CHAPTER ONE

1.0 Introduction

Plantain (Musa AAB) is a major source of carbohydrate in diets of people from Latin America, through most of Africa and from countries of South-east Asia (Marriott and Lancaster, 1983). It is estimated that 60 million people in West Africa derive more than 25% of their carbohydrate intake from plantain (Oritz and Vuylsteke, 1996). In Ghana, they have a higher contribution to the Agricultural Gross Domestic Product (AGPD) than cereals (MOFA, 2006). According to Lescot (2000) its per capita annual consumption is higher than maize and yam.

Annual production in Ghana is about 1.8 million metric tons of which only 0.5 tonnes is exported (Lescot, 2000). Several varieties of plantain are cultivated in West Africa. These are classified as French Horn Plantain, False Horn Plantain, or the True Horn Plantain (Ahiekpor, 1996, Hemeng *et al.*, 1996). The local names of the sub varieties of French Horn plantain include Apempa, Oniaba and Nyeretia apem. That of the False Horn are Borodewuo, Apantu pa, Borode sebo and Osoboaso while the True Horn sub varieties comprise Asamienu and Aowin. All these native varieties are classified as triploids with AAB as the genomic group. Pest and diseases have affected the production of these native varieties, the most notable being the fungal disease Black Sigatoka *(Mycosphaerella fijiensis)* (Stover and Simmonds, 1987; Swennen, 1990). Yield losses due to the disease are highly significant ranging from 20 to 50%. Under very severe conditions yield losses may be as high as 80% (Hemeng and Banful, 1994). In view of this, new hybrids were introduced from Honduras in 1994 to supplement the landraces.

The Tetraploid hybrids are high yielding and disease tolerant. The Tetraploids are produced when female fertile triploid landraces of plantain (AAB genomes) are crossed to diploid accessions of *M.acuminata* or *M. balbisiana* that are resistant to black Sigatoka disease. They belong to the AAAB genomic group.

Plantain is however a seasonal and highly perishable crop. Ogazi (1982) reported that over 80% of the crop is harvested during the period of September to February, and that there is much wastage during this period as some of the products do not store for a long period. This results in seasonal unavailability and limitations on the use by urban populations. Therefore, there is a need to develop preservation methods for this crop.

Air-drying is considered to be one of the simplest and most economical ways of commercially processing fruit and vegetables (Brennan *et al.*, 1990). Air-drying could be considered as appropriate to developing countries as the product, suitably packaged, can be stored for several months without the risk of spoilage and can be milled into flour and rehydrated for a variety of uses (Marriott and Lancaster, 1983).

In hot-air drying of plantain, enough water must be removed to lower the water activity to a level which inhibits the growth of microorganisms and reduces the rate at which enzymatic and non-enzymatic reactions occur. Thus, one of the primary requirements in using hot-air drying is to understand the phenomena involved in the drying process, to be able to predict drying times, establish the distribution of moisture throughout the solid pieces during drying and the influence of the processing variables such as air temperature and velocity, pretreatment and the size of the pieces on drying behaviour (Johnson *et al.*, 1998).

Pretreatments have been used commercially to accelerate the drying of fruits. Dipping fruits for several seconds in pretreatment solutions greatly reduces the drying time (Radler, 1964; Bolin, Petricci, and Fuller, 1975). They are applied to the surface of the fruit by dipping; resulting in a coating which apparently breaks down the cuticular fruit surface, resulting in a reduced resistance to moisture loss and this increases the drying rate (Ponting and McBean, 1970). Pretreatments also lead to the bleaching of the plantain to prevent browning of its flour.

Functional property has been defined by Matil (1971) as those characteristics that govern the behaviour of nutrients in food during processing, storage, and preparation as they affect food quality and acceptability. Some of the important functional properties that influence the utility of most starchy staples, such as plantain, include the drying characteristics, water binding capacity, swelling power, solubility, emulsion capacity, oil absorption capacity, whipability, foam stability and viscosity

Though drying has been widely used to promote food preservation as the reduction of moisture content brings down microbial activity and extends product life one must consider the other changes that accompany drying, even more so in the case of cellular materials, which may be greatly affected by the dehydration process.

1.1 Justification

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 has however been having an increasing surplus production since 2001 (Dankye *et al.*, 2007). It is estimated that in 2010, there will be a surplus of 633,000 Mt and in 2015 about 852,000 Mt. This means that these surpluses have to be exported, processed or go to waste (Dankye *et al.*, 2007).

A reduction in moisture content potentially increases shelf life and hence prevents excessive post harvest loss and that drying is an alternative to a developing country like Ghana where there is deterioration due to poor storage, weather conditions and processing facilities.

Dickson and Benneh (1988) reported that the daily sunshine duration in Ghana ranges between 6-8 hours and that dehydration of agricultural produce in the open air is a common practice. Abdelhaq and Labuza (1987) argued that there are many problems in sun drying such as the slowness of the process, the exposure to environmental contamination, the uncertainty of the whether and the manual labour required. Due to these difficulties, more rapid, safe and controllable methods are required. Hot-air drying is an alternative drying method. Using hot air dryers leads to a more uniform, hygienic and attractive products that can be produced rapidly (Karathanos and Belessiotis, 1997).

Musa *et al.* (2005) argued that there is often a decrease in the quality of dried products because most conventional techniques use high temperature during the drying process.

The process may introduce undesirable changes in appearance and will cause modification in texture, flavor and color as well. This is not in agreement with the increasing demand of consumers for the highest quality finished product

Besides, air drying is an energy-intensive operation, and a better understanding of the drying process is important if drying efficiency is to be increased while maintaining product quality. The main objective of any drying process is to produce a dried product of desired quality at a minimum cost and maximum output, and to optimize these factors consistently (Chua *et al*., 2001). Conventional air-drying is consequently cost intensive because it is a simultaneous heat and mass transfer process accompanied by phase change (Barbanti *et al*., 1994). A pre-treatment can be used to reduce the initial water content or to modify the crop tissue structure in a way that the air-drying time becomes faster (Fabiano *et al.*, 2007).

The agricultural sector produces surpluses of plantain, cassava, yam and cocoyam. It is estimated that about 30% of Ghana's annual food harvest goes to waste due to little investment in the nation's food processing industry. Currently, over 90% of the foodstuffs are sold in their raw forms. This situation limits the opportunities for efficient and cost-effective distribution. It further takes income from the small food processors and makes domestically consumed processed foods more expensive. Value-added processing would lead to higher profits (Dankye *et al.,* 2007).

Unripe plantain is traditionally processed into flour in West and other Central African countries (Ukhum and Ukpebor, 1991). The preparation method consists of peeling of the fruits with the hands, then cutting the pulp into small pieces, and air drying them after which the dried pulp is then milled into flour. The colour of the flour obtained is more or less dark due to the action of browning enzymes. Some improvement of this traditional method, by blanching the plantain pulp, by soaking in a sodium metabisulfite solution or in a citric acid solution followed by draining and drying resulted in the production of a more or less whitish flour (Ngalani, 1989). That not withstanding, little work has been done in this area to ascertain the influence of these pretreatments and temperature on other functional properties of the plantain flour whilst considering the cultivar of the plantain.

It is also worthy to note that some of the instant plantain fufu companies import plantain flour to Ghana despite the surpluses in plantain production (Dankye *et al.*, 2007). Converting plantain into flour could contribute to reduced losses and allow the food industry to store the product throughout the year. In order to use plantain flours as ingredient for the food industry it is necessary to characterize their chemical, nutritional composition as well as their functional properties. Based on the aforementioned reasons, the title of the project is Drying characteristics of pretreated pulp of triploid and tetraploid plantain varieties and the general and specific objectives are as outlined below.

1.3.1 The general objective is:

To investigate the influence of pretreatment on the air drying characteristics of Triploid and Tetraploid pulp of plantain.

1.3.2 Specific objectives

The specific objectives of the study include the following:

1. To determine the effect of pretreatment and temperature on the drying rates of the various plantain varieties.
2. To investigate a suitable thin-layer model for the drying processes.
3. To investigate the influence of pretreatment on physico-functional properties such as water binding capacity, bulk density, pH, solubility, swelling power and rehydration ratio.

CHAPTER TWO

2.0 LITERATURE REVIEW

2.1 Review of the Taxonomy of plantain and banana

According to Chesman, who in 1948 pioneered the modern classification of bananas (Simmonds, 1966), most edible bananas and plantains belong to the *Eumusa* section of the genus *Musa* (family Musaceae) and are derived from the species *Musa acuminata* Colla and *M. balbisiana* Colla, which correspond roughly to two species originally described by Linnaeus in his general botanical work *Systema Naturae* (1758) to which he gave the names *M. sapientum* and *M. paradisiaca,* the first referring to a plant producing horn-shaped fruit and similar to the modern "French Plantain," and the second to a type similar to the most popular dessert banana of the tropics, the "Silk Fig." Both of Linnaeus's designations were soon widely applied, with any plantain being referred to as *M. sapientum* and all dessert types being referred to as *M. paradisiaca.* This outdated nomenclature is still used in some modern reference books and papers.

The great majority of banana and plantain cultivars are the products of evolution in the Eumusa series of the genus *Musa.* The one exception to this origin for the edible cultivars is the Fe'i group of bananas which had its origin in the Australimusa series of the same genus. These bananas of the Australimusa series have a basic chromosome number of ten compared with eleven for those of the Eumusa series (Simmonds, 1966). The Fe'i bananas have no known usefulness in banana breeding.

The cultivars of the Eumusa series had their origins in two wild species, *Musa acuminata* and *Musa balbisiana.* The starchiness of plantain fruit in comparison to the sweetness of banana fruit is attributed to the *M. balbisiana* genome. The dry matter content in the ripe fruit of cultivars with one-third or more *M. balbisiana* genes is about 6% greater than that of pure *M. acuminata* cultivars (Simmonds, 1962).

Ploidy and genomic composition of the different clones are designated by A and B to represent the genomes of *M. acuminata* and *M. balbisiana*, respectively. Based on the chromosome number and scorings for the preponderance of characteristics from each of the two parental species (Simmonds and Shepherd, 1955), these A and B abbreviations are used to form groups for classification and identification of specific cultivars (Simmonds, 1962).

The term "plantain" as a name for bananas that are eaten only when cooked, has been widely and loosely used to refer to both the AAB and ABB triploid groups of starchy bananas. By comparison, the ABB cultivars have angular, thick, almost straight fruits, which are much shorter than those of the AAB plantains (Simmonds, 1966).

2.2 Contribution of plantain to the Ghanaian economy

Of the total contribution of all crops to the Agricultural Gross Domestic Product (AGDP) of 64%, plantain is next to roots and tubers and contributes 9% while cereals' and other crops contribute 7% and 2% respectively (Table 2.1) thereby emphasizing the importance of plantain in the economy of Ghana.

Table 2.1: Contribution of Various Sub-sectors to Agricultural GDP.

Sub Sector	Contribution to Agric. GDP
Crops (Total)	**64**
- Roots and Tubers	46
- Plantain	9
- Cereals	7
- Others	2

Source: SRID, MOFA 2006

2.2.1 Importance and benefits of plantain consumption

Plantains and Bananas are among the cheapest foods to produce in Ghana. Among the staple foods, plantains have the second highest per capita consumption after cassava (Table 2.2). Plantains are also important sources of food particularly in the Ashanti, Brong Ahafo and Eastern regions.

Plantain is known to be low in sodium (Chandler, 1995). It contains very little fat and no cholesterol; therefore it is useful in managing patients with high blood pressure and heart disease. They are free from substances that give rise to uric acid therefore, they are ideal for patients with gout or arthritis. Due to the low sodium and protein content, plantain is used in special diets for kidney disease sufferers. The capacity of the plantain to neutralize free hydrochloric acid suggests its use in peptic ulcer therapy (Gowen, 1995).

A fully ripe plantain mixed with milk powder is especially recommended for ulcer patients. The low lipid and high palatability combination is ideal for the diet of obese people (Gowen, 1995). The plantain plant has also some medical properties. The leaves can be pounded and applied to the wound to suppress bleeding. They are also very important sources of rural income (Ortiz and Vuylsteke, 1996). They are attractive to farmers due to their low labour requirement for production compared with cassava, maize, rice and yam (Marriott and Lancester, 1983)

2.2.2 Supply and demand of plantain

Total domestic production of plantain, production available for human consumption and national consumption in Ghana are given in Table 2.3. A biological production of 85% is assumed for the production available for human consumption. There is a positive correlation between national consumption and the population. As the population increases so is the consumption of plantain. This means that plantain will remain an important staple for many Ghanaians in the years ahead. Plantain has however been having an increasingly surplus production since 2001 (Table 2.3). This means that these surpluses have to be exported, processed or may go to waste. Considering the export and value added potential of plantain, these surpluses could be cosmetic. There is therefore the need for processing into various products to curtail the surpluses.

Table 2.2: Per capita consumption of some selected food crops

Commodity	**Kg/capita/year ***				
	1980	**1985**	**1990**	**1995**	**2000**
Plantain	82.2	82.5	83.0	84.2	88.8
<u>Root and Tubers</u>					
Cassava	145.2	146.3	148.0	149.7	151.4
Yam	44.2	43.8	43.3	42.8	42.3
Cocoyam	N/A	N/A	54.0	55.0	56.0
<u>Cereals</u>					
Maize (milled)	38.4	39.2	40.3	41.4	42.5
Rice	12.4	12.7	13.3	13.9	14.5
Millet	8.5	9.4	5.1	12.6	9.0
Sorghum	13.0	14.4	9.3	21.7	14.8

Source: SRID, MOFA (2006)

* In the absence of a household consumption survey, these estimates have been based on food available for human consumption from both domestic and import sources.

Table 2.3: Estimated Domestic Plantain Supply and Demand

Year	Total Domestic Production ('000Mt)	Production available for human consumption ('000Mt)	Per capita consumption (Kg/Annum)	Estimated National Consumption ('000Mt)	Surplus ('000Mt)	Population (Millions)
1996	1,823.0	1,549.6	91.5	1,486.8	67.8	17.7
1997	1,577.5	1,595.9	89.2	1,512.0	83.9	18.0
1998	1,912.8	1,625.9	91.8	1,528.8	97.1	18.2
1999	2,046.2	1,739.3	96.1	1,545.6	193.7	18.4
2000	1,943.9	1,652.3	88.8	1,562.4	89.9	18.6
2001	2,073.9	1,762.8	93.2	1,587.6	175.2	18.9
2002	2,300.0	1,995.0	100.2	1,629.6	325.4	19.4
2003	2,329.0	1,979.7	100.2	1,663.2	316.5	19.8
2004	2,381.0	2,023.9	101.8	1,764.0	259.9	21.0

Source: Compiled by Dankye *et al.* (2007) from MOFA (SRID) various reports

2.3 Drying of agricultural products

Earliest investigations on drying theory have been those of Lewis (1921) and Sherwood (1929). Sherwood classified general mechanisms of drying under the following three cases.

1. Evaporation of water takes place at the solid surface and the resistance to the internal diffusion of liquid is small as compared with the total resistance to the removal of vapour from surface.

2. Evaporation of water takes place at the solid surface and the resistance to the internal diffusion of liquid is great as compared with the resistance to the removal of vapour from the surface.
3. Evaporation of water takes place in the interior of the solid and the resistance to the internal diffusion of liquid is great as compared with the total resistance to the removal of vapour.

He further explained that drying of a particular material need not be restricted to one of the above cases. The drying resistance of very wet solids is similar to the evaporation of the liquid from the liquid surfaces. This is an example of the first case and the rate of drying is usually constant. As drying proceeds the liquid content decreases and the mechanism of drying changes usually to one of the other two cases. The rate of drying decreases with an initial period of constant rate of drying and the moisture at which drying rate starts falling is called critical moisture content. Thus when the moisture content of a material is less than the critical moisture content, no constant rate period appears.

It should be noted that the drying rate also depends on air velocity, air humidity and the temperature of drying air. Sherwood also classified the periods of drying rate as follows:

1. Constant rate period
2. First falling rate period
3. Second falling rate period

The constant rate period is not a characteristic of normal agricultural drying. It is seasonally well established that drying of all agricultural products practically takes place in the falling rate period (Charkraverty, 1963).

The process of drying should be approached from two points of view; the equilibrium rate relationship and the drying rate relationship. The equilibrium rate relationship is established when the food product is exposed to a continual supply of air at constant temperature and humidity, with a fixed partial pressure for the vapour. The product will lose moisture by evaporation or gain moisture from the air until the vapour pressure of the moisture of the product equals the fixed partial pressure of the vapour. The food product and the gas are then in equilibrium and the moisture content of the solid is in equilibrium with the surrounding conditions. This is known as equilibrium moisture content. In the drying rate relations, there are the constant-rate period and falling-rate period. In constant rate period, the rate of evaporation under any given set of air conditions is independent of the solid and is essentially the same as the rate of evaporation from a free liquid surface under the same conditions. The rate of drying during this period is dependent upon the:

a) Difference between the temperature of the wetted surface at constant air velocity and relative humidity.
b) Difference in humidity between air stream and wet surface at constant air velocity and temperature.
c) Air velocity at constant air temperature and humidity.

The food product is entirely dried in the falling rate period. The falling-rate period starts after the constant drying rate period and corresponds to the drying cycle where all the surface is no longer wetted and the wetted surface continually decreases until, at the end of this period, the surface is dry. The cause of falling off in the rate of drying is due to the inability of the moisture to be conveyed from the centre of the body to the surface at rates comparable with the moisture evaporation from its surface to the surrounding.

The falling rate period is characterised 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 (Minkah, 2007).

2.4 Thin layer drying models

In the past 60 years, 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 models (Mohammadi *et al.,* 2008). Drying of many fruits and other agricultural products has been successfully predicted (Muthukumarappan and Gunasekaran, 1994; Afzal and Abe, 1998; Baini, and Langrish, 2007). 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. The comprehensive review of these equations is reported in detail by Jayas *et al.* (1991). 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.

Lewis (1921), cited by Jayas *et al.* (1991), suggested an equation that assumes the rate of change in moisture content is proportional to the difference between moisture content and equilibrium moisture content of the food.

$$\mathbf{MR} = \frac{\mathbf{M_t} - \mathbf{M_C}}{\mathbf{M_o} - \mathbf{M_c}} = \mathbf{exp}(-\mathbf{k\,t}) \qquad (\mathbf{1})$$

Where MR = moisture ratio,

M_t = moisture content at time, t (% w.b.),

M_c = equilibrium moisture content (% w.b.),

M_o = initial moisture content (% w.b.),

k = drying constant determined from the experimental data (h^{-1})

t = time (h)

Other authors ague that for long drying times equation one can be simplified to MR = M_t/M_o instead of MR = $M_t - M_c/ M_o - M_c$ due to the fact that values of equilibrium moisture content, Mc are relatively small compared to M_t or M_o (Doymaz, 2004; Doymaz and Pala, 2002; Lomauro *et al*., 1985)

Because of its simplicity, equation 1 has been widely used to describe drying of different crops (Bruce 1985; O'Callaghan *et al*., 1971; Sabbah *et al.*, 1972). The equation, however, cannot describe the drying rate accurately throughout the drying period (Jayas *et al*., 1991). A modified drying equation was obtained from equation (1) by Henderson and Pabis (1961), with another constant added:

$$\mathbf{MR = a\,exp(-b\ t)} \qquad (\mathbf{2})$$

Where,

a = empirical drying constant and

b = empirical drying constant (h^{-1})

Equation 2 was used by several researchers to model drying of mulberry, grains and oilseeds (Doymaz, 2004; Henderson and Pabis 1961; Wang and Singh 1978; Moss and Otten, 1989). To overcome shortcomings of the Lewis model (Equation 1), Page (1949) suggested equation 3 as a drying model.

$$\mathbf{MR = exp(-k\ t^{y})} \qquad (\mathbf{3})$$

Where

k = empirical drying constant (h^{-1}) and

y = empirical drying constant

Many researchers have used equation 3 to describe thin-layer drying rates (Hulasare, 1997; Misra and Brooker, 1980; White *et al*., 1973; Syarief *et al.*, 1984; Wang and Singh, 1978; Hutchinson and Otten, 1983; Bruce, 1985; Pathak *et al*., 1991).

The above equation is a modification of the theoretical model, known as the exponential or the Newtonian model (Sun and Woods, 1994). The model is described as (Nellist, 1976; Colson and Young, 1990; Pattey *et al*., 1988; Crisp and Woods, 1994)

$$\frac{dM}{dt} = -k(M_t - M_c) \qquad (4)$$

where k is the drying constant.

Equation 3 assumes that resistance to moisture movement and thus gradients within the material are negligible (Colson and Young, 1990). At constant temperature, pressure and humidity, this equation is valid if drying is characterized by "*falling-rate"*regime (Nellist, 1976) which is a characteristic of drying of low moisture content products. As quoted in Sun and Woods (1994), this model has been successfully used for banana (Hofsetz *et. al*., 2007); barley (Sharp, 1982; Bruce, 1985), paddy (Kachru *et al*., 1980), and shelled corn (Westerman *et al*., 1973). The drying constants in thin-layer drying equations vary with temperature (Yunfei and Morey, 1987; Verma *et al*., 1985)

Equation 5 is the general form of a two-term model that uses the first two terms of a general series solution of Fick's second law

$$MR = A \exp(-B t) + C \exp(-D t) \qquad (5)$$

Where A, B = empirical drying constants

C, D = empirical drying constants (h^{-1})

Equation 5 has been applied by Doymaz (2004) in the thin-layer drying kinetics of white mulberry. He further applied a modified version of the Page equation (Equation 6) in the same work only to conclude that the Logarithmic model (Equation 7) best described the drying process.

$$MR = \exp(-k\,t)^{y} \qquad (6)$$

Where k = empirical drying constant (h^{-1}) and

y = empirical drying constant

$$MR = a\exp(-k\,t) + c \qquad (7)$$

Where a, c = empirical drying constants

k = empirical drying constant (h^{-1})

2.5 Goodness-of Fit Statistics for thin layer drying models

Thin-layer drying models are evaluated and compared by using statistical measures. Consequently, the quality of the fitted models is evaluated. Some of these measures can be described as follows:

2.5.1 Root mean square error (RMSE)

It signifies the noise in the data. Lower values of root mean square error are choosen as criteria for goodness of fit (Demir *et al.*, 2004; Doymaz, 2005b; Wang *et al.*, 2007):

$$\mathbf{RMSE} = \left[\frac{\sum_{i=1}^{n}(MR_{pre,i} - MR_{exp,i})^2}{N}\right]^{\frac{1}{2}} \quad (8)$$

2.5.2 Mean sum of squares of errors (MSE) or (χ^2)

It is the mean square of the deviations between the experimental and calculated moisture levels (Iguaz *et al.*, 2003; Lopez *et al.*, 2000; Panchariya *et al.*, 2002). Several authors (Kingsly and Singh, 2007; Yaldiz and Ertekin, 2004; Sarsavadia *et al.*, 1999) used the term-reduced chi square (χ^2) instead:

$$\chi 2 = \left[\frac{\sum_{i=1}^{n}(MR_{pre,i} - MR_{exp,i})^2}{N - Z}\right] \quad (9)$$

Where (equation 8, 9, 11)

$MR_{exp,i}$ is the ith experimental moisture ratio

$MR_{pre,i}$ is the ith predicted model moisture ratio

N is the number of sampling times and

z is the number of constants in the drying model.

2.5.3 Coefficient of determination (R^2)

This is equivalent to the ratio of the regression sum of squares (SSR) to the total sum of squares (SST), which explains the proportion of variance accounted for in the dependent variable by the model. It evaluates how well the model fits the data. It has been used by various authors to evaluate drying models. Higher values for R^2 are used as goodness of fit for the models (Doymaz, 2007; Panchariya *et al.*, 2001; Saeed *et al.*, 2006; Singh *et al.*, 2006). The SSE and the SST can be calculated from the following formulae: Regression sum of squares:

$$\mathbf{SST} = \sum_{i=1}^{N} (\mathbf{Y_i} - \mathbf{Y})^2 \qquad (\mathbf{10})$$

$$\mathbf{SSE} = \frac{\sum_{i=1}^{n} (\mathbf{MR_{pre,i}} - \mathbf{MR_{exp,i}})^2}{\mathbf{N}} \qquad (\mathbf{11})$$

Where SSE is the reduced sum of square error

2.5.4 The standard error of estimate (SEE)

It represents the fitting ability of a model in relation to the number of data points (Sun, 1999), and measures the dispersion of the observed values about the regression line (Basunia and Abe, 1999; Basunia and Abe, 2001a; Mwithiga and Olwal, 2005)

2.6 Drying rate

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 (Afzal and Abe, 1998; Dadali *et al.*, 2007b) however, 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 and Belessiotis, 1999). Such properties are the moisture diffusivity, thermal conductivity, density, and specific heat and inter phase heat and mass transfer coefficients. Sometimes, in the literature instead of these properties, the drying constant, is used. This is a lumped parameter of the properties (Saeed *et al*., 2008)

The drying rate can be expressed as (Ceylan *et al.*, 2007; Doymaz, 2007; Ozbek and Dadali, 2007)

$$\textbf{Drying rate} = \frac{\mathbf{M_{t+dt} - M_t}}{\mathbf{dt}} \qquad (\mathbf{12})$$

where,

M_t = moisture content at a specific time (g water g dry base-1)

M_{t+dt} = moisture content at t+dt (g water g dry base-1)

t = drying time (h)

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. Thompson and Foster (1963), on the other hand, stated that the effects of drying-air temperature and flow rate can be combined into an expression of drying speed represented by the moisture reduction in percentage per hour. Trim and Robinson (1994) argue that drying rate generally increases with increasing moisture content and air temperature or decreases with decrease in humidity.

Cape and Percy (1996) shared the opinion that another factor implicated 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.

2.7 Effective moisture diffusivity

In general, drying of foods takes place in two periods, a constant rate period and falling rate period. After a short heating period a constant rate period followed by a falling rate period which is the dominating period during drying process. The mechanism of moisture movement within a hygroscopic solid during the falling rate period can be represented by effective moisture diffusion phenomena which include liquid diffusion, vapour diffusion and other possible mass transfer mechanisms. Effective moisture diffusivity is used to represent an overall mass transport property of water in food materials (Dadali *et al*., 2007b). During drying it is assumed that diffusivity, explained with Fick's diffusion equation, is the only physical mechanism to transfer water to the surface (Ozbek and Dadali, 2007). Effective moisture diffusion which is affected by composition, moisture content, temperature and porosity of the material is used due to limited information on the mechanism of moisture movement during drying and complexity of the process (Afzal and Abe, 1998).

Doymaz and Akgun (2005) reported effective moisture diffusivity values in the range of 0.3 to 1.1 x $10^{-8}m^2/s$ in a temperature range of 50 to 110^oC and stressed that the values increased with increasing temperature. Doymaz (2004) on analysis of the drying kinetics of the white Mulberry reported that moisture diffusivities were affected by pretreatments. The diffusivity of heat shocking and ethyl oleate treatments in his work increased up to three times that of the natural fruit.

Kingsly *et al.* (2007) reported values in the ranged from 1.68 to 2.84 x 10^{-9} m^2/s for thin layer drying characteristics of organically produced tomatoes. The moisture diffusivity increased as drying air temperature was increased and due to the influence of blanching on internal mass transfer of tomato during drying, blanched samples had higher moisture diffusivity values.

The temperature dependence of the effective diffusivity was represented by an Arrhenius relationship (Madamba *et al.*, 1996, Sanjuan *et al.*, 2003) through which activation energy could be derived. Kingsly *et al.* (2007) reported activation energy values of 21.1 and 22.41 kJ/mol for untreated and blanched samples respectively, for the tomato slices.

2.8 Rehydration

One of the quality parameters of dried food is their ability to reconstitute, that is, their ability to return to their original shape and appearance upon soaking in water (Kordylas, 1990). Kordylas asserts that dried food may be converted to the humid form by the addition of water. Thus the food is soaked in water until enough water is taken by the pieces. He further stressed that the rate of rehydration is dependant on the temperature of soak water, hence the warmer the water the shorter the soaking time.

Rehydration behaviour was studied in grapes by Gabas *et al.* (1999), Nameko and Shitake (2000) by using different process parameters, like immersion time and water temperature. These researchers reported and affirmed that temperature increases rehydration rate due to decreased viscosity of the immersion medium and effect of temperature on the structure of food material. Most studies to assess the water intake rate by food materials were based on Fick's laws of diffusion using appropriate experimental equations (Hsu, 1983). To simplify the mode of water absorption and solute outflow, a non-exponential empirical equation was proposed by Peleg (1988), which has been successfully applied to milk powder, rice, dasheen leaves, cherry tomato and various legumes (Maharaj and Sankat, 2000; Sopade and Obekpa, 1990)

Loss in the ease of rehydration is caused by physical shrinkage and distortion of cells and capillaries, but much also results from chemical or physiological changes at the colloidal level (Potter and Hotchkiss, 1998).

According to Potter and Hotckiss (1998) heat and salt concentration effect from water removal can partially denature proteins, which cannot fully reabsorb water and become less hydrophilic. Sugars and salt escape from damaged cells in to the water used to reconstitute rehydrated foods, resulting in loss of tugor. These and other chemical changes make reabsorption of water by dried products somewhat less in original water content and contribute to altered texture.

2.9 Effects of drying on food

Several factors will influence the nutritional content of the food and the type and level of losses due to processing. These include the genetic make-up of the plant or animal, the soil in which it is grown, use of fertilizer, prevailing weather, maturity at harvest, packaging, storage conditions and method of preparation for processing. The storage conditions and handling after processing are also important to the nutritive value of the food (Morris *et al.*, 2006).

There are two processes occurring during drying, the addition of heat and the removal of moisture from the food. Heating can be both beneficial and detrimental to nutrient content of foods. It generally improves the digestibility of foods, making some nutrients more available. A typical example is the protein in legumes, which is made more digestible by heating because of the inactivation of anti-nutrients such as trypsin inhibitors (Morris *et al.*, 2006).

According to Fellows (2000) all products undergo changes during drying and storage that results in the reduction in their quality compared to fresh material. The physical and chemical changes occurring during drying or processing will improve certain characteristics of the final product, but in most cases, a loss of nutrients and organoleptic properties has been reported (Karel and Young, 1989; Nykanen and Nykanen, 1987; Garcia *et al.,* 1988; Paakkonen *et al.,* 1989)

The proper handling of these reactions ensures that the product has a high nutritional value as well as significant extended shelf life. Drying method and the physiochemical changes that occur during drying seem to affect the quality properties of the dehydrated product. More specifically, drying method and processing conditions affect significantly the color, texture, nutritional content, density and porosity and sorption characteristics of the material. So the raw material may end up as a completely different product depending on the type of drying method and conditions applied (Krokida and Maroulis, 2001a; Krokida and Maroulis, 2001b)

2.9.1 Texture and colour

Ramana and Taylor (1994) argue that textural behavior of a food product is related to its structure. These characteristics depend on the chemical and biophysical characteristics of the products (Moshenin, 1986; Bourne, 1992; Thiagu and Ramana, 1993). Changes to the texture and colour of the food are important cause of quality deterioration. The nature and extent of pretreatment, the type and extent of size reduction each affect the texture of rehydrated vegetables and fruits (Fellows, 2000). The loss of texture in these products is caused by the gelatinization of starch, crystallization of cellulose and localized variation in the moisture content during drying which set up internal stresses (Achanta and Okos, 1995). These rapture, crack, compress and permanently distort the relative rigid cells to give the food a shriveled appearance (Akonor, 2007).

In general rapid drying and high temperature causes greater changes to the texture of the food than do moderate rates of drying and lower temperatures. As water is removed during drying, solutes move from the interior of the food to the surface. Evaporation of water causes concentration of solutes at the surface. Higher temperatures cause complex chemical and physical changes to the solutes at the surface and the formation of a hard impermeable skin. This is termed case hardening (Achanta and Okos, 1995) and it reduces the rate of drying to produce a food with a dry surface and moist interior. It is minimized by controlling the drying conditions to prevent excessively high moisture gradient between the interior and the surface of the food (Akonor, 2007).

Drying does not cause marked physical damage to grains such as maize. However, rapid drying with heated air or excessive exposure to the sun can raise the internal kernel temperature to such levels that the endosperm crack from stress. Stressed grains may shatter or be scratched during handling, making them more susceptible to attack by microbes (Paulsen and Hill, 1985; Dendy and Dobrszczyk, 2001; Kreyger, 1972). There are a number of causes of colour loss or change in dried foods. Drying changes the suface characteristics of the food and hence alters its reflectivity and colour (Krokida *et al*., 2000). Chemical changes to carotenoid and chlorophyll in fruits and vegetables' pigments are caused by heat and oxidation during drying.

The development of colour due to enzymatic and non-enzymatic browing is one of the major problems that occurs during the processing and storage of dehydrated foods. Browning reactions also produce off flavor development and loss of nutritional value. Enzymatic browning is due to the effect of enzymes that catalyse the hydroxylation and oxidation of phenolic compounds. Non-enzymatic browning is a Maillard reaction involving amino groups and reducing sugars that results in brown polymeric pigments. The rates of both are strongly influenced by composition, temperature, water activity and pH (Crapiste and Rotstein, 1997). Dendy and Dobrszczyk, (2001) have noted that very high temperatures can cause deterioration (Maillard browning and in the case of wheat damage to gluten. Chemical and thermal treatment such as sulfating or blanching are used control enzymatic browning by enzyme inactivation in fruits and vegetables (Fellows, 2000).

2.9.2 Flavour and aroma

Heat not only vaporizes water during drying but causes loss of volatile components from the food and as a result most dried foods have less flavour than the original material. This invariably occurs to at least a small degree (Potter and Hotchkiss, 1998). The extent of volatile matter loss depends on the temperature and moisture content of the food and on the vapor pressure of the volatiles and their solubility in water vapor. Volatiles which have a high relative volatility and diffusivity are lost at the early stages of drying. The open porous structure of dried food allows access to oxygen, which is a second cause of aroma loss to oxidize of volatile components and lipid storage. Complete prevention of flavor loss is yet proven virtually impossible, and so methods of trapping and condensing the evolved vapours from the drier and then adding them back to the dried products are sometimes employed (Potter and Hotchkiss, 1998). Additional techniques involve addition to dried products of essence and flavour preparation derived from other sources as well as methods of minimizing flavour loss by incorporating gums into certain liquid foods prior to drying.

2.9.3 Nutritional value

The effect of food processing on nutrient content will depend on the sensitivity of the nutrient to the various conditions prevailing during the process. The nutrient retention may vary with a combination of conditions, such as the characteristics of the food being processed, and the concentration of the nutrient in the food. For example, sensitivity of vitamin C to heat varies with pH. It should be noted that the macronutrient and vitamin content of foods are more likely to be affected by processing than the mineral content. In considering the effects of processing on nutrient content of specific foods, it should be considered whether the food is one that serves as a worthwhile source of a particular nutrient. The losses of protein (amino acids) during blanching of green peas, for instance, might be of more relevance to the diet than that of vitamin C from the same source (Morris *et al.,* 2006).

Heating is a major processing procedure to stabilize food for extended storage by inactivating enzymes and microbial spores. However, its effects on the nutritional value of products cannot be overemphasized. The nutritional quality of food is diminished with processing because of nutrient sensitivity to heat, pH, oxygen or a combination of these factors (Kramer, 1977)

According to Bender (1966), storage and most processing procedures such as cooking and drying have very little effect on the carbohydrate content of most foods. Mild heating improves the digestibility of proteins and carbohydrates. However, damage can be caused if inappropriate temperature or processing times are used (Erbersdobler, 1985). The effect of drying on protein is expressed as a decrease in the digestibility and biological value of the protein (Karel, 1985).

Heating does not generally change the total dietary fibre content (Jones *et al.,* 1990), however, heat treatment cause insoluble dietary fibre content to increase as a result of the complexing of its components with protein and amino acids (Matalas *et al*., 2001). Wet processing such as cooking and blanching may also change some fibre properties for example, the amount of soluble fibre in fruit may increase by partial breakdown of pectin (Arthey and Ashurt, 2001).

Lipid quality is affected by dehydration. The peroxides formed when the lipids react with proteins and vitamins, or decompose to secondary products promote off flavors, strong odours and organoleotic rancidity (Karel, 1985). The exclusion of oxidizing agents is an important consideration while drying food.

The stability and degradation rate of vitamins such as ascorbic acid, thiamine and riboflavin are highly affected by temperature, moisture, pH, ionic strength and metal traces. Because it is practically heat sensitive at high moisture contents, heating and oxidation may destroy considerable amounts of ascorbic acid during the drying of fruits and vegetables (Crapiste, 1995). While riboflavin is relatively stable, significant losses of beta carotene may occur. The carotene content of vegetables is decreased as much as 80% if processing is accompanied without enzyme inactivation. The best commercial method will permit drying with losses in the order of five percent of carotene (Salunkhe, 1974)

The fat soluble vitamins are mostly contained within the dry matter of the food and hence are not concentrated during drying. However, as water is removed, heavy metals catalysts become more reactive and hence increase the rate of oxidation. Fat soluble vitamins are lost by the interaction with the peroxides formed thereof (Fellow, 2000). Nagra and Khan (1989) have observed that generally, processing leads to losses in vitamin A. Mulokozi and Svanberg (2003) studying the effect of traditional open sun drying and solar cabinet drying on carotene content and vitamin A activity of green leafy vegetables observed that solar drying resulted in significant retention of carotene and vitamin A.

The main cause of loss of vitamin E during the processing of cereals undoubtedly is fractionation of the kernel coupled with lipid oxidation (Mattern, 1991). Pond *et al.* (1971) showed that air and oven drying of corn had very little effect on vitamin E. content No difference were observed in total vitamin E content or in proportions of tocopherol isomers in corn after drying in a forced air oven or a fluidized bed dryer at temperatures ranging from ambient to 143^{o}C. Processing does not destroy minerals; however, their amounts may reduce during cooking, washing and trimming due to leaching. Mineral losses can occur due to redistribution of K and Ca from edible to non-edible parts of food.

2.10 Pretreatment in drying

Pretreatments have been used commercially to accelerate the drying of fruits. Dipping fruits for several seconds in pretreatment solutions greatly reduces the drying time (Radler, 1964, Bolin *et al*., 1975). They are applied to the surface of the fruit by dipping; resulting in a coating which apparently breaks down the cuticular fruit surface, resulting in a reduced resistance to moisture loss and this increases the drying rate (Ponting and McBean, 1970). Fruits and vegetables that are to be dehydrated are pretreated to prevent discoloration by oxidation, keep a fresher color, have a more pliable texture, help retain vitamins A and C, and in most cases to accelerate the rate of drying.

2.10.1 Blanching

Enzymes are known to catalyse the oxidation of phenols to quinines which in turn form coloured compounds. Peroxidase, polyphenol oxidase and ascorbic acid oxidase are the three main enzymes implicated in enzyme oxidation (Okos *et al*., 1992)

Blanching involves subjecting raw commodities to boiling or near boiling temperature for short periods. The principal function of blanching is to inactivate enzymes but the operation also partially cooks the tissue and renders the cell membranes more permeable to moisture (Lee, 1983). The process can either be carried out in water or steam. Water blanching is basically the immersion of the commodity in a container of boiling or near boiling water temperature for the necessary time while in steam stem blanching the product is exposed to steam. Steam blanching is often preferred to water blanching because there is a smaller loss of nutrients by leaching and in some vegetables, the dried product has an extended shelf life (Maharaja and Saankat, 1996).

The time of exposure to the heating medium required for a given produce depends on particle size, temperature, depth of load and blanching medium. Peroxidase activity is widely used as an index of blanching because peroxidase is the most heat stable enzyme found in vegetables (Akonor, 2007).

Tayo (2004) analyzed the effect of blanching and ripening on functional properties of plantain (*Musa AAB*) flour and concluded that blanching considerably reduced the emulsion capacity and viscosity, while bulk density, water and oil absorption capacities were increased by it. Lee (1983) further asserts that blanching stabilizes pectin, so that higher rehydration capacity and lower rehydration losses are achieved. Accordingly, it inactivates enzymes, thereby decreasing carotene content and thiamine loss appreciably whilst loss in ascorbic acid is observed.

Table 2.10.1: Losses in Nutrients During Blanching food Item

Food item	**Nutrient**	**Loss in steam blanching %**	**Loss in water blanching %**
Peas	Vitamin C	12	26
Peas	Amino acids	13	25
Spinach	Amino acids	60	80

Source: Lund (1975)

Muyonga *et al*. (2007) produced flour from steamed and unsteamed unripe bananas and analyzed them to determine the effect of steaming on physicochemical properties. Steaming of bananas prior to dehydration slowed dehydration of banana slices, increased water uptake, density and solubility of flour and decreased viscosity, setback, breakdown, discoloration and vitamin C content. Banana flour produced with predehydration steaming gives pastes of low paste bulk density, which is desirable for weaning and supplementary foods.

In water blanching a wide variation of temperature may be possible, but it can cause a loss of soluble nutrients. Water soluble vitamins may be lost due to leaching, thermal destruction or enzyme oxidation during water blanching. Alzamora *et al*. (1985) studying the water soluble vitamin losses during the blanching of peas found that blanching at higher temperatures could reduce leaching losses. Blanching also results in some degree of chlorophyll degradation with subsequent formation of pheophytin. The extent of chlorophyll conversion is related to the degree of blanching. In unblanched, dehydrated spinach, destruction of chlorophyll is positively correlated with the moisture content and was affected very little by oxygen content of dried spinach (Dutton *et al.*, 1943). Moshea *et al*. (1995), studied the effect of blanching an the anti-nutritional content of cabbage turnip, sweet potato and peanut leaves. Levels of tannic, phytic and oxalic acid were reduced by conventional and microwave blanching and hence recommended blanching as an effective method for reducing anti nutritional factors in green vegetables.

Meanwhile according to Dandamrongrak *et al*. (2003) blanching could provide a major means of reducing processing cost through increased drying efficiency in flour processing using the new plantain and banana varieties yet further research is necessary to improve product quality because treatments that produced the greatest improvement in drying performance also had the greatest effect in reducing product quality.

2.10.2 Metabisulfite preatreatment

Sulfur and sulfite compounds have been used for centuries to prevent discoloration and reduce spoilage during the preparation, dehydration, storage, and distribution of many foods. Sulfites are added to foods to act as an anti-oxidant and prevent browning., this will however increase the loss of thiamine. Brekke and Allen (1967) analyzed the effect of drying method such as air blast drying, drum drying, and freeze-drying on banana. The dehydrated products were evaluated subjectively and by objective moisture and color analyses. They concluded that treatment with sulfur dioxide before drying improved the product. Horsfall *et al.* (2005) worked on chemical composition, functional and baking properties of wheat-plantain composite flours and observed that blanching of plantain slices in hot 1.25% $NaHSO_3$ solution resulted in bleaching of plantain slices with reduced browning of dehydrated products and stability of packaged flour.

2.10.3 Other pretreatments

Citric acid pretreatment has been reported in literature (Doymaz, 2005) Citric acid or lemon juice may also be used as antidarkening and antimicrobial pretreatments. According to Doymaz (2005), such pretreatments break the waxy cuticular fruit surface, resulting in reduced resistance to moisture and thereby increasing the drying rate. Other pretreatment such as the use of fatty acid esters has also been reported in literature (Radler,1964; Bolin, Petrucci and Fuller, 1975). These pretreatments are known to reduce the drying time.

Bongirwar and Sreenivasan (1977) worked on a method of partial dehydration of fruits (bananas) by osmosis in sugar syrup of 70% concentration and accordingly the fruit was reduced to about 50% of its original weight by the process of osmosis, after which it was drained, washed and vacuum dried, which gave best results. Flavour, colour, appearance and texture attributes were maximally retained

2.11 Functional properties

Matil (1971) defined functional property as those characteristics that govern the behaviour of nutrients in food during processing, storage, and preparation as they affect food quality and acceptability.

2.11.1 Effect of processing on certain functional properties of food

2.10.1.1 Bulk density

Ojinnaka *et al*. (2009) studied the effects of starch modification on functional, sensory and cookies qualities of cocoyam when subjected to acid and enzyme modification treatment, and made the observation that there were significant differences ($p<0.05$) in the bulk densities of the starch samples. Acid and enzyme treated samples had the highest bulk densities of 0.75 g/mL whereas native starch had the lowest bulk density of 0.62 g/mL. According to Bhattacharya and Prakash, (1994) bulk density of foods increases with increase in starch content. Meanwhile Okezie and Bello (1988) stressed that high bulk density of protein material is important in relation to its packaging. The results of the bulk density of the starch samples also shows that the native starch from the cultivars of cocoyam will be good for developing foods that requires more protein while the modified starches will be good for energy foods. Higher bulk density products are known to exhibit better packaging properties than those with low bulk density.

2.11.1.2 Solubility in water

Ojinnaka *et al*. (2009) reported no significant difference in the solubility of the cocoyam starch samples. Their values ranged from 10.00-26.67%. Both acid and enzymes modified starches had the same solubility in cold water with their corresponding untreated starches. Bremiller (1993) also reported that modification of starches could bring about increased solubility of the starches. Bainbridge *et al*. (1996) stated that good quality starch with a high starch content and paste viscosity will have a low solubility and a high swelling volume and swelling power.

2.11.1.3 Swelling power

Ojinnaka *et al*. (2009) revealed significant differences among pretreated starch samples. In his work, acid treated starches had the highest swelling index whereas the native starch samples had the lowest swelling index. The results also indicated that there were variations in swelling index amongst the various modifications.

2.11.1.4 Least gelation property

Gelling ability could be due to the nature of the starch and protein and also their interaction during processing. According to Oduro *et al*. (2006) it is an index of water absorption capacity of flour and it determines the percentage of the flour that is capable of forming a gel. Gelatinization affects digestibility and texture of starch containing foods, leaching amylase enhances susceptibility of starch to enzyme attack (Richard, 1991) and the textural quality when starch is incorporated in food products such as creams, soups, puddings, pie filling and many sauces in viscosity (Osman, 1967). It is also observed that gel forming capacity increased in concentration of starch samples (Lawal *et al*., 2004). Sester (1993) reported that acid hydrolysis may make starch to loose its ability to gel. Oluwatooyin *et al.* (2003) compared the physicochemical properties and pasting characteristics of flour and starch from red and white sweet potato cultivars and observed that the least gelation concentration significantly decreased when sweet potato flour was parboiled. Decreases of about 166% and 133% for red and white variety flours, respectively, were measured.

2.11.1.4 Water and oil absorption capacity

Water absorption capacity is the ability of starch or flour to absorb water and swell for improved consistency in food. It is desirable in food systems to improve yield and consistency and give body to the food. The functionality of white and red varieties of sweet potatoes were examined by measuring their water and oil absorption capacities as well as their least gelation concentration (Oluwatooyin *et al.*, 2003) Parboiling improved the water absorption of the potatoes by 175 and 173% for the red and white varieties, respectively. This is because parboiling helps to stabilize potato color and stop enzymatic and antinutritional activity in the flour, when potato flour is desired as a thickener. It was also observed that both the red and white varieties of the potato starch had the same water absorption capacity. Thus, sweet potato flour as a binding agent in food systems may be more effective in unparboiled form. The starches, however, did not show any difference in their water absorption capacity, indicating similar gelation properties. Overall, the results indicated that the red and white varieties of potatoes were quite close in their water absorption capacities, although the white variety was slightly higher. It should be noted that previous studies reported higher capacities (Tian *et al.*, 1991), suggesting that the varieties tested by Oluwatooyin *et al.* (2003) have unusually low water absorption capacity.

Meanwhile the analysis of the oil absorption capacity of the flours and starches by Oluwatooyin *et al.* (2003) showed a non significant differences between native and parboiled flours, between flours and starches, and between red and white varieties. Only the native red sweet potato flour had a higher oil absorption capacity compared with the parboiled red sweet potato flour. Parboiling reduced the oil absorption capacity of red sweet potato flour by 25%. Overall, the oil absorption capacity of red and white sweet potato products was lower than that reported for native and toasted African breadfruit kernel (91% and 96%, respectively) and toasted wheat flour (148%). This he attributed to the lower protein content of sweet potato preparations (4.38-8.75%) as compared to African breadfruit kernel (17%) and toasted wheat flour (10%).

Onwuka and Onwuka (2005) when studying the effects of ripening on the functional properties of plantain and plantain based cake observed that the unripe plantain flour demonstrated a higher water absorption capacity and swelling capacity than the firm ripe plantain. These higher values were associated with higher starch content in the unripe plantain flour whose complex molecule will demand more water during hydrolysis than sugar molecules (Ihekoronye and Ngoddy, 1985). Onwuka and Onwuka (2005) further asserted that the high water absorption and swelling capacities have both economic and culinary advantage. Therefore, the unripe plantain flour will seem better in the production of pastry and baking foods.

2.11.1.5 pH and total titratable acidity

pH values give a measure of the acidity or alkalinity of a product, while titratable acidity gives a measure of the amount of acid present. Assessment of pH and titratable acidity of banana, cooking banana and plantain are used primarily to estimate consumption quality and hidden attributes. They could be considered as indicators of fruit maturity or ripeness. Acids make an important contribution to the post- harvest quality of the fruit, as taste is mainly a balance between the sugar and acid contents, hence post-harvest assessment of acidity is important in the evaluation of the taste of the fruit (Dadzie and Orchard, 1996)

2.12 Methods of drying

The increasing need for producing efficient high quality and convenient products at a competitive cost has led to the employment of several drying methods in practice (Saravacos, 1967; 1983). Also different drying processes adopt different devices and mechanisms but all involve sensible and latent heat for removing moisture (Yuan-kuang 2003). Each drying method has some characteristic drying parameters, which can be regulated, changing the way the moisture transport mechanism and the drying rate. It has been proved that the moisture transport mechanism and the drying rate at which the material is dried are related to the quality properties of the dried product. The most commonly used drying method include sun drying, convectional air drying, vacuum drying and osmotic drying (Krokida and Maroulis, 2001a).

Sun drying of crops is common practice in most developing countries. Generally, it applies to exposing the crops to solar radiation by spreading in the sun on a suitable surface such as mats, concrete floors, etc and drying on the stalk by standing in bundles (Arinze, 1987). Fleming *et al*. (1987) have agued that sun drying has three important attributes, namely; low capital cost, low running cost and independence from fuel supplies. Arinze (1987) maintains that loss of moisture in sun drying is however intermittent and irregular and the drying rate is very low, thus increasing the risk of spoilage during the drying process. Again, the final moisture of the dried products can be high because of low air temperatures and high relative humidities, a condition which can result in spoilage of crop during storage. Other disadvantages of sun drying include lack of hygiene and inadequate security (Dicko, 1987).

In the air convection method, hot air supplies the heat for evaporation. Driers in this category have an insulated enclosure, and a means of heating the air. They also have means of supporting the food to be dried and device to collect the dried food. Air may be heated directly or indirectly. In the former method, air is in direct contact with combustion gases. In indirect heating, the air is heated in contact with a hot surface, which is heated by a convection method. A direct method may contaminate the food product which is not the case with indirect heating (Manay and Shadakssharaswamy, 2001). The simplest type of air convection driers are the solar and biomass driers. Other driers in this category include cabinet, fluidized bed and spray driers.

Vacuum driers are employed to lower the temperature of drying. This method of drying food is expensive but gives high quality foods. The drying system consist of a vacuum chamber that can withstand external air pressure and contains shelves or other supports to hold food. The drying chamber is evacuated by a suitable device maintained outside the vacuum chamber. The water that evaporates from the food is suitably condensed. The temperature of the food and the rate of water removal are controlled by controlling the degree of vacuum and the intensity of heat output. Because of the low temperature used, there is minimum flavour change and other kinds of heat damage in this method of drying. Freeze dryer is an example of dryers that employs vacuum in its operation (Akonor, 2007).

Another group of driers worth mentioning is the drum or roller dryer. These are limited to be used with liquid foods, puree and mashes can be applied as thin films. The food to be dried is applied as a continuous thin layer unto the surface of a revolving drum or between a pair of drums moving in opposite direction generally heated by steam. The dried thin layer of food on the drun is scraped by a scraper blade positioned at a point on the drum. The drum temperature may be kept above 100^{o}C by using stem under pressure. Generally, the drum is kept at 150^{o}C when a film of food 1.6 mm in thickness gets dried in one minute or less (Manay and Shadakssharaswamy, 2001). For heat resistant food products, drum drying is one of the least expensive dehydration methods. Drum drying food generally will have a somewhat more cooked character than the same material sprayed dried.

CHAPTER THREE

3. MATERIALS AND METHODS

3.1 Source of sample

Three cultivars of plantain produced by Crop Research Institute of the Centre for Scientific and Industrial Research (CSIR), Fumesua were obtained and used for the study. The varieties were two triploids (False Horn and French Horn) and a Tetraploid (FHIA-21). These varieties were chosen based on their consistent agronomic performance and post harvest qualities. Physiologically matured samples that were beyond 90 days after flowering were used in the study.

3.2 Proximate Analysis

3.2.1 Moisture

Two grams (2 g) each of fresh False horn, French horn and FHIA 21 plantain samples were weighed in triplicates and dried at 105^{o}C in an air oven (Genlaboven model D35, MIDO/3/SSF, England) to a constant weight. Samples were removed, cooled in a dessicator and weighed. The procedure was repeated for each sample and the moisture content calculated and expressed as a percentage of the mass of sample taken (AOAC 1990)

3.2.2 Ash

Two grams (2 g) of sample was weighed into a previously ignited and cooled crucible. The crucible with its content was placed in a muffle furnace (Gallenkamp, England) at 600^{o}C for two hours. The crucible with its content was cooled and weighed, and the weight of ash expressed as a percentage of the fresh matter. The process was done in triplicate (AOAC, 1990).

3.2.3 Protein

The percentage protein of sample was determined by the Micro-Kjeldahl method of protein determination (AOAC, 1990). Two main steps are involved in this method.

3.2.3.1 Digestion

In triplicate, two grams (2 g) of sample was weighed unto a filter paper pre-folded like an envelope and introduced in to the kjeldhal flask. Half spoonfuls of selenium based catalyst and anti bumping agents were added. About 25 ml of conc. H_2SO_4 acid was added and the flasks shaken to get the samples thoroughly wet. The flask was placed on distillation rack, the heater turned on and the sample digested until the solution became clear. The flask was allowed to cool to room temperature when a clear solution was obtained. The digested sample was transferred into 100 ml volumetric flasks and made up to the make with distilled water.

3.2.3.2 Distillation and titration

Twenty-five millilitres of 2% boric acid was pipettted into a 250 ml Erlenmeyer flask and two drops mixed indicator added, followed by 18 ml of 40% NaOH. The conical flask with its contents was placed under the condenser in a position that left the tip of the condenser completely immersed in the solution. Ten millilitres of the digested sample was poured into the steam jacket. The stopcock was closed to drive the liberated ammonia in to the collection flask and steam forced from the decomposition chamber by shutting the stop cock on the steam tap outlet. Distillation continued until the boric acid turned bluish green. The set up was then disconnected and the distillate titrated against 0.1N H_2SO_4 to a faint pink endpoint. The same procedure was used to prepare a blank where a similar piece of filter paper minus sample was used. The percentage protein was obtained by multiplying the percentage nitrogen by the appropriate conversion factor of 6.25.

3.2.4 Fat

Two grams (2 g) of sample was weighed directly into the extraction thimble, plugged with glass wool, and placed in an extraction tube. A clean dry 250 ml soxhlet flask was weighed, filled with 200 ml of petroleum ether (BP. 40-60^{o}C), and the set up refluxed for three hours.The extractor was disconnected, and the thimble lifted and drained. The apparatus was reconnected and the distillation continued, using the siphon to reclaim the ether. After refluxing, the flask was removed to a steam bath for evaporation of final few millilitres of ether and then dried in an oven at 60^{o}C overnight. The flask was cooled in a dessicator and weighed. The fat obtained was expressed as a percentage of the weight of the sample taken (AOAC, 1990).

3.2.5 Fibre

The sample was transferred from the crude fat determination into a 750 ml Erlenmeyer flask and approximately 0.5 g of asbestos added. Two hundred millilitres of boiling 1.25% H_2SO_4 added immediately, flasks were set on hot plate and connected to cold finger condenser. The contents were allowed to come to boil and remained so until samples were thoroughly wet. After 30 min, the flasks were removed and immediately filtered through the linen cloth in a funnel and washed with boiling water until no longer acidic. The charged asbestos was washed back into the flask with 200 ml boiling 1.25% NaOH. The flask was connected to a condenser and its content allowed to boil for 30 minutes, after which it was filtered through linen cloth and thoroughly washed with boiling water. The residue was transferred into gooch crucibles with water and washed with 15 ml alcohol. The crucible and content was dried for 1 hour at 100^{o}C, cooled in a dessicator and weighed. The crucible was ignited in an electric furnace for 20 min, cooled and reweighed (AOAC, 1990).

3.2.6 Mineral Analysis

Mineral analysis was performed using the procedure described by AOAC (1990) and Allen *et al*. (1984). The analytical procedures used for sample treatment for AAS analysis are as follows: One gram (1 g) sample was weighed into a pyrex glass conical flask. Ten milliliters (10ml) concentrated nitric acid was introduced into the flask with a straight pipette. Five milliliters (5 ml) of perchloric acid was also added. The mixture was heated on an electro- thermal heater for about twenty (20) minutes until a clear digest was obtained. The digest was cooled to room temperature and diluted to 50 ml with distilled water. The diluent was filtered into a plastic vial for AAS analysis

3.3 Drying

3.3.1 Drying equipment

An experimental gas dryer was used in the study. This consist of a wooden chamber on a wooden stand, a compartment at the base for housing the gas burner, and a single door serving as the main opening. The drying compartment had ten moveable trays with wire mesh base. The walls of the chamber are double layered and it has an air gap of 0.02 m thickness.

3.3.2 Sample preparation prior to drying

Finger samples were collected from the second hand from the proximal end of the bunch following the recommendation of Baiyeri and Ortiz (2000) the same day the bunch was harvested. Samples were immersed in a plastic bowl with potable water and then peeled with the aid of a stainless kitchen knife. The pulp was then sliced into cylindrical pieces with same thickness of 10 mm.

3.3.3 Pretreatment

Sliced samples from each variety were thoroughly mixed and divided into four. One portion was dipped in citric acid (CIT) (1% w/w) for one minute. Another was dipped in sodium Meta bisulfate (MBS) (21 g/l) for one minute. A third portion was steam blanched (BLA) for 10 minutes. The fourth portion was not pretreated and it served as the control (CON). Accumulation of moisture on the sliced surface as a result of the pretreatment was drained before samples were transferred to the dryer.

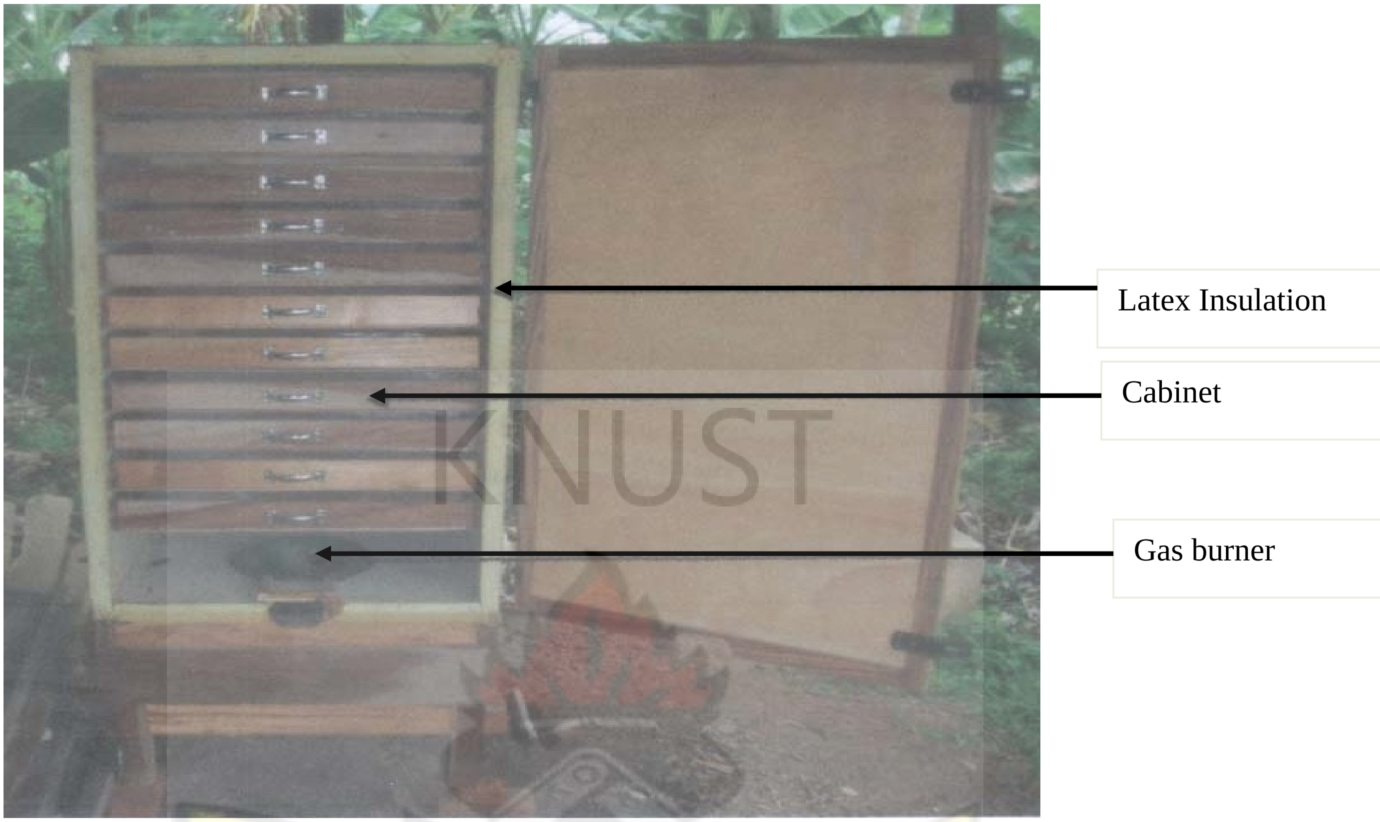

Figure 3.1 Gas dryer

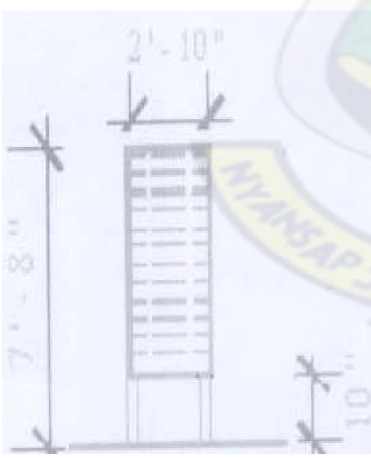

Figure 3.2 Front view

Figure 3.3 Side view

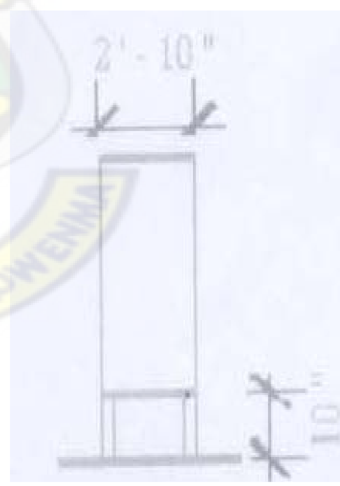

Figure 3.4 Back view

3.3.4 Drying process

The plantain samples all of equal thickness of 10 mm and diameters of 34 cm, 27 cm and 30 cm for False horn, French horn and FHIA-21 respectively were placed on trays with wire mesh base (0.2 m x 0.2m; an average of 30 discs each for False horn, French horn and FHIA-21) in a single layer. These trays (one for each variety) were placed on the same tray (0.72 m x 0.45 m) of the dryer. Drying experiments were conducted at 50, 60, 70 and 80°C (±1°C). 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 (Triton 201, USA) of 0.01g accuracy. Drying curves of moisture ratio over drying period were constructed to depict drying profile graphically. Dried samples were then milled using an end runner mill to produce flour for functional analysis.

3.4 Modeling of drying curves

In this study two thin layer drying models were examined to describe the drying curves of False Horn, French Horn and FHIA-21 with four treatments and four temperatures. The selected mathematical models were Page (Diamante and Munro, 1993) equation 13 and the Logarithmic model (Yaldiz and Erteken, 2004) equation 14. These models were chosen because of their wide application in modeling of agricultural produce successfully.

$$\mathbf{MR = exp\ (-k\ t^{y})} \qquad \mathbf{(13)}$$

MR = a exp (-k t) + c **(14)**

Nonlinear regression using the software package STATGRAPHICS CENTURION IV was used to obtain each constant of the selected mathematical models. Moreover the criteria such as coefficient of determination R^2, reduced chi-square (χ^2) and root mean square error (RMSE) were calculated to evaluate the fitting of a model to experimental data. The highest values of R^2 and lowest values for (χ^2) and RMSE were chosen for goodness of fit. These parameters were calculated as follows.

$$\mathbf{RMSE} = \left[\frac{\sum_{i=1}^{n}(MR_{pre,i} - MR_{exp,i})^2}{N}\right]^{\frac{1}{2}} \qquad (15)$$

$$\chi 2 = \left[\frac{\sum_{i=1}^{n}(MR_{pre,i} - MR_{exp,i})^2}{N - Z}\right] \qquad (16)$$

MRexp,i is the ith experimental moisture ratio

MRpre,i is the ith predicted model moisture ratio

N is the number of sampling times and

z is the number of constants in the drying model.

3.5 Effective moisture diffusivity

The effective moisture diffusivity was calculated by the following equation (Crank, 1975)

$$\mathbf{MR} = \frac{\mathbf{M_t - M_C}}{\mathbf{M_o - M_C}} = \frac{8}{\pi^2}\sum_{n=0}^{\infty}\frac{1}{(2n+1)^2}\ exp\left[\frac{-(2n+1)^2\pi^2\ \mathbf{D_{eff}}\ \ \mathbf{t}}{4L^2}\right] \qquad (17)$$

Where

D_{eff} is the effective moisture diffusivity (m^2s^{-1})

L is the half thickness which in this case is 5mm

t is the drying time

For long drying times equation 17 can be written as

$$\mathbf{MR} = \frac{\mathbf{M_t - M_C}}{\mathbf{M_o - M_C}} = \frac{8}{\pi^2}\ exp\left[\frac{-\pi^2\ \mathbf{D_{eff}}\ \ \mathbf{t}}{\mathbf{4L^2}}\right] \qquad (18)$$

Several researchers have demonstrated that equation (18) could further be simplified to a straight line equation (19) (Dadali *et al*., 2007b).

$$\mathbf{InMR} = \mathbf{In}\left[\frac{8}{\pi^2}\right] - \left[\frac{\pi^2\mathbf{D_{eff}}\ \ \mathbf{t}}{\mathbf{4L^2}}\right] \qquad (19)$$

The effective moisture diffusivities were calculated by plotting experimental drying data in terms of ln(MR) versus time (equation 19) and the plot gives a straight line with a slope of

$$\mathbf{Slope} = \frac{\pi^2\mathbf{D_{eff}}}{\mathbf{4L^2}} \qquad (20)$$

3.6 Activation energy

The temperature dependence of the effective diffusivity was represented by an Arrhenius relationship (Madamba *et al*., 1996, Garcia-Pascal and Mulet, 2003)

$$\mathbf{D_{eff} = D_o \ exp\left[\frac{E_a}{RT}\right]} \qquad (\mathbf{21})$$

Where

D_{eff} is effective moisture diffusivity (m^2/s)

D_o is the pre-exponential factor of the Arrhenius equation (m^2/s)

E_a is the activation energy (KJ/mol)

R is the universal gas constant (KJ/mol K)

T is the absolute temperature (K)

The natural logarithm of Deff as a function of the reciprocal of absolute temperature (K) was plotted and the slope was evaluated to find the activation energy.

$$\mathbf{Slope = \frac{E_a}{R}} \qquad (\mathbf{22})$$

3.7 Selected functional properties of flour

3.7.1 Moisture

Two grams (2 g) each of flour produced from False horn, French horn and FHIA 21 plantain samples were weighed in triplicates and dried at 105°C in an air oven (Genlaboven model D35, MIDO/3/SSF, England) to a constant weight. Samples were removed, cooled in a desiccator and weighed. The procedure was repeated for each sample and the moisture content calculated and expressed as a percentage of the mass of sample taken (AOAC, 1990)

3.7.2 Swelling power and solubility

Swelling power and solubility determinations were carried out based on a modification of the method of Oduro *et al*. (2006). One (1 g) of flour was transferred into a weighed graduated centrifuge tube (50ml). Deionized water was added to give a total volume of 40ml. the suspension was stirred just sufficiently and uniformly avoiding excessive speed since it could cause fragmentation of the starch granules. The sample in the centrifuge tube was heated at 85^{o}C in a thermostatically controlled temperature water bath (Grant type) for 30 min with constant stirring. The tube was then removed, wiped dry on the outside and cooled to room temperature. It was centrifuged for 15 min at 2200 rpm. The solubility was determined by evaporating the supernatant and weighing the residue. The sediment paste was weighed. The percentage solubility and swelling power were then calculated.

3.7.3 Water binding capacity

Water binding capacity of the flour was determined by the method of Medcalf and Gilles (1965). An aqueous suspension of flour was made by dissolving 2 g of flour in 40 ml of distilled water. The suspension was agitated for one hour on a Griffin flask shaker, after which it was centrifuged (Mistral 300E, UK) for 10 min at 2200 rpm. The free water was decanted from the wet flour, drained for 10 min and the wet flour weighed. The water binding capacity was then calculated. Determinations were done in triplicate.

3.7.4 pH

The pH of the flour was determined by the method of Oduro *et al*. (2006). Ten grams of the flour was weighed, dissolved in 20 ml of distilled water to form a slurry and allowed to stand for 10 min. The pH of the slurry was measured with the Corning pH meter (Model 240, Corning Science Products and Corning, New York, USA).

3.7.5 Bulk Density

The bulk density was determined according to Horsfall *et al.* (2005). Twenty grams (20 g) of flour was weighed into a graduated cylinder. The cylinder was then tapped for ten times and the volume was read on the graduated cylinder. The bulk density was then calculated.

3.7.6 Rehydration ratio

Ten grams (10 g) of flour was loaded into aluminum sample dishes. Five hundred milliliters (500 ml) of distilled water was transferred into a glass jar and a tripod was also placed in the jar. The dishes were placed on the tripod in the jar which was then tightly closed and kept at room temperature until equilibration. The dishes were periodically weighed until equilibrium was reached. The rehydration percentage was used to express the rehydration of the of the plantain flour (Lewicki, 1998).

3.8 Study design and statistical analysis

A completely randomized design was adopted in the study. For the effect of temperature and treatment on the selected functional properties a 3x4x4 factorial design was used where the main factors were the four temperatures and the four treatment conditions. Treatment effects were statistically analyzed for variance using STATGRAPHICS CENTURION XV and treatment means were separated using Fischer's Least Significant Difference of means. The moisture ratio of the dried plantain was modeled using the relevant thin layer drying model. Graphical descriptions of data were done using Microsoft Excel – Microsoft Office 2007.

CHAPTER FOUR

4.0 RESULTS AND DISCUSSION

4.1 Proximate analysis of French Horn, False Horn and FHIA-21

Data on the proximate analysis of French Horn, False Horn and FHIA-21 are presented in Table 4.1.1. Moisture level was appreciably high in FHIA-21 (69.5%) compared to French Horn (62.50%) and False Horn (61.1%). This could be attributed to the banana characteristic in the FHIA 21. This results indicated that False Horn (triploid) may have higher dry matter than FHIA-21 (tetraploid) and French Horn (triploid).

Table 4.1.1 Comparison of the proximate and mineral analysis of French Horn, False Horn and FHIA-21

PARAMETER	FRENCH HORN	FALSE HORN	FHIA- 21
MOISTURE (%)	62.5 (1.24)^{a}	61.10 (1.51)^{ab}	69.50 (2.04)^{c}
ASH (%)	1.82 (0.30)^{a}	2.29 (0.11)^{ab}	2.45 (0.03)^{b}
PROTEIN (%)	5.03 (0.02)^{a}	3.06 (0.00)^{b}	3.72 (0.04)^{c}
FAT (%)	1.24 (0.42)^{a}	3.47 (0.06)^{b}	4.05 (0.12)^{c}
FIBRE (%)	0.5 (0.09)^{a}	0.69 (0.04)^{ab}	1.62 (0.54)^{c}
CARBOHYDRATE (%)	28.91 (1.18)^{a}	29.39 (1.40)^{a}	18.66 (2.09)^{b}
MINERALS			
K (mg/100g)	794.5 (4.30)^{a}	1068.00 (3.7)^{bc}	1150.00 (4.80)^{c}
Na (mg/100g)	33.1 (0.04)^{a}	39.83 (0.06)^{b}	43.20 (0.8)^{c}
P(mg/100g)	0.75 (0.02)^{a}	0.95 (0.03)^{b}	0.52 (0.09)^{c}
Fe (mg/100g)	0.71 (0.02)^{a}	0.87 (0.04)^{b}	1.01 (0.01)^{c}
Ca (mg/100g)	15.40 (0.83)^{a}	21.4 (0.99)^{b}	7.50 (1.24)^{c}

Mean values with the same superscript on the same row are not significantly different at 5% level. Parameters in bracket are the standard deviations.

The moisture content showed no significant difference ($p<0.05$) between French and False Horn and this could be attributable to the fact that these two varieties belong to the same genomic group. Meanwhile that of FHIA-21 was significantly different from the two triploids. The value obtained for FHIA-21 and French Horn were higher than what was reported (60% and 53% respectively) by Dzomeku *et al*. (2006) whereas that of False Horn was slightly lower than that reported (61.6%) by Onwuka and Onwuka, (2005). The difference might be due to age of the plantain as well as agronomic and environmental factors. Since moisture contents of the three varieties were all greater than 61% the implication is that the composition is mainly moisture and carbohydrate and this is consistent with plantains.

Moisture content is known to have influence on general energy and nutrient density. The low water content in plantain is reported to have an influence on general energy and nutrient density (Gowen, 1995). The lower the moisture content the greater the energy content due to the high carbohydrate content.

Though the ash content of the three varieties were low, FHIA-21 recorded the highest ash (2.45%) content whereas French Horn recorded the lowest (1.82%) and were significantly different ($p<0.05$). The ash content of False Horn however was not significantly different from that of FHIA-21. The high ash content of FHIA-21 is further justified by the fact that it recorded appreciably high values in three of the five mineral values as shown on Table 4.1.1. It recorded 1150.00 mg/100g, 43.20 mg/100g, 0.52 mg/100g, 1.01 mg/100g and 7.5 mg/100g for K, Na, P, Fe and Ca respectively. This indicated that the levels of K, Na and Fe in FHIA-21 were significantly higher than False and French Horn. It is reported that plantains are rich in vitamin B_6 and the combination of the vitamin B_6 and potassium makes it nature's brain food, since these two substances are essential for proper brain function (Gowen, 1995).

The sodium levels were low while potassium levels were high; however, the high potassium provides a protective effect in instances of excessive sodium intake (Meneely and Batterbee, 1976). The high potassium level in the hybrid may be an added advantage of FHIA-21 over False and French Horn for use as a therapy (Dzomeke *et al.*, 2006). As regards iron, plantain is a poor source, however, unlike other foods the iron provided by plantain is 100% utilizable by the human body as reported by Dzomeke *et al.* (2006).

French Horn recorded lower values in all mineral parameters determined. Meanwhile for Ca and P, False Horn recorded higher values than FHIA-21. Calcium and phosphorous are vital for the bone. This was consistent with the ash content recorded in False Horn. The values herein obtained were lower than reported values by Adeniji and Tenkouano (2008), (K, 1160 mg/100g; Na, 49.8 mg/100g; P, 120 mg/100g, Fe, 9.46 mg/100g and Ca, 75 mg/100g) Table 4.1.1. This discrepancy could be attributed to differences in morphological traits and physiochemical characteristics.

The crude protein content of the three varieties was significantly different ($p<0.05$). French Horn (5.03%) recorded the highest protein content where as FHIA-21 (3.06) recorded the lowest. The crude protein content obtained was comparatively higher than those recorded in literature for some other Musa spp. Oduro *et al.* (2006) reported 1.09% for cooking banana whereas Onwuka and Onwuka (2005) reported 2.8% for False horn. These values may be due to environmental difference especially soil used in cultivation. The protein content obtained indicates that French Horn is comparatively rich in protein and could be taken as a high source of protein among Musa species.

Dietary fibre and fat content were significantly different ($p<0.05$) among the three plantain varieties. FHAI-21 recorded the highest values for both dietary fibre (1.62%) and fat (4.05%) content whereas French Horn (fibre, 0.5%; fat 1.24%) recorded the lowest signifying a higher calorific value for the tetraploid.

FHIA-21 had the lowest carbohydrate (18.66%) content which may be due to the high moisture of this variety. Also the low carbohydrate content can be attributed to high values obtained for all other parameters apart from moisture. False Horn (29.39%) recorded the second highest carbohydrate content though it had lower moisture content than French Horn (28.91%) and this is further attributable to high values obtained for the other parameters apart from moisture.

Although the protein and lipid contents of these plantain flours were low compared with infant formula from commercial outlets, fortification of wheat-plantain flour with animal protein sources such as powdered milk and ground crayfish would improve the nutrient contents of these flours.

4.2 Effect of temperature and pretreatment on drying curves

Moisture ratio versus drying time for the sliced pulp of French Horn, False Horn and FHIA-21 plantain varieties with initial moisture contents 62.5 (%Wb), 61.1 (%Wb) and 69.5 (%Wb) under four treatment conditions and four temperatures of 50 ^{o}C, 60^{o}C, 70^{o}C and 80^{o}C are presented in Figures 4.1.1. to 4.1.12. Generally it was seen that moisture ratio decreased continuously with drying time and increased with decrease in drying temperature. There were no significant effects ($p>0.05$) on the effect of pretreatment on the moisture ratio of the three plantain varieties meanwhile the moisture ratio of blanched (BLA) French Horn, False Horn and FHIA-21 were higher than fresh untreated (CON), sulphited (MBS) and citric acid (CIT) treated samples. Blanching may have caused the gelatinization of plantain starches, resulting in decreased rate of moisture movement from within the material to the surface during air-drying. Similar results were reported during air-drying of blanched banana by Dandamrongrak *et al*. (2003). Also moisture ratio values were independent of the initial moisture content of the three plantain varieties. The rates of moisture loss for all three varieties of plantain pretreated differently were initially high. However two-thirds of the time was spent removing the last third of the moisture content due to the slow diffusion process.

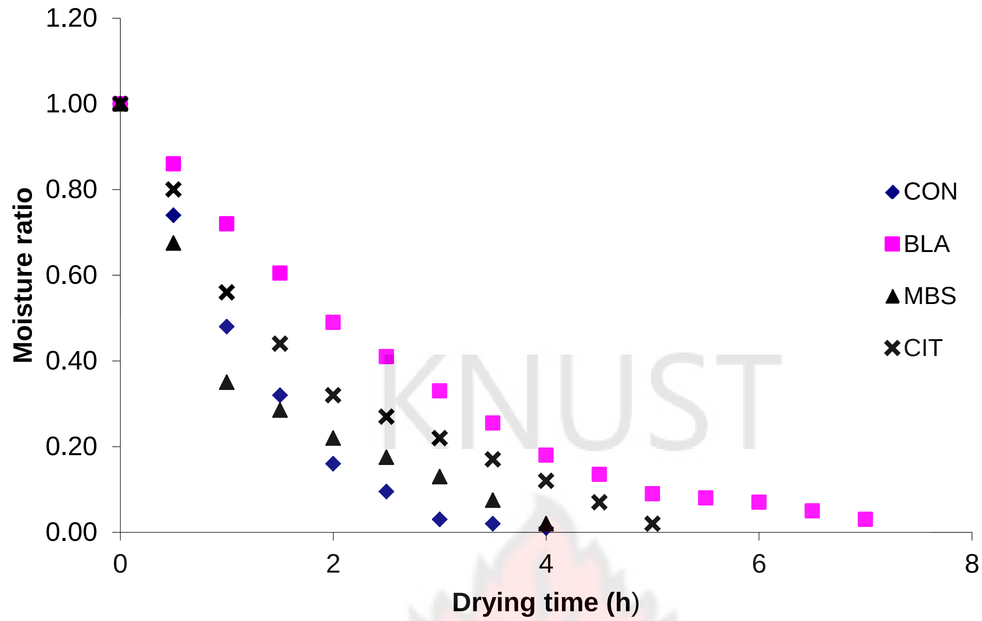

Figure 4.2.1 Effect of different pretreatments on the drying of French Horn plantain at 80^{o} C

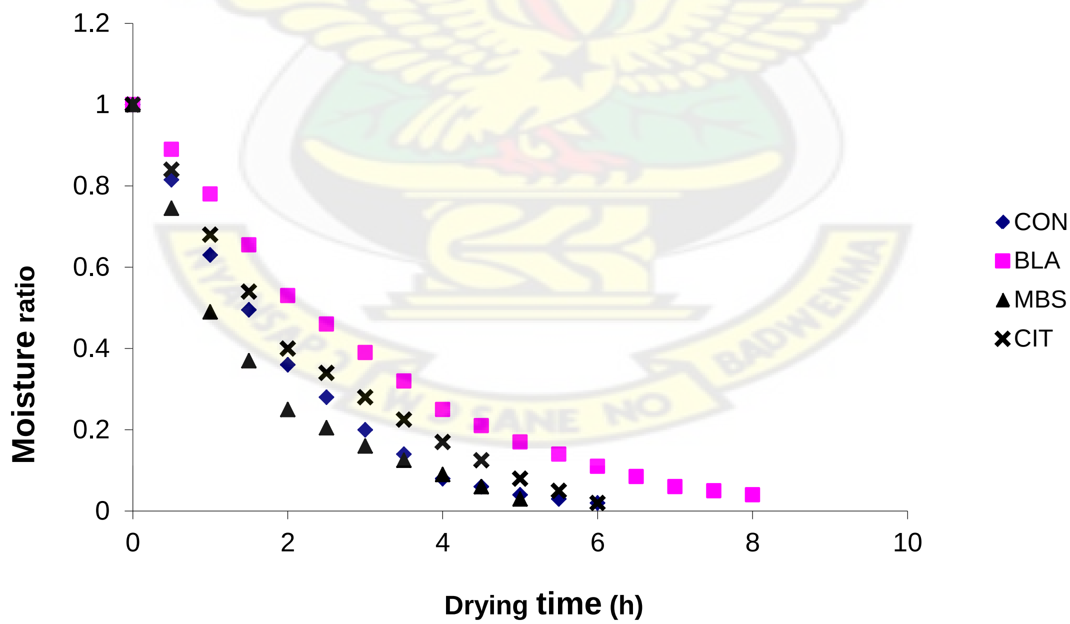

Figure 4. 2.2 Effect of different pretreatments on the drying of French Horn plantain at 70^{o} C

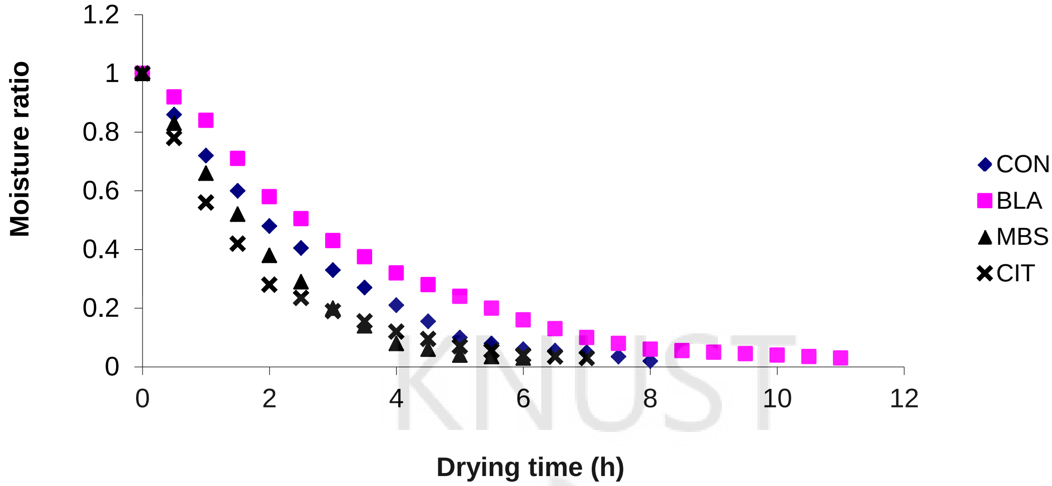

Figure 4. 2.3 Effect of different pretreatments on the drying of French Horn plantain at 60^{o} C

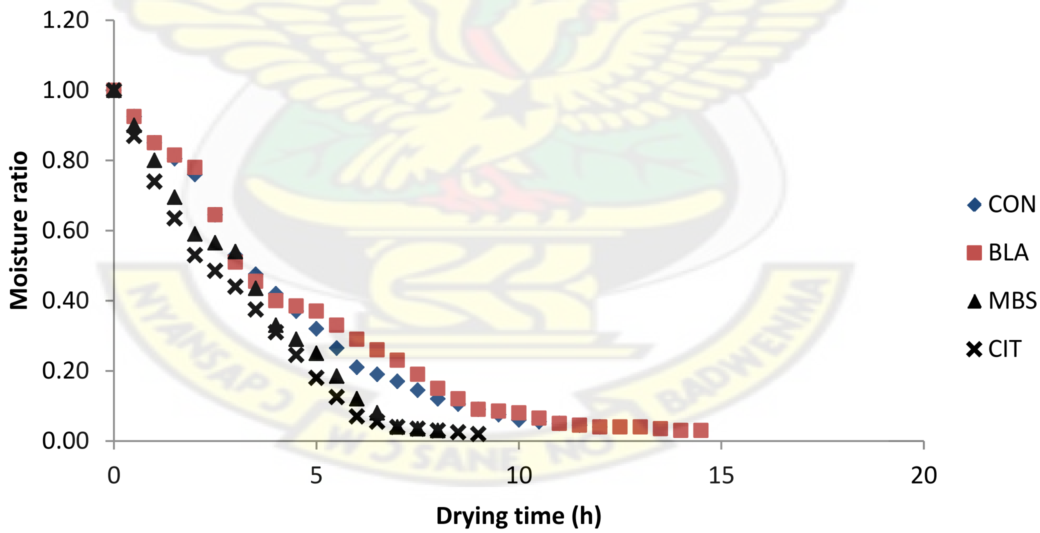

Figure 4. 2.4 Effect of different pretreatments on the drying of French Horn plantain at 50^{o} C

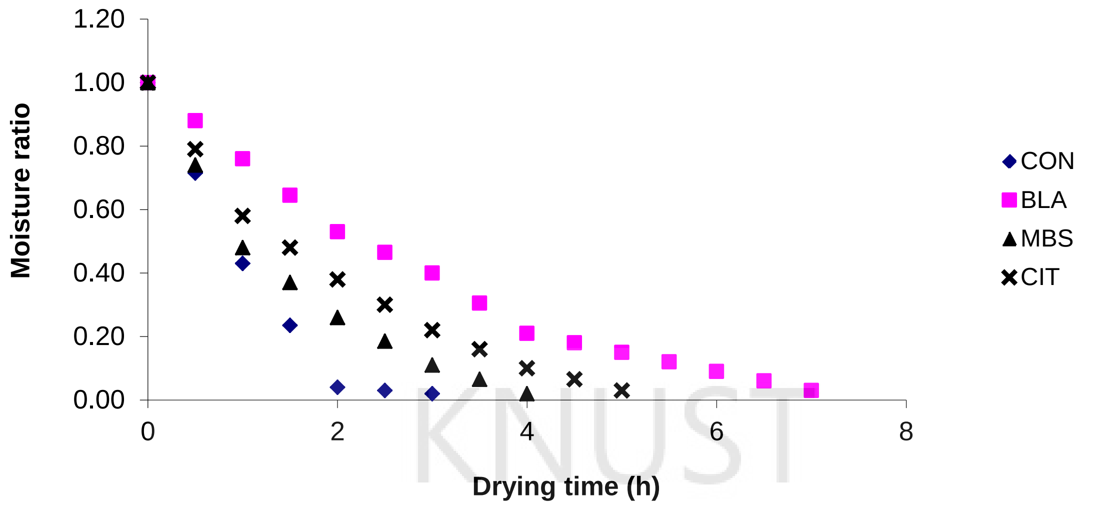

Figure 4.2.5 Effect of different pretreatments on the drying of False Horn plantain at 80^{o} C

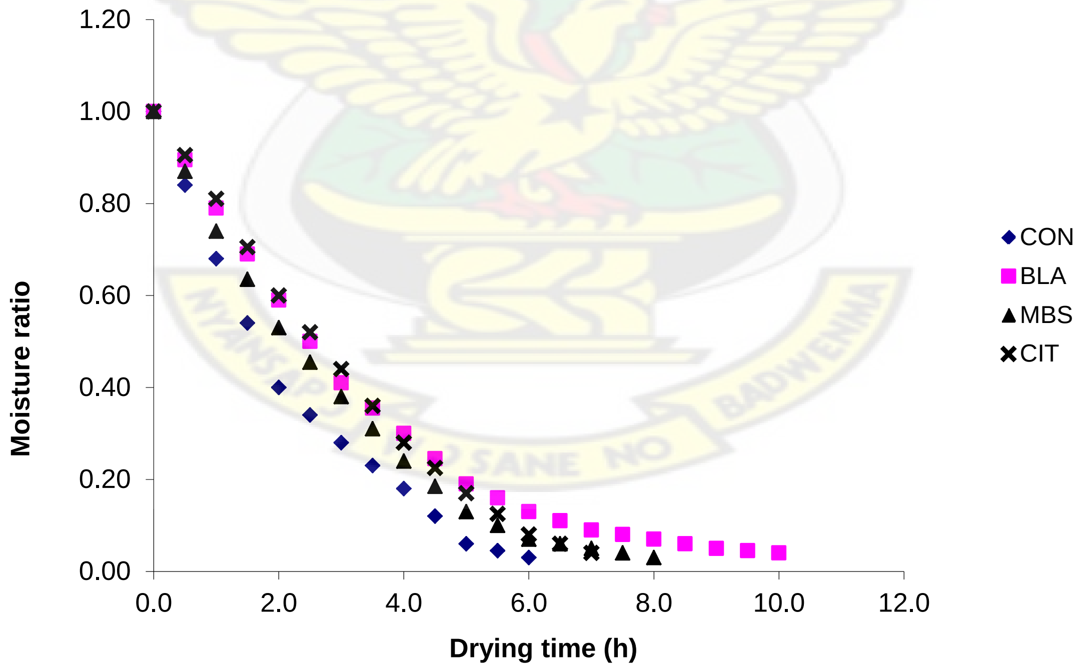

Figure 4.2.6 Effect of different pretreatments on the drying of False Horn plantain at 70^{o} C

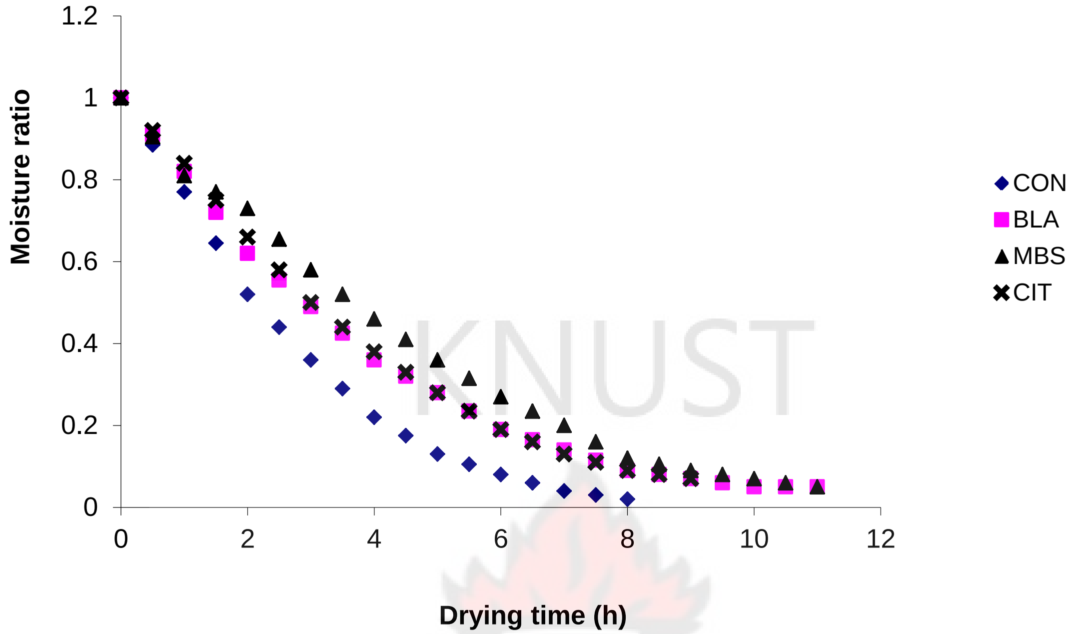

Figure 4.2.7 Effect of different pretreatments on the drying of False Horn plantain at 60° C

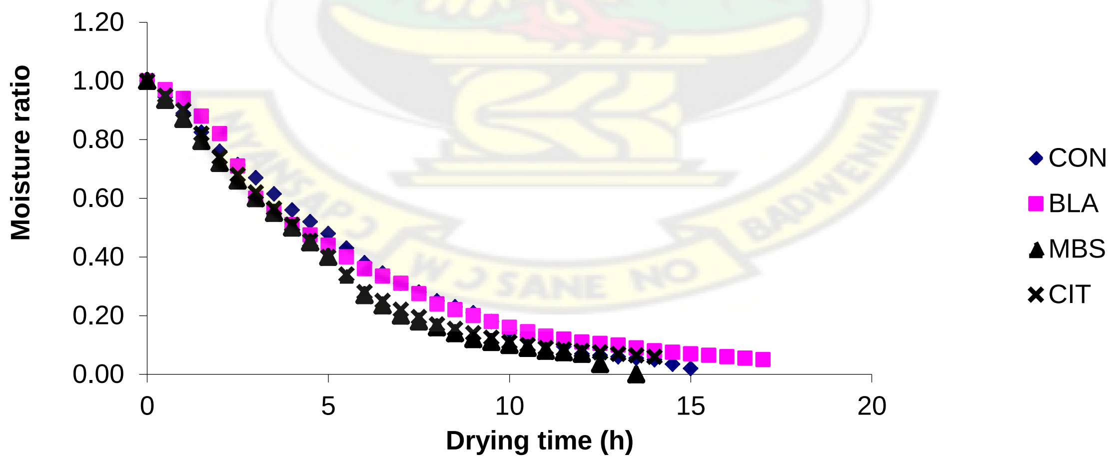

Figure 4.2.8 Effect of different pretreatments on the drying of False Horn plantain at 50° C

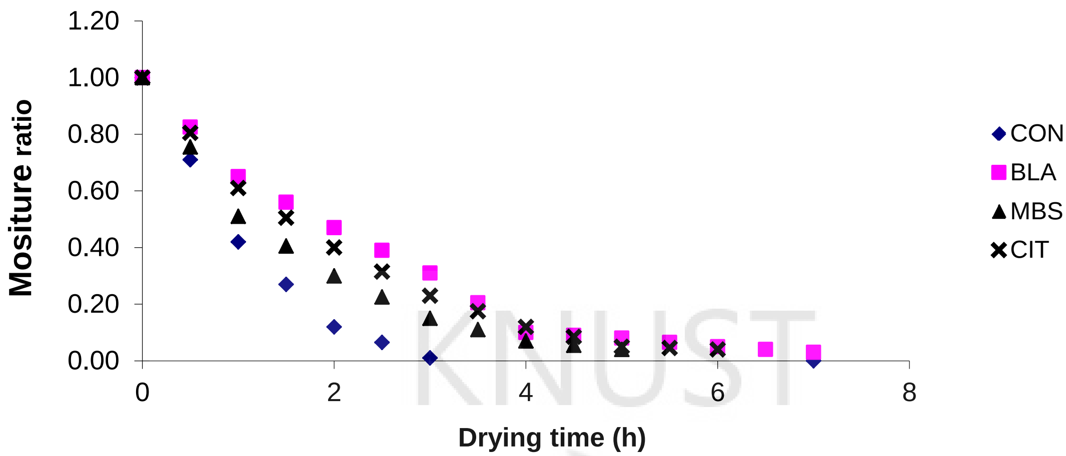

Figure 4.2.9 Effect of different pretreatments on the drying of FHIA-21 plantain at 80^{o} C

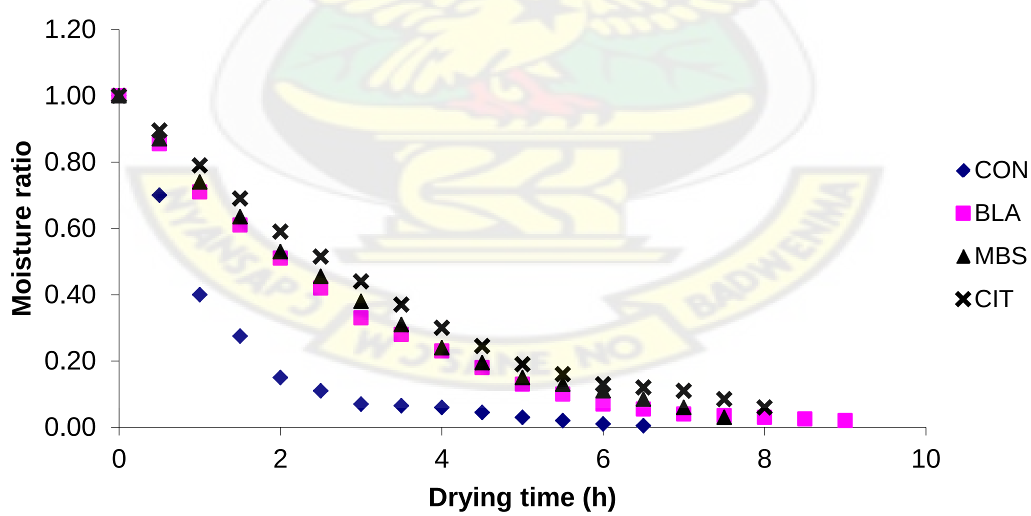

Figure 4.2.10 Effect of different pretreatment on the drying of FHIA-21 plantain at 70^{o} C

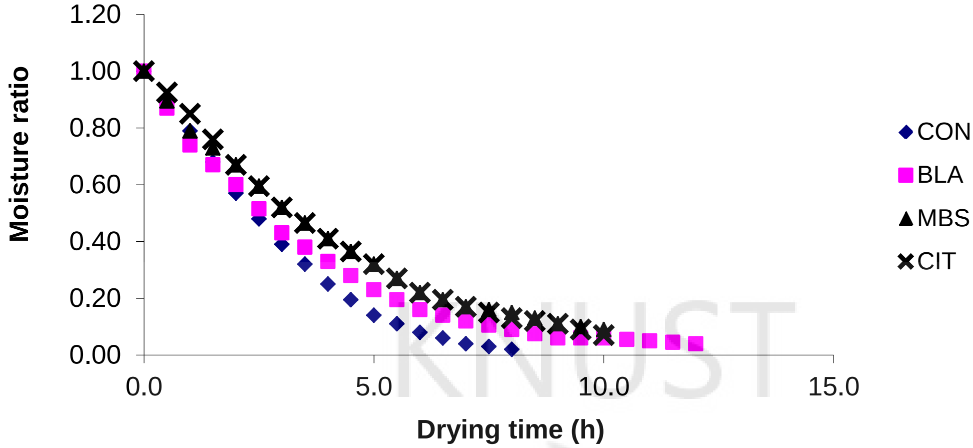

Figure 4.2.11 Effect of different pretreatment on the drying of FHIA-21 plantain at 60° C

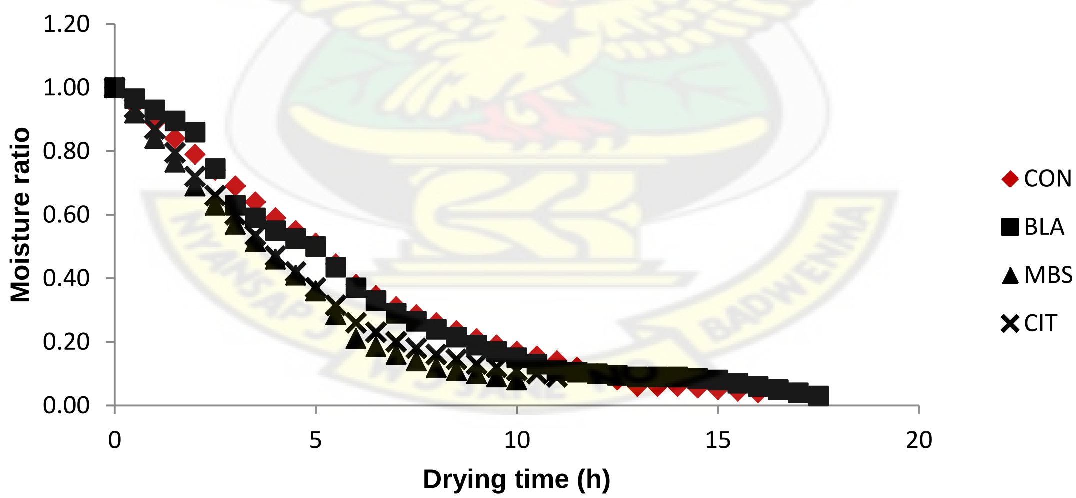

Figure 4.2.12 Effect of different pretreatment on the drying of FHIA-21 plantain at 50° C

4.3 Effect of temperature and pretreatment on drying rate and drying time

Drying rate curves for French Horn, False Horn and FHIA-21 showing the effect of pretreatment are presented in Figure 4.2.1. – 4.2.12. 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 banana (Demirel and Turhan, 2003; Maskan, 2000).

Table 4.3.1 Effect of pretreatment and temperature on average drying rate (kg water/hr) of French Horn, False Horn and FHIA-21

VARIETY		TEMPERATURE			
	PRETREATMENT	**80°C**	**70°C**	**60°C**	**50°C**
FRENCH HORN	CON	0.65(0.17)[b]	0.43(0.12)[b]	0.33(0.09)[b]	0.20(0.03)[a]
	BLA	0.34(0.08)[a]	0.29(0.06)[a]	0.23(0.06)[a]	0.16(0.19)[a]
	MBS	0.68(0.27)[c]	0.55(0.19)[c]	0.42(0.10)[c]	0.27(0.21)[a]
	CIT	0.43(0.14)[b]	0.40(0.09)[b]	0.38(0.17)[c]	0.30(0.30)[b]
FALSE HORN	CON	0.75(0.15)[d]	0.37(0.09)[c]	0.29(0.06)[b]	0.15(0.02)[ab]
	BLA	0.31(0.05)[a]	0.24(0.06)[a]	0.21(0.05)[a]	0.13(0.04)[a]
	MBS	0.58(0.16)[c]	0.29(0.07)[a]	0.19(0.04)[a]	0.17(0.03)[c]
	CIT	0.46(0.12)[b]	0.28(0.03)[ab]	0.22(0.03)[a]	0.16(0.03)[c]
FHIA-21	CON	1.06(0.23)[c]	0.62(0.21)[b]	0.40(0.07)[b]	0.20(0.04)[a]
	BLA	0.52(0.15)[a]	0.42(0.13)[a]	0.33(0.12)[a]	0.19(0.04)[a]
	MBS	0.73(0.24)[b]	0.44(0.10)[a]	0.31(0.08)[a]	0.29(0.04)[b]
	CIT	0.59(0.17)[ab]	0.38(0.07)[a]	0.30(0.05)[a]	0.26(0.04)[b]

CON: Control; BLA: Blanched; MBS: Sodium Meta bisulfate; CIT: Citric acid. Means with the same letter for a column of a particular variety are not significantly different at 5%. Values in bracket are standard deviations.

Initially, drying rates were highest when moisture 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 that 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 break the molecular bond of the moisture and since constant energy was supplied it took a longer time to break therefore drying rate decreased as moisture content decreased.

The effect of increasing the drying temperature on the drying rates was investigated for all the three plantain varieties. As expected the increase in drying temperature resulted in a significant increase ($p<0.05$) in drying rate (Table 4.2.1). In similar but separate studies, Henderson and Henderson (1968) and Barre *et al.* (1971) reported that drying rate values are dependent upon drying temperature during the drying of corn and this presupposes that the moisture holding capacity of heated air according to Hall (1980) increases with increasing temperature. Differences in the initial moisture content of the plantain varieties also affected the drying rate at constant temperatures ($p<0.05$). French and False Horn varieties generally dried faster compared to FHIA-21 due to differences in initial moisture content. According to Meas (1999) the higher the moisture content the longer the drying takes and this was in line with the observations made here in that FHIA-21 (69.5% Wb) had drying times which were significantly ($p<0.05$) longer than French Horn (62.5% Wb) and False Horn in most treatments and temperature variations. Though French Horn was higher in moisture compared to False Horn, it had a shorter drying time and this could be attributed to a high amount of free water in the variety compared with False horn. This short drying time of False Horn compared with FHIA-21 can partly be attributed to the high moisture content of FHIA-21 and partly as a result of the large surface area of False Horn compared to FHAI-21, thereby enhancing quick removal of moisture. This notwithstanding, the average drying rates of FHIA-21 were significantly higher ($p<0.05$) than the other two varieties (Table 4.2.1)

The drying behavior of the three varieties of plantain showed significant differences in terms of the treatments at the various temperatures as evident from the drying curves (Figures 4.1.1 - 4.1.12). It was observed that at 80^{o}C French Horn (Figure 4.1.1) drying times for CON, BLA, MBS and CIT were 4, 7, 4 and 5 hours respectively indicating that CON and MBS had higher drying rates than CIT and BLA pretreatments. This observation was altered as the temperature decreased till it reached a drying temperature of 50^{o}C. At 50^{o}C (Figure 4.1.4) it was observed that CIT and MBS had a much higher drying rates than CON and BLA treatments (Table 4.2.1). False Horn (Figure 4.1.4-8) exhibited a similar trend. The drying times for CON was lower indicating high drying rates than MBS, CIT and BLA pretreatments. The trend kept changing with decreasing temperature till 50^{o}C (Figure 4.1.8). At 50^{o}C, MBS and CIT pretreated slices recorded drying times which were comparatively lower than CON, and BLA.

The effect of CIT and MBS pretreatments at lower temperatures became more prominent with FHIA-21 (Figure 4.1.9-12) where drying times for CON, BLA, MBS and CIT treatments at 80^oC were 3, 7, 5 and 6 hours respectively and that of 50^oC were 16, 17, 10 and 11 hours respectively. This indicates high drying rates for CON at 80^oC with CIT and MBS recording higher drying rates at 50^oC (Table 4.2.1). The general observation that CIT and MBS had less effect on the drying rates at 80^oC compared to the CON treatment could be attributed to the ineffectiveness of those treatments as antioxidants as their molecular structures may be broken down at high temperatures. This could further explain why CIT and MBS were effective at lower temperatures compared to higher ones. Citric acid and Sodium metabisulfite are known to release carbon dioxide and sulfur dioxide upon reaction with water thereby making it a strong reducing agent.

The MBS and CIT pretreatments in the three plantain varieties at 50^oC saved 33% and 25% of drying time respectively for French horn, 16% and 6.5% for False Horn, and 37.5% and 31% for FHIA-21. BLA pretreatment in all varieties had the slowest drying rate. This may be attributed to the steam which partially cooked the sliced surfaces thereby ceiling the surface pores preventing ease of removal of moisture from the interior to the surface during dehydration. In separate studies blanching did not result in reduced drying time in banana due to the effect of starch gelatinization (Dandamrongrak *et al*., 2003). Also blanching of potato did not increase the rate of drying because of starch gelatinization (Alzamora *et al*., 1980) that resulted in reduced porosity (Mate *et al*. 1998). Muyonga *et al*. (2000) made the same observation when flour produced from steamed and unsteamed unripe bananas was analyzed and asserted that steaming of bananas prior to dehydration slowed dehydration of the banana slices.

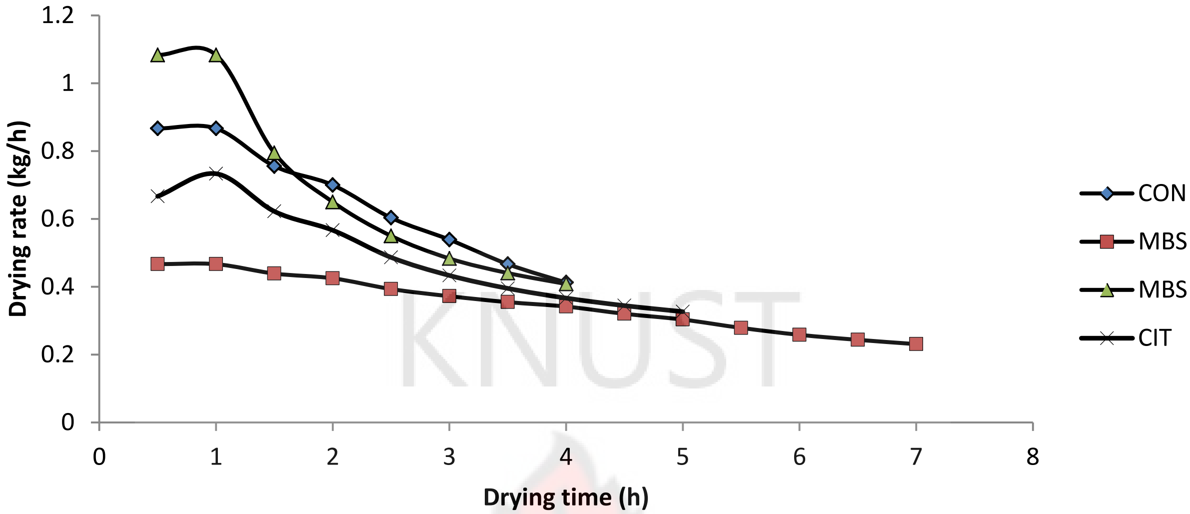

Figure 4.3.1 Drying rate curve for French Horn pretreated differently and dried at 80°C

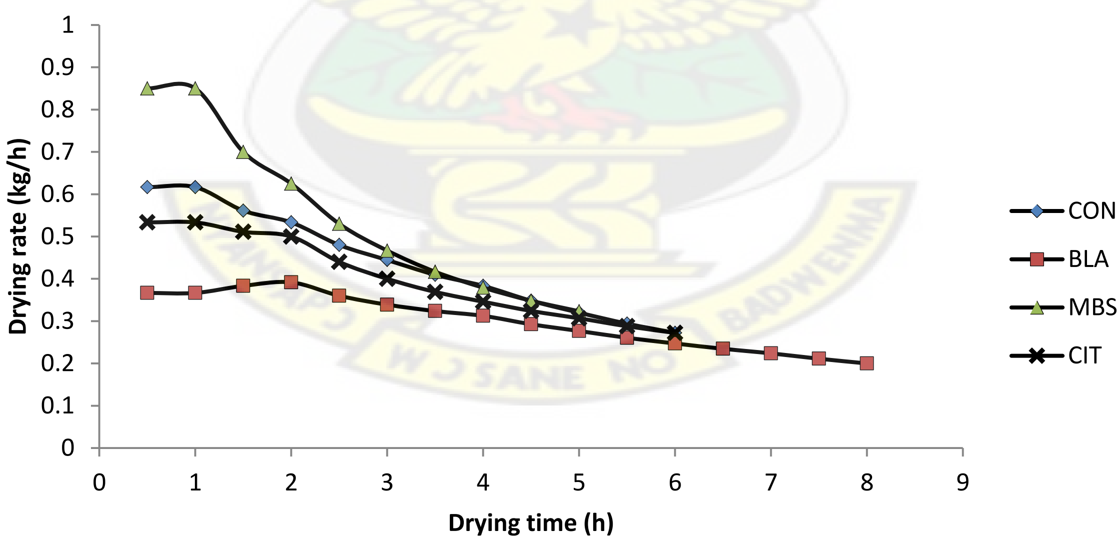

Figure 4.3.2 Drying rate curve for French Horn pretreated differently and dried at 70°C

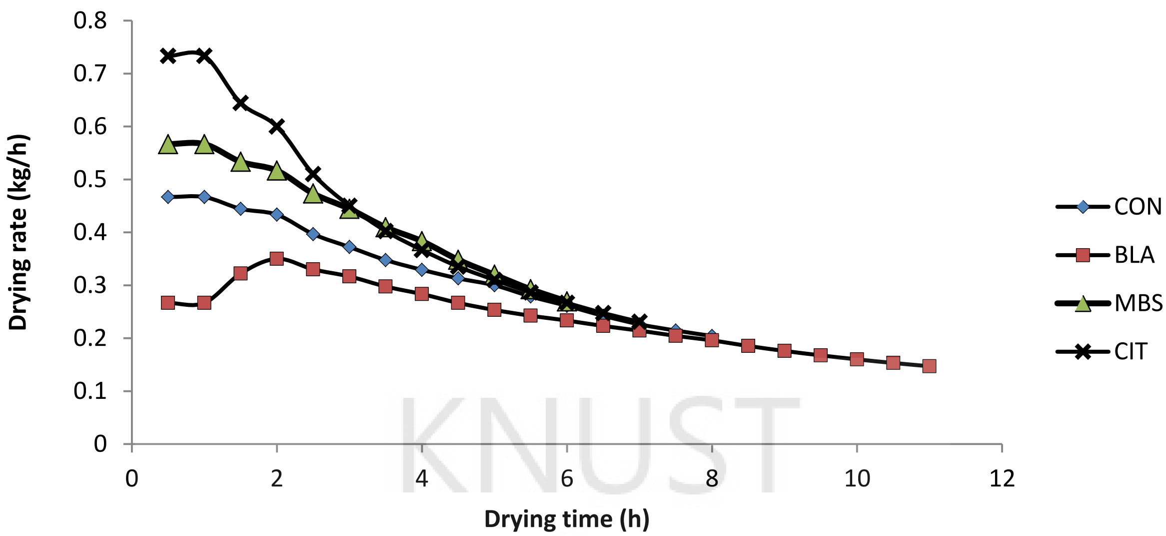

Figure 4.3.3 Drying rate curve for French Horn pretreated differently and dried at 60°C

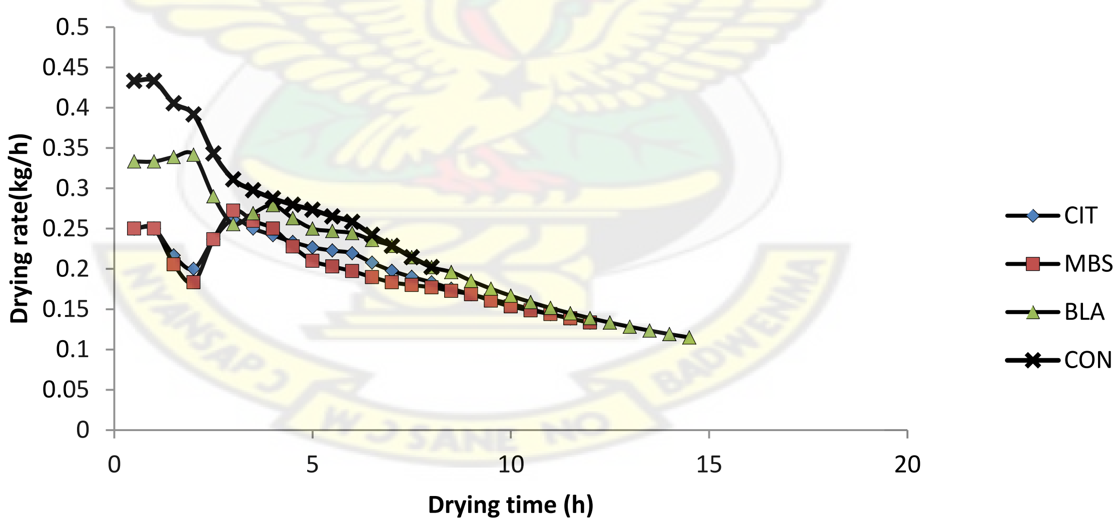

Figure 4.3.4 Drying rate curve for French Horn pretreated differently and dried at 50°C

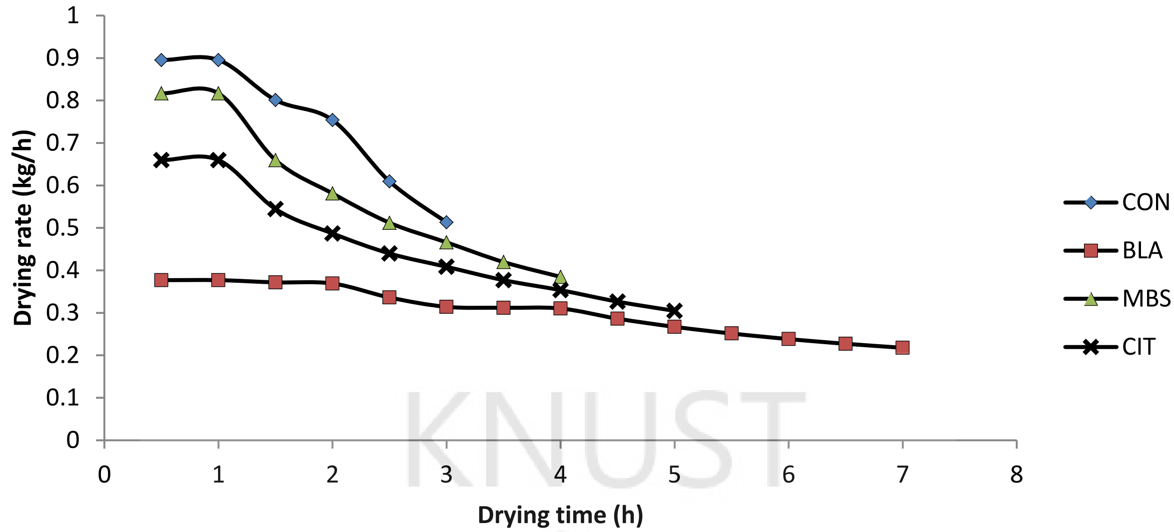

Figure 4.3.5 Drying rate curve for False Horn pretreated differently and dried at 80°C

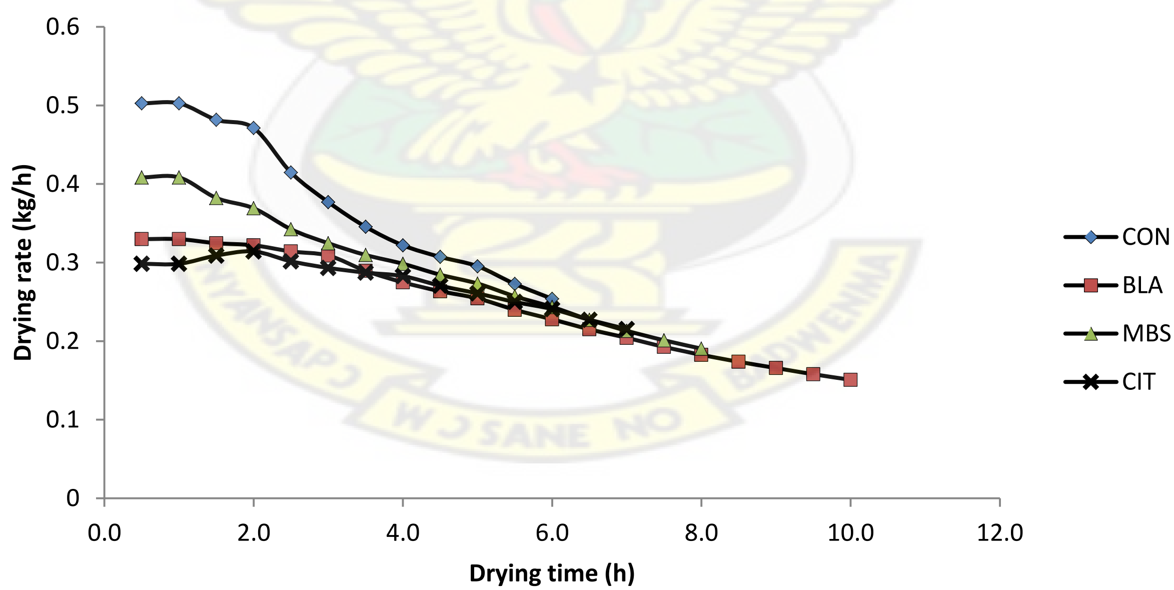

Figure 4.3.6 Drying rate curve for False Horn pretreated differently and dried at 70°C

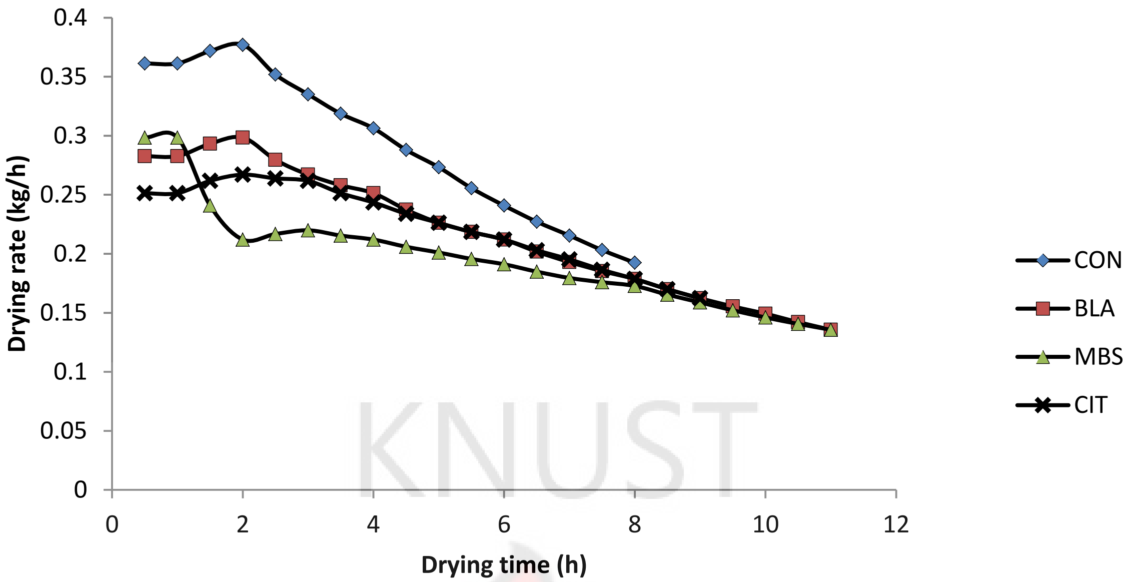

Figure 4.3.7 Drying rate curve for False Horn pretreated differently and dried at 60°C

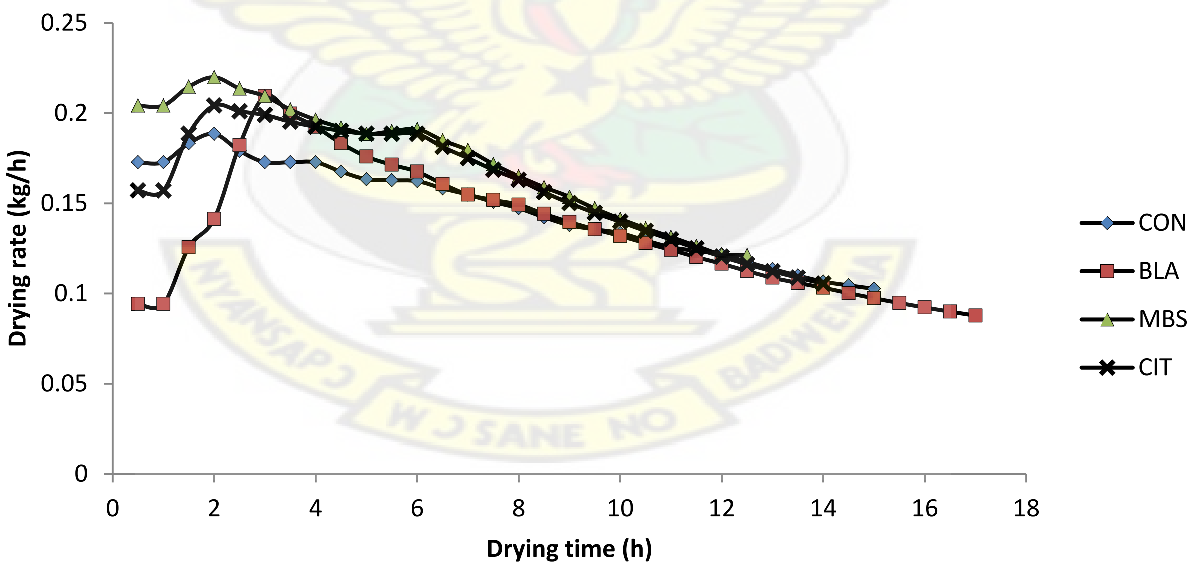

Figure 4.3.8 Drying rate curve for False Horn pretreated differently and dried at 50°C

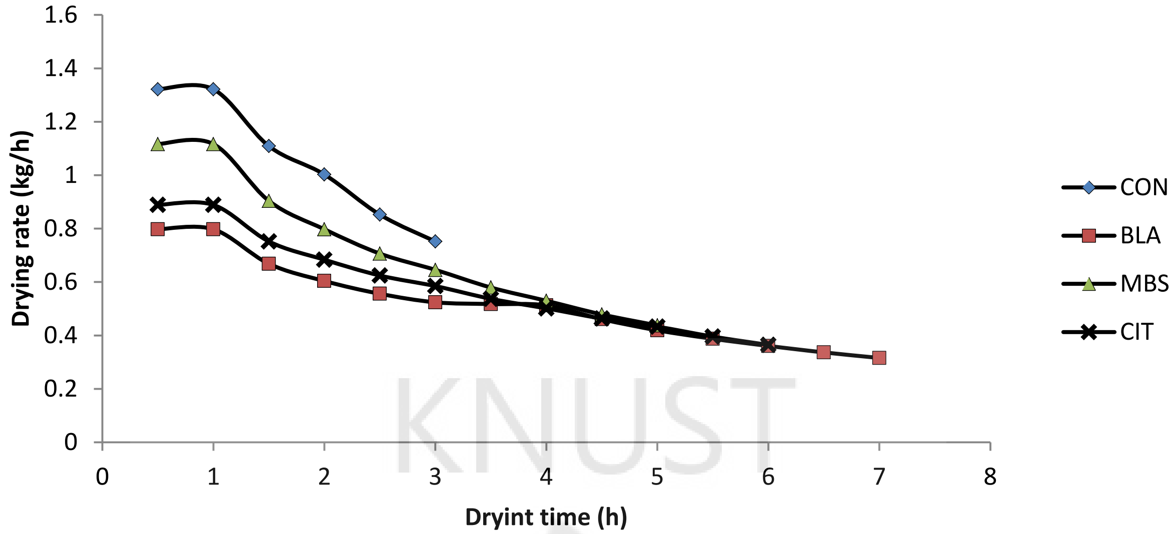

Figure 4.3.9 Drying rate curve for FHIA-21 pretreated differently and dried at 80°C

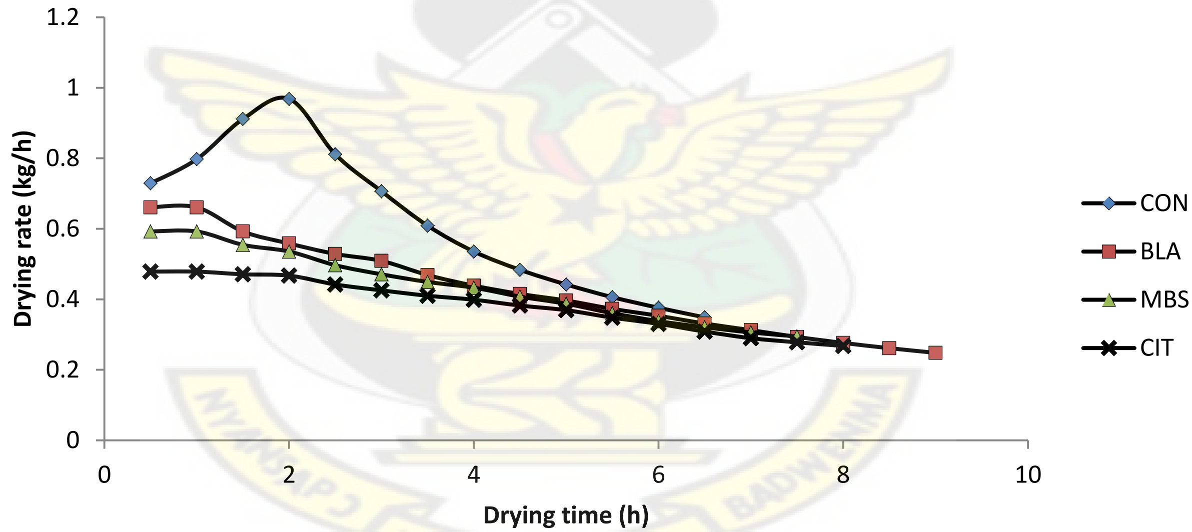

Figure 4.3.10 Drying rate curve for FHIA-21 pretreated differently and dried at 70°C

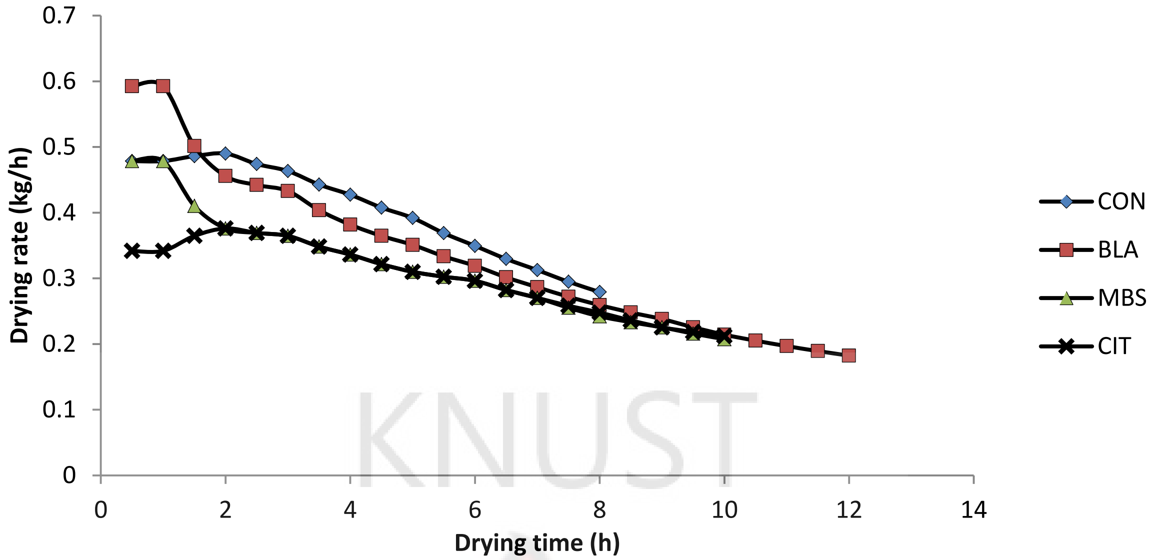

Figure 4.3.11 Drying rate curve for FHIA-21 pretreated differently and dried at 60°C

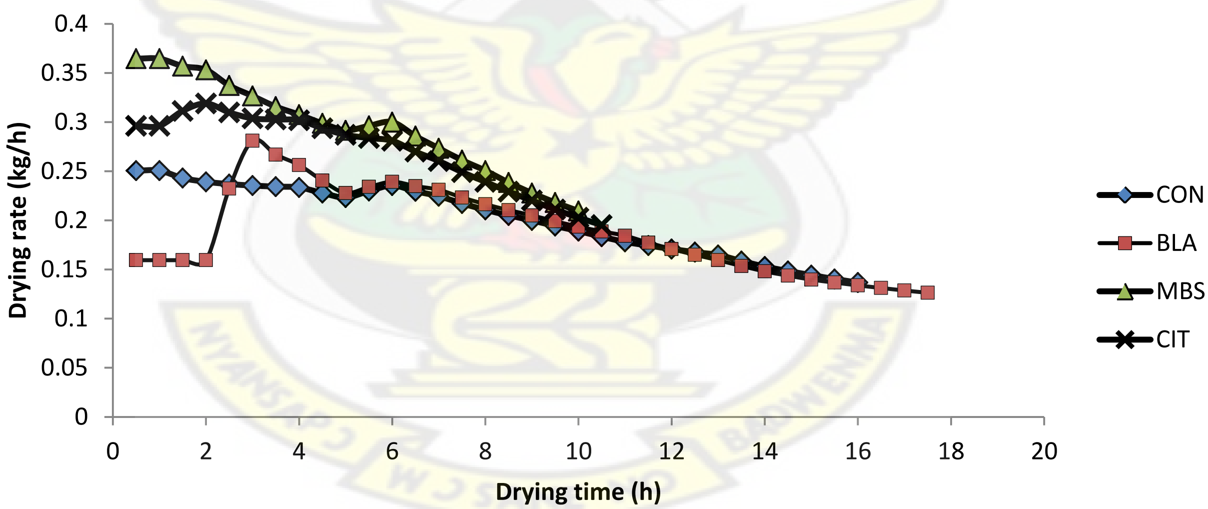

Figure 4.3.12 Drying rate curve for FHIA-21 pretreated differently and dried at 50°C

4.4 Modeling of drying curves

The statistical results for the Page and Logarithmic models and their constants together with drying times for the CON, BLA, MBS, and CIT treatments for various temperatures are presented from Table 4.3.1 – 6. For both models the fit was good in general presenting R^2 values greater than 0.980. Observing the three parameters used in the analysis of goodness of fit, French Horn had R^2 values ranging from 0.985 to 0.999; RMSE values in the range of 0.0072 to 0.034 and χ^2 values in the range of 0.00017 to 0.0015 for the Page model (Table 4.3.1). It had R^2 values ranging from 0.985 – 0.995; RMSE values in the range of 0.013 to 0.033 and χ^2 values in the range of 0.0002 to 0.0013 for the Logarithmic model (Table 4.3.2).

False Horn had R^2 values ranging from 0.994 to 0.999; RMSE values in the range of 0.0042 to 0.02 and χ^2 values in the range of 0.00019 to 0.00052 for the page model (Table 4.3.3). It had R^2 values ranging from 0.985 to 0.995; RMSE values in the range of 0.013 to 0.033 and χ^2 values in the range of 0.0002 to 0.0013 for the logarithmic model (Table 4.3.4).

FHIA-21 had R^2 values ranging from 0.991 to 0.999; RMSE values in the range of 0.007 – 0.028 and χ^2 values in the range of 0.000054 to 0.0009 for the Page model (Table 4.3.5). It had R^2 values ranging from 0.989 to 0.999; RMSE values in the range of 0.009 to 0.071 and χ^2 values in the range of 0.0001 to 0.0062 for the Logarithmic model (Table 4.3.6). These values were comparable to 0.993 to 0.998, 0.0337 to 0.0882 and

0.00011 to 0.00057 for R^2, RMSE and χ^2 respectively for the Page model and 0.996 to 0.999, 0.0092 to 0.0303 and 0.000020 to 0.00041 for R^2, RMSE and χ^2 for the Logarithmic model during the modeling of Olive cake (Akgun and Doymaz, 2005). It can be seen that these reported values indicate that the Logarithmic model fitted the experimental date better. Similar results have been reported in other studies (Doymaz, 2004; Doymaz and Pala, 2001; Hofsetz *et al*., 2007)

It can therefore be said that the Page model fitted the experimental data slightly better in all three varieties of plantain based on the estimation of R^2, X^2 and RMSE. This is because higher values for coefficient of determination (R^2) with corresponding lower values of root mean square error (RMSE) and reduced chi-square (χ^2) are choosen as criteria for goodness of fit (Doymaz, 2007; Panchariya *et al.*, 2001; Saeed *et al.*, 2006; Singh *et al.*, 2006; Demir *et al.*, 2004; Doymaz, 2005b; Wang *et al.*, 2007):

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The predicted and experimental values for French Horn (CON), False Horn (CON) and FHIA-21 (CON) dried at 60^{o}C using the Page model are plotted and shown at Figure 4.3.1, Figure 4.3.2 and Figure 4.3.3 respectively. Similar results were obtained at other temperatures. It was seen that the drying curves of all models tend to under or overestimate the experimental data at different stages of the drying process. Generally similar results were found for the other pretreatments dried at 50, 70 and 80^{o}C.

The estimated values for k and y constants of the Page model ranges from 0.137702 to 0.845 h^{-1} and 0.8825 to 1.339 respectively for French Horn (Table 4.3.1), 0.098613 to 0.862269 h^{-1} and 1.07077 to 1.49407 respectively for False (Table 4.3.3), and 0.090207 to 0.843248 h^{-1} and 1.02009 to 1.33845 respectively for FHIA-21 (Table 4.3.5).

It was observed that the k values increased with temperature for specific pretreatment, whereas the y values generally decreased with increasing temperature. The y parameter is empirical and some authors have related this parameter to the process conditions (Azzous *et al*., 2002). The k parameter has been associated with the drying rate, being a measure of the rate of moisture transfer from the material, and in this way, an increase in the k parameter with temperature has been reported in literature during the drying of agricultural products (Karathanos and Belessiotis, 1999). An increase in the process drying temperature increases the moisture transfer rate from the material which results in an increase in the k values.

The estimated values for k, a, and c constants of the Logarithmic model ranges from 0.146632 to 0.926367 h^{-1}, 0.954876 to 1.4576 and -0.093948 to 0.135861 respectively for French Horn (Table 4.3.2), 0.125662 to 0.70753 h^{-1} , 1.058820 to 1.4065894 and -0.38032 to -0.01675 respectively for False Horn (Table 4.3.4), and 0.024761 to 0.90472 h^{-1}, 1.00322 to 0.108965 and -0.7921 to 0.108965 respectively for FHIA-21 (Table 4.3.6).

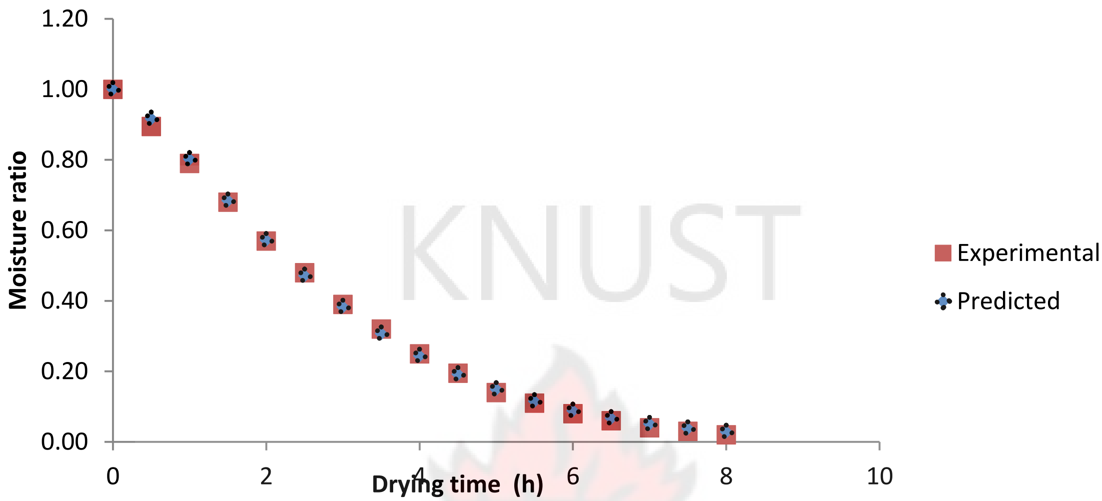

Figure 4.4.1 Comparison of experimental and predicted moisture ratio against drying time for FHIA 21 (CON) dried at 60°C using the Page model

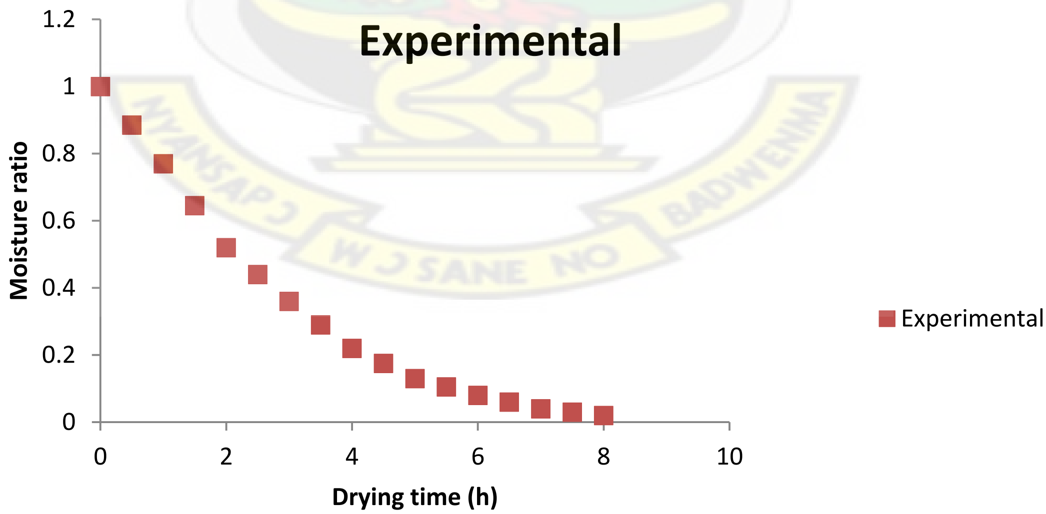

Figure4.4.2 Comparison of experimental and predicted moisture ratio against drying time for False Horn (CON) dried at 60°C using the Page model

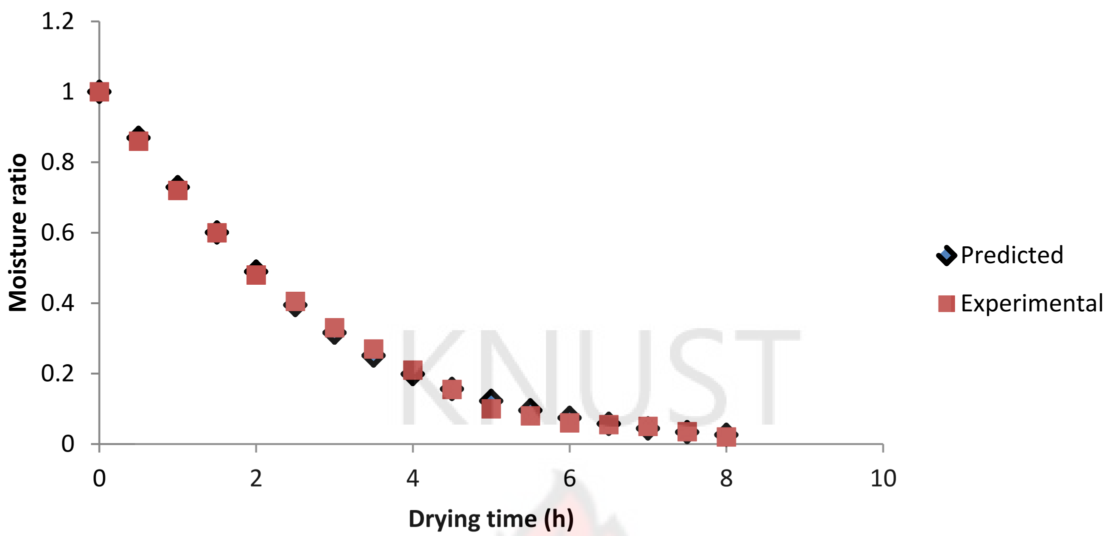

Figure 4.4.3 Comparison of experimental and predicted moisture ratio against drying time for French Horn (CON) dried at 60^{o}C using the Page model

Table 4.4.1 Analysis of the modeling of moisture ratio and drying time for pretreated French Horn using Page model

VARIETY	TREATMENT	DRYING TIME (h)	PARAMETER		R^2	X^2	RMSE
			k	y			
FRENCH HORN (80^{o}C)	CON	4	0.71946	1.30187	0.999	0.00017	0.01162
	BLA	7	0.30594	1.21786	0.998	0.00017	0.01230
	MBS	4	0.85405	0.88274	0.996	0.00153	0.03448
	CIT	5	0.53045	1.02873	0.994	0.00062	0.02248
FRENCH HORN (70^{o}C)	CON	6	0.44451	1.19393	0.999	0.00009	0.00892
	BLA	8	0.26014	1.19682	0.999	0.00005	0.00722
	MBS	5	0.66345	0.96805	0.997	0.00034	0.01534
	CIT	6	0.38631	1.13442	0.997	0.00032	0.01642
FRENCH HORN (60^{o}C)	CON	8	0.31616	1.17672	0.999	0.00014	0.01252
	BLA	11	0.21732	1.19744	0.998	0.00017	0.01276
	MBS	6	0.40617	1.25638	0.999	0.00009	0.00907
	CIT	7	0.57699	0.97222	0.997	0.00029	0.01591
FRENCH HORN (50^{o}C)	CON	12	0.13770	1.31292	0.997	0.00026	0.01568
	BLA	14.5	0.14557	1.22950	0.993	0.00069	0.02549
	MBS	8	0.17488	1.33903	0.985	0.00156	0.03712
	CIT	9	0.25027	1.19693	0.989	0.00108	0.03111

Table 4.4.2 Analysis of the modeling of moisture ratio and drying time for pretreated French Horn using Logarithmic model

VARIETY	TREATMENT	DRYING TIME (h)	PARAMETER			R^2	X^2	RMSE
			k	a	c			
FRENCH HORN (80^{o}C)	CON	4	0.67609	1.11611	-0.09394	0.995	0.00071	0.02361
	BLA	7	0.31853	1.12882	-0.10959	0.997	0.00030	0.01612
	MBS	4	0.92637	0.95488	+0.04602	0.985	0.00138	0.03357
	CIT	5	0.51159	1.03021	-0.02733	0.995	0.00050	0.02065
FRENCH HORN (70^{o}C)	CON	6	0.45477	1.09093	-0.07190	0.998	0.00026	0.01498
	BLA	8	0.28504	1.11760	-0.08986	0.998	0.00020	0.01328
	MBS	5	0.68847	0.98635	+0.01955	0.997	0.00031	0.01601
	CIT	6	0.36874	1.10096	-0.09183	0.998	0.00020	0.01300
FRENCH HORN (60^{o}C)	CON	8	0.34044	1.08722	-0.66557	0.998	0.00024	0.01460
	BLA	11	0.27107	1.09401	-0.04625	0.996	0.00039	0.01904
	MBS	6	0.43306	1.11381	-0.08562	0.996	0.00050	0.02058
	CIT	7	0.60524	0.99099	+0.02069	0.998	0.00021	0.01365
FRENCH HORN (50^{o}C)	CON	12	0.19963	1.15216	-0.09338	0.991	0.00090	0.02890
	BLA	14.5	0.19494	1.11539	-0.06720	0.990	0.00095	0.02986
	MBS	8	0.14663	1.45760	-0.45764	0.994	0.00066	0.02412
	CIT	9	0.24733	1.13565	+0.13586	0.993	0.00067	0.02460

Table 4.4.3 Analysis of the modeling of moisture ratio and drying time for pretreated False Horn using Page model

VARIETY	TREATMENT	DRYING TIME (h)	PARAMETER		R^2	X^2	RMSE
			k	y			
FALSE HORN (80°C)	CON	8	0.26318	1.25940	0.999	0.00005	0.00642
	BLA	11	0.20259	1.26334	0.999	0.00005	0.00659
	MBS	11	0.13824	1.16687	0.996	0.00042	0.01958
	CIT	9	0.17254	1.17255	0.999	0.00002	0.00427
FALSE HORN (70°C)	CON	6	0.38542	1.13636	0.996	0.00042	0.01885
	BLA	10	0.23569	1.18458	0.999	0.00006	0.00755
	MBS	8	0.26895	1.21983	0.998	0.00024	0.01441
	CIT	7	0.18845	1.38910	0.998	0.00027	0.01539
FALSE HORN (60°C)	CON	8	0.26318	1.25940	0.999	0.00004	0.00642
	BLA	11	0.20259	1.26334	0.999	0.00005	0.00659
	MBS	11	0.13824	1.16687	0.996	0.00042	0.01958
	CIT	9	0.17254	1.17255	0.999	0.00002	0.00427
FALSE HORN (50°C)	CON	15	0.09861	1.27873	0.998	0.00017	0.01279
	BLA	17	0.12146	1.17305	0.994	0.00052	0.02217
	MBS	12.5	0.12852	1.12625	0.998	0.00023	0.01429
	CIT	14	0.12364	1.2549	0.997	0.00025	0.01533

Table 4.4.4 Analysis of the modeling of moisture ratio and drying time for pretreated False Horn using Logarithmic model

VARIETY	TREATMENT	DRYING TIME (h)	PARAMETER			R^2	X^2	RMSE
			k	a	c			
FALSE HORN (80°C)	CON	6	0.36723	1.10274	-0.09383	0.997	0.00020	0.01540
	BLA	10	0.28471	1.10820	-0.04401	0.996	0.00034	0.01759
	MBS	8	0.28496	1.12946	-0.11239	0.997	0.00028	0.01571
	CIT	7	0.18189	1.40658	-0.38032	0.998	0.00025	0.01474
FALSE HORN (70°C)	CON	6	0.36723	1.10274	-0.09383	0.997	0.00028	0.01540
	BLA	10	0.28471	1.10820	-0.04401	0.996	0.00034	0.01759
	MBS	8	0.28496	1.12946	-0.11239	0.997	0.00028	0.01571
	CIT	7	0.18189	1.40658	-0.38032	0.998	0.00025	0.01474
FALSE HORN (60°C)	CON	8	0.29923	1.13774	-0.10436	0.997	0.00031	0.01641
	BLA	11	0.23459	1.08745	-0.05951	0.998	0.00015	0.01158
	MBS	11	0.14976	1.22699	-0.21798	0.996	0.00039	0.01877
	CIT	9	0.19499	1.19334	-0.16243	0.998	0.00023	0.01442
FALSE HORN (50°C)	CON	15	0.12566	1.20502	-0.17805	0.998	0.00031	0.01641
	BLA	17	0.17513	1.09236	-0.01675	0.994	0.00015	0.01158
	MBS	12.5	0.16817	1.15546	-0.16831	0.994	0.00039	0.01877
	CIT	14	0.18335	1.11999	-0.05655	0.992	0.00023	0.01442

Table 4.4.5 Analysis of the modeling of moisture ratio and drying time for pretreated FHIA-21 using Page model

VARIETY	TREATMENT	DRYING TIME (h)	PARAMETER		R^2	X^2	RMSE
			k	**y**			
FHIA – 21 (80°C)	CON	3	0.83699	1.29471	0.998	0.00028	0.01422
	BLA	7	0.36539	1.16685	0.991	0.00091	0.02802
	MBS	5	0.61169	1.02009	0.998	0.00020	0.01289
	CIT	6	0.44853	1.09622	0.998	0.00023	0.01398
FHIA – 21 (70°C)	CON	6.5	0.84323	1.02975	0.995	0.00047	0.02017
	BLA	9	0.31139	1.15052	0.999	0.00013	0.01068
	MBS	7.5	0.28011	1.16258	0.999	0.00012	0.01034
	CIT	8	0.22599	1.20306	0.999	0.00010	0.00938
FHIA – 21 (60°C)	CON	8	0.22072	1.33845	0.999	O.00009	0.00918
	BLA	12	0.26443	1.04920	0.998	0.00014	0.01142
	MBS	10	0.19635	1.10203	0.998	0.00017	0.01235
	CIT	10	0.17231	1.18608	0.999	0.00005	0.00702
FHIA – 21 (50°C)	CON	16	0.09021	1.29873	0.999	0.00014	0.01150
	BLA	17.5	0.09721	1.27605	0.994	0.00059	0.02350
	MBS	10	0.14449	1.26787	0.995	0.00044	0.01992
	CIT	11	0.13778	1.23473	0.998	0.00015	0.01178

Table 4.4.6 Analysis of the modeling of moisture ratio and drying time for pretreated FHIA-21 using Logarithmic model

VARIETY	TREATMENT	DRYING TIME (h)	PARAMETER			R^2	X^2	RMSE
			K	a	c			
FHIA-21 (80^{o}C)	CON	3	0.68425	1.16437	-0.15102	0.997	0.00048	0.01860
	BLA	7	0.36784	1.08572	-0.79210	0.992	0.00090	0.02795
	MBS	5	0.60291	1.01381	-0.01218	0.998	0.00623	0.07137
	CIT	6	0.43060	1.06023	-0.05849	0.999	0.00514	0.06593
FHIA-21 (70^{o}C)	CON	6.5	0.90472	1.00322	+0.01485	0.996	0.00041	0.01864
	BLA	9	0.33689	1.06788	-0.05041	0.998	0.00018	0.01265
	MBS	7.5	0.28219	1.11428	-0.10261	0.999	0.00010	0.00955
	CIT	8	0.02476	1.13439	-0.10848	0.997	0.00029	0.01608
FHIA- 21 (60^{o}C)	CON	8	0.25694	1.20058	-0.16336	0.996	0.00043	0.01939
	BLA	12	0.28104	1.01572	-0.00749	0.998	0.00015	0.01042
	MBS	10	0.20367	1.07366	-0.06678	0.998	0.00021	0.01376
	CIT	10	0.20070	1.12429	-0.09113	0.998	0.00022	0.01406
FHIA -21 (50^{o}C)	CON	16	0.12960	1.18019	-0.13855	0.995	0.00047	0.02107
	BLA	17.5	0.16319	1.13134	-0.04315	0.989	0.00104	0.03130
	MBS	10	0.16068	1.22515	-0.20351	0.993	0.00062	0.02371
	CIT	11	0.17405	1.15121	-0.10897	0.995	0.00050	0.02145

4.5 Effective moisture diffusivity (D_{eff})

The results obtained have shown that internal mass transfer resistance due to the presence of a falling rate drying period controls drying time. During the drying it was assumed that diffusivity, explained with Fick's diffusion equation, is the only physical mechanism to transfer water to the surface (Dadali *et al*., 2007b). Effective moisture diffusion which is affected by composition, moisture content, temperature and porosity of the material was used due to limited information on the mechanism of moisture movement during drying and complexity of the process (Afzal and Abe, 1997).

The values of D_{eff} at the various temperatures and treatments are presented in Table 4.4.1 for French Horn, False Horn and FHIA-21. The moisture diffusivity values were affected by the pretreatments as well as temperature as they increased with increase in temperature for all treatments. The values for all experiments ranged from 7.54×10^{-10} to 2.37×10^{-9} m^2/s depending on pretreatment for French Horn, 5.17×10^{-10} to 3.11×10^{-9} m^2/s for False Horn and 1.29×10^{-10} to 3.98×10^{-9} m^2/s for FHIA-21. These values are comparable to $1\text{-}3 \times 10^{-11}$ mentioned for the drying of apricot in the temperature range of 50 -80^oC (Abdelhaq and Labuaza, 1987) and 2.32×10^{-10} to 2.76×10^{-9} m^2/s for mulberries dried at 60-80^oC (Doymaz, 2004). Observing the moisture diffusivity values for French Horn plantain (Table 4.4.1) reveals that D_{eff} values of BLA pretreatment were lower at constant temperature when compared to other treatments. For example at 60^oC, D_{eff} values calculated for the various treatments for French Horn were 1.42×10^{-09} for CON, 9.59×10^{-10} for BLA, 1.80×10^{-09} for MBS, and 1.35×10^{-09} for CIT indicating that D_{eff} values for BLA were 1.5 to 3 times lower than the other treatments. Similar results were obtained for all other temperatures and plantain varieties. This could be attributed to the low drying rates compared to the other pretreatments. Higher D_{eff} values were recorded for the CON treatment at high temperatures whereas at low temperatures MBS and CIT recorded higher D_{eff} values compared to that of CON throughout the experiment for French horn, False Horn and FHIA-21. This indicates that CON pretreatment had a greater effect on the mass transfer of plantain slices at higher temperature whereas CIT and MBS had a greater effect at 50^{o}C. Comparison of the effect of MBS and CIT revealed that the MBS had higher Deff values for French (Table 4.4.1) and False horn (Table 4.4.1) whereas CIT had the higher D_{eff} values for FHIA-21 (Table 4.4.1) at constant temperatures.

The temperature dependence of the effective diffusivity was represented by an Arrhenius relationship (Madamba *et al*., 1996; Sanjuan *et al.*, 2003) through which activation energy (Ea) were determined. The activation energy of the three plantain varieties based on the four pretreatments are presented in Table 4.4.2. CIT pretreatment recorded the lowest Ea for French horn (11.88 KJ/mol) and FHAI-21 (27.24 KJ/mol). This justifies the influence of CIT pretreatment on the internal mass transport of French and False horn. The Ea value recorded for French (CIT) is lower than those reported in literature (21.1 and 22.41 kJ/mol) for untreated and blanched samples respectively, for tomato slices (Kingsly *et al.,* 2007) whereas that of FHIA-21 (CIT) was higher.

Though the effective moisture diffusivity values for BLA pretreatments were generally lower compared to the other treatments, it recorded the lowest Ea value for False horn plantain. Similar results were reported by Kingsly *et al*. (2007) when blanched tomato slices recorded higher moisture diffusivity value yet had a higher Ea value compared to the unblanched samples.

The effect of the lack of pretreatment on plantain slices were made evident as the CON treatment recorded highest Ea values throughout the pretreatments. This may be attributed to the lack of tissue modification as in the case of the other pretreatments. The highest Ea value was recorded for FHIA-21 (CON, 56.61 KJ/mol). This might be due to the high moisture content of the variety and that pretreatment proved to be more effective here than the other varieties. Ea values reported are corresponds to reported activation energies for food materials (Saravacos and Maroulis, 2001)

Table 4.5.1 Values of effective diffusion coefficient obtained at various temperatures and treatments for French Horn, False Horn and FHIA-21

Pretreatment	Temperature of drying air (^{o}C)	Effective diffusion coefficient (m^2/s)		
		French Horn	False Horn	FHIA-21
CON	80	2.37 x 10^{-09}	3.11 x 10^{-09}	3.98 x 10^{-09}
CON	70	1.88 x 10^{-09}	1.60 x 10^{-09}	2.05 x10^{-09}
CON	60	1.35 x 10^{-09}	1.36 x 10^{-09}	1.38 x 10^{-09}
CON	50	8.10 x 10^{-10}	6.64 x 10^{-10}	5.96 x 10^{-10}
BLA	80	1.39 x 10^{-09}	1.29 x 10^{-09}	1.48 x 10^{-09}
BLA	70	1.15 x 10^{-09}	9.62 x 10-^{10}	1.29 x10^{-09}
BLA	60	9.59 x 10^{-10}	8.44 x 10^{-10}	5.93 x 10^{-10}
BLA	50	7.54 x 10^{-10}	5.17 x 10^{-10}	5.40 x 10^{-10}
MBS	80	2.31 x 10^{-09}	2.49 x 10^{-09}	1.83 x 10^{-09}
MBS	70	1.63 x 10^{-09}	1.28 x 10^{-09}	1.20 x 10^{-09}
MBS	60	1.80 x 10^{-09}	9.87 x 10^{-10}	6.97 x 10^{-10}
MBS	50	1.34 x 10^{-09}	7.00 x 10^{-10}	7.65 x 10^{-10}
CIT	80	1.85 x 10^{-09}	1.82 x 10^{-09}	1.61 x 10^{-09}
CIT	70	1.81 x 10^{-09}	1.27 x 10^{-09}	9.81 x 10^{-10}
CIT	60	1.42 x 10^{-09}	8.72 x 10^{-10}	7.45 x 10^{-10}
CIT	50	1.31 x 10^{-09}	6.96 x 10^{-10}	6.58 x 10^{-10}

Table 4.5.2 Activation energy (KJ/mol) for the drying of pretreated plantain varieties

Variety	CON	BLA	MBS	CIT
French Horn	33.10	18.73	15.29	11.88
False Horn	44.50	26.76	37.54	28.99
FHIA-21	56.61	35.23	30.85	27.24

4.6 Effect of pretreatment and temperature on selected functional properties

4.6.1 Moisture content

The effect of temperature and pretreatment on the moisture content of flour produced from the False Horn, French Horn and FHIA-21 are presented in Table 4.5.1. It was observed that temperature and treatment had a significant effect ($p < 0.05$) on the moisture contents of the three plantain varieties. For French Horn the lowest moisture content was recorded for CON treatment at 80^{o}C (2.44%) whereas the highest value was for BLA treatment at 50^{o}C (5.75%). This might be due to the high moisture diffusivity of the untreated sample (CON) at 80^{o}C (Table 4.4.1) and the low diffusivity of the BLA pretreatment (Table 4.4.1) resulting in higher equilibrium moisture content at the drying temperature of 50^{o}C.

It was generally observed that moisture content increased with decrease in temperature except for the CIT treatment which recorded otherwise. This observation for CIT pretreatment could further be attributed to the effectiveness of it at lower temperatures. The general observation may be due high moisture diffusivity at high temperature leading to more moisture being removed. It was also observed that at higher temperature the moisture content of CON was lower compared to all the other treatments yet at lower temperatures MBS and CIT exhibits the reverse except for BLA treatment.

Similar observations were made for False Horn with the lowest moisture content being recorded for CON (2.20%) treatment at 80^{o}C and the highest CIT (5.45%) at the same temperature. Just like French Horn, It was generally observed that moisture content

increased with decrease in temperature except for the CIT treatment which recorded otherwise. For FHIA-21 BLA treatment at 80^{o}C recorded the lowest moisture content (1.82%) whereas that of 50^{o}C recorded the highest (4.90%).

These values obtained for the three plantain varieties are consistent with those obtained (2.36% - 11.75%) in literature (Emperatríz *et. al*., 2008; Kayisu *et al*., 1981) and are indicative of flours with a stable shelf life (<20.0% moisture) making them acceptable for the established goal.

4.6.2 Solubility

The effect of temperature and pretreatment on the solubility of flour produced from the False Horn, French Horn and FHIA-21 are presented in Table 4.5.2. It was observed that temperature and pretreatment had a significant effect ($p < 0.05$) on the solubility of the three varieties. For French Horn, BLA pretreatment at 80^{o}C recorded the lowest value (0.38%) whereas it also recorded the highest (4.67%) at 50^{o}C. This was in agreement with observation made by Muyonga *et al.* (2007) when flour produced from steamed banana recorded high solubility compared to unsteamed banana prior to dehydration. For French variety the general observation was that solubility increased with decrease in temperature used for the drying of the plantain for all the treatments. Significant difference ($p < 0.05$) occurred between pretreatments at constant temperature and within pretreatments at different temperatures as indicated in Table 4.5.2.

The lowest solubility value recorded for False Horn was for BLA pretreatment at 80^{o}C (0.01%) whereas the highest was for CIT treatment at 80^{o}C (0.83%). It was generally observed that solubility values increased with increase in temperature used for the drying of the variety except for BLA treatment which exhibited the reverse.

For FHIA-21, MBS treatment at 50^{o}C had the lowest solubility (0.26%) value whereas CIT treatment at 80^{o}C recorded the highest (0.94%). High solubility for the CIT pretreatment for FHIA-21 and False Horn could possibly be due texture modifying action of citric acid which enhances flexibility of the flour in food preparation (Owuamanam, 2007).

The general observation was that solubility increased with increase in the temperature used for drying except for French Horn. This was to be expected since the solubility of most materials tends to increase with increase in temperature. The generally observed low solubility for the three plantain varieties treated in different ways and dried at different temperatures could be attributed to the inability of hydrogen bonds to continue to be disrupted when the aqueous suspension of flour is raised above its gelatinization range so that water molecules can become attached to the liberated hydroxyl groups (Richard *et al*., 1991).

4.6.3 Swelling power

The effect of temperature and pretreatment on the swelling power of flour produced from the False Horn, French Horn and FHIA-21 are presented in Table 4.5.3. Bainbridge *et al.* (1996) stated that good quality starch with high starch content and paste viscosity will have a low solubility and high swelling volume and power. A similar observation was made in that whilst the solubility values were low the swelling powers were appreciably high. The swelling power may be attributed to the low levels of fat by the three plantain varieties. This is because high levels of fat leads to the formation of amylose-lipid complexes that restrict swelling. It might also be due to a more highly ordered internal arrangement of the starch granules as found in yam with a swelling capacity of 9% (Soni, *et al.*, 1985).

The swelling capacity ranged from 7.69% (MBS at 50^{o}C) to 10.72% (BLA at 50^{o}C) for French Horn, 7.15% (CON at 80^{o}C) to 10.9% (BLA at 80^{o}C) False Horn and 7.14% (BLA at 80^{o}C) to 10.28% (BLA at 50^{o}C) for FHIA -21. This indicated that BLA pretreatment was effective in increasing the swelling power of the three plantain varieties. The high swelling power of French Horn compared to the other varieties may be due to the low level of fat (Table 4.1.1) in the variety. These values were comparable those reported for soybean fortified yam flour (6.8 - 9.6%) by Jimoh and Olatidoye (2009). Generally the plantain samples showed a better swelling capacity than cassava and this could be because of the small particle size of plantain starch and its highly digestible nature (Ojinnaka *et al*., 2009). The variant swelling power could be due to amylose/amylopectin ratio and by the characteristics of amylose and amylopectin in

terms of molecular weight distribution, degree of branching, length of branches and conformation of the molecules (Hoover and Ratnayake, 2002).

The general observation was that pretreatment and temperature had a significant effect ($p<0.05$) on the swelling power of the three plantain varieties as indicated in Table 4.4.3. It was also observed that plantain varieties dried at lower temperature had a higher swelling power compared to those dried at higher temperatures except for MBS pretreatment for French Horn; BLA, MBS and CIT pretreatment for False Horn. This general observation can be attributed to the deteriorative effect of high temperature on the molecular conformation of the starch present. This is in agreement with observations made by Muyonga *et al.* (2000).

4.6.4 Water binding capacity

Water binding capacity is an indication that particular flour would be useful in food system such as bakery products which require hydration to improve handling characteristics. Giami and Alu (1993) assert that water binding capacity of 1.25 g/g and above is an indication of good bakery material. The effect of temperature and pretreatment on the water binding capacity of flour produced from the False horn, French horn and FHIA-21 are presented in Table 4.5.4.

The water binding capacity ranged from 0.40 g/g (CIT at 80^{o}C) to 0.60 g/g (BLA at 50^{o}C) for FHIA-21, 0.37 g/g (BLA at 50^{o}C) to 0.67 g/g (CIT at 50^{o}C) for French Horn

False Horn and 0.44 g/g (MBS at 80^{o}C) to 0.82 g/g (CIT at 50^{o}C). These values were lower than what were reported for other flours. Oduro *et al*. (2006) reported 1.54 g/g for the water binding capacity of FHIA-03 a hybrid cooking banana. Mepba *et al*. (2007) reported 0.65-2.84 g/g for wheat/plantain flour. These lower values could be associated with lower carbohydrate content in these plantain flours whose complex molecule will demand less water during hydrolysis (Oduro *et al*., 2006). Higher water binding capacities can also be attributed to loose association of starch polymers in the granules (Soni *et al*., 1985) which might not be the case for these plantain flours. High water absorption and swelling capacities have both economic and culinary advantage. It is evident that CIT pretreatment at 80^{o}C provided the highest water binding capacity for all three varieties and that it proved to be significantly different ($p<0.05$) from the other pretreatments at the same temperature among the various varieties. The increase in water binding capacity as a result of CIT pretreatment could suggest possible increase in the level of their incorporation into food formulation like dough in other to improve its handling characteristics and also to maintain freshness of the product.

4.6.5 pH

Assessment of pH in plantain is used primarily to estimate consumption quality and hidden attributes. Acids make an important contribution to the post-harvest quality of the fruit, as taste is mainly a balance between the sugar and acid contents, hence post-harvest assessment of acidity is important in the evaluation of the taste of the flours.

Analysis of variance for pH of the flours produced from various varieties indicated that pH of the flours was significantly ($p<0.05$) affected by the interaction of temperature used in the drying of the plantain varieties and the treatments undertaken. However, for some pretreatments pH decreased with increase in drying temperature and for other the vice versa depending on the particular plantain variety (Table 4.5.5).

For French Horn, pH increased with increase in drying temperature for all treatments except for CON treatment which exhibited otherwise. The pH values recorded ranged from 5.25 (CIT at 50^{o}C) to 6.52 (CON at 50^{o}C). For False Horn, pH increased with decreasing drying temperature for all treatments. pH values recorded were in the range of 5.71 (BLA at 80^{o}C) to 6.85 (CON at 50^{o}C). Similar observation was made for FHIA-21 in that pH increased with decrease in the drying temperature for all pretreatments. pH were in the range of 5.31 (MBS at 50^{o}C) to 6.75 (CIT at 50^{o}C) . Emperatríz *et al.* (2008) reported values in the range of 4.6 – 6.1 when plantain flours were produced from different dehydration procedures. Dadzie (1998) reported values within the range of 6.0 – 6.5. Deviations from reported values could be attributed to variations in temperature and pretreatment as well as differences in the morphology of the plantain varieties.

One observation that is common to all the plantain varieties is the fact that higher pH values were recorded at lower drying temperature indicating the significant role temperature had on the measured pH. These differences could also be attributed to depolymerisation caused by the different thermal treatments and pretreatments, hence producing acid terminal residues in the starch molecules (Emperatríz *et al.,* 2008).

4.6.6 Bulk density

According to Bhattacharya and Prakash (1994) bulk density of foods increases with increase in starch content. Meanwhile, Okezie and Bello (1988) stresses that high bulk density of food material is important in relation to its packaging. However according to the results listed in Table 4.5.6, there were no significant effect (p>0.05) of drying temperature and treatment on the bulk density of the three plantain varieties. Though insignificant (p>0.05), variations in temperature and pretreatments affected the bulk densities of the flours.

For French Horn, decrease in drying temperature generally resulted in increase in bulk density except for the MBS treatment where increase in drying temperature resulted in decrease in bulk density. Bulk densities measured ranged from 0.50 (CIT at 50^{o}C, MBS at 50^{o}C & 60^{o}C) to 0.58 (BLA at 50^{o}C). For False Horn decrease in drying temperature resulted in an increase in bulk density for CON, MBS and CIT treatments except BLA. Bulk density values ranged from 0.57 (CON at 50^{o}C & 60^{o}C, MBS at 50^{o}C) to 0.66 (CIT at 50^{o}C).

For FHIA-21 there were generally increases in bulk density with decreasing drying temperature for BLA, MBS and CIT treatments with the exception of CON treatment. Bulk densities ranged from 0.50 (CON at 50^{o}C) to 0.62 (CIT at 50^{o}C & 60^{o}C, CON at

70^{o}C and 80^{o}c). Though there were no significant difference ($p>0.05$) between bulk densities of the three plantain varieties the highest bulk density was recorded for False horn followed be French and then FHIA-21. The generally low bulk density of the flours could be an advantage in the formulation of baby foods where high nutrient density to low bulk density is desired. The results further indicated that the triploids had a higher bulk density than the tetraploid. Thus flour obtained from the triploids showed a higher density than the tetraploid, which demonstrates a greater compactness of their particles.

4.6.7 Rehydration ratio

One of the quality parameters of dried food is their ability to reconstitute, that is, their ability to return to their original shape and appearance upon soaking in water (Kordylas, 1990). Meanwhile Ponting *et al*. (1966) and Mazza (1983) concluded that reduced rehydration of pretreated dried fruits were as largely caused by the coating on the fruits and vegetables. Ponting *et al*. (1966) also pointed out that less rehydration would be an advantage for dried fruits as snack products because of low hygroscopicity of pretreated dried products since they can be exposed for several hours without becoming sticky and mouldy. According to the results listed in Table 4.5.7 there were no clear effects of drying temperature and treatment on the rehydration ration of flour produced from three plantain varieties. Rehydration ratio ranged from 1000.31 x 10^{-3} (CON at 50^{o}C) to 1001.47 x 10^{-3} (CIT at 50^{o}C); 1000.22 x 10^{-3} (CON at 50^{o}C) to 1002.85 x 10^{-3} (MBS at 80^{o}C) and 1000.11 x 10^{-3} (BLA at 50^{o}C) to 1020.00 x 10^{-3} (CIT at 60^{o}C) for French Horn, False Horn and FHIA-21 respectively.

Rehydration ratio were at its lowest when False and French Horn were given the control (CON) pretreatment with a drying temperature of 50^{o}C whereas BLA with a drying temperature of 50^{o}C recorded the lowest rehydration ration for FHIA-21. This observation can be attributed to the lack of coating on the sliced surfaces of the CON samples for False and French horn plantain varieties. This further affirms the differences between the triploids and tetraploid. Meanwhile it was generally observed that lower rehydration ratios among the three varieties were measured at 50^{o}C drying temperature. Among the three varieties there were no clear cut trends in variation of rehydration ratio with variation in drying temperature. However variations in pretreatment resulted in variation in rehydration ratio, though insignificant ($p>0.05$) as can be verified from Table 4.5.7. The generally low rehydration ratios determined is an indication that flours produced from these three plantains varieties have good keeping qualities based on their low hygroscopicity and that they can be exposed for long without becoming sticky or going mouldy.

CHAPTER FIVE

5.0 CONCLUSION AND RECOMMENDATION

5.1 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 triploid and the tetraploid 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. Between varieties FHIA-21 had the highest drying rate followed by French Horn and False Horn then in almost all temperature and treatment variations.

It was observed that MBS and CIT treatments in the three plantain varieties at 50^oC saved 33% and 25% of drying time respectively for French Horn, 16% and 6.5% for False Horn, and 37.5% and 31% for FHIA-21. Meanwhile the BLA pretreatment among all three varieties slowed the drying process. The effect of CIT and MBS pretreatments increased as the drying temperature decreased. This therefore indicates that these pretreatments would be necessary when drying at lower temperatures.

According to the results of the mathematical modeling of the drying of French Horn, False Horn and FHIA-21 the best model for describing the drying characteristic of French Horn, False Horn and FHIA-21 pulp slices was the Page model. The results of regression analysis indicated that this model could be used to model the drying behavior which is useful for simulation studies of drying systems.

The moisture diffusivity values were affected by the pretreatments as well as temperature as they increased with increasing temperature for all pretreatments. The effect of the pretreatments are justified by the low activation energies recorded by CIT (11.88 KJ/mol and 27.24 KJ/mol for French Horn and FHIA-21 respectively) and BLA (26.76 KJ/mol for False Horn) pretreatments.

Comparison of the proximate analysis of the three varieties indicated marked variations in the nutritional status of the three plantain varieties with FHIA-21 comparing favorably with that of False and French Horn in terms of ash, fat fibre, potassium, sodium and iron.

The results of the study further indicated that temperature and pretreatment significantly affected the selected functional properties ($p < 0.05$). For French Horn it was generally observed that moisture content increased with decreasing temperature except for the CIT treatment which recorded otherwise. Similar observations were made for FHIA-21 and False Horn. The implication is that temperature and treatment can be varied to produce the desired moisture content for a particular usage.

BLA at drying temperature of 50°C resulted in the highest solubility for French Horn, CIT at 80°C for False Horn and FHIA-21. Low solubility values were recorded by BLA treatment at 80°C for both False Horn and French Horn whereas MBS at 50°C had the lowest.

High swelling values were recorded for all varieties by the BLA treatment at 80°C for both French Horn and False Horn, and 50°C for FHIA-21.CIT treatment at 80°C resulted in the highest water binding capacity for all three plantain varieties.

Increasing drying temperature resulted in increase in pH for FHIA-21, False horn and French Horn (CON treatment for French did not show that trend). Highest pH values were obtained by the CON treatment at 50°C for French Horn and False Horn. Meanwhile CIT at 50°C treatment resulted in the highest pH for FHIA-21.

The bulk densities of the flour were affected by temperature and treatment though at insignificant levels. The general observation were that decrease in drying temperature resulted in increase in bulk densities for the three varieties. The triploids (False and French Horn) had a higher bulk density than the tetraploid (FHIA-21) upon treatment and temperature variations.

Lower rehydration ratio were recorded at drying temperature of 50°C for all treatments. Meanwhile the CON treatment at drying temperature of 50°C produced the lowest rehydration ratio for French and False Horn with BLA recording the lowest for FHIA-

21. The generally low rehydration ratio of the flours is an indication that these flours have very good keeping qualities and that they can be exposed for long periods of time without becoming sticky.

The results obtained confirm the feasibility of producing starch flour with moisture contents with adequate levels for a stable shelf life. These flours have considerable contents of dietary fiber and starch, as well as different functional behaviors that make them of interest as ingredients for food production. The results also show that the functional properties of the flours are affected by the different temperatures and treatments. Moreover, information is made available for the applicability of the flours as a function of their different functional properties as resulting from effects of the different pretreatments.

5.2 Recommendations

Based on the work of this study, the following areas for further research are recommended:

I. Thickness of plantain slices would need to be differentiated in other to find out the optimum drying rate and its effect on the thin layer modeling of the drying process.

II. Effects of drying on other plantain quality attributes such as starch, protein, fat, ash, minerals and other biochemical properties should be considered.

III. Other plantain hybrids and native varieties should be given the same pretreatments to find out if the effects on them would be similar to those obtained for French Horn, False Horn and FHIA-21 in this study.

IV. The same pretreatments should be applied to the plantain pulp and dried at a higher temperature (for example, 100^{o}C) to verify if the quality of treated plantain will be the same as affected by the treatments so that the high temperature drying would be the most recommended.

V. The dryer should be replicated on a large-scale and processors encouraged using them as they are safe, give products with quality functional properties and requiring smaller space and little expertise to operate as compared to others.

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APPENDICES

Appendix 1: Formulae for various calculations

Moisture determination

$$\%Moisture = \frac{(\text{wt of crucible + fresh sample}) - (\text{wt of crucible +dried sample})}{\text{Weight of fresh sample}} \times 100$$

Ash determination

$$\%Ash = \frac{(\text{weight of crucible + ash}) - (\text{weight of crucible})}{\text{Weight of sample}} \times 100$$

Crude fat determination

$$\%\ Crude\ fat = \frac{\text{weight of fat}}{\text{Weight of sample}} \times 100$$

Crude fibre determination

$$\%\ crude\ fibre = \frac{(\text{wt of crucible + sample before ignition}) - (\text{wt of crucible + ash})}{\text{Wt of fresh sample}} \times 100$$

Crude protein determination

$$\%\ crude\ protein = \frac{100\ (V_s - V_b) \times N \times 0.01401}{10\ w}$$

Where V_s = Titre value of the sample

V_b = Titre value of the blank

W = weight of sample

N = conversion factor

Swelling power

$$Swelling\ power = \frac{(\text{Wt of tube + sample after centrifuge}) - (\text{Wt of sample + tube})}{\text{Weight of sample}} \times 100$$

Solubility

$$\% \text{ solubility} = \frac{Wn - Wr}{Ws} \times 100$$

Where Wn = weight of supernatant solution from swelling experiment

Wr = weight of residue after evaporation

Ws = weight of sample.

Water binding capacity determination

$$\text{Water binding capacity} = \frac{Wc - (Wt - Wb)}{Ws}$$

Where Wc = weight of sample and centrifuge tube after centrifuge and decantation

Wt = weight of sample and centrifuge tube

Wb = weight of centrifuge tube.

Ws = weight of sample.

Bulk density determination

$$\text{Bulk density (g/cc)} = \frac{\text{Mass of sample}}{\text{Volume of sample}}$$

Rehydration ratio determination

$$\text{Rehydration ratio} = \frac{\text{Mass after rehydration}}{\text{Mass before rehydration}}$$

Appendix 2A: Data on MR and drying time for French horn, False and FHAI-21 at 80°C under the different pretreatments

Time (h)	MR											
	CON			BLA			MBS			CIT		
	FaH	FrH	F21	FaH	FrH	F21	FaH	FrH	F21	FaH	FrH	F21
0.0	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
0.5	0.72	0.74	0.71	0.88	0.86	0.83	0.74	0.68	0.76	0.79	0.80	0.81
1.0	0.43	0.48	0.42	0.76	0.72	0.65	0.48	0.35	0.51	0.58	0.56	0.61
1.5	0.24	0.32	0.27	0.65	0.61	0.56	0.37	0.29	0.41	0.48	0.44	0.51
2.0	0.04	0.16	0.12	0.53	0.49	0.47	0.26	0.22	0.30	0.38	0.32	0.40
2.5	0.03	0.10	0.07	0.47	0.41	0.39	0.19	0.18	0.23	0.30	0.27	0.32
3.0	0.02	0.03	0.01	0.40	0.33	0.31	0.11	0.13	0.15	0.22	0.22	0.23
3.5		0.02		0.31	0.26	0.21	0.07	0.08	0.11	0.16	0.17	0.18
4.0		0.01		0.21	0.18	0.10	0.02	0.02	0.07	0.10	0.12	0.12

4.5				**0.18**	**0.14**	**0.09**			**0.06**	**0.07**	**0.07**	**0.09**
5.0				**0.15**	**0.09**	**0.08**			**0.04**	**0.03**	**0.02**	**0.05**
5.5				**0.12**	**0.08**	**0.07**						**0.05**
6.0				**0.09**	**0.07**	**0.05**						**0.04**
6.5				**0.06**	**0.05**	**0.04**						
7.0				**0.03**	**0.03**	**0.03**						

CON: Control; BLA: Blanched; MBS: Sodium meta bisulfite: CIT: Citric acid. FaH:False horn: FrH: French horn; F21: FHIA-21.

Appendix 2B: Data on MR and drying time for French horn, False and FHAI-21 at 70^{o}C under the different pretreatments

Time (h)	**MR**											
	CON			**BLA**			**MBS**			**CIT**		
	FaH	**FrH**	**F21**	**FaH**	**FrH**	**F21**	**FaH**	**FrH**	**F21**	**FaH**	**FrH**	**F21**
0.0	**1.00**	**1.00**	**1.00**	**1.00**	**1.00**	**1.00**	**1.00**	**1.00**	**1.00**	**1.00**	**1.00**	**1.00**
0.5	**0.84**	**0.81**	**0.70**	**0.90**	**0.89**	**0.86**	**0.87**	**0.74**	**0.87**	**0.91**	**0.84**	**0.90**
1.0	**0.68**	**0.63**	**0.40**	**0.79**	**0.78**	**0.71**	**0.74**	**0.49**	**0.74**	**0.81**	**0.68**	**0.79**
1.5	**0.54**	**0.49**	**0.28**	**0.69**	**0.65**	**0.61**	**0.64**	**0.37**	**0.64**	**0.71**	**0.54**	**0.69**
2.0	**0.40**	**0.36**	**0.15**	**0.59**	**0.53**	**0.51**	**0.53**	**0.25**	**0.53**	**0.60**	**0.40**	**0.59**
2.5	**0.34**	**0.28**	**0.11**	**0.50**	**0.46**	**0.42**	**0.46**	**0.21**	**0.46**	**0.52**	**0.34**	**0.52**
3.0	**0.28**	**0.20**	**0.07**	**0.41**	**0.39**	**0.33**	**0.38**	**0.16**	**0.38**	**0.44**	**0.28**	**0.44**
3.5	**0.23**	**0.14**	**0.07**	**0.36**	**0.32**	**0.28**	**0.31**	**0.12**	**0.31**	**0.36**	**0.22**	**0.37**
4.0	**0.18**	**0.08**	**0.06**	**0.30**	**0.25**	**0.23**	**0.24**	**0.09**	**0.24**	**0.28**	**0.17**	**0.30**

4.5	**0.12**	**0.06**	**0.05**	**0.25**	**0.21**	**0.18**	**0.19**	**0.06**	**0.20**	**0.23**	**0.12**	**0.25**
5.0	**0.06**	**0.04**	**0.03**	**0.19**	**0.17**	**0.13**	**0.13**	**0.03**	**0.15**	**0.17**	**0.08**	**0.19**
5.5	**0.05**	**0.03**	**0.02**	**0.16**	**0.14**	**0.10**	**0.10**		**0.13**	**0.13**	**0.05**	**0.16**
6.0	**0.03**	**0.02**	**0.01**	**0.13**	**0.11**	**0.07**	**0.07**		**0.11**	**0.08**	**0.02**	**0.13**
6.5			**0.01**	**0.11**	**0.08**	**0.06**	**0.06**		**0.09**	**0.06**		**0.12**
7.0				**0.09**	**0.06**	**0.04**	**0.05**		**0.06**	**0.04**		**0.11**
7.5				**0.08**	**0.05**	**0.04**	**0.04**		**0.03**			**0.09**
8.0				**0.07**	**0.04**	**0.03**	**0.03**					**0.06**
8.5				**0.06**		**0.03**						
9.0				**0.05**		**0.02**						
9.5				**0.05**								
10.0				**0.04**								

CON: Control; BLA: Blanched; MBS: Sodium meta bisulfite: CIT: Citric acid. FaH:False horn: FrH: French horn; F21: FHIA-21.

Appendix 2C: Data on MR and drying time for French horn, False and FHAI-21 at 60^{o}C under the different pretreatments

Time (h)	**MR**											
	CON			**BLA**			**MBS**			**CIT**		
	FaH	**FrH**	**F21**	**FaH**	**FrH**	**F21**	**FaH**	**FrH**	**F21**	**FaH**	**FrH**	**F21**
0.0	**1.00**	**1.00**	**1.00**	**1.00**	**1.00**	**1.00**	**1.00**	**1.00**	**1.00**	**1.00**	**1.00**	**1.00**
0.5	**0.89**	**0.86**	**0.90**	**0.91**	**0.92**	**0.87**	**0.91**	**0.83**	**0.90**	**0.92**	**0.78**	**0.93**
1.0	**0.77**	**0.72**	**0.79**	**0.82**	**0.84**	**0.74**	**0.81**	**0.66**	**0.79**	**0.84**	**0.56**	**0.85**
1.5	**0.65**	**0.60**	**0.68**	**0.72**	**0.71**	**0.67**	**0.77**	**0.52**	**0.73**	**0.75**	**0.42**	**0.76**
2.0	**0.52**	**0.48**	**0.57**	**0.62**	**0.58**	**0.60**	**0.73**	**0.38**	**0.67**	**0.66**	**0.28**	**0.67**
2.5	**0.44**	**0.41**	**0.48**	**0.56**	**0.51**	**0.52**	**0.66**	**0.29**	**0.60**	**0.58**	**0.24**	**0.60**
3.0	**0.36**	**0.33**	**0.39**	**0.49**	**0.43**	**0.43**	**0.58**	**0.2**	**0.52**	**0.50**	**0.19**	**0.52**
3.5	**0.29**	**0.27**	**0.32**	**0.43**	**0.38**	**0.38**	**0.52**	**0.14**	**0.47**	**0.44**	**0.16**	**0.47**
4.0	**0.22**	**0.21**	**0.25**	**0.36**	**0.32**	**0.33**	**0.46**	**0.08**	**0.41**	**0.38**	**0.12**	**0.41**
4.5	**0.18**	**0.155**	**0.20**	**0.32**	**0.28**	**0.28**	**0.41**	**0.06**	**0.37**	**0.33**	**0.09**	**0.37**
5.0	**0.13**	**0.10**	**0.14**	**0.28**	**0.24**	**0.23**	**0.36**	**0.04**	**0.32**	**0.28**	**0.07**	**0.32**
5.5	**0.11**	**0.08**	**0.11**	**0.23**	**0.20**	**0.20**	**0.32**	**0.04**	**0.27**	**0.24**	**0.06**	**0.27**
6.0	**0.08**	**0.06**	**0.08**	**0.19**	**0.16**	**0.16**	**0.27**	**0.03**	**0.22**	**0.19**	**0.04**	**0.22**
6.5	**0.06**	**0.05**	**0.06**	**0.17**	**0.13**	**0.14**	**0.24**		**0.20**	**0.16**	**0.04**	**0.20**
7.0	**0.04**	**0.05**	**0.04**	**0.14**	**0.10**	**0.12**	**0.20**		**0.17**	**0.13**	**0.03**	**0.17**

7.5	**0.03**	**0.03**	**0.03**	**0.115**	**0.08**	**0.11**	**0.16**		**0.16**	**0.11**		**0.15**
8.0	**0.02**	**0.02**	**0.02**	**0.09**	**0.06**	**0.09**	**0.12**		**0.15**	**0.09**		**0.13**
8.5				**0.08**	**0.05**	**0.08**	**0.11**		**0.13**	**0.08**		**0.12**
9.0				**0.07**	**0.05**	**0.06**	**0.09**		**0.11**	**0.07**		**0.11**
9.5				**0.06**	**0.04**	**0.06**	**0.08**		**0.10**			**0.09**
10.0				**0.05**	**0.04**	**0.06**	**0.07**		**0.09**			**0.07**
10.5				**0.05**	**0.03**	**0.06**	**0.06**					
11.0				**0.05**	**0.02**	**0.05**	**0.05**					

CON: Control; BLA: Blanched; MBS: Sodium meta bisulfite: CIT: Citric acid. FaH:False horn: FrH: French horn; F21: FHIA-21.

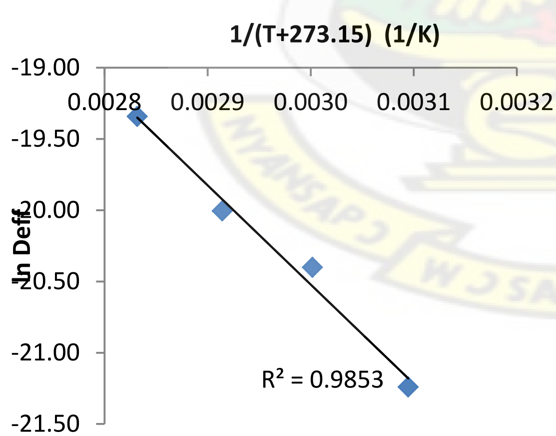
Appendix 2D: Data on MR and drying time for French horn, False and FHAI-21 at 50^{o}C under the different pretreatments

Time (h)	**MR**											
	CON			**BLA**			**MBS**			**CIT**		
	FaH	**FrH**	**F21**	**FaH**	**FrH**	**F21**	**FaH**	**FrH**	**F21**	**FaH**	**FrH**	**F21**
0.0	**1.00**	**1.00**	**1.00**	**1.00**	**1.00**	**1.00**	**1.00**	**1.00**	**1.00**	**1.00**	**1.00**	**1.00**
0.5	**0.95**	**0.93**	**0.95**	**0.97**	**0.93**	**0.97**	**0.94**	**0.90**	**0.92**	**0.95**	**0.87**	**0.94**
1.0	**0.89**	**0.85**	**0.89**	**0.94**	**0.85**	**0.93**	**0.87**	**0.80**	**0.84**	**0.90**	**0.74**	**0.87**
1.5	**0.83**	**0.81**	**0.84**	**0.88**	**0.82**	**0.90**	**0.80**	**0.70**	**0.77**	**0.82**	**0.64**	**0.80**
2.0	**0.76**	**0.76**	**0.79**	**0.82**	**0.78**	**0.86**	**0.72**	**0.59**	**0.69**	**0.74**	**0.53**	**0.72**
2.5	**0.72**	**0.65**	**0.74**	**0.71**	**0.65**	**0.75**	**0.66**	**0.57**	**0.63**	**0.68**	**0.49**	**0.66**
3.0	**0.67**	**0.53**	**0.69**	**0.60**	**0.51**	**0.63**	**0.60**	**0.54**	**0.57**	**0.62**	**0.44**	**0.60**
3.5	**0.62**	**0.48**	**0.64**	**0.56**	**0.46**	**0.59**	**0.55**	**0.44**	**0.52**	**0.57**	**0.38**	**0.54**
4.0	**0.56**	**0.42**	**0.59**	**0.51**	**0.40**	**0.55**	**0.50**	**0.33**	**0.46**	**0.51**	**0.31**	**0.47**
4.5	**0.52**	**0.37**	**0.55**	**0.48**	**0.39**	**0.53**	**0.45**	**0.29**	**0.41**	**0.46**	**0.25**	**0.42**
5.0	**0.48**	**0.32**	**0.51**	**0.44**	**0.37**	**0.50**	**0.40**	**0.25**	**0.36**	**0.40**	**0.18**	**0.37**
5.5	**0.43**	**0.27**	**0.45**	**0.40**	**0.33**	**0.44**	**0.34**	**0.19**	**0.29**	**0.34**	**0.13**	**0.32**
6.0	**0.38**	**0.21**	**0.38**	**0.36**	**0.29**	**0.37**	**0.27**	**0.12**	**0.21**	**0.28**	**0.07**	**0.26**
6.5	**0.35**	**0.19**	**0.35**	**0.34**	**0.26**	**0.33**	**0.24**	**0.08**	**0.19**	**0.25**	**0.06**	**0.23**
7.0	**0.31**	**0.17**	**0.31**	**0.31**	**0.23**	**0.29**	**0.20**	**0.04**	**0.16**	**0.22**	**0.04**	**0.20**

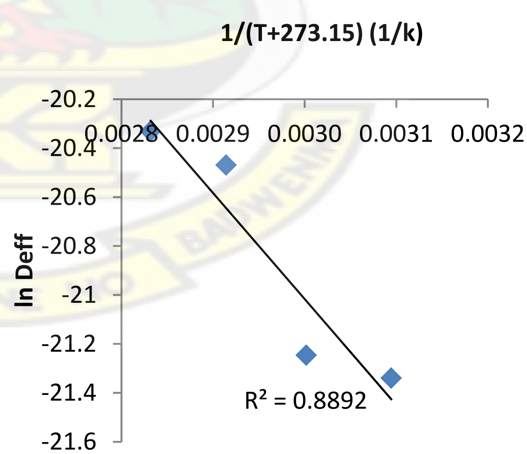
7.5	**0.28**	**0.15**	**0.29**	**0.28**	**0.19**	**0.27**	**0.18**	**0.04**	**0.14**	**0.20**	**0.04**	**0.18**
8.0	**0.25**	**0.12**	**0.26**	**0.24**	**0.15**	**0.24**	**0.16**	**0.03**	**0.12**	**0.17**	**0.03**	**0.16**
8.5	**0.23**	**0.11**	**0.24**	**0.22**	**0.12**	**0.22**	**0.14**		**0.11**	**0.16**	**0.03**	**0.15**
9.0	**0.21**	**0.09**	**0.21**	**0.20**	**0.09**	**0.19**	**0.12**		**0.10**	**0.14**	**0.02**	**0.13**
9.5	**0.18**	**0.08**	**0.19**	**0.18**	**0.09**	**0.17**	**0.11**		**0.09**	**0.13**		**0.12**
10.0	**0.15**	**0.06**	**0.17**	**0.16**	**0.08**	**0.15**	**0.10**		**0.08**	**0.11**		**0.11**
10.5	**0.14**	**0.06**	**0.16**	**0.15**	**0.07**	**0.13**	**0.09**			**0.10**		**0.10**
11.0	**0.12**	**0.05**	**0.14**	**0.13**	**0.05**	**0.11**	**0.08**			**0.09**		**0.09**
11.5	**0.10**	**0.05**	**0.12**	**0.12**	**0.05**	**0.11**	**0.08**			**0.09**		
12.0	**0.07**	**0.04**	**0.10**	**0.11**	**0.04**	**0.10**	**0.07**			**0.08**		
12.5	**0.07**		**0.08**	**0.11**	**0.04**	**0.10**	**0.04**			**0.08**		
13.0	**0.06**		**0.06**	**0.10**	**0.04**	**0.09**				**0.07**		
13.5	**0.06**		**0.06**	**0.09**	**0.04**	**0.09**				**0.07**		
14.0	**0.05**		**0.06**	**0.08**	**0.03**	**0.09**				**0.06**		
14.5	**0.04**		**0.06**	**0.08**	**0.03**	**0.09**						
15.0	**0.02**		**0.05**	**0.07**		**0.08**						
15.5			**0.05**	**0.07**		**0.07**						
16.0			**0.04**	**0.06**		**0.06**						
16.5				**0.06**		**0.05**						
17.0				**0.05**		**0.04**						
17.5						**0.03**						

CON: Control; BLA: Blanched; MBS: Sodium meta bisulfite: CIT: Citric acid. FaH:False horn: FrH: French horn; F21: FHIA-21.

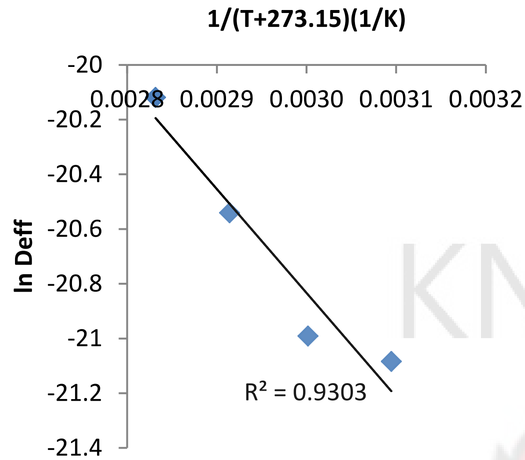
Appendix 3A: Graphs of ln Deff against 1/T of FHAI-21 for CON, BLA, MBS and CIT



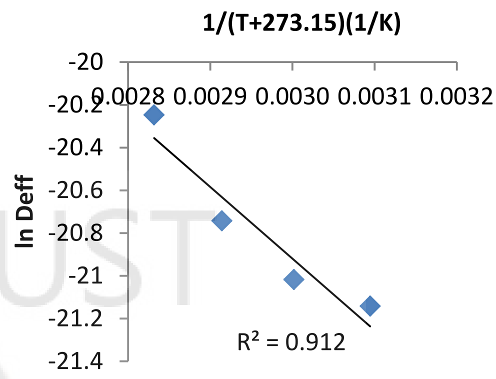
CON



BLA

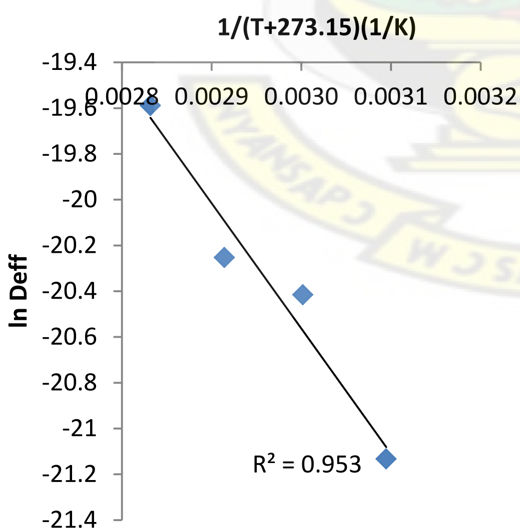


MBS

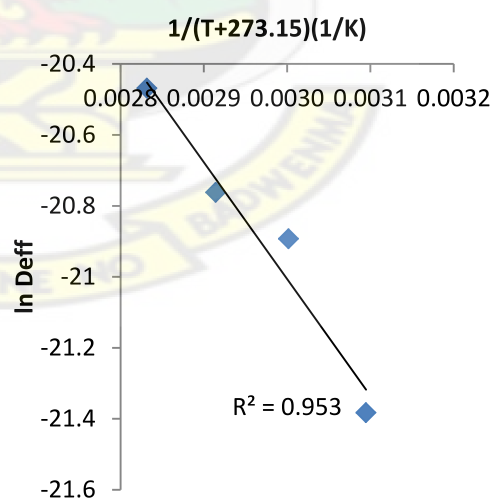


CIT

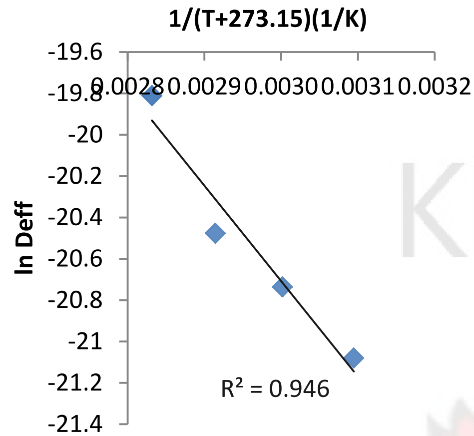
Appendix 3B: Graphs of ln Deff against 1/T of False Horn for CON, BLA, MBS and CIT



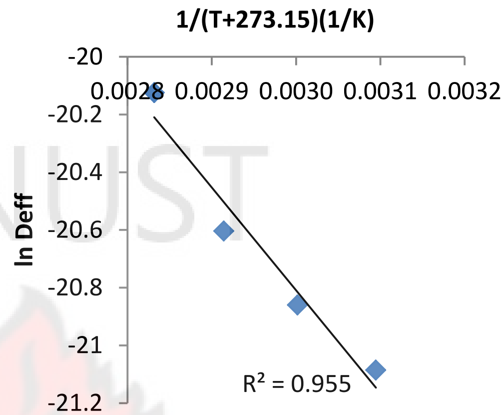
CON



BLA

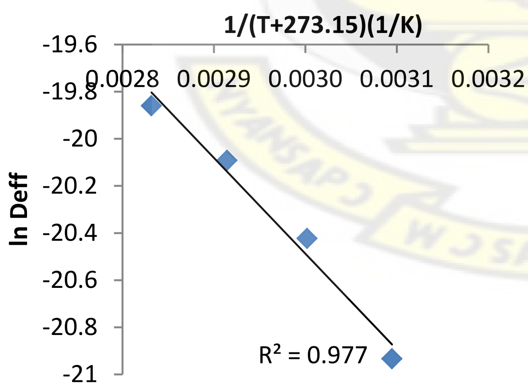


MBS

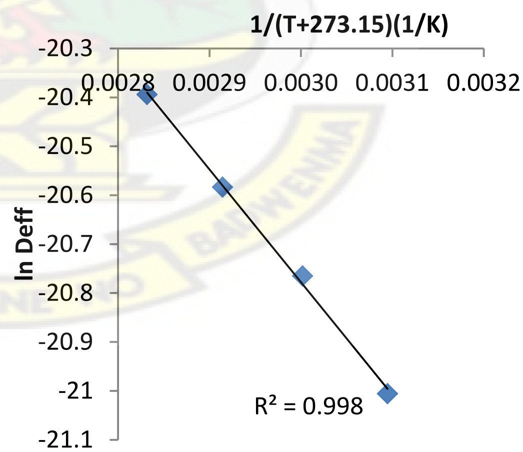


CIT

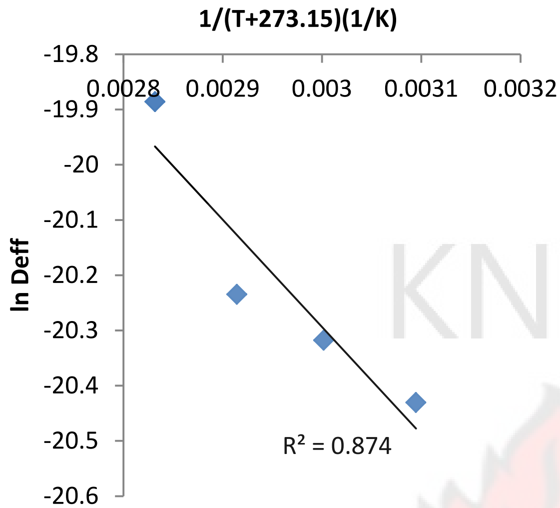
Appendix 3C: Graphs of ln Deff against 1/T of French Horn for CON, BLA, MBS and CIT



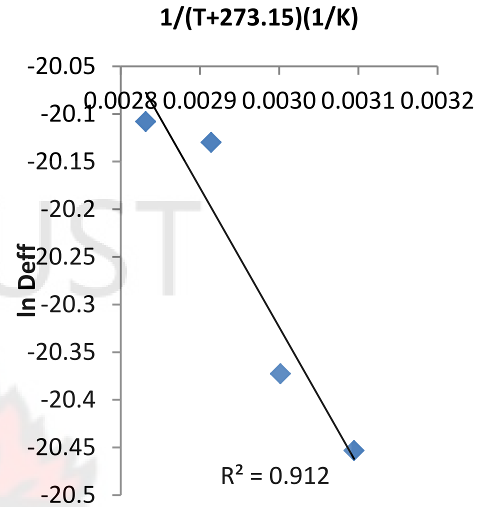
CON



BLA



MBS



CIT

Graphs of ln Deff against 1/T of French horn for CON, BLA, MBS and CIT