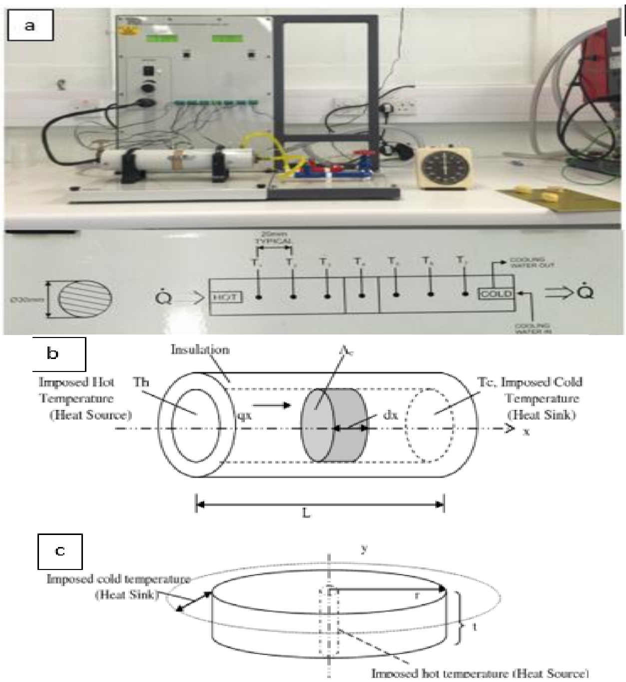

**Fig.5(a) TD1002A - Linear Heat Conduction Experiment Unit (LHTEU) with TD1002 Heat Transfer Experiments Base Unit) b & c, Diagram for heat conduction along a well-insulated cylindrical rod.**

this research, as it was not one of the objectives to meet in this study.

The equipment for Linear Heat Conduction Experiment shown in fig. 5 – TD1002A - has a wooden bar of circular cross-section made up of two sections with an interchangeable middle section. It is mounted on a base platen with a clear schematic of the experiment layout. The first brass section includes three thermocouples and the electric heater (heat source). The second brass section includes a small water-cooled chamber (heat sink) and three more thermocouples. The interchangeable middle section was modified with wood for this experiment to prevent heat loss during the experiment. Each middle section has a thermocouple. The electric heater and thermocouples connect to sockets on the Heat Transfer experiments base unit, which also supplies the cold water feed and drain for the heat sink. The cooling water flow and the heater power were turned on until the materials attained temperature equilibrium; the temperatures were then recorded along the bar. Insulation around the bar reduced heat loss by convection and radiation. A power of 20Watts was used throughout the experiment. The diameter of each ginger rhizome chopped out from the gingers supplied were 30mm in diameter and 18mm in thickness.

*Procedure  the Linear Heat Conduction experiment*

- The room temperature was initially measured.
- The clip located in the middle of the insulated wooden rod (cylinder) was opened and the ginger rhizomes inserted.
- Thermal paste was applied between the adjacent faces of the wooden material to reduce temperature gradient across the joints. The ginger rhizome was then inserted into the central section at the middle of the cylinder.
- The main water supply was opened. The red valve was completely opened for water inlet to the cylinder.
- The power supply and the control board were switched on.
- The heater was switched on, and set  to 20Watts.
- The initial temperatures of the thermocouples $\boldsymbol{T_1}, \boldsymbol{T_2}, \boldsymbol{T_3}, \boldsymbol{T_4}, \boldsymbol{T_5}, \boldsymbol{T_6},$ and$\boldsymbol{T_7}$ were measured.
- The temperature of the thermocouples at different time range were subsequently also measured.
- After the temperature measurements, the heater control was turned to zero; the heater, the control board and the main power supply were switched off. After waiting for approximately five (5) minutes for the temperature of the water in the cylinder to cool down, the red valve and main water supply were turned off.

*Procedure adopted during Drying*

The Ginger Drying experiment was conducted according to ASAE Standard S352.2 (*Convection Oven*). Before the experiment started, the whole apparatus was operated for at least 15-30 minutes to stabilize the humidity, air temperature and velocity in the dryer. Drying was started at 08:00am and continued until the specimen reached the final moisture content at time set for the experimental. The weight losses of the sample in the environmental chamber were recorded during the drying period of 2 and 24 hours with electronic balance (EK-200g, Max 200$\pm$0.01g). At the end of drying, the dried sample was collected for the measurement of its' thermal conductivity using the linear heat conduction equipment.

*Determination of Moisture Contents*

- The initial mass of the ginger sample was recorded using 0.00001g "Analytical Plus Electronic Balance"
- The ginger was placed into an environmental chamber at constant temperature of 10°C - 60°C for a time period of 2 and 24 hours.
- Then the mass of the dried ginger sample was recorded for the time periods 2 and 24 hours.

- Mass of the ginger sample was examined regularly till it reached an equilibrium value (Final mass).
- Moisture content of the ginger was computed.

*Determination of Thermal Conductivity*

Thermal conductivity of a material is defined as the capacity of a body or any material to transmit or conduct heat. Thermal conductivity is dependent on the following factors:

- Material structure
- Moisture content
- Density of material
- Pressure and temperature (operating conditions) (Netzsch, 2015)

Fig.6 shows dried and ground (powdered) ginger rhizomes. The thermal conductivity is mathematically expressed as:

$$k = \frac{QL}{\Delta TA} \qquad (8)$$

where

$A = Cross - sectionalarea(m^2)$

$\mathrm{k = thermal\ conductivity} \left(\frac{\mathrm{W}}{\mathrm{m}}\mathrm{K}\right)$

$\mathrm{Q = Amount\ of\ heat\ transfered\ through\ the}$

$\mathrm{material} \left(\frac{\mathrm{j}}{\mathrm{s}}\right) \mathrm{(Watts)}$

$\Delta\mathrm{T = change\ in\ temperature(K)}$

$\mathrm{L = distance\ between\ \ T_4 - T_3(m)}$

**Fig. 6: Powdered ginger rhizomes with Thermal Conductivity of 0.0503W/m. K**

## IV RESULTS AND DISCUSSIONS

This study investigated two important features of convective drying of ginger rhizomes:

1. moisture content characteristics
2. thermal conductivity of each sample at varying drying times and temperatures using the linear heat conductions experimental unit.

The data on moisture contents of ginger rhizomes dried for 2 hours and for 24 hours respectively were plotted in figs.7 and 8 as a function of temperature. The best fit to the data was found to be a straight line. These figures represent the drying curves in terms of the moisture content. The reduction of moisture with increase in temperature is evidence of drying. The drying rate is given in moisture reduction per degree rise in temperature. The characteristics of these curves are given in table 1.

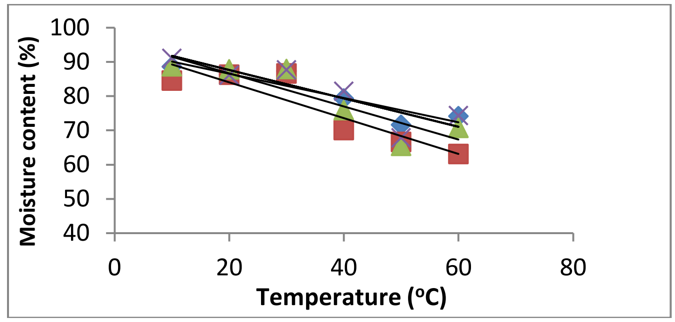


Fig. 7 Moisture content of rhizomes dried for 2 hours, plotted as a function of temperature.

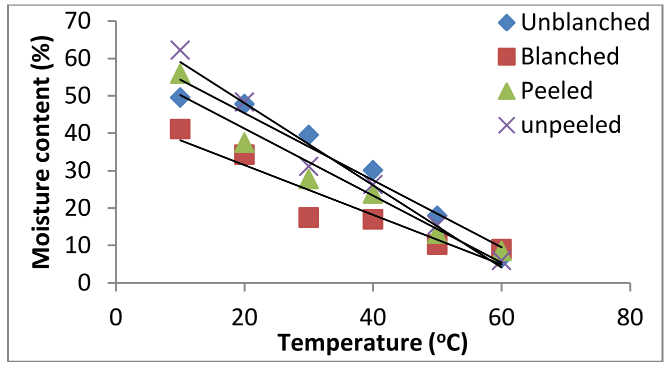


Fig. 8 Moisture content of rhizomes dried for24 hours, plotted as a function of temperature.

Table 1: Data for moisture content

| Drying time | | Slope | Intercept | R-squared |
|---|---|---|---|---|
| 2 Hrs | Unbleached | -0.3558 | 93.70 | 0.8395 |
| | Blanched | -0.5224 | 94.51 | 0.8219 |
| | Peeled | -0.4829 | 96.36 | 0.7974 |
| | Unpeeled | -0.4137 | 95.92 | 0.7693 |
| Average | | -0.4437 | 95.12 | 0.807 |

| Drying time | | Slope | Intercept | R-squared |
|---|---|---|---|---|
| 24 Hrs | Unbleached | -0.896 | 63.30 | 0.9627 |
| | Blanched | -0.6656 | 44.82 | 0.8949 |
| | Peeled | -0.8955 | 59.15 | 0.9469 |
| | Unpeeled | -1.099 | 70.05 | 0.9774 |
| Average | | -0.8890 | 59.33 | 0.9455 |

Table 1 shows as expected that the ginger rhizomes dried for a longer time have higher average reduction in moisture given by the slopes of the graphs as 0.889/°C for 24 hours drying and 0.4437/°C for 2 hours drying, giving 50.1% in moisture reduction rate. The intercept which theoretically gives the terminal moisture content (at 60°C) is lower at 24 hours drying (59.33%) compared to 95.12% on dry basis at 2 hours of drying, as expected. This final moisture content is rather higher than expected. This shows that either more time is given for the drying or drying temperature is increased. The preliminary moisture contents are however higher as expected. The goodness-of-fit, on the average is higher for ginger dried for 24 hours than for that dried for 2 hours. All these show the superiority of higher temperature drying. These also show that the results vary with the methods of preparation of the ginger. The unpeeled ginger gave the highest results while the blanched ginger gave the lowest results for 24 hour drying. The results at 2 hours drying are not consistent as the shortness of the time prevented the attainment of equilibrium.

Cletus, 2007 and Eze & Agbo, 2011 demonstrated that the preliminary moisture content is essential for demonstrating the drying procedure. The limit is around 87.98% and 84.97% moisture content (wet basis) to 75.73% and 68.70% (wet basis) under blanched condition and to the moisture content 81.98 % (wb) and 77.46% (wb) under non blanched condition after 20 hours in solar dryer at 50°C to 60°C respectively (Hoque *et al.*, 2013). Split ginger rhizomes dried from initial moisture content of 87.98% (wb) to 22.54% and 32.96% (wb) under blanched and unblanched conditions for 32 hours at 50°C. This implies that the drying rate of ginger rhizomes increases with an increase in drying temperature (Hoque *et al.*, 2013). In this study, the results of final moisture content (dry basis) can be seen to be higher than the literature values.

The results for the thermal conductivities are presented in figs 9 and 10. The curves were fitted to polynomial functions of order two and the resulting equations are given on table 2.

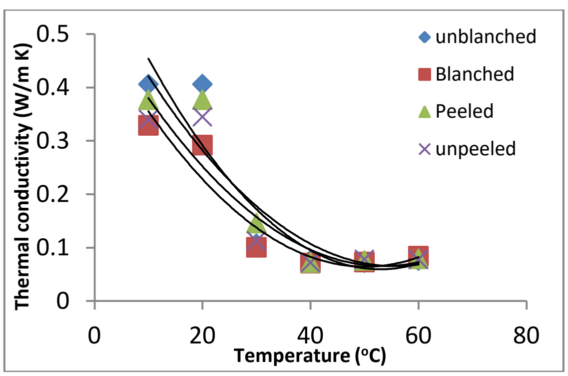


Fig. 9. Effects of temperature on the thermal conductivities of ginger rhizomes dried for 2 hours

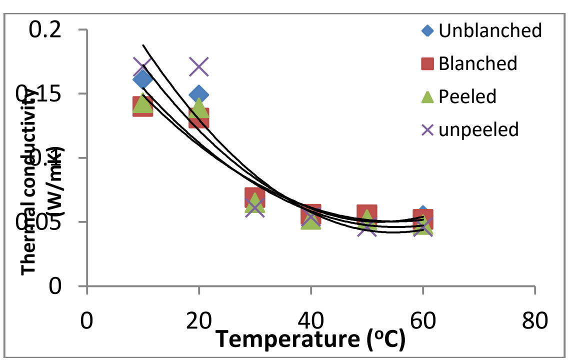


Fig. 10. Effects of temperature on the thermal conductivities of ginger rhizomes dried for 24 hours

Table 2a: For products dried for 2 hours (fig. 9)

| | | | |
|---|---|---|---|
| Unblanched | K = | $7x10^{-5}T^2 - 0.0071T + 0.2367$ | $R^2 = 0.9067$ |
| Blanched | K = | $5x10^{-5}T^2 - 0.0054T + 0.1974$ | $R^2 = 0.9139$ |
| Peeled | K = | $5x10^{-5}T^2 - 0.0058T + 0.2074$ | $R^2 = 0.8875$ |
| Unpeeled | K = | $7x10^{-5}T^2 - 0.008T + 0.2602$ | $R^2 = 0.8614$ |

Table 2b: For products dried for 24 hours (fig. 10)

| | | | |
|---|---|---|---|
| Unblanched | K = | $0.0002T^2 - 0.0227T + 0.6588$ | $R^2 = 0.6588$ |
| Blanched | K = | $0.0002T^2 - 0.0181T + 0.5184$ | $R^2 = 0.9106$ |
| Peeled | K = | $0.0002T^2 - 0.019T + 0.5937$ | $R^2 = 0.8804$ |
| Unpeeled | K = | $0.0002T^2 - 0.0178T + 0.5409$ | $R^2 = 0.8551$ |

Figures 9 and 10 have similar shapes and can be seen as drying curves. The thermal conductivities were high at low drying times as was the case with moisture contents and decrease to almost asymptotic values at higher drying times at 60°C. The intercepts which give the expected conductivities at very low temperatures are higher for 2 hour-dried ginger averaging to 0.578 W/mK and at 24 hours of drying, 0.225 W/mK, by a factor of 61.1%. The thermal conductivity for 24 hour-dried ginger approximates to the thermal conductivity of dried ginger. It is noted that the unpeeled ginger has the highest thermal conductivity (0.2602 W/mK) when dry compared with the bleached ginger that has the lowest value (0.1974 W/mK) at higher drying time of 24 hours. It is worth noting that the unpeeled ginger also has the highest moisture content at 24 hours drying and the blanched also has the lowest value in both cases. Previous studies concluded that peeled and bleanched ginger allows a decreased in the resistance of this product to water transportation within the internal and external part because the outer skin of the rhizomes as observed from the unblanched and unpeeled provides slight resistance due to its' non-permeability which causes rigidity during the drying process therefore disallowing water easy transportation through it.

## V. CONCLUSIONS

The following conclusions were drawn from this study:

- The results obtained for moisture content of ginger rhizomes clearly indicate that drying at significantly short time (say two hours) will not reduce the moisture sufficiently to reduce the effects of pest and bacterial infections.
- The drying rate at higher drying times (24 hours) was 0.889/°C and 0.4437/°C for 2 hours drying, giving 50% in moisture reduction rate. The intercept which theoretically gives the initial moisture content at 0°C is lower at 24 hours drying (59.33%) compared to 95.12% on dry basis at 2 hours of drying, as expected.
- The result of this study shows that the lowest moisture content (5.98%) is obtained for unpeeled ginger while the highest is the blanched (9.04%) all for 24 hour-drying and at 60 °C.
- The average moisture content for 2 hours drying at 60°C was 70.6% while for 24 hours drying, it was an average

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of 7.55%. which is close to the target of 4 – 7% desired for this research. This is better than the result of 22.54% obtained at 50°C under blanched condition drying for 32 hours (Hoque *et al.*, 2013). Eze and Agbo (2011) reported that the principal processing of ginger rhizomes involved sorting, washing, soaking, splitting or peeling and drying to moisture content 7-12%.

- The significance of drying ginger for a longer time at even lower temperatures around 60°C has been shown in this work. At higher temperatures ginger shrinkages and surface decolouration may occur. As can be seen, good results are achievable at temperature of 60°C to sustain the quality of the products.
- The thermal conductivity for 24 hour-dried ginger at 60°C approximates to the thermal conductivity of dried ginger and it is 0.050 W/mK on the average, with unpeeled ginger giving the lowest value of 0.046 W/mK and unblanched ginger giving the highest value of 0.055 W/mK.
- The results show the superiority of the use of convective drying method over all other methods.

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Description of the Changes:

Abstract: The experimental result was included.

Results and Discussions: From the simulation tables, graphs were plotted.

References: Stated in details.