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Full Length Research Paper

Effects of chips sizes on thin layer drying characteristics of some plantain varieties (Dwarf *cavendish* and Musa *sapientum*)

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Abstract

The study investigates the effects of varying chips sizes of plantain varieties during drying condition. The drying was carried out at 50, 60, 70 and 80^0C using convective air flowing at a velocity of 2.2 m/s. The experimental set up was performed in a processing and storage laboratory. The plantain samples werecut into equal sizes of thicknesses: 2cm, 3cm, 4cm, and 5cm for the two varieties used in the experiment. The moisture content decreases with drying time for the two varieties, but the drying period of each variety were not the same. The study further shows that drying rate was higher at 80^0C than 50^0C and that the entire drying process took place in the falling rate period. Drying time varied from one variety to the other depending on the initial moisture content, pretreatment and drying air temperatures. As expected the increase in drying temperature resulted in an increase in drying rate. The study indicates that the method of drying is more efficient on 2cm thickness than 5cm especially in Musa *sapientum*variety of the banana. The Musa *sapientum*varietyhad the highest drying rate than Dwarf *Cavendish* varietyin almost all temperatures and treatment variations. In this investigation, Newton's law was used as a major equation to determine the moisture diffusivity in the two varieties.The obtained average value of effective moisture diffusivity ranged from 1.18 x 10^{-2} m^2/s to 3.73 x 10^{-2} m^2/s while the activation energy is 0.200 kJ/mol for temperature range from 50^oC to 80^oC.

Key words: Plantain chips, Thin layer drying, Temperatures, Effective Diffusivity, Activation energy

INTRODUCTION

Plantain is the common name for herbaceous plants of the genus Musa. There is no formal botanical distinction between bananas and plantains, and the use of either term is based purely on how the fruits are consumed (Oke et. al 1998).Bananas are almost always eaten raw, while plantains tend to be cooked or otherwise processed, and are used either when green or unripe (and therefore starchy) or overripe (and therefore sweet). An average plantain has about 220 calories and is a good source of potassium and dietary fiber (Randy et.al. 2007). Plantains are staple food in the tropical regions of the world, the tenth most important staple that feeds the world. Plantains are treated in much the same way as potatoes and with a similar neutral flavour and texture when the unripe fruit is cooked by steaming, boiling or frying. Plantain fruit all year round and this makes the crop a reliable all-season staple food, particularly in developing countries with inadequate food storage, preservation and transportation technologies. In Africa, plantains and bananas provide more than 25 percent of the carbohydrate requirements for over 70 million people (Oke et. al. 1998).Uganda produces 9.5 million metric tons of plantain while India harvested over 24.5 million metric tons of bananas in 2009. Production of plantain is seasonal whilst consumption is all year round and therefore there is the need to cut down on post-harvest losses by processing them into forms with reduced moisture content. Plantain production has been onthe increase since 2001 while it's estimated that in 2015, there will be a surplus of about 852,000 MT which will have to be exported, processed or will be wasted (Dankyi et al., 2007). Drying kinetics is generally evaluated experimentally by measuring the weight of a drying sample as a function of time. Drying curves may be represented in different ways; moisture ratio versus time, drying rate versus time, averaged moisture content versus time. Several theories on the mechanism of moisture migration have been reviewed and only capillary and liquid diffusion theories are, generally, applicable to the drying of food materials. Drying process can be described completely using an appropriate drying model, which is made up by differential equations of heat and mass transfer in the interior of the product and at its inter phase with the drying agent. Thus, knowledge of transport and material properties is necessary to apply any transport equation (Karathanos et. al. 1999). Such properties are the moisture diffusivity, thermal conductivity, density, and specific heat and inter phase heat and mass transfer coefficients. Hill and Pyke (1997) stated that drying takes place when there is a net movement of water going out of the food product into the surrounding so that the food would give up its moisture content. He further stated that the drying rate is determined by how fast the moisture migrates or diffuses from the interior to the surrounding air.

The effects of drying-air temperature and flow rate can also be combined into an expression of drying speed represented by the moisture reduction in percentage per hour. Trim and Robinson (1994) observed that drying rate generally increases with increasing moisture content and air temperature observed decreases with decrease in humidity. Cape and Percy (1996) shared the opinion that another factor noted in explaining the rate of water loss in food is the effective area across which water may be lost and that large surface area ensure rapid transfer of moisture to the surface and the ease with which moisture is removed by the air current. The drying of agricultural materials involves simultaneous heat and mass transfer to and from the material. In the simplest of terms, the discipline of heat transfer is concerned with only two things: Temperature, and the flow of heat. Temperature represents the amount of thermal energy available, whereas heat flow represents the movement of thermal energy from place to place.(Murugean, et. al. 2002, Margaris and Ghiaus 2007). Thus during drying vapour is generated throughout the material, transferred to the surface and removed by airflow at the surface (Johnson, et. al. 1998). Heat is transferred to the material by conduction causing the moisture to change from liquid phase to vapour and evaporate at the surface. Therefore, the drying process involves inter-phase mass transfer from the wet material to the gaseous drying agent (heated air), which may be illustrated as a transport of moisture from material core to its surface, followed by evaporation at the surface of the material, and dissipation of water vapour into the bulk of the gaseous agent (Margaris and Ghiaus2007).Drying permits a reduction of losses during storage from causes such as premature and unseasonable germination of the produce, development of moulds and proliferation of insects. Drying is a thermo-physical and a physio-chemical action and its dynamic principles are governed by heat and mass transfer laws inside and outside of the product. Drying is the most effective unit operation for protection of agricultural produce and save storage of agricultural products (Onwuka, 2005).The rate of drying during this period is dependent upon the difference between the temperature of the wetted surface at constant air velocity and relative humidity. Sun, oven and solar drying are the popular drying methods used in drying these food crops. Drying is the phase of the post-harvest system during which the product is rapidly dried until it reaches the “safe moisture” level. Researchers have established that drying takes place under falling rate period. The falling rate period is characterized by increasing temperature both at surface and within the solid. Furthermore, changes in air velocity have much smaller effect on the period than during the constant-rate period. The falling-rate period of drying is controlled largely by the product and is dependent upon the movement of moisture within the material from the centre to the surface by liquid diffusion. Effective moisture diffusivity is used to represent an overall mass transport property of water in food materials (Dadaliet al., 2007). During drying it is assumed that diffusivity, explained with Fick’s diffusion equation, is the only physical mechanism to transfer water to the surface. Effective moisture diffusion is affected by composition, moisture content, temperature and porosity of the material.

Theoretical consideration of the Drying process

The study of drying behavior of different materials has been the subject of interest for various investigators on both theoretical and practical grounds. In the course of studies conducted regarding the drying behavior of various agricultural products, many mathematical models have been used to describe the drying process of which thin-layer drying models are the most common(Mohammadi*et al.,* 2008). According to Parti (1993), mathematical models that describe drying mechanisms of grain and food can also provide the required temperature and moisture information. Thin-layer drying equations fall into three categories namely, theoretical, semi-theoretical, and empirical models. Semi-theoretical models are derived based on theoretical model (Fick’s second law) but are simplified and added with empirical coefficients in some cases to improve curve fitting. In the empirical models a direct relationship is derived between moisture content and drying time and the parameters associated with it have no physical meaning at all. The diffusion equation which describes the drying rate of the plantain chips formulated by Lewis in line with Newton’s law (Sahay and Singh 2005) is,

$$\frac{dm}{dt} = -k\ (m - m_e) \qquad (1)$$

This is reduced further by the famous integration of equation (1) to obtain page model equation.

$$\frac{M - M_e}{M_o - M_e} = MR = \exp(-K_t) \qquad (2)$$

Where,
M_o = Initial moisture content (g water/100 g solid)
t = Drying time (mins)
k = Drying constant (1/min)
m = Moisture content at a particular instance (g water/100g solid)
M_e = Equilibrium moisture content,
MR = Moisture content
In describing moisture diffusion during drying of spherically shaped objects
According to Doymaz, 2004

$$MR = \frac{m}{M_o} \qquad (3)$$

$$MR = \frac{6}{\pi^2}\exp\left(\frac{-\pi^2}{c} . \frac{D_{efft}}{R^2}\right) \qquad (4)$$

Geankopolis, 2003

Simplifying further,

$$\frac{m}{M_o} = A_e - k_t \qquad (5)$$

In linear form,

$$l_n \frac{m}{M_e} = l_n A - kt \qquad (6)$$

(Ehiem and Simonyan, 2011)

Where,

$$A = \frac{6}{\pi^2}\ and\ k = \frac{\pi^2 D\ eff}{6R^2} \qquad (7)$$

The activation energy require for the effective diffusion according to Rafiee et al 2008 and reported by Ehiem et al, 2011 is given by,

$$D = D_o\ exp\ \left(\frac{Eo}{TR}\right) \qquad (8)$$

$$In\ D_{eff} = \ln D_o - \left(\frac{Eo}{TR}\right) \qquad (9)$$

The activation energy is obtained through the plotting of D_o vs. $^1/_T$
where,
D_o = Effective diffusivity of O^ok(m^2/min)
R = Universal gas constant
D_{eff}= effective diffusivity at T^oK (m^2/min)

MATERIALS AND METHODS

Plantains used in this experiment were purchased in Mokola at Nigeria Horticulturist Research Institute (NIHORT) in Ibadan,Nigeria(Dwarf Cavendish and Musa *sapientum*), thesevarieties were chosen based on their consistent agronomic performance and post harvest qualities.Samples were prepared for the experiment same day the bunch was harvested and immersed in a plastic bowl with potable water and then peeled with the aid of a stainless kitchen knife. The pulp were then sliced into cylindrical pieces with different thickness of 2cm, 3cm, 4cm and 5cm and the sliced plantain chips were then transferred to the trays in the dryer. The samples were placed on the same tray in the dryer. Drying experiments were conducted at 50, 60, 70 and 80°C (±1°C) using convective air flowing at a velocity of 2.2m/s. The dryer was allowed to run for 30 min to reach the set drying air temperature conditions. The rate of drying and the drying profile of the various plantain cultivars were determined by evaluating the moisture content of the samples taken at a constant interval of 30 minutes by a digital balance of OHAUS CS200 China, capacity 200g by 0.1g accuracy. One layer of the slice was spread thinly on a sample holder in a cabinet dryer. Initial weights of samples were measured by means of a digital balance. Subsequently, the samples were measured continuously every 30 minutes until there was no change in six successive readings. At this point the sample was considered to have attained its equilibrium moisture content of the drying environment. The procedure was replicated four times for each drying temperature. The experiment was performed in the processing and storage laboratory of Federal Institute of Industrial Research Oshodi using a Hot air oven, schutzart DIN memmertGmbh and CO.KG, 40050-IP20 Germany (Figure 1.)

RESULTS AND DISCUSSION

The results of the experiment are presented in tables 1 and 2 for the two varieties. Drying curves of drying rate over drying period were constructed to depict drying profile graphically. The plot of drying curve is presented in figures 2 to 8 and shows that moisture content of plantain decreases with an increase in temperature for both varieties. It also showed that the drying of variety A (Dwarf Cavendish) of plantain proceeded more rapidly at higher air temperatures than variety B (Musa Sapientum). As the material dries, removal of moisture from the inside became slower thereby requiring more energy to detach water molecules from the solid matrix. The plot also showed that drying time required attaining equilibrium moisture content decreased as the temperature increased. The plot further shows that drying rate was higher at 80^0c than 50^0c and that the entire drying

Figure 1. Hot air oven used for the experiment

Table 1.Drying rate during dryingfor variety A (Musa *sapientum*) Exotic plantain

Thickness (cm)	**Initial weight (g)**	**Wt 30mins drying (g)**	**Wt 60mins drying (g)**	**Wt 90mins drying (g)**	**Wt 120mins (g)**	**Wt 150 mins(g)**	**Wt 180 mins(g)**
Drying rate at temperature 50^0c							
2	1.2	0.9	0.8	0.7	0.5	0.3	0.3
3	2.1	1.8	1.8	1.6	1.4	1.4	1.3
4	2.7	2.3	2.2	2.0	1.8	1.7	1.7
5	2.9	2.7	2.4	2.2	2.0	1.9	1.9
Drying rate at temperature 60^0c							
2	1.2	0.8	0.7	0.4	0.4	0.3	0.3
3	2.1	1.6	0.6	0.5	0.4	0.4	0.2
4	2.7	2.3	2.1	1.9	1.7	1.5	1.5
5	2.9	2.7	2.4	2.1	2.0	1.7	1.7
Drying rate at temperature 70^0c							
2	1.2	0.6	0.5	0.3	0.3	0.2	0.2
3	2.1	1.8	1.6	1.4	1.2	1.2	1.1
4	2.7	2.2	2.0	1.8	1.7	1.5	1.5
5	2.9	2.7	2.5	2.3	2.0	1.8	1.8
Drying rate at temperature 80^0c							
2	1.2	0.5	0.4	0.3	0.3	0.2	0.2
3	2.1	1.6	1.4	1.2	1.2	1.2	1.1
4	2.7	2.2	1.9	1.6	1.5	1.5	1.5
5	2.9	2.6	2.4	2.1	1.7	1.7	1.6

process took place in the falling rate period. Some authors observed that drying of most agricultural materials takes place only in the falling rate period. This indicates that diffusion was the dominant mechanism of moisture movement in drying plantain. Effect of temperature on drying rate and drying time, drying rate curves for showing the effect of pretreatment generally, drying rates decreased with decreasing moisture contents, and drying occurred in the falling rate period. The drying was also characterized by either a no constant rate or a short constant rate (at the early part of the drying processes). These observations are in agreement with previous literature studies on the convective drying of plantain (Satimehin and Alabi, 2005, Ndukwu and Nwabuisi, 2011, Ehiem and Simonyan, 2011).Initially, drying rates were highest when moisture

Table 2. Drying rate during drying for variety B (Dwarf Cavendish) Banana plantain

Thickness (cm)	Initial weight (g)	Wt 30mins drying (g)	Wt 60mins drying (g)	Wt 90 mins drying (g)	Wt 120 mins(g)	Wt 150 mins(g)	Wt 180 mins(g)
Drying rate at temperature 50^0c							
2	2.5	2.2	1.8	1.8	1.8	1.5	1.4
3	2.9	2.6	2.1	2.1	2.0	1.8	1.8
4	4.4	4.1	3.6	3.6	3.3	3.0	3.0
5	5.1	4.9	4.4	4.4	4.1	4.0	4.0
Drying rate at temperature 60^0c							
2	2.5	2.2	1.9	1.6	1.7	1.5	1.5
3	2.9	2.5	2.4	2.0	2.0	1.8	1.8
4	4.4	3.9	3.6	3.4	3.4	3.0	3.0
5	5.1	4.8	4.4	4.3	4.3	4.0	4.1
Drying rate at temperature 70^0c							
2	2.5	2.0	1.8	1.6	1.5	1.5	1.4
3	2.9	2.5	2.2	1.9	1.8	1.8	1.7
4	4.4	3.9	3.4	3.1	3.0	3.0	2.9
5	5.1	4.7	4.4	4.1	4.0	4.0	3.8
Drying rate at temperature 80^0c							
2	2.5	1.9	1.7	1.5	1.5	1.4	1.3
3	2.9	2.4	2.1	1.9	1.8	1.8	1.7
4	4.4	3.8	3.3	3.1	3.0	3.0	2.9
5	5.1	4.6	4.3	4.0	4.0	4.0	3.8

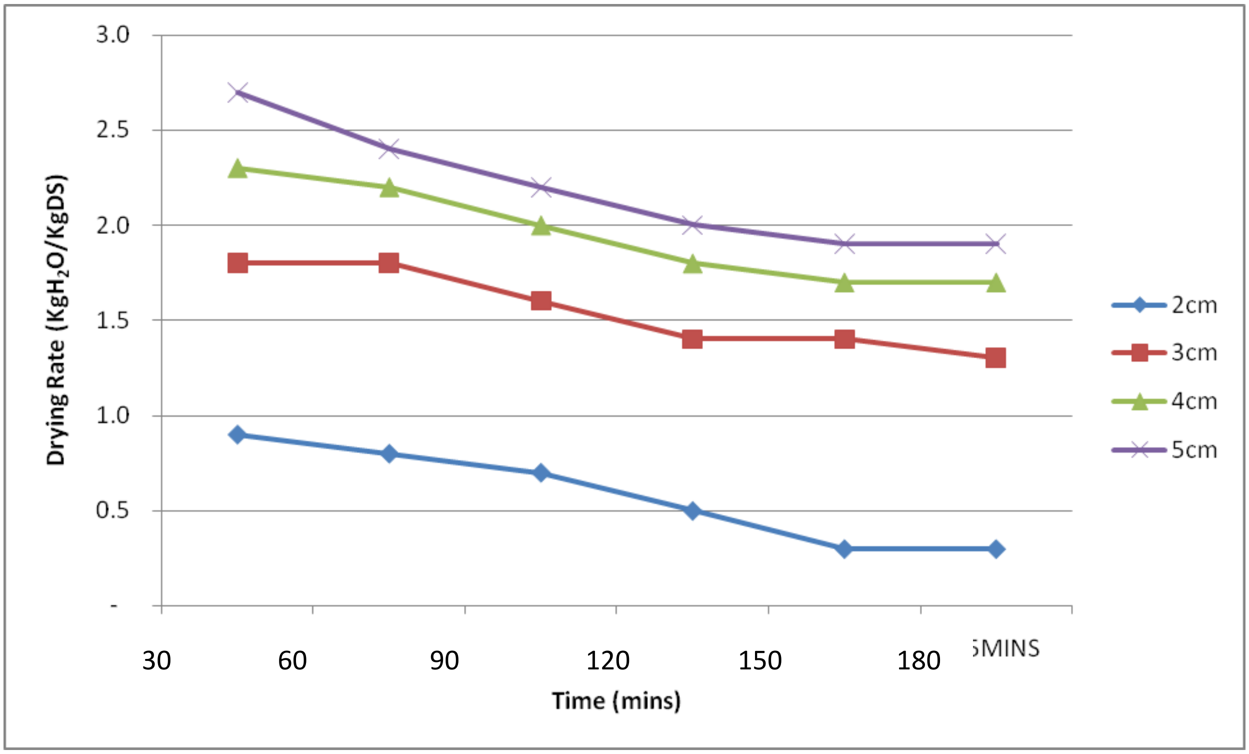

Figure 2. Variation of drying rate against various times in dryer at 50°C for Variety A (Musa *sapientum*)

contents were higher, after which the drying rate decreased steadily with decreased moisture contents. This trend could be due to the removal of free moisture near the surface of the plantain slices at the early stages of drying. Drying rate is a function of temperature and time, and more moisture was removed due to the low internal resistance of moisture at the beginning of the drying. As drying increased more energy was required to

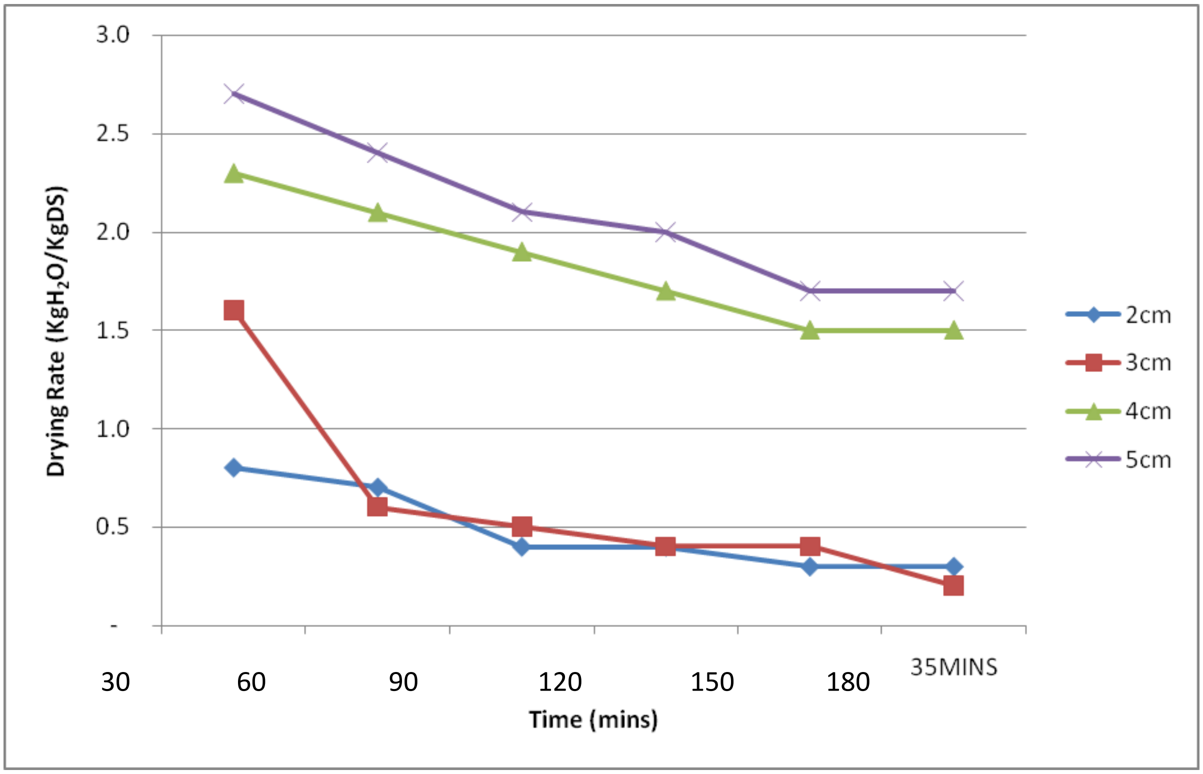

Figure 3. Variation of drying rate against various times in dryer at 60°C for Variety A(Musa *sapientum*)

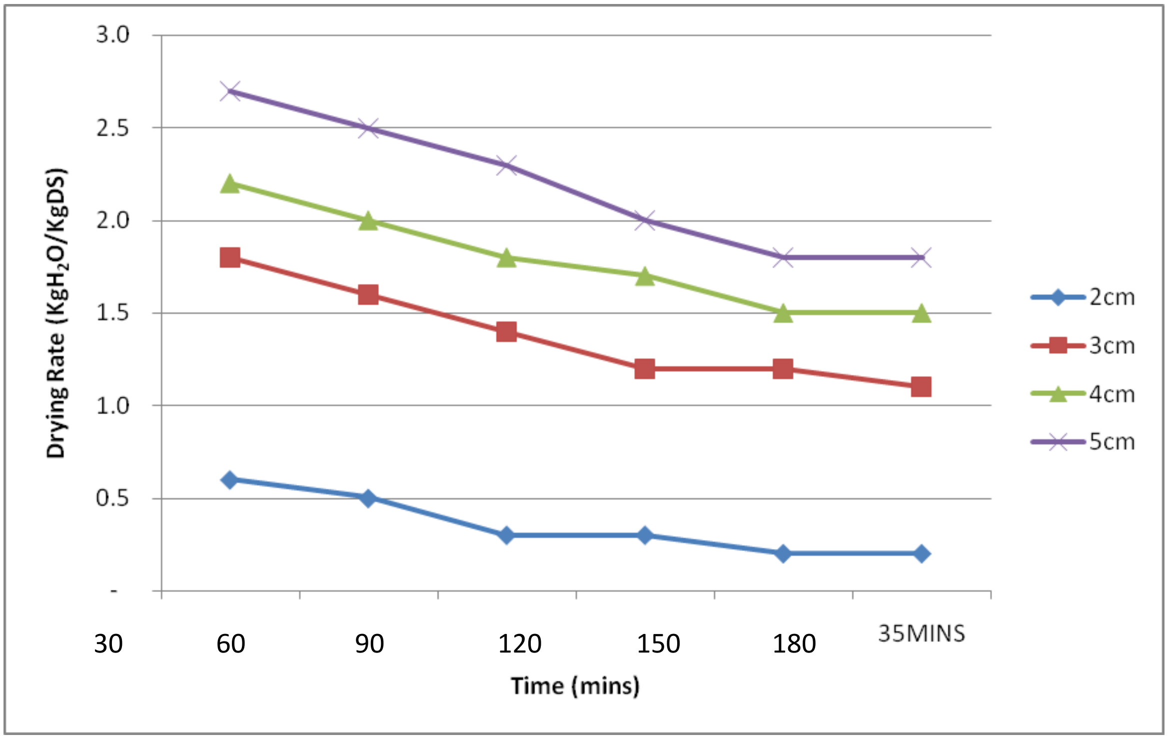

Figure 4. Variation of drying rate against various times in dryer at 70°C for Variety A(Musa *sapientum*)

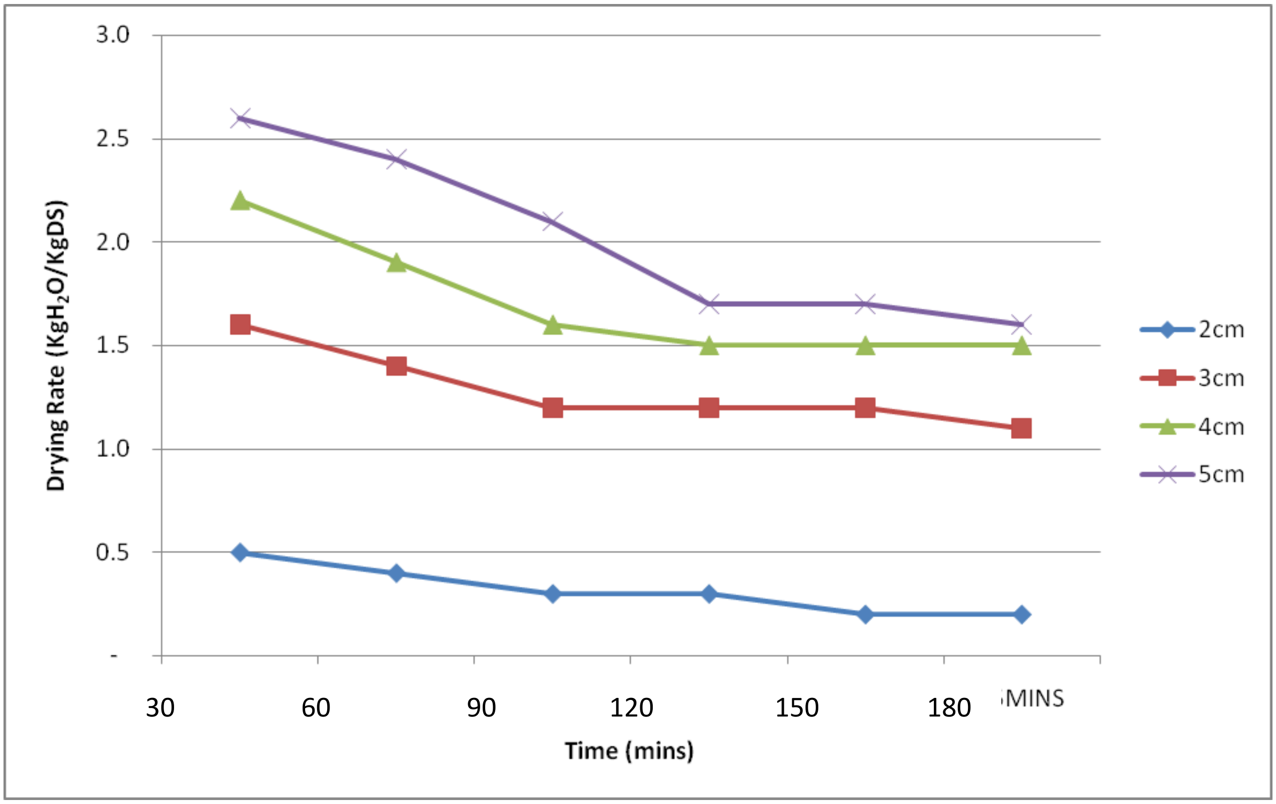

Figure 5. Variation of drying rate against various times in dryer at 80^{o}C for Variety A(Musa *sapientum*)

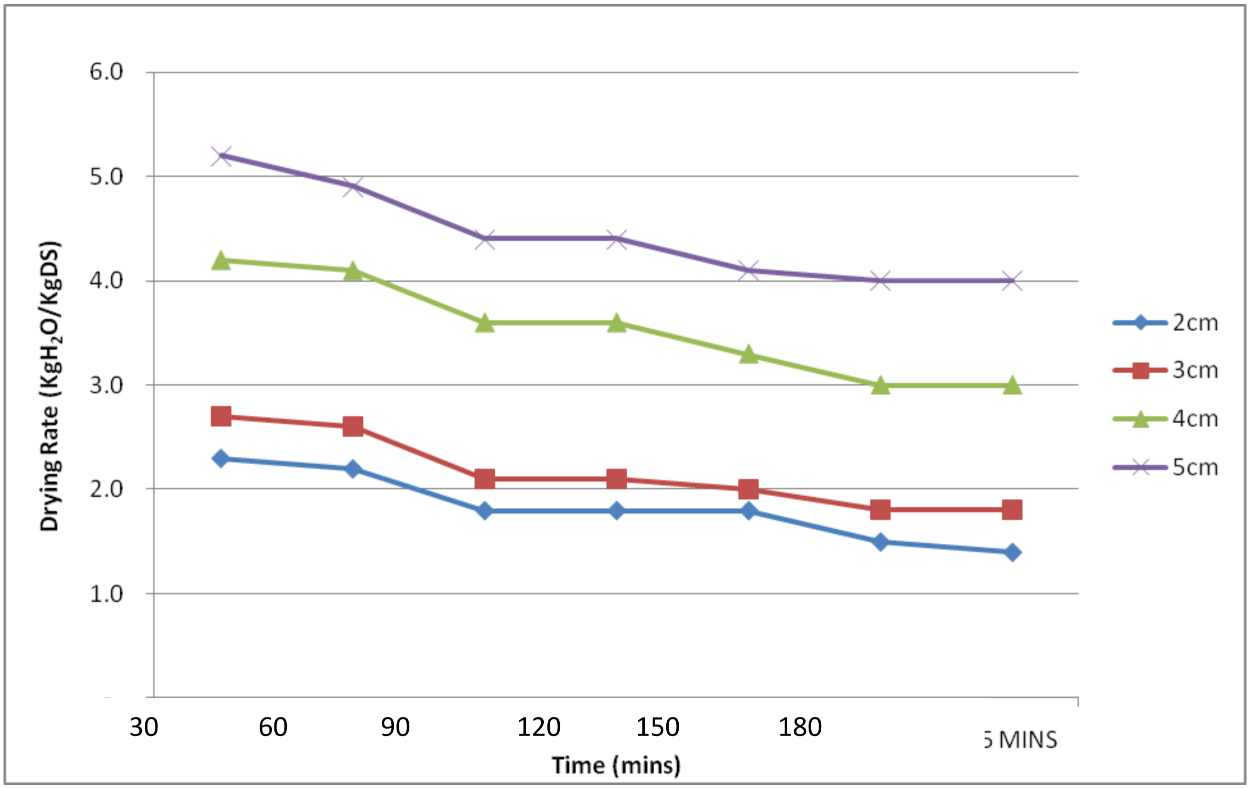

Figure 6. Variation of drying rate against various times in dryer at 50^{o}C for Variety B (Dwarf Cavendish)

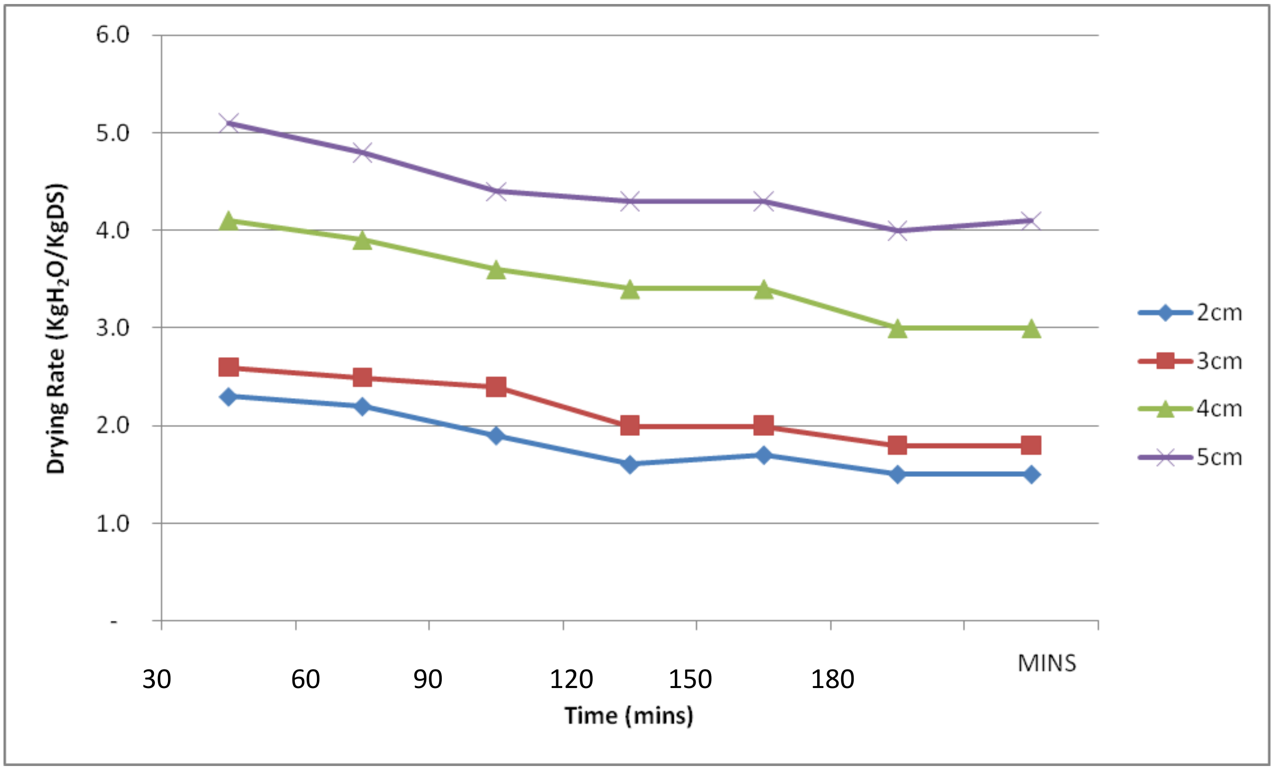

Figure 7. Variation of drying rate against various times in dryer at 60°C for Variety B (Dwarf Cavendish)

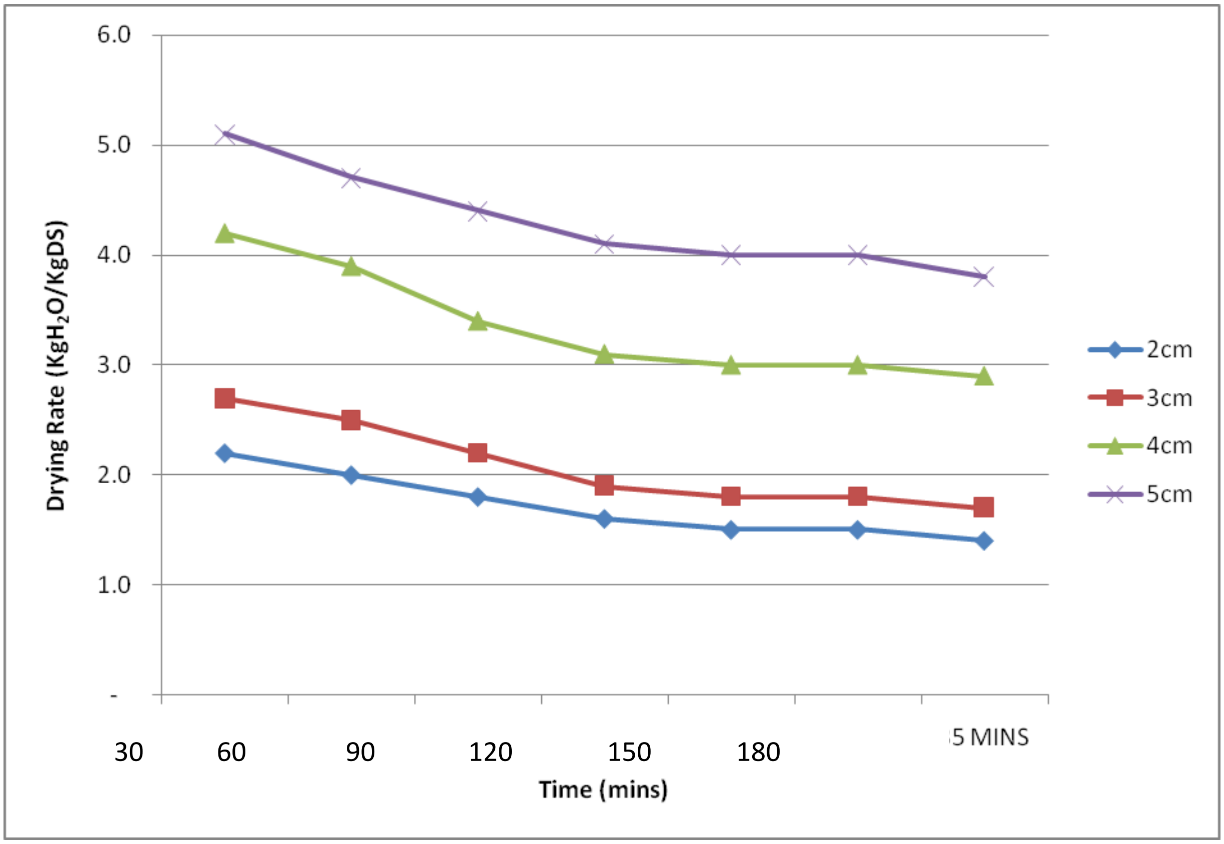

Figure.8. Variation of drying rate against various times in dryer at70°C for Variety B (Dwarf Cavendish)

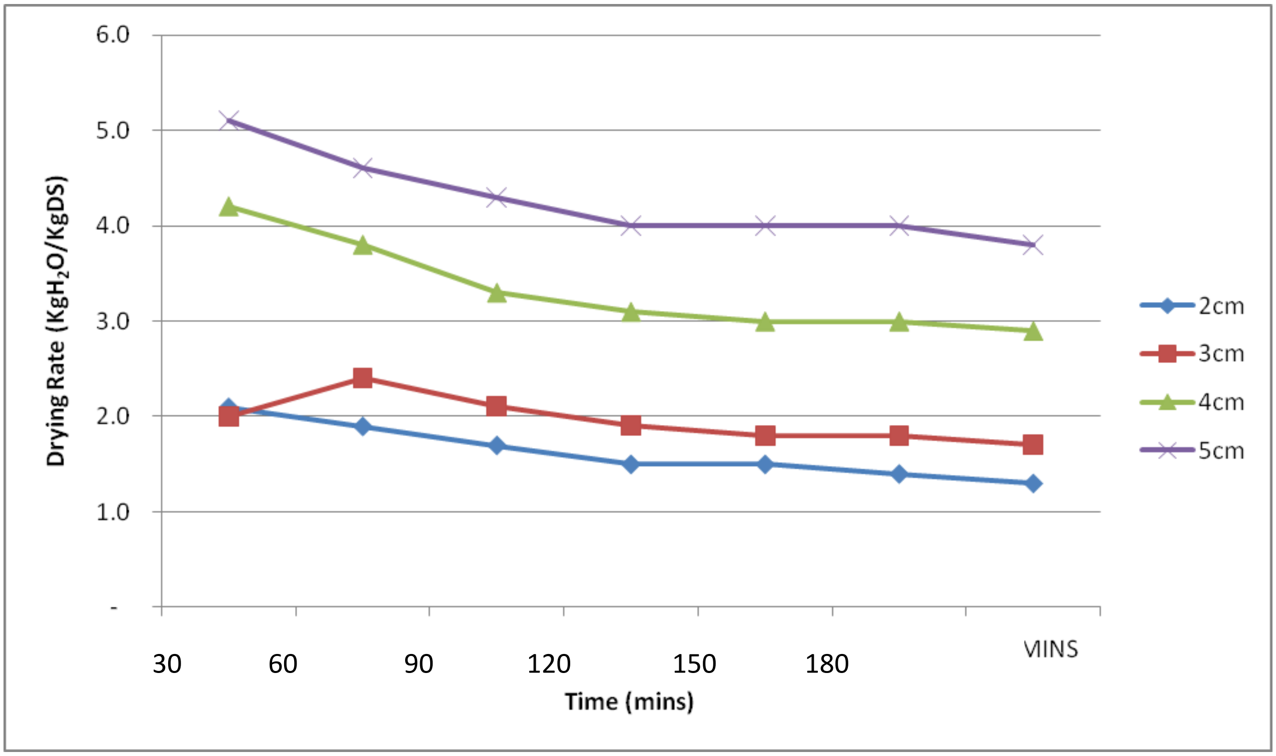

Figure 9. Variation of drying rate against various times in dryer at 80^{o}C for Variety B (Dwarf Cavendish)

Table 3. Drying parameters of Plantain chips at various temperatures

Temp (T)	L(cm)	K(1/min)	D (m^2/s)
50^{o}c	1.0	0.0166	0.00672
50^{o}c	1.50	0.0166	0.01009
50^{o}c	2.00	0.0166	0.01345
50^{o}c	2.50	0.0166	0.0168
60^{o}c	1.00	0.0196	0.0079432
60^{o}c	1.50	0.0196	0.0119148
60^{o}c	2.00	0.0196	0.0158865
60^{o}c	2.50	0.0196	0.0794326
70^{o}c	1.00	0.0226	0.009159
70^{o}c	1.50	0.0226	0.0137386
70^{o}c	2.00	0.0226	0.0183181
70^{o}c	2.50	0.0226	0.0228976
80^{o}c	1.0	0.0256	0.0103748
80^{o}c	1.50	0.0256	0.0155623
80^{o}c	2.00	0.0256	0.0829989
80^{o}c	2.50	0.0256	0.00414499

break the molecular bond of the moisture and drying rate decreases as moisture content also decreases. The values of effective diffusivity were calculated for each drying temperature and presented in table 3. The effective moisture diffusivity ranged between 1.18 x 10^{-2} m^2/s to 3.73 x 10^{-2} m^2/s. The plot of the lnDVs. 1/T produces the slope which corresponds tothe activation energy. The activation energy is 0.200 kJ/mol for temperature range from 50^{o}C to 80^{o}C.

CONCLUSION

The results of the study suggest that temperature and pretreatment have an impact on the air drying characteristics and some functional properties of the two plantain varieties at various combinations. Initial moisture content, pretreatment and temperature had a significant effect on the air drying rates of the plantain varieties. Drying time varied from one variety to the other depending on the initial moisture content, pretreatment and drying air temperature. As expected the increase in drying temperature resulted in an increase in drying rate. The study indicates that the method of drying is more efficient on 2cm thickness because it can be store for a long period of time than 5cm especially in variety B(Musa Sapientum) banana plantain, which will still have some moisture left and it will allow quick spoilage. Variety B (Musa Sapientum) had the highest drying rate than variety A (Dwarf Cavendish) in almost all temperature and treatment variations.

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