KWAME NKRUMAH UNIVERSITY OF SCIENCE AND TECHNOLOGY,

KUMASI.

COLLEGE OF ENGINEERING

DEPARTMENT OF AGRICULTURAL ENGINEERING

BY: ESTHER AGYABENG FOFIE

(PG 5944811)

DRYING CHARACTERISTICS AND EFFECT OF DIFFERENT DRYING METHODS ON THE BEHAVIOR AND NUTRITIONAL CONTENT OF RIPE BANANA (*MUSA SAPIENTUM*) DISCS

BY

AGYABENG FOFIE, ESTHER (MISS)
BSc. (Hons.) Agricultural Engineering

A Thesis presented to the Department of Agricultural Engineering, Kwame Nkrumah University of Science And Technology, Kumasi in Partial Fulfillment of the Requirement of the degree of

MASTER OF SCIENCE
FOOD AND POST HARVEST ENGINEERING

College of Engineering

AUGUST, 2013

KWAME NKRUMAH UNIVERSITY OF SCIENCE AND TECHNOLOGY, KUMASI.

COLLEGE OF ENGINEERING

DEPARTMENT OF AGRICULTURAL ENGINEERING

DRYING CHARACTERISTICS AND EFFECT OF DIFFERENT DRYING METHODS ON THE BEHAVIOR AND NUTRITIONAL CONTENT OF RIPE BANANA (*MUSA SAPIENTUM*) DISCS

BY

ESTHER AGYABENG FOFIE (MISS)

AUGUST, 2013

DECLARATION

"I hereby declare that I have wholly undertaken this study reported herein under supervision of Prof. K. A. Dzisi and Mr. E. A. Amankwah and that except portions where references have been duly cited, this thesis is the outcome of my research."

Esther Agyabeng Fofie (Student)	…………… Signature	01/11/2013 …………… Date
Certified by Prof. K. A. Dzisi Principal Supervisor	…………… Signature	Nov 01, 2013 …………… Date
Certified by Mr. E. A. Amankwah Co-Supervisor	…………… Signature	01/11/2013 …………… Date
Certified by Ing. Prof. Ebenezer Mensah Head of Department	…………… Signature	01/11/2013 …………… Date

ACKNOWLEDGEMENT

First and foremost my sincere gratitude goes to the Almighty God for taken me this far and making this project a success, may His holy name be praised forever. My profound gratitude also goes to my supervisors, Prof. K. A. Dzisi and Mr. E. A. Amankwah for their intense supervision, guidance, patience and support. This project wouldn't have been successful without you. May God richly bless you.

My appreciation also goes to all the lectures of Agricultural Engineering department especially to Dr. E.H.Y. Bobobee and Dr. E. Ofori for their encouragement and support throughout my graduate studies. To Mr. Osei Tutu of Biological Science department and all the technicians of the department of Wildlife and range management at the Faculty of Renewable Natural Resources for the assistance.

To all my friends and loved ones especially Akua, Asher, Sando, Oppong, Bernard, Mawusi and Justice for your friendship.

Finally to my dear parents Rev. and Mrs. Agyabeng Fofie and my siblings Lydia, Emmanuel and Abigail, your love, support and encouragement keep me going.

DEDICATION

This thesis is dedicated to God Almighty, My Parents and my siblings.

ABSTRACT

The focus of this research was to analyze the drying characteristics and nutritional quality of banana (*Musa sapientum*) slices of 5mm thickness using different drying methods namely: oven (OV), open sun (OSD), natural convection solar (NC) and forced convection solar (SD) systems. Six (6) mostly used drying models were used to predict the experimental drying data using the OV system under constant temperature conditions. The prediction fitted very well. Two banana samples each (same variety) were considered for all drying methods. While one sample was untreated the other was treated with ascorbic acid at 3g/660ml concentration. This was to investigate the effect of treatment on the drying behaviors of banana slices. Though ascorbic acid treatment did not have any significant effect on the drying behavior, it affected the vitamin C content. The parameters determined in the OV at temperature between 50 – 70°C were used to predict the drying trajectory of banana under variable solar conditions of temperatures between 38 - 60°C (SD), 38 –70°C (NC) and 27-38°C for OSD. The rate constant and effective diffusivity showed a strong dependency on temperature. Effective moisture diffusivity was between 2.01×10^{-11} and 3.02×10^{-11} m^2/s for oven drying. The activation energy was 25.73 kJ/mol for untreated and 31.58 kJ/mol for treated samples for OV drying. Analysis of nutritional content showed that different drying methods have varying effect on them. Bacterial count was 1.375×10^2 cfu/ml on fresh banana sample and between 5.620×10^2 and 2.575×10^4 cfu/ml on dried sample.

Table of Contents

DECLARATION ... ii
ACKNOWLEDGEMENT ... iii
DEDICATION ... iv
ABSTRACT ... v
List of Figures ... viii
List of Tables ... ix
CHAPTER ONE ... 1
1.0 INTRODUCTION ... 1
1.1 Problem Statement ... 3
1.2 Justification ... 4
1.3 Objectives ... 5
1.3.2 Specific Objectives ... 5
CHAPTER TWO ... 6
2.0 LITERATURE REVIEW ... 6
2.1 Banana ... 6
2.2 Drying Methods ... 7
2.2.1 Open sun drying ... 7
2.2.2 Solar dryers ... 8
2.3 Solar Dryers and their designs ... 8
2.4 Factors Affecting Food Drying ... 9
2.4.1 Temperature ... 10
2.4.2 Air flow and velocity ... 10
2.4.3 Relative humidity ... 11
2.5 Thin layer drying models ... 11
2.5.1 Drying rate ... 12
2.5.2 Effective moisture diffusivity (D_{eff}) and Activation Energy (E_a) ... 14
2.6 Effect of drying on the nutrient content of banana ... 15
2.6.1 Proximate Analysis ... 16
2.6.2 Mineral content ... 18
2.6.3 Importance and effects of drying on the Vitamin C ... 19
2.7 Pretreatment in drying ... 20
2.8 Influence of drying on micro-organisms ... 22
CHAPTER THREE ... 24

3.0 MATERIALS AND METHODS 24
3.1 Sample Preparation 24
3.2 Moisture content 24
3.3 Drying procedure 27
3.4 Determination of effective moisture diffusivity (D_{eff}) 28
3.5 Determination of Activation energy (E_a) 30
3.6 Curve fitting 31
3.7 Proximate Determination 32
3.7.1 Moisture content determination 33
3.7.2 Crude fat determination 33
3.7.3 Crude fiber determination 33
3.7.4 Ash Determination 34
3.7.5 Crude Protein/Total nitrogen determination 34
3.7.6 Total carbohydrate content 35
3.8 Mineral analysis 35
3.9 Vitamin C determination 36
3.10. Microbial load determination 36
CHAPTER FOUR 37
4.0 RESULTS AND DISCUSSION 37
4.1 Temperature and treatment effect under Oven (OV) conditions 37
4.2 Drying rate curve under oven (OV) condition 38
4.3 Moisture diffusivities (D_{eff}) under oven (OV) condition 39
4.4 Predicting the experimental drying data using various models 41
4.5 Drying rate against moisture content 45
4.6 Drying under variable conditions 47
4.7 Prediction of drying rate Constants under variable conditions 49
4.8 Effect of drying methods on nutritional content of fresh and dried banana 54
4.9 Bacterial (Plate) Count of Fresh and Dried Banana. 59
CHAPTER FIVE 62
5.0 CONCLUSION 62
REFERENCES 63
Appendices 70

List of Figures

Figure 1: *Musa sapientum* 25
Figure 2: Digital caliper 25
Figure 3: Data logger......26
Figure 4: Forced convection solar dryer......26
Figure 5: Natural convection solar dryer......27
Figure 6: Banana slices on drying trays 27
Figure 7: Drying behavior of treated and untreated samples at varying temperatures for 5mm thickness. 37
Figure 8: Drying Rate for treated and untreated samples for 50°C, 60°C and 70°C at 5mm....39
Figure 9:Ln(MR) agaist Time (t) in hours......40
Figure 10: Fitted curve with the Henderson and Pabis model at 50, 60, 70 °C for 5mm OV dried banana slices dried. 42
Figure 11: Drying rate against moisture (kg/kg db) of for treated and untreated 5mm banana samples for all temperatures......46
Figure 12: The drying behaviour of forced convection (SD), natural convection (NC), and open sun drying (OSD). 47
Figure 13: Comparison of performance of drying methods on treated and untreated banana slices 48
Figure 14: Relation between trajectory and predicted moisture curves, temperature (°C) and relative humidity (%) for forced convection solar dryer (SD) 51
Figure 15: Relation between predicted (Pred) and observed (Obs) curves, temperature (°C) and Relative Humidity for natural convection solar dryer (NC)......52
Figure 16: Relation between predicted (Pred) and observed (Obs) moisture curves, temperature (°C) and relative humidity for open sun drying (OSD) 53
Figure 17: Plate count of fresh and dried samples of different drying methods. 60

List of Tables

Table 1: Diffusivities (D_{eff}) and activation Energies (Ea) of some dried products 15
Table 2: Mathematical models applied to fit the drying curves 31
Table 3: Diffusivities for different temperatures and treaments for oven drying.....................41
Table 4: Parameter estimation for treated and untreated banana slices at 5mm thickness.......42
Table 5: Variation of drying rate constants for different drying methods and days.................50
Table 6a:Proximate analysis of fresh and dried banana for different drying methods.............55
Table 6b:Proximate analysis of fresh and dried banana for different drying methods...........556
Table 7:Effects of different drying methods on minerals (Phosphorus (P), Potassium (K), and magnesium (Mg) 57
Table 8: Effects of different drying methods on Vitamin C...58

CHAPTER ONE

1.0 INTRODUCTION

Ghana produces a number of fruits, mostly for domestic consumption. Banana (*Musa* spp.) is among the major tropical fruits produced in Ghana and it is becoming more important food item at both producer and non-producer countries (FAO, 2008). Bananas play a vital role in the diets of humans. Accordingly, the dietary value per 100 g of banana (wet basis) include 70% water, 23% carbohydrate, 1.2% protein, 0.2% fat, 2.6% crude fiber, 3% others and 88 calories (Elkhoreiby, 2003).

In Ghana, banana constitutes about 13% of the total horticultural exports and is among the cheapest staple foods produced (FAO, 2001). Total domestic banana production was estimated to be about 100,000 metric tons with a per capita consumption of about 4.1 kg/annum in Ghana (FAO, 2004). Although banana has a lesser importance as a basic food item, it has become an important export commodity. Bananas are the most exported fruits in terms of volume and they rank second after citrus fruit in terms of value (FAO, 2008). Local producers in Ghana exported 62,000 tons of banana to the Euro zone in 2009 and 52,000 tons in 2010 (Daily Guide, 2012) representing 1% of the total export from around the world.

Fresh banana fruits are highly perishable and bulky which requires processing into a more stable and convenient form (Taiwo and Adeyemi, 2009). Consequently, the bulk transportation to distant places is expensive and their condition on arrival in the importing country may be less than satisfactory. The difficulties with the short storage life of bananas are worsened by the poor transportation and marketing system in developing countries like Ghana. Banana has an average storage life of 7 to 28 days under optimum storage temperature of 14°C (Chia and Huggins, 2003). Due to high temperature in the tropics and subtropics it is very difficult to store ripe banana up to 28 days. It is estimated that more than 30% of the banana production are lost after harvest (Adeniji et al., 2010). These losses are due to rapid ripening, poor handling, inadequate storage and transportation challenges and lack of food processing techniques. Much effort is therefore needed in the area of generating an effective and efficient technology that minimizes postharvest loss of banana fruits. Drying brings about a substantial reduction in weight and volume, thereby minimizing packaging, storage and transportation cost. This enables storability of the product under high ambient temperatures and humidities especially in developing countries (Adeniji et al., 2010) such as Ghana. Drying of fruits is one of the technologies, which can enhance the shelf life of fruits. Besides, it improves nutrition in diets, minimizes seasonal gluts and reduces transportation cost.

Bananas are dried normally in the oven and fruit dehydrators. Hot air drying of food materials has advantages such as control of products quality, achievement of hygienic conditions and reduction of product loss (Abano and Sam-Amoah, 2011). Food scientists have found out that by reducing moisture content of food to between 10% and 20% (wb), bacteria, yeast and moulds are all prevented from spoiling it.

Bananas like other fruits can also be dried in the open sun and in solar dryers. In comparison to natural sun drying, solar dryers can generate higher air temperatures and lower relative humidity. This leads to higher drying rates resulting in shorter drying times, lower product moisture contents and reduced exposure to contaminants such as insects, rodents, dust and microbial infestation during drying and storage periods (Amunugoda et al., 2013). Solar drying involves ambient air flowing through enclosed structures called solar collectors that convert solar radiation into heat and indirectly channeled into a drying chamber as compared to open sun drying which directly exposes the food to the sun. Currently, different types of solar dryers are being used to dry bananas worldwide. In Ghana, though sun drying is commonly used for drying most crops, little attempts have been made for drying of fruits in general and solar drying of bananas is not an exception. Ghana has favourable conditions for solar drying of food products. In order to efficiently utilize these potentials and minimize the postharvest loss and increase food availability throughout the year while maintaining quality, there is the need for the utilization of efficient solar dryers systems. Newer techniques of drying such as heated air drying, conventional oven, natural and forced convection solar dryers and mixed-mode solar crop dryers have been developed (Dzisi et al., 2012; Forson et al., 2006; Das et al., 2004; Motevali et al., 2010; Adom et al., 1999, Amankwah et al., 2012). With the 6-8 sunshine hours per day (Dickson and Benneh, 1988) fruits can be dried using solar systems.

1.1 Problem Statement

Banana is the most exported fruit in the world and Ghana as well. The bulk transportation to distant places is expensive and its condition on arrival in the importing country may be less than satisfactory if transportation is delayed. Again banana is highly perishable and requires about 15°C prolonging the shelf life for two weeks and this is highly unachievable in Ghana.

A reduction in moisture content potentially increases shelf life and hence prevents excessive post-harvest loss. Drying is an alternative processing method for a developing country like Ghana where there is deterioration due to poor storage, irregular weather conditions and inadequate processing facilities pose a major challenge.

The daily sunshine duration in Ghana ranges between 6-8 hours and open sun drying is a common practice used in dehydrating of agricultural produce (Dickson and Benneh, 1988).

According to Chayjan (2012), there are many challenges associated with open sun drying. These include of slowness in the drying process leading to longer drying time, the exposure to environmental contamination, the uncertainty of the weather and the manual labour required. Due to these difficulties, more rapid, safe and controllable methods of drying are needed.

Oven drying and solar drying are alternative drying methods, however the former is an energy intensive venture. Using solar dryers leads to a more uniform, hygienic and attractive product that can be produced rapidly (Karathanos and Belessiotis, 1999).

Moreover, dried tropical fruits are imported and sold on our local supermarkets despite the larger production and wastages of banana and other fruits after production in the country.

1.2 Justification

Converting dried banana into chips and flour could be used in food extrusion and baby foods which will contribute to reduced postharvest losses and allow the food industry to store and use the product throughout the year. In order to use dried banana as ingredient for the food industry it is necessary to characterize its nutritional composition as well as microbiological status as most authors do not associate the effects of drying on the nutritional properties and microbial status in their works.

One of the most important aspects of drying technology is the modeling of the drying process (Darvishi et al., 2012). Drying is a complex thermal process in which unsteady heat and moisture transfer occur simultaneously. From an engineering design perspective, it is important to develop a better understanding of the controlling parameters of this complex process. Mathematical models of the drying processes are used for designing new or improving existing drying systems or even for the control of the drying process.

1.3 Objectives

1.3.1 General Objective

To determine the effects of different drying methods (OV, OSD, NC and SD) on the drying behavior, quality and nutritional properties of *Musa sapientum* as well as using the drying parameters of constant temperature (oven) conditions to predict the drying trajectory under variable (solar) conditions.

1.3.2 Specific Objectives

- To determine the drying characteristics and drying behavior of treated and untreated banana (*Musa sapientum*) under constant conditions and variable air conditions.
- To determine the effect of the different drying methods on the microbiological and nutritional content of treated and untreated dried banana slices.
- To predict the drying trajectory of banana slices under variable conditions using the parameters under constant conditions.

CHAPTER TWO

2.0 LITERATURE REVIEW

2.1 Banana

Bananas and plantains have been used as staple in human diet since the dawn of recorded history. They are the fourth most important food in the world today after rice, wheat and maize (Nelson et al., 2006).

Banana has a higher contribution to the Agricultural Gross Domestic Product (AGDP) than cereals (MOFA, 2006). In volume, world exports of fresh banana exceed 14.1 million metric tons of which Ghana contributed about 1% in 2006. Banana is exported primarily from developing countries to industrialized countries, the latter accounting for close to 90% of world net imports (FAO, 2008).

Banana fruits can be harvested when about 75% matured; occurs at 75-80 days after opening of the first hand. Harvest may be delayed up to 100-110 days after opening of the first hand.

Banana is a perishable fruit and one of the techniques used to extend its shelf life for consumption, reducing packing and transportation costs, improving sensorial attributes and preserving some nutritional value is by drying. Many banana products are now produced on an industrial scale (Khin and Yee, 2011). Post harvest losses can be reduced and surplus unmarketable banana fruits can be useful, if these fruits are dehydrated and processed into banana chips and powder. The banana powder could be used for the production of jam, soft drinks, alcoholic beverages, baby foods, vinegar and other confectionary items (Mahendran and Prasannath, 2008).

2.2 Drying Methods

Drying is a method of food preservation that works by removing water from the food. Drying inhibits the growth of bacteria and preserves the quality and hence reduces post harvest loss. Producing high quality dried agricultural products at a relatively lower cost has led to employment of several drying methods in practice. Drying processes adopt different devices and mechanisms but all involve sensible and latent heat for removing moisture (Ayim, 2011). 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 proven that the mechanism for moisture transport and the rate at which the material is dried are related to the quality properties of the dried product. The most commonly used drying methods include sun drying, solar cabinet drying and convectional air (oven) drying (Ayim, 2011; Amankwah et al., 2012; Abano and Sam Amoah., 2011; Doymaz, 2010; Kalawole and Ogunwola 2012).

2.2.1 Open sun drying

In tropics and subtropical countries the most common method used to preserve and process agricultural products is the open-air and unpredictable sun's energy. Apart from, being subject to rainfall, wind-borne dirt and dust, infestation by insects, rodents and other animals attack, products may be seriously degraded to the extent that sometimes they become market valueless and inedible and results in loss of food quality. The dried products may have adverse economic effects on domestic and international markets (Ogheneruona and Yusif, 2011) notwithstanding the discomfort it brings to bear on the consumer.

2.2.2 Solar dryers

The challenges associated with open-air sun drying can be solved by the use of a solar dryer. A solar dryer comprises a collector (coated aluminum plate as absorbing material interspersed with an air gap and covered with glass cover plate), a drying chamber and sometimes a chimney. The conditions in tropical countries make the use of solar energy for drying food practically attractive and environmentally friendly (Amunugoda et al., 2013). Dryers have been developed and used to dry agricultural products in order to improve market value and shelf life (Amankwah et al., 2012). Most of these either use an expensive source of energy such as electricity or a combination of solar energy and some other form of energy. Most projects of this nature have not been adopted by the small scale farmer, either because the final design and data collection procedures are frequently inappropriate or the cost has remained unaffordable. Again the subsequent transfer of the technology from the researcher to the end user has been nothing effective.

2.3 Solar Dryers and their designs

Solar dryers are devices that use solar energy to dry substances. In fact solar energy has long been used by humans to dry things.

The two main groups of solar dryers are the direct and indirect solar dryers. Though there are many designs of solar dryers world-wide, experimental and technical evaluations carried out in Ghana have shown that natural and forced convection solar dryers, and cabinet dryers can all be used to dry fruits and root tubers (Amankwah et al., 2012). The dryers have the capacity to dry fruits within four days. Bananas are sliced before drying and the optimal slice thickness for proper drying for best quality has to be determined. In an experiment conducted by Abano and Sam -Amoah (2011) they suggested thickness for banana slice as 5 mm. In their experiment however they dried the fruits using the oven. There are two basic types of solar dryers appropriate for use for drying agricultural products: natural convection dryers and forced convection dryers.

Sarsavadia et al. (1999) developed a natural convection dryer to dry grapes with temperatures ranging between 50-55°C. Hassanian (2009) also used natural convection solar dryers and recorded temperatures between 14°C – 48°C. It took nearly 45 hours to dry banana to 25% wb moisture content. Gutti et al. (2012) worked on a natural convection solar dryer with heat storage. It took 24, 27 and 21 hours respectively to dry tomatoes, onion and pepper to 0.25, 0.6 and 0.5 kg/kg dry basis moisture content.

Gutti et al. (2012) again worked on forced convection solar dryers with heat storage. It took 14, 15 and 12 hours in forced convection solar dryers to dry tomatoes, onion and pepper at 3.0kg/kg respectively to about 0.25kg/kg, 0.6kg/kg and 0.5kg/kg db moisture content respectively.

2.4 Factors Affecting Food Drying

There are three major factors affecting food drying: temperature, humidity and air flow. They are interactive. In solar drying, increasing the vent area by opening vent covers will decrease the temperature and increase the air flow, without having a great effect on the relative humidity of the entering air. In general, more air flow is desired in the early stages of drying to remove free water or water around the cells and on the surface. Reducing the vent area by partially closing the vent covers will increase the temperature and decrease the relative humidity of the entering air and the air flow. This would be the preferred set up during the later stages of drying when the bound water needs to be driven out of the cells and to the surface.

2.4.1 Temperature

Kotwaliwale et al. (2005) found that banana dried at lower temperature and retained more brightness compared with the samples dried at higher temperature. There is a diversity of opinions on the ideal drying temperatures. According to Scanlin (1997) food begins cooking at 82°C. All opinions surveyed fall between 35° and 82°C, with 43°–60°C being most common. Recommended temperatures vary depending on the food being dried. By far the research of quite a few others leads to the conclusion that in higher temperatures (up to 82°C) increase the rate of drying. Scanlin (1997) found that it took approximately 5 times as long to dry food at 40°C as it did at 80°C. Scanlin (1997) recommended drying temperatures for fruits and vegetable at 37°–60°C, temperatures over 65°C can result in case hardening and 35°– 40.5°C for drying of herbs.

2.4.2 Air flow and velocity

The second of three factors affecting food drying is air flow rate, which is the product of the air velocity and vent area. The drying rate increases as the velocity and quantity of hot air flowing over the food increases. Natural convection air flow is proportional to vent area, dryer height (from air intake to air exhaust), and temperature. However air flow is also inversely proportional to the temperature in a solar dryer. Ideally one would want both high temperatures and air flow. This can be difficult to achieve in a solar dryer. Air velocity in a natural convection collector is affected by the distance between air inlet and air exhaust, the temperature inside the dryer and the vent area. The greater the distance between the air inlet and air exhaust, the greater the velocity. It is often measured in meters per second (m/s). With constant temperatures, 1.15m/s air velocity dries twice as rapidly as still air. At 2.3 meters per second, drying occurs three times more rapidly than in still air (Scanlin, 1997). Axtell

& Bush (1991) suggested air velocities between 0.5 to 1.5 m/s and even higher air velocities between 1.5 to 5 meters per second.

2.4.3 Relative humidity

Relative humidity is the third factor affecting food drying. That is the higher the relative humidity the longer the drying time. More air will then be required while the temperatures will need to be higher. For every 27°C increase in temperature doubles the moisture holding capacity of the air (Desrosier, 1963). This moist air cannot hold as much moisture as less humid air could and as a result drying takes longer than it might in a dryer climate. High humidity also makes higher temperatures desirable for drying in a humid climate.

2.5 Thin layer drying models

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 (Doymaz, 2010). Drying of many fruits and other agricultural products have been successfully investigated (Ceylan et al., 2007; Afzal and Abe, 1998; Baini and Langrish, 2007). According to Parti (1993), mathematical models that describe drying mechanisms of grains 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. Jayas et al. (1991) have reported in detail a comprehensive review of these equations. Based on theoretical model (Fick's second law) semi - theoretical models are derived 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 (Dzisi et al., 2012).

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 as shown in equation (1).

$$\frac{dM}{dt} = -k(M - M_e) \tag{1}$$

Where M, M_e and k are the moisture content (kg water/kg dry matter), equilibrium moisture content (kg water/kg dry matter) and dry rate constant, k is considered as constant but some researchers have shown that k varies over time (Amankwah et al., 2012).

2.5.1 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, average moisture content versus time. Several theories on the mechanism of moisture migration have been reviewed (Afzal and Abe, 1998; Dadali et al., 2007). However, only capillary and liquid diffusion theories are, generally, applicable to the drying of food materials.

The drying process can be described completely using an appropriate drying model, which is made up of differential equations of heat and mass transfer from 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 literature instead of these properties, the drying constant, is used (Ayim, 2011). The drying rate can be expressed as (Ceylan *et al.*, 2007; Doymaz, 2010; Ozbek and Dadali et al., 2007):

$$\boldsymbol{Drying\ rate} = \frac{\boldsymbol{M_{t+dt} - M_t}}{\boldsymbol{dt}} \quad \textbf{(2)}$$

where,

M_t = moisture content at a specific time (db^{-1})

M_{t+dt} = moisture content at t+dt (db^{-1})

t = drying time (s)

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. Drying rate generally increases with higher moisture content and air temperature (Trim and Robinson, 1994).

From Cape and Percy (1996) another implicated factor in explaining the rate of water loss in food is the effective area across which water may be lost such that large surface area ensures rapid transfer of moisture to the surface and the ease with which moisture is removed by the air current.

2.5.2 Effective moisture diffusivity (D_{eff}) and Activation Energy (E_a)

In general, drying of foods -take place in two periods, a constant rate period and falling rate period. The mechanism of moisture movement within a hygroscopic substance during the falling rate period can be represented by effective moisture diffusion phenomena. These phenomena 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., 2007). During drying it is assumed that diffusivity, explained with Fick's diffusion equation, is the only physical mechanism to transfer water to the surface (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). Table 1 shows reported diffusivities and activation energies of some selected agricultural products dried at constant temperatures.

Activation energy for drying is the energy required to initiate mass diffusion from a wet food material during drying (Mittal, 1999).

From Table 1, Doymaz (2010) reported D_{eff} of banana to be in the range of 3.74×10^{-11} - 2.148×10^{-10} m/s^2 and E_a value of 32.65 kJ/mol. Abano and Sam Amoah (2011) also mentioned values of 7.87×10^{-5}- 14.94×10^{-5} m/s^2. Islam et al. (2012) found moisture diffusivity values to be 1.25×10^{-10}, 1.67×10^{-10} and 2.19×10^{-10} m^2/s at for 55, 60 and 65 °C respectively and found E_a to be 51.21 kJ/mol.

Table 1: Diffusivities (D_{eff}) and activation Energies (E_a) of some dried products

Product	Diffusivities (D_{eff}) m/s^2	Activation Energy (E_a) kJ/mol	Temperature (°C)	References
Plantain	5.40×10^{-8} - 3.98×10^{-9}	35.23 and 56.61	50-80	Dzisi et al. (2012)
Green banana	1.25×10^{-10} - 2.19×10^{-10}	51.21	60-65	Islam et al. (2012)
Gros michel	7.87×10^{-5} - 14.94×10^{-5}	-	60-70	Abano and Sam Amoah (2011)
Banana	7.37×10^{-11} - 2.15×10^{-10}	32.65	50-80	Doymaz, (2010)
Banana	1.29×10^{-10} - 3.91×10^{-9}	12.30–24.09	40-80	Falade and Ogunwola (2012)
Plantain	3.8×10^{-10} - 8.62×10^{-9}	12.15–19.93	40-80	Falade and Ogunwola (2012)
Banana	8.8×10^{-11} - 2.290×10^{-10}	-	70-100	Thuwapanichayanan et al. (2011)

Falade and Ogunwola (2012) dried fresh and osmotic banana and plantain at 40, 50, 60, 70 and 80°C, at a constant speed of 1.5 m/s. The authors recorded values for D_{eff} to be in the range of $1.29 \times 10^{-10} – 3.91 \times 10^{-9}$ and $3.8 \times 10^{-10} – 8.62 \times 10^{-9}$ m/s^2 for banana and plantain respectively and Ea to be in the range of 12.30–24.09 kJ/mol banana and 12.15–19.93 kJ/mol plantain.

2.6 Effect of drying on the nutrient content of banana

There are two processes occurring during drying; the addition of heat and the removal of moisture from the food. It generally improves the digestibility of foods, making some nutrients more available. Several factors influence the nutritional content of the food products. These include the type and level of processing, genetic make-up of the plant or animal, the soil in which it was grown, use of fertilizer, prevailing weather, and maturity at harvest, packaging, storage conditions and method of preparation before drying. The storage conditions and handling after processing are also important to the nutritive value of the food (Morris et al., 2006).

Some researchers (Agoreyo et al., 2011) have reported about the potential effect of heat on the nutrient content in various ways. It can either increase the concentrations of some nutrients by making them more available or decrease the concentration of some nutrients (Morris et al., 2006). Therefore it is appropriate to determine its content before and after drying. These include proximate composition, vitamin C and mineral content.

2.6.1 Proximate Analysis

Proximate analysis is a type of scientific inquiry done to determine the approximate amounts of substances within a material (Leigh, 2012). This is utilized by different types of scientists to study such things as animal feed, coal, and bio-fuels. This information can be used to create quality controls for various materials; they are fundamental to the assessment of the nutritive quality of the food/feed being analyzed and ensure that they do not contain hazardous chemicals and determine whether they are healthy enough to be consumed by humans or animals.

The components of proximate analysis are moisture, ash, fat, crude protein, crude fibre and carbohydrates. Moisture content of food/feed or processed product gives an indication of its shelf life and nutritive values. Low moisture content is a requirement for a long storage life. Water content affects food quality. It provides a medium to support microbial growth, the more water that is present, the greater the opportunity for microbes to grow (Shewfelt, 2009) cited by (Aishah and Rosli, 2013). Low moisture reduces its susceptibility to microbial attack. Ash content reflects the presence of minerals and provides an estimate of the quality of the product, since high levels may indicate contamination. Minerals are not destroyed by heating, and they have low volatility compared to other food components (Agoreyo et al., 2011).

In an experiment conducted by Moris et al. (2006) they experienced an increase in ash, fiber and magnesium contents and attributed it to the decrease in moisture content which tends to increase concentration.

Agunbiade et al. (2006) reported on the effects of dehydration and rehydration of the physiochemical properties of chips produced banana and plantain. The crude fibre, ash and protein content in both samples were found to be lower than fresh samples. The processing led to observations from fresh to dehydrated sample in proximate composition of crude protein (8.80-2.91% and 13.20-6.30%), crude fibre (3.00-1.36% and 2.60-1.58%), ash content (13.40-2.42% and 8.80-2.91%) for banana and plantain respectively. They also found an appreciable increase in the carbohydrate content (61.74-82.29% and 74.99-86.40%) and fat content (6.40-6.81 and 2.59-2.82).

Agoreyo et al. (2011) worked on drying of plantain, cocoyam and yam. The analysis of proximate was compared with dried samples of plantain. Carbohydrates decreased from fresh 86 to 83% for solar and to 80.19% for oven. Fiber also increased from 5% fresh to 10% and 9.14% for oven, sun and solar dried samples respectively. Ash content also increased for 2.75% to 4.80% for sun, 5.45% oven and 5.50% for solar dryers. Protein decreased from 5% to 4.1%, 3.70% and 3.30% for sun, oven and solar drying respectively. They attributed the changes to moisture removal and application of heat.

2.6.2 Mineral content

The banana, besides constituting an expressive carbohydrate source (highly energetic), is still rich in potassium (K), sodium (Na), phosphorus (P), chlorine (Cl), magnesium (Mg), sulfur (S), silicon (Si), calcium (Ca), vitamins: A, B1, B2, and B3 (niacin) that are essential for the development of the human body (Padovani, 1989) in Padilla et al., (2004), but do not supply much vitamin C or vitamin A, relative to other fruits. Bananas contain natural sugars and supply a good deal of vitamins and nutrients that makes it a healthy choice for most people.

Bananas are considered a good source of K and Mg in the diet, and the data support these assertions. Average K content of banana is 358 mg/100 g fresh weight (Hoy et al., 2012). Daily Required intake (DRI) is 3789mg for male and 2408 mg for females (Hoy et al., 2012). Therefore, 100 g of banana fruit would provide 9.5% and 15 % of the K requirement for the male and females respectively. Magnesium content averaged 32 mg/100g. The DRI for Mg is 320 mg for female adults and 400–420 mg for male adults. Bananas (100 g) would supply about 9% (males) to 11% (females) of the DRI for Mg. Again banana contain 26mg/100g for Phosphorus, 10.3 mg/100 g vitamin C (Decuypere, 2013).

Again, Agoreya et al. (2011) experienced an increase in ash content and a corresponding increase in macronutrients of plantain, cocoyam and white yam in oven at 70°C for 48h and solar 60°C for 30h and sun drying. The authors attributed the increase in Mg content to the application of heat. Mg increased in plantain from 22.11 mg/100 g to 25, 23 and 25.80 mg/100 g for sun, oven and solar drying respectively. Again Mg increased in yam drying from 10.3 mg /100 g to 15.30, 14.10 and 16.50 mg/100 g and in cocoyam 10 mg/100 g to 15.3, 14.10 and 16.50 mg/100 g for sun, oven and solar drying respectively.

Osunde and Makama (2007) experienced a decreased in Mg content of blanched tomato, sweet pepper and okra under sun drying. Tomato decreased from 179.6 mg/100 g to 169.6 mg/100 g, sweet pepper 706.3 mg/100 g to 693.6 mg/100 g and onion 251.6 mg/100 g to 242.36 mg/100 g.

2.6.3 Importance and effects of drying on Vitamin C

Vitamin C is an essential substance found mainly in fruits and vegetables. Vitamin C in diets prevents scurvy and also plays the role of biological antioxidant. Humans have no capability to manufacture the enzyme L-gulolactone oxidase, which is responsible for the synthesis of ascorbic acid unlike some animal species (Ruta et al, 2012). Ascorbic acid which is a white crystalline and odorless substance has a polar characteristic, which is easily soluble in water. Pure ascorbic acid is stable when exposed to air, light, and ambient temperature for a long period. However, in aqueous solutions or in foods, its stability is related to the storage conditions and to the composition of the matrix. Vitamin C can be easily degraded, depending on many variables such as pH, temperature, light, and presence of enzymes, oxygen, and metallic catalyzers (Moser and Bendich, 1990). Due to the importance of vitamin C for human nutrition many studies on food processes take vitamin C as a quality indicator.

Karim and Adebowale (2009) reported that processing methods can lead to losses of vitamin C. This was seen in preparation of apple flakes. Losses of Vitamin C were 8% during slicing, 62% from blanching, 10% from pureeing and 5% from drum drying.

Reports have also shown that vitamin C degradation could be as high as 80-95% during air-dehydration of fruits (Mishkin, 1983; Karim and Adebowale, 2009). This limits the air-dehydration of fruits (McMinn and Magee, 1997).

Maharaj and Sankat (1996) investigated the quality of dasheen leaves dried under natural and forced convection and the effect of different pretreatments on them. Steam blanching, water blanching, and alkali blanching were applied in this leafy vegetable before air drying. Even without pretreatments and at 60°C temperatures, the influence of the kind of dryer on the vitamin C content was clearly observed. Losses of ascorbic acid in samples dried under natural convection and forced convection were higher than 90% and 81.8 to 72.6% respectively when temperatures ranging from 40 to 70 °C were used. This difference was attributed to the reduced drying time under forced convection.

Lee and Labuza (1975) studied the rate of ascorbic acid destruction as a function of both water activity and moisture content with respect to sorption hysteresis to predict the extent of deterioration of ascorbic acid during storage in the intermediate moisture range. He concluded that ascorbic acid destruction rates were increased with increasing water activity and ascorbic acid was more rapidly destroyed in the desorption system than in the adsorption system due to a decrease in viscosity and possible dilution in the aqueous phase.

Vitamin C degradation kinetics has been studied by Jin et al. (2011). From the studies as moisture content reduces, rate of Vitamin C degradation initially increases. Concurrently, the reduced moisture content, the fate of Vitamin degradation reduces such that the overall concentration effect is greater than the overall degradation effects giving the dehydrated product higher vitamin C content than the fresh product.

2.7 Pretreatment in drying

Pretreatment is common in most processing operations employed to improve product safety, quality or process efficiency during drying (Ayim et al. 2012; Masamba et al.

2013; Korus, 2011; Jha, 1996). Pretreatments have been used experimentally and commercially to accelerate the drying of fruits. Many light-colored fruits, such as banana and apples, darken rapidly when cut and exposed to air. If not pretreated, these fruits will continue to darken after they are dried. There are different types of pretreatments; amongst them are ascorbic acid, honey and sugar, metabisulphate, sulphite dip, salt solution and blanching. Dipping fruits for several seconds in pre-treatment solutions greatly reduces the drying time (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).

The aim of pre-treating in fruits and vegetables is to prevent discoloration by oxidation (Demirel & Turhan, 2003; Doymaz, 2004 cited by Pan et al., 2008), maintenance of fresher color, more pliable texture, retention of vitamins such as vitamins A and C, and in most cases, to accelerate the rate of drying. Effects of different pretreatments on dried banana characteristics were studied by Masamba et al. (2013). They reported that sodium metabisulfite did not affect vitamin C retention.

Abano and Sam - Amoah (2011) reported that Sugar and honey when heated forms a gelatinous coat around the banana, which is impermeable to moisture loss. This sticky coat also prevents moisture loss from the products treated with honey. Sugar also becomes more viscous when melted, and this viscous fluid expands to fill the pore spaces in the banana slices on heating. This prolongs the rate of moisture removal from samples pre-treated with sugar and honey dip.

Salt solution and lemon juice although seem to lose moisture in the early stages of drying, they do not really loosen as much water molecules as ascorbic acid will when exposed to long hours of heat and hence insensitive to prolonged heat (Abano and Sam Amoah, 2011).

Ascorbic acid pretreatment tends to loosen the water molecules in the banana slices when exposed to prolonged heat and thereby aid drying (Abano and Sam-Amoah, 2011). Ascorbic acid treatment also increases the vitamin C content when pretreated with samples.

Selman (1994) showed that the loss of vitamin C in blanched vegetables varied from 20 to 70%, while Puupponen - Pimiä et al. (2003) in (Ruta et al., 2012) reported 20–30% losses in brassica vegetables. In contrast, however, a higher level of the vitamin C was recorded in banana after blanching (Mahendran and Prasannath, 2008)

2.8 Influence of drying on micro-organisms

Living organisms thrive well in moisture contents above 30% wb. Therefore by reducing the moisture content below this level water activity is reduced thus preventing growth of moulds, bacteria and yeast.

Banana fruits can be contaminated by microorganisms through skin penetration, natural opening or mechanical damage. Microbial spoilage of fruits may be due to bacteria or fungi causing the fruits to be undesirable, reducing the market value and may also cause some side effects such as gastroenteritis, when consumed (Prescott et al., 2002; Al-Zaemey et al., 1989) cited by (Oyewole, 2012) . Post-harvest diseases can cause serious losses of fruits both in terms of quantity and quality. Fruits with microorganisms have no market value (Oyewole, 2012).

Higher temperatures (57°–82°C) destroy bacteria, enzymes (70°C), fungi, eggs and larvae. Food will be pasteurized if it is exposed to 57°C for 1 hour or 80°C for 10–15 min (Scalin, 1997). Most bacteria will be destroyed at 74°C and all will be prevented from growing between 60°–74°C. Between 16 and 60°C bacteria can grow and many survive, although bacteria, yeasts and moulds all require 13% or more moisture content for growth.

CHAPTER THREE

3.0 MATERIALS AND METHODS

3.1 Sample Preparation

Raw banana *(Musa sapientum)* (Figure 1) were bought on a local market at Juaben in the Ashanti region of Ghana. Primary processes such as cleaning, washing, and peeling were done. The banana was hand peeled and manually cut with a stainless steel knife. The digital caliper (01407A, Neiko, USA) (Figure 2) was also used to determine the diameter of the banana slices which was averaged to be 2.5cm and weighed with a balance of 0.01accuracy.

3.2 Moisture content

To account for variability in banana slices, the initial moisture content was measured before the slices were pretreated. The moisture contents of the banana samples were determined gravimetrically by drying the sample at 105°C until a constant weight was obtained. The result was expressed as percentage of moisture loss in dry basis (db). Moisture content (MC) was calculated as:

$$\%MC\ (db) = \frac{W_w - W_d}{W_d} \times 100 \tag{3}$$

Where *MC* is expressed on dry basis (W_w is initial weight and W_d is the weight of solids.).

Figure 1: ***Musa sapientum***

Figure 2:* *Digital caliper

Figure 3: Data logger

Figure 4: Forced convection solar dryer

Figure 5: Natural convection solar dryer

Figure 6: Banana slices on drying trays

3.3 Drying procedure

The sliced banana samples were grouped into treated (with ascorbic acid) and untreated. One hundred and thirty grammes (130g) each of treated and untreated banana slices were placed and drained (for the treated samples) on aluminum perforated (2x2 cm) trays (Figure 6), and covered with a piece each of nylon sieve (1x1 mm). These were then placed in the drying chamber in such a way that they are subjected to the same condition of heat from the air. The dryers used were namely OV a Beveiliging conventional oven (model: DMV 1250, Holland) at air temperatures of 50, 60 and 70 °C; and solar systems: NC (Figure 5), SD (Figure 4) and OSD. The data logger (Figure 3) was used to record temperatures in the solar systems. The forced convection dryer (SD) produced temperatures between 38 - 60°C degrees whiles the natural convection system (NC) produced temperatures ranging between 38 – 70°C. While the samples dried in the oven (OV) were done continuously at constant temperature that of the solar system were done under variable solar conditions. At the end of each day drying the samples were placed in tight zipped transparent plastic bags and kept in ambient condition till drying was continued the next day when the sun is on. The period of experiment was 11-14th February, 2013. The drying samples were weighed (with OHAUS, PA2102, ±0.01g) at 1hr interval till constant weight was achieved. Air temperatures were determined using K-type thermocouple and with a data logger (Agilent instrument, 34970A, USA) and humidity with thermo-hygrometer (Hanna Instruments HI91610C) in NC and SD systems. The dried samples at the end of drying were placed in tight zipped transparent plastic bags and labeled for storage in the freezer for further analysis.

3.4 Determination of effective moisture diffusivity (D_{eff})

Moisture removal from food products depends on the nature of bonds between water molecules as well as structure and composition of the food (Singh et al., 2006). Jin et al. (2011) stated that the effective diffusivity in food products depends on how moisture is distributed in the composition of food (food matrix) and how moisture interacts with those components.

In drying, diffusivity is used to indicate the flow of moisture from the material. In the falling rate period of drying, moisture removal is controlled mainly by molecular diffusion. Diffusivity is influenced by shrinkage, case hardening during drying, moisture content and temperature of the material (Singh et al., 2006). The falling rate period of drying of biological materials is best described by Fick's diffusion model as:

$$\frac{\partial M}{\partial t} = \frac{\partial^2 y}{\partial X^2} \tag{4}$$

A diffusion model based on the Fick's second law of diffusion was used to describe the transport of moisture inside banana slices. Assuming uniform initial moisture distribution and negligible external resistance, the solution of eq. (3) as proposed by Crank (1975) is:

$$\frac{M - Me}{Mo - Me} = MR = \frac{8}{\pi^2} \sum_{n=0}^{\infty} \frac{1}{2n+1} \exp\left[-(2n+1)^2 \pi^2 \frac{D_{eff} t}{L^2}\right] \tag{5}$$

The first term (n=0) of eq. (5) yields:

$$MR = \frac{8}{\pi^2} \exp\left[-\pi^2 \frac{D_{eff} t}{L^2}\right] \tag{6}$$

Where,

MR = the moisture ratio,

M_e = the equilibrium moisture content (EMC) (db),

M_0 = the initial moisture content (db),

M = the moisture content at time (db),

L = the characteristic length (average total volume/average total surface area (m)) of the banana slice,

t = the time (s),

D_{eff} = the moisture diffusivity (m^2/s), n is the number of terms.

Taking the natural logarithm of eq. (6) and re-arranging gives:

$$\ln(MR) = \ln\frac{8}{\pi^2} - \left[\pi^2 \frac{D_{eff} t}{L^2}\right] \tag{7}$$

By plotting lnMR against time a straight line curve is obtained giving a negative slope as:

$$\textbf{Slope} = \frac{\pi^2}{L^2} D_{eff} \tag{8}$$

Where D_{eff} is the effective diffusivity (m^2/s).

3.5 Determination of Activation energy (E_a)

The dependency of D_{eff} on temperature can be shown using the Arrhenius type of equation as (Jin et al., 2011)

$$Deff = D_o exp\left(\frac{-E_a}{RT}\right) \tag{9}$$

For obtaining E_a, the above equation can be made linear as follows:

$$ln(D_{eff}) = ln(D_o) - \left(\frac{E_a}{R}\right)\left(\frac{1}{(T)}\right) \tag{10}$$

Where

E_a = activation energy ($kJmol^{-1}$),

R = universal gas constant ($8.3143 Jmol^{-1}K^{-1}$),

T = absolute air temperature (K) and

D_o = the pre exponential equation (m^2s^{-1})

Drying kinetic equation commonly applied as reported by Zogzas et al., (1996) is:

$$\frac{dM}{dt} = -k(M - M_e) \tag{11}$$

The solution yields:

$$\frac{M - M_e}{M_o - M_e} = \exp(-kt) \tag{12}$$

Equating equations (6) and (12) the following is obtained:

$$k = \frac{\pi^2}{L^2} D_{eff} - \ln\left(\frac{8}{\pi^2}\right) \tag{13}$$

Where k is the drying rate constant (s^{-1}). Eq. (13) indicates the relationship between the drying rate constant and effective diffusion coefficient and the characteristic length. Meanwhile, $8/\pi^2$ can be equated to unity (1) with no significant effect on the value of rate constant determined.

3.6 Curve fitting

Six (6) thin layer drying models (Table 2) were used in fitting the experimental drying curves under constant oven conditions.

Table 2: Mathematical models applied to fit the drying curves

No.	Model name	Model equation	References
1	Lewis	$M=(M_o-M_e)\exp(-kt)+M_e$	Westerman et al., (1973)
2	Henderson and Pabis	$M=a(M_o-M_e)\exp(-kt)+M_e$	Yagcioglu et al., (1999)
3	Two term exponential	$M=(M_o-M_e)(a\exp(-kt)+(1-a)\exp(-kat))+M_e$	Yaldiz et al., (2001)
4	Verma (Diffusion)	$M=(M_o-M_e)(a\exp(-k_1t)+(1-a)\exp(-k_2t))+M_e$	Verma et al., (1985)
5	Two term	$M=(M_o-M_e)(a\exp(-k_1t)+b\exp(-k_2t))+M_e$	Rahman et al., (1998)
6	Page	$M=(M_o-M_e)\exp(-kt^n)+M_e$	Guarte, 1996

To determine the supremacy of the mathematical models three indices were applied, which included coefficient of determination (R^2) and mean square error (*MSE*). For the most suitable model, *MSE* values should assume the lowest while R^2 the highest and closest to unity (Demirel and Turhan, 2003). These parameters are estimated as follows:

$$R^2 = \frac{\sum_{i=1}^{N}\left[X_{exp,i} - X_{pre,i}\right]^2}{\sum_{i=1}^{N}\left[\bar{X}_{exp,i} - X_{pre,i}\right]^2} \qquad (14)$$

The MSE is given as:

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

Where, X_{exp} is the experimental data set (moisture content), X_{pre} is the predicted data set, N is the number of observations, *i* is the *ith* observation and $\bar{X}$ is the mean of experimental data set.

$$\bar{M} = \frac{1}{N}\sum_{i=1}^{N} M \qquad (16)$$

3.7 Proximate Determination

Proximate and mineral analysis were conducted on the raw samples and the finished product using the methods described in A.O.A.C (1996) to determine the moisture, ash, crude fiber, crude protein, total carbohydrate content. All determinations were done in duplicates.

3.7.1 Moisture content determination

Two grammes (2.0g) of each sample was weighed and transferred into a previously dried and weighed glass crucible. The crucibles were placed in an oven (Genlab oven model D35, MIDO/3/SSF, England) and thermostatically controlled at 105°C for 5hours. The crucibles were removed and placed in a dessicator to cool, and weighed. The crucibles were placed in the oven and heated, cooled and weighed repeatedly until a constant weight was obtained.

3.7.2 Crude fat determination

Two grams (2g) of moisture free samples was transferred to a 22x80mm whatman paper thimble. A cotton wool ball was placed into the thimble to prevent the loss of the sample. 250ml round bottom flask was weighed accurately. About 200 ml petroleum spirits, B. P 60-80 was put into each flask and the apparatus assembled. Quick fit condensers were connected to the soxlet extractors and refluxed for about 16 hours on low heat on heating mantle. After the period, the flasks were removed and the solvent evaporated on a steam bath. The flasks were heated for 30minutes in an oven at 105°C. It was then cooled to room temperature in a desiccator and the flask and contents weighed.

3.7.3 Crude fiber determination

The sample from crude fat determination was transferred into a 750ml Erlenmeyer flask and 0.5g asbestos added. Two hundred milliliters (200ml) boiling 1.25% H_2SO_4 was added to the flask immediately. The flask was then set on the hot plate connected to cold finger condensers. The contents were allowed to boil and remained so until samples were thoroughly wet. It was removed after 30 minutes and immediately filtered using the cheese cloth into the funnel and washed with boiling water until the water was no more acidic. The charged asbestos was washed back into flask with

1.25% NaOH. The flask was then connected to the condenser and boiled for 30 minutes. This was then filtered through the cheese cloth and washed thoroughly with boiling water until washings were no longer acidic. The charge asbestos was washed back into the flask with 200ml boiling of NaOH solution. The flask was connected to a condenser and contents allowed to boil for 30minutes. They were filtered through linen cloth and thoroughly washed with boiling water.

The residue was transferred into a Gooch crucible with water and washed with about 15ml ethanol after which the crucible with its content was dried for 1 hour at 100°C, cooled in a desiccator and reweighed. The crucible was ignited in an electric furnace (Genlaboven model D35, MIDO/3/SSF, England) for 20 minutes, cooled and reweighed. The percentage crude fiber was then calculated from the weight loss.

3.7.4 Ash Determination

Two grams (2g) of the moisture free sample was transferred into previously ignited and weighed crucibles and placed in muffle furnace (Gallenkamp, England) which was pre-heated to 600°C for 2hours. Crucible was removed, cooled slightly in a desiccator. It was then weighed and the ash content was calculated.

3.7.5 Crude Protein/Total nitrogen determination

I. Digestion

The moisture free sample was firstly digested. Two grammes (2g) of the sample, half spoonful of selenium based catalyst tablets and a few anti bumping agents were transferred to the digestion flask. The flask was then placed in a digestion burner and heated slowly until the resulting solution became clear. It was then cooled to room temperature. The digested solution was transferred into a 100ml volumetric flask and topped up to the mark.

II. Distillation

The distillation apparatus was flushed at least 10 minutes before use. A 25ml of 2% boric acid was transferred into a 250ml conical flask using a pipette and 2 drops of mixed indicator added. The conical flask with its contents was placed under the condenser in a position that left the tip of the condenser completely immersed in solution. Ten millimeters 10ml of the digested banana sample was measured and poured into the steam jacket. An excess of 40% NaOH (about 15-20ml) was added to the decomposition flask after which the funnel stopcock was closed. The steam was forced through the decomposition chamber by shutting the stopcock on the stream trap outlet. This drove out the ammonia in the collection flask.

III. Titration

The receiving flask was lower so the condenser tip was just above the liquid. The end of the condenser was washed with 0.1N HCl solution until the solution turned colorless. This was repeated for each sample, and then the same procedure followed for water (as the blank). The average titre values were used in the determination for protein component.

3.7.6 Total carbohydrate content

The difference between 100 and the summations of protein, crude fat, fiber, moisture and the ash of the samples was expressed as total carbohydrate content.

3.8 Mineral analysis

Potassium content of the samples were determined by digesting the ash of the samples with Perchloric acid and nitric acid, and then taking the readings on a Jenway digital flame photometer Phosphorus was determined by Vanado-molybdate colorimetric method (Ologhobo and Fetuga, 1983). Magnesium was determined spectrophotometrically by using Buck 200 atomic absorption spectrophotometer (Buck Scientific, Norwalk United Kingdom (UK)) (Essien et al., 1992) and their absorbance compared with standards of absorption of these minerals.

3.9 Vitamin C determination

Vitamin C was determined using the method of Benderitter et al. (1998). Briefly 75ul of DNPH (2g of Dinitrophenyl hydrazine, 230 mg Thiourea and 270mg $CUSO_4.5H_2O$ in 100ML 5M H_2SO_4) was added to 500µl reaction mixture 300µl of the banana sample with 100µl 13.3% TCA and water, respectively). The reaction mixture was subsequently incubated for 3hours at 37°C, the 0.5 ml H_2SO_4 65%(v/v) was added to the medium, and the absorbance was measured at 520nm, and the vitamin c content of the sample was subsequently calculated using a vitamin C standard curve.

3.10. Microbial load determination

A 1 ml portion of each appropriate dilution was inoculated unto malt extract agar (BDH) using the pour plating technique with plates incubated at 37°C in a Gallenkamp incubator (model IH-150, Gallenkamp Co Ltd, UK) for 48 h. The colonies were counted using a Gallenkamp Colony Counter (Gallenkamp Co Ltd, UK). Counts were expressed as log of the colony forming unit (CFU) g~1 of okra sample. All parameters were monitored on fresh weight basis, with the exception of vitamin C content which was expressed on drying matter (DM) basis.

4.1 Temperature and treatment effect under Oven (OV) conditions

Drying involves the removal of moisture from the center of a food to the atmosphere. Temperature gradient is considered as the driving force and consequently has a great effect on the rate of moisture removal. Some researchers (Abano and Sam-Amoah, 2011; Dzisi et al, 2012) have reported of employing pre-treatment to hasten drying. Drying behavior of treated and untreated banana slices for all temperatures have been presented in Figure 7. It was observed that the higher the temperature the lesser the drying time.

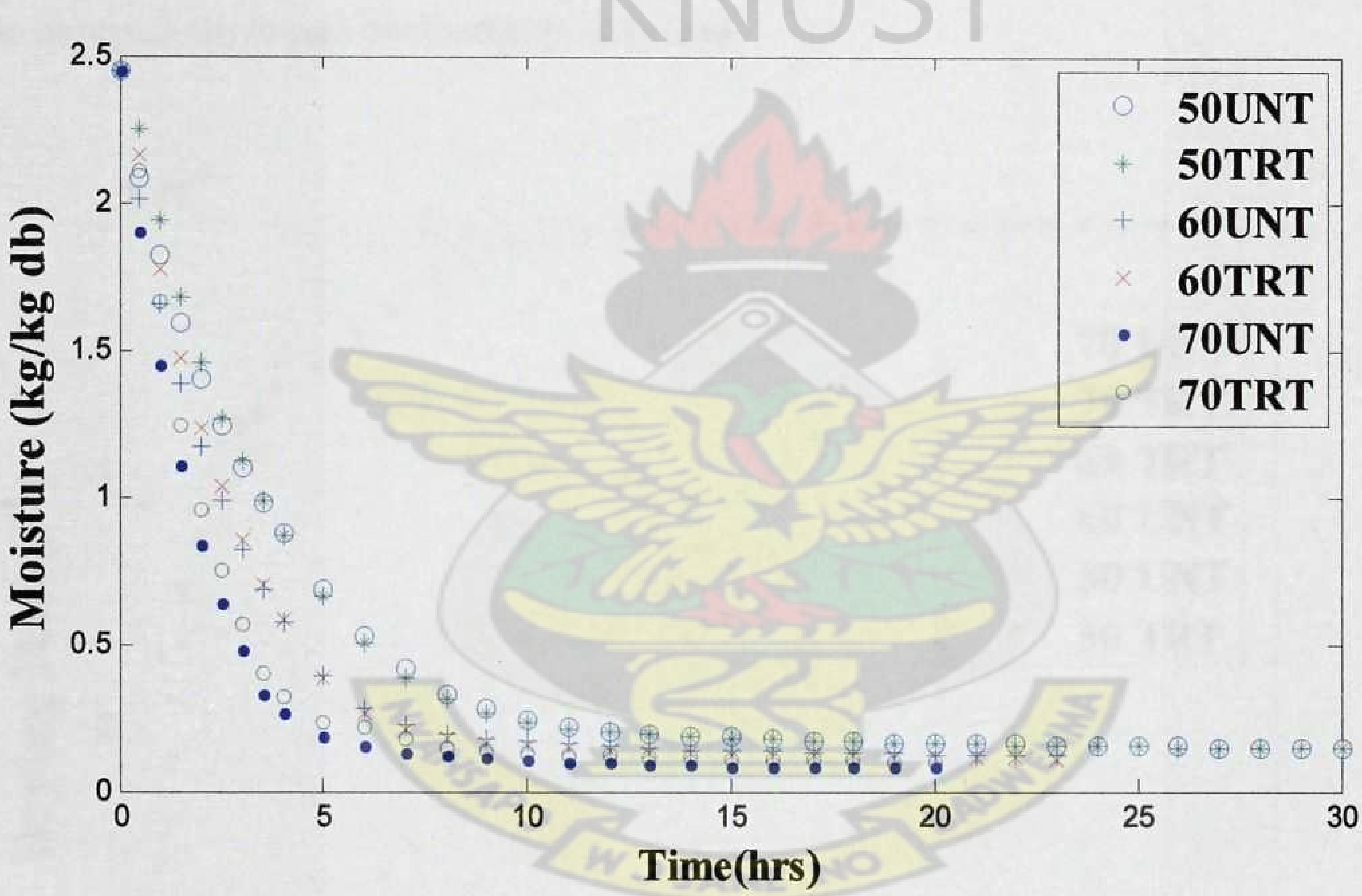


Figure 7: Drying behavior of treated and untreated samples at varying temperatures for 5mm thickness.

Drying at 70°C took 23 and 20 hours for both treated and untreated samples to dry to 0.11 and 0.12 kg/kg (db) respectively and 23 hours for treated and untreated samples to reach 0.08 and 0.10 kg/kg at 60°C. It took 30 hours for both treated and untreated samples to dry to moisture content of 0.146 kg/kg (db) at 50°C. Although drying took a longer time at 50°c equilibrium moisture content was higher than 60°C and 70°C drying temperatures. Abano and Sam-Amoah (2011) stated that ascorbic acid treatment aid drying when exposed to prolonged temperatures and this was observed in the final moisture contents although the differences were not significant. From the drying curve it was also observed that the ascorbic acid pretreatment had no significant effect on the drying behavior of banana of 5mm thickness.

4.2 Drying rate curve under oven (OV) condition

Drying rate is defined as the amount of moisture removed per unit time from a material. The drying rate versus drying time has been presented in Figure 8. Drying rate observed decreased continuously with time.

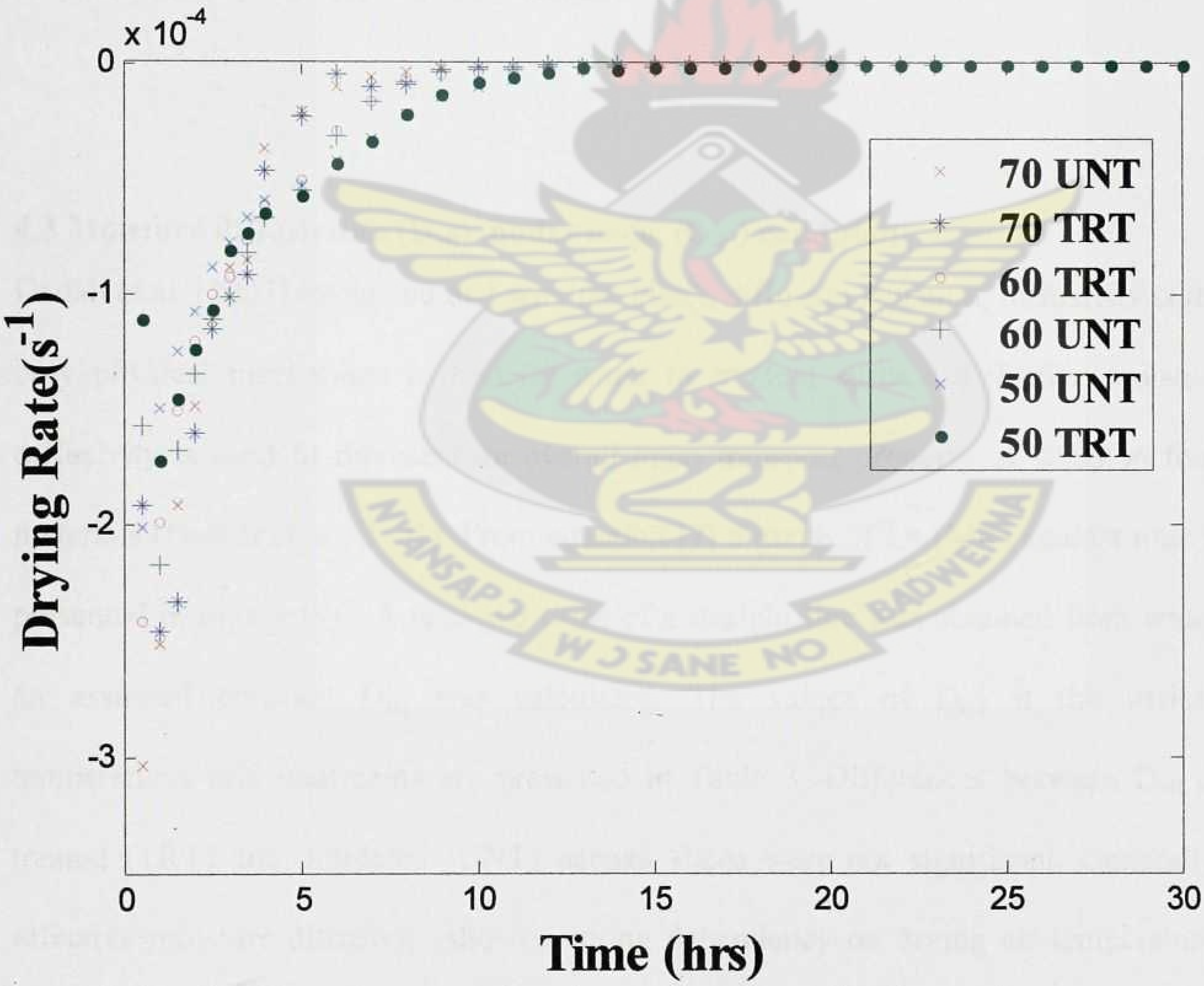


Figure 8: Drying Rate for treated and untreated samples for various temperatures at 5mm thickness

Figure 8: Drying Rate for treated and untreated samples for various temperatures at 5mm thickness

In figure (8), there was no constant rate period observed and drying occurred in the falling-rate period. The curves typically demonstrated smooth diffusion-controlled drying behavior under all conditions (Doymaz, 2010). Moreover, an important influence of drying temperature on drying rate could be observed in these curves. Drying rate increased with increases of drying temperature and the highest values of drying rate were obtained during the experiment at 70°C for both untreated and the treated banana samples. Most of moisture was removed by the 10th hour. The results are generally in agreement with observations of research done by Dzisi et al. (2012); Doymaz, (2010) and Akpinar and Bicer (2006).

4.3 Moisture diffusivities (D_{eff}) under oven (OV) condition

Dadali et al. (2007) explained that with the Fick's diffusion equation, diffusivity is the only physical mechanism to transfer water to product surface. Effective moisture diffusivity is used to represent an overall mass transport property of water in food materials (Dadali et al., 2007). From equation (7) a graph of Ln (MR) against time is presented in Figure (9). A negative slope of a straight line was obtained from which an assumed constant D_{eff} was calculated. The values of D_{eff} at the various temperatures and treatments are presented in Table 3. Differences between D_{eff} of treated (TRT) and untreated (UNT) banana slices were not significant. Generally, effective moisture diffusivity showed strong dependency on drying air temperature. D_{eff} ranged between 2.01–3.32 x10^{-11} m^2/s. This conforms to literature values for drying of banana.

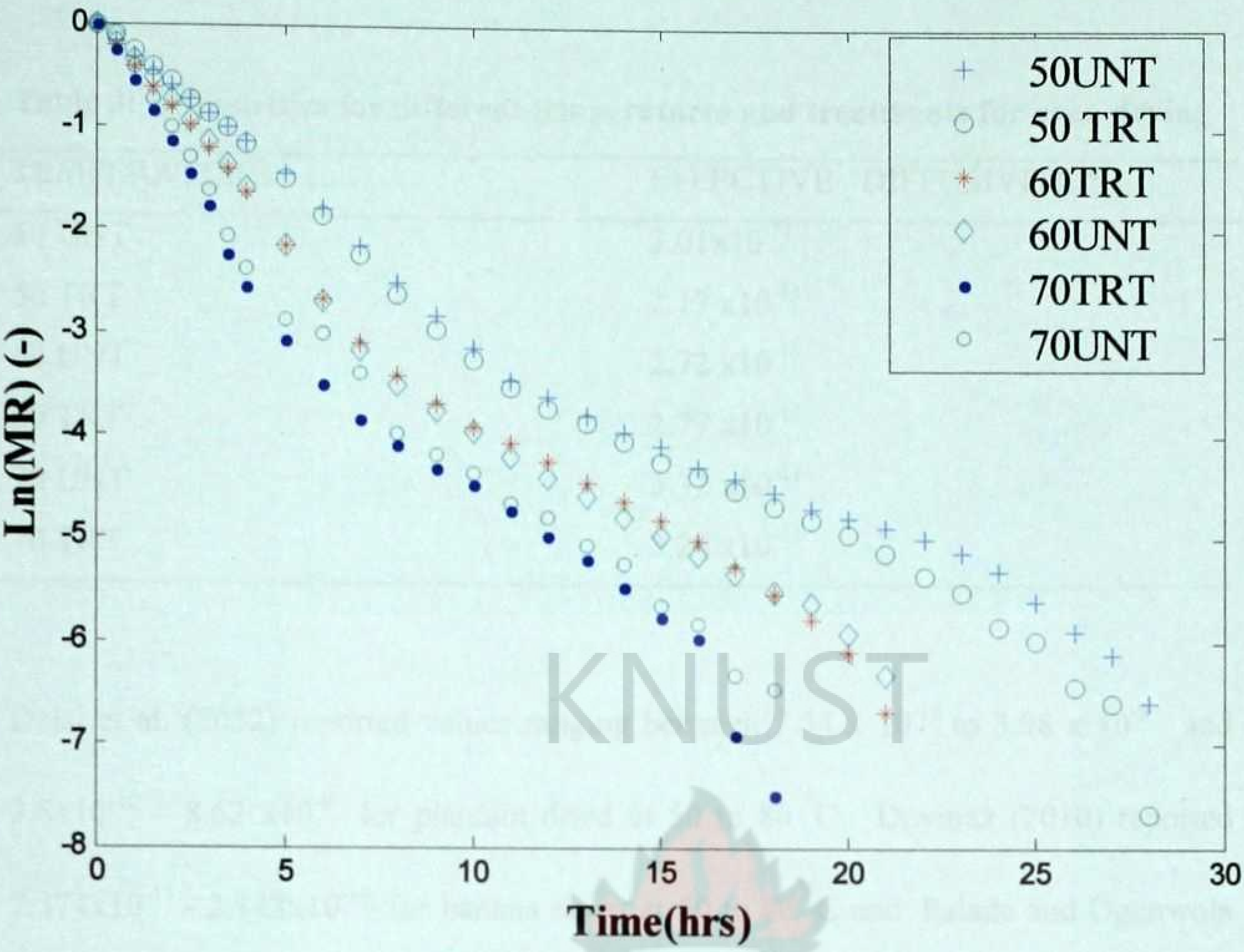


Figure 9: Ln (MR) against Time (t) in hours.

The moisture diffusivity values were not significantly affected by the treatments. Moisture diffusivities depended strongly on Tempeartures as effective moisture diffusivities were higher in higher temperatures than lower temperatures. 70 °C had higher diffusivities than 60°C and 50 °C. values of effective moisture diffusivities are presented in table 3. 70TRT recorded 3.26 x10^{-11} m/s^2 and 3.32 x10^{-11} m/$s^2$for 70UNT, 60TRT recorded 2.77 x10^{-11} m/s^2 and 2.72 x10^{-11} m/s^2 for 60TRT. Again 50 UNT recorded m/s^2 2.01x10^{-11} m/s^2 and 2.17 x10^{-11} m/s^2.

Table 3: Diffusivities for different temperatures and treatments for oven drying

TEMPERATURE	EFFECTIVE DIFFUSIVITIES
50 UNT	$2.01x10^{-11}$
50 TRT	$2.17 x10^{-11}$
60 UNT	$2.72 x10^{-11}$
60 TRT	$2.77 x10^{-11}$
70 UNT	$3.32 x10^{-11}$
70 TRT	$3.26 x10^{-11}$

Dzisi et al. (2012) reported values ranging between 7.54×10^{-10} to 3.98×10^{-9} and $3.8x10^{-10} - 8.62 x10^{-9}$ for plantain dried at 50 to 80 ^{o}C. Doymaz (2010) reported $7.374x10^{-11}$ - $2.148x10^{-10}$ for banana slices at 50 to 80 ^{o}C and Falade and Ogunwola (2012) as $1.29 x10^{-10} - 3.91 x10^{-9}$ for banana dried at 40 to 80 ^{o}C

4.4 Predicting the experimental drying data using various models

In selecting the model that gave the best of fit, lowest MSE and highest R^2 values were taken into consideration. The drying parameters, MSE and R^2 for various temperatures for various models are presented in Table 4 (a-f). The Henderson and Pabis model was selected as goodness of fit since it had the less number of parameters with least MSE and highest R^2.

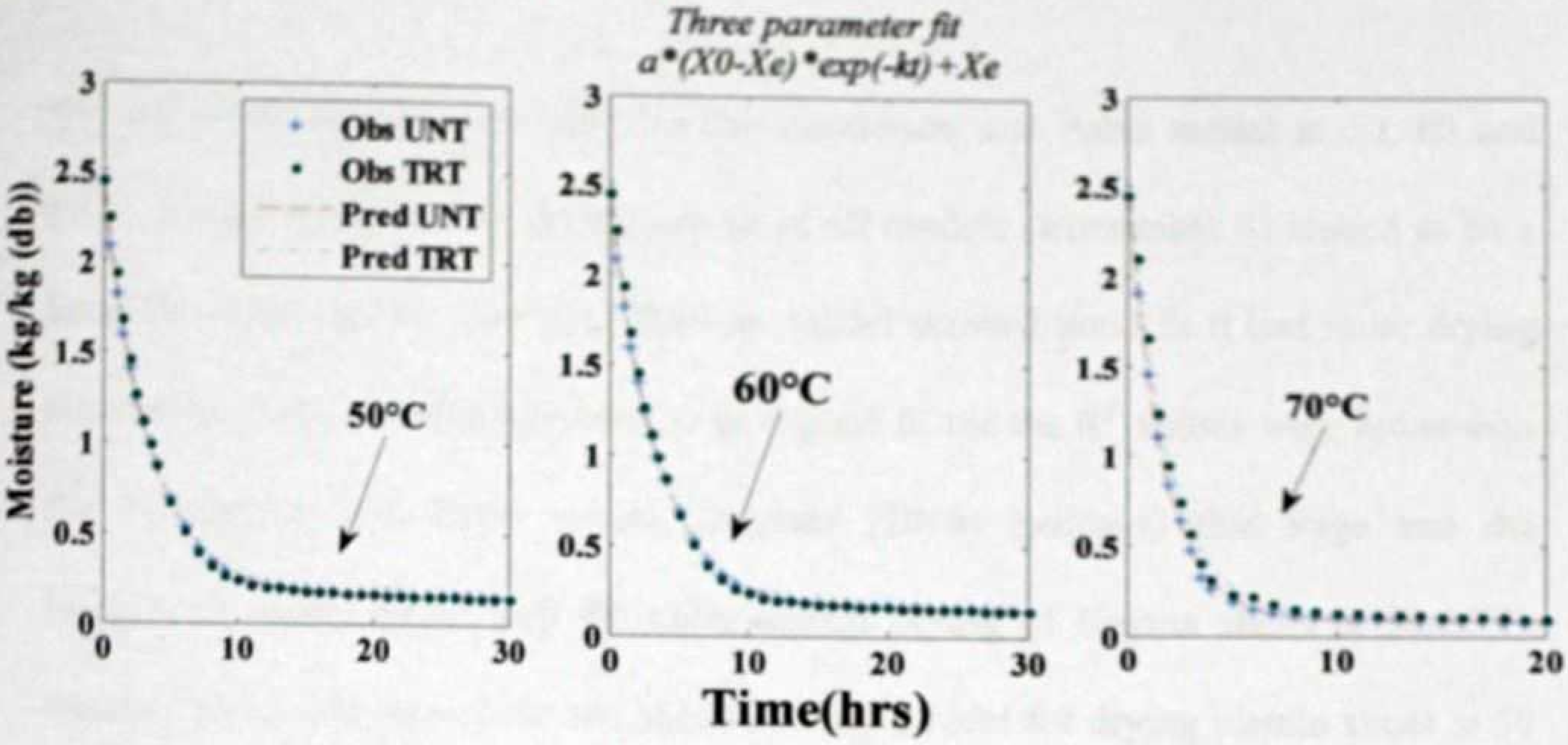


Figure 10: Fitted curve with the Henderson and Pabis model at 50, 60, 70 °C for 5mm OV dried banana slices.

From Table 4 all the models had a high R^2 values of 0.99. In all cases R^2 values were greater than 0.99 indicating a good fit. Figures 10 shows the comparison of predicted

Table 4: Parameter estimation for treated and untreated banana slices at 5mm thickness

(a) Lewis model

Method	K	Me	Mse	R^2
50 TRT	$8.346x10^{-05}$	0.1506	$2.65\ x10^{-04}$	0.9993
50 UNT	$8.043\ x10^{-05}$	0.1405	$9.88\ x10^{-04}$	0.9977
60 TRT	$1.136\ x10^{-04}$	0.1240	$2.40\ x10^{-04}$	0.9994
60 UNT	$1.053\ x10^{-04}$	0.1011	$1.50x10^{-03}$	0.9966
70 TRT	$1.606\ x10^{-04}$	0.0825	$5.82\ x10^{-04}$	0.9985
70 UNT	$1.3946x10^{-04}$	0.0979	$3.2x10^{-03}$	0.9925

(b) Henderson and Pabis model

Method	k	A	Me	Mse	R^2
50 TRT	$8.23x10^{-05}$	0.9895	0.1492	$2.297\ x10^{-04}$	0.9994
50 UNT	$8.42x10^{-05}$	1.0365	0.1451	$5.719\ x10^{-04}$	0.9987
60 TRT	$1.13\ x10^{-04}$	1.0017	0.1242	$2.391\ x10^{-04}$	0.9994
60 UNT	$1.10\ x10^{-04}$	1.0383	0.1056	$9.864\ x10^{-04}$	0.9978
70 TRT	$1.64\ x10^{-04}$	1.0165	0.0838	$4.949\ x10^{-04}$	0.9987
70 UNT	$1.47\ x10^{-04}$	0.1025	0.1025	$2.3x10^{-02}$	0.9946

and experimental moisture ratio for the Henderson and Pabis model at 50, 60 and 70°C. It was seen that the drying curves of all models (from table 4) tended to be a good fit. Although the two term showed model showed good fit it had more drying parameters. Lewis model also tend to be a good fit the the R^2 values were lower than the Henderson and Pabis model. Doymaz (2010) indicated that Page and the Logarithm model fitted well for experimental drying of banana slices at 50-80°C. Dzisi et al. (2012) also chose the Modified Page Model for drying platain slices at 50 to 80°C . In contrast however the Henderson and Pabis fitted well for describing the experimental drying data of banana slices dried at 50-70°C in this work.

(c) Two Term Exponential model

TEMP	k_1	Me	a	Mse	R^2
50 TRT	8.23×10^{-05}	0.1492	0.9895	6.60×10^{-04}	0.9983
50 UNT	8.50×10^{-05}	0.1451	1.0365	7.20×10^{-03}	0.9830
60 TRT	1.14×10^{-04}	0.1242	1.0017	1.29×10^{-04}	1
60 UNT	1.40×10^{-04}	0.1056	1.0383	6.90×10^{-04}	0.9844
70 TRT	1.630×10^{-04}	0.0838	0.00838	8.45×10^{-04}	0.9978
70 UNT	1.467×10^{-04}	0.1025	0.1025	9.10×10^{-03}	0.9788

(d) Diffusion (Verma) model

Method	k_1	k_2	Me	a	Mse	R^2
50 TRT	8.12×10^{-05}	3.34×10^{-02}	0.1478	0.9794	2.30×10^{-04}	0.9995
50 UNT	8.04×10^{-05}	8.04×10^{-05}	0.1405	0.2385	5.72×10^{-04}	0.9980
60 TRT	1.14×10^{-04}	1.14×10^{-04}	0.1240	0.5578	2.39×10^{-04}	0.9994
60 UNT	1.05×10^{-04}	1.05×10^{-04}	0.1011	0.1214	9.86×10^{-04}	0.9980
70 TRT	1.60×10^{-04}	1.60×10^{-04}	0.00825	0.2051	5.82×10^{-04}	0.9985
70 UNT	1.39×10^{-04}	1.39×10^{-04}	0.0979	0.1788	1.40×10^{-03}	0.9968

(e) **Two Term model**

Method	k_1	k_2	Me	a	b	Mse	R^2
50 TRT	$8.23x10^{-05}$	$8.23x10^{-05}$	0.1492	0.495	0.495	$2.30x10^{-04}$	0.9994
50 UNT	$8.42x10^{-05}$	$8.42x10^{-05}$	0.1457	0.518	0.518	$5.72x10^{-04}$	0.9987
60 TRT	$1.14x10^{-04}$	$1.14x10^{-04}$	0.1242	0.501	0.501	$2.39x10^{-04}$	0.9994
60 UNT	$1.10x10^{-04}$	$1.10x10^{-04}$	0.1056	0.519	0.519	$9.86x10^{-04}$	0.9978
70 TRT	$1.64x10^{-04}$	$1.64x10^{-04}$	0.0084	0.508	0.508	$4.95x10^{-04}$	0.9987
70 UNT	$1.48x10^{-04}$	$1.48x10^{-04}$	0.1025	0.526	0.526	$2.3 x10^{-03}$	0.9946

(f) **Page model**

Method	K	Xe	n	Mse	R^2
50 TRT	$9.512 x10^{-05}$	0.1483	0.9859	$2.52 x10^{-04}$	0.9994
50 UNT	$2.563 x10^{-05}$	0.1571	1.1229	$1.87 x10^{-04}$	0.9996
60 TRT	$9.272 x10^{-05}$	0.1271	1.0225	$2.12 x10^{-04}$	0.9995
60 UNT	$2.48 x10^{-05}$	0.1212	1.1602	$1.64x10^{-04}$	0.9996
70 TRT	$7.092x10^{-05}$	0.0916	1.0931	$1.72 x10^{-04}$	0.9996
70 UNT	$1.41 x10^{-05}$	0.1229	1.2585	$4.16x10^{-04}$	0.9990

There existed a strong relationship between rate constant and temperature. The dependency of rate constant on temperature for both untreated and treated banana slices was shown in the Arrhenius type equation

$$k = k_o exp\left(\frac{-E_a}{RT}\right) \tag{17}$$

Where k_o, Ea and R have their usual meanings. The natural logarithm of eq. (10) gave a straight line of negative slope from which the activation energy was determined. In equations (18) and (19), k_o for the untreated and treated samples using the Henderson and Pabis model were respectively 1.21 and 10.44 while that of E_a were 25.74 and 31.58 kJ/mol

$$k = 1.21\ exp\left(\frac{-25735.87}{R(T+273)}\right) \text{ untreated} \quad (18)$$

$$k = 10.44\ exp\left(\frac{-31581.8}{R(T+273)}\right) \text{ treated} \quad (19)$$

Activation energy, Ea (kJ/mol) which is the minimum amount of energy required to initiate mass diffusion from a wet food material during drying (Mittal, 1999). These were calculated from with high correlation coefficients (R^2 = 0.997 for treated and R^2 = 0.998 for untreated), indicating a good fit. Ea obtained in this work are comparable to existing literature cited by Doymaz, (2010) for banana slices, 32.65 kJ/mol and Dzisi et al. (2012) for plantain slices as 35.23 and 56.61kJ/mol.

Values of the energy of activation fell within the general range of 12.7–110 kJ/mol for food materials (Zogzas et al., 1996).

4.5 Drying rate against moisture content

Drying rate of the treated and untreated banana slices against moisture content is presented in Figure 11. Drying rate generally decreased with decreased moisture content. There existed a strong dependency of drying rate on temperature. The slight initial increased rate was due to the free moisture near the surface of the product being removed early in the process. Treatment did not show much effect on drying rate with moisture. Three periods of drying rates were observed and below 0.2 kg/kg db drying rates were almost the same as noted by Jannot et al. (2004). At the initial drying process the internal resistance to moisture diffusion is low. As the drying progresses, more energy was required to break the molecular bond of the moisture and though constant energy was supplied it therefore led to decreased drying rate.

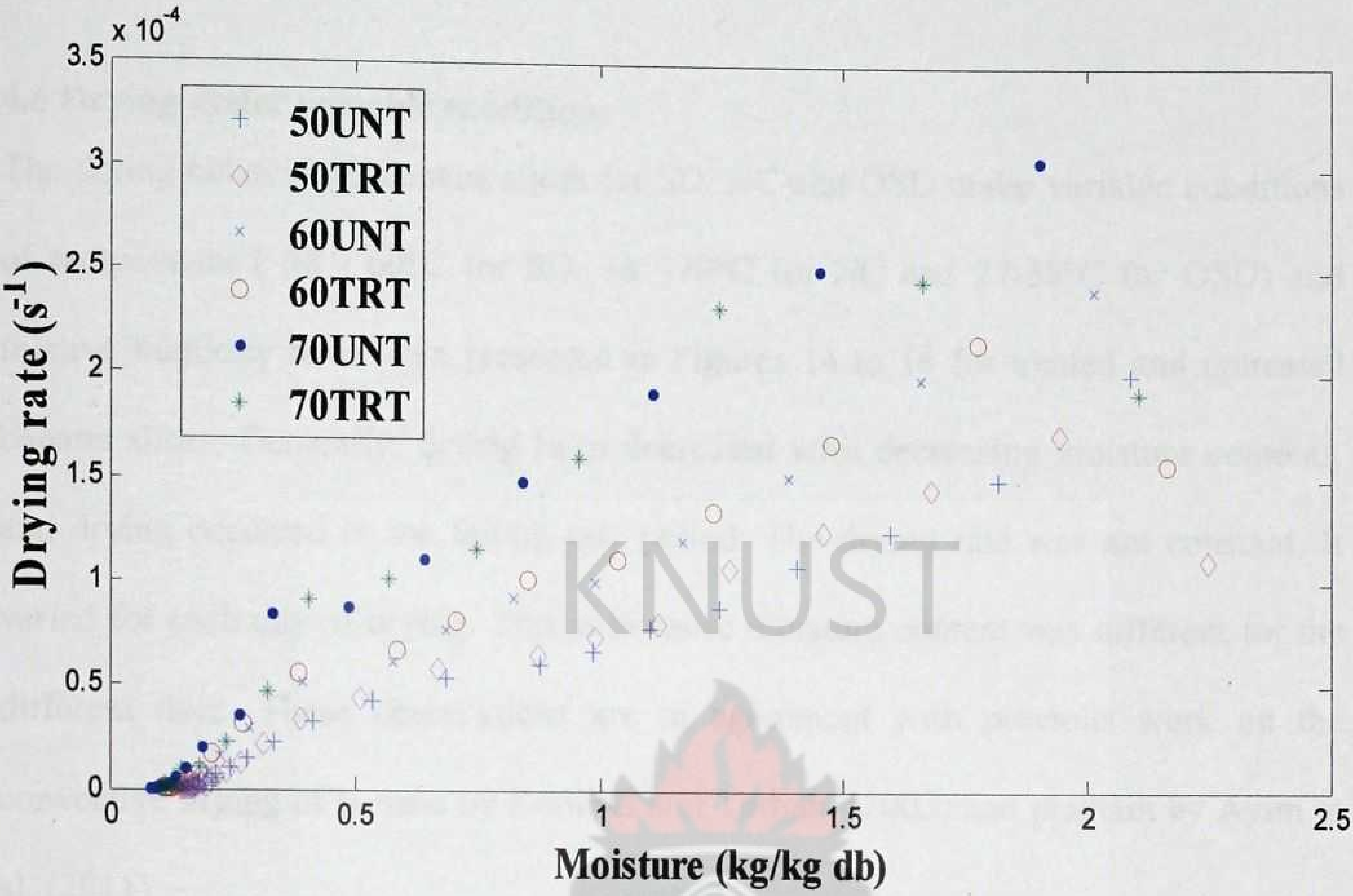


Figure 11: Drying rate against moisture (kg/kg db) for treated and untreated 5mm banana samples for all temperatures.

Moisture removal decreases with decreasing moisture for all temperatures of 50°C, 60°C and 70°C. In general, the time required to reduce the moisture ratio to any given level was dependent on the drying condition, being the highest at 50°C and lowest at 70°C. This shows that the drying rate is a strong function of temperature and moisture content. Drying rate is highest at the beginning of the first hour for untreated sample. This is a result of low internal resistance of moisture at the beginning of drying; therefore when energy is impacted moisture can easily move to the surface to be evaporated. As the drying progressed, more energy was required to break the molecular bond of the moisture and though constant energy was supplied, it took a longer time to break the bond, therefore drying rate decreased. Moisture removal was very low at 0.2kg/kg signifying a strong dependence of moisture removal on moisture availability.

4.6 Drying under variable conditions

The drying behavior of banana slices for SD, NC and OSD under variable conditions of temperature (38 - 60°C for SD, 38 –70°C for NC and 27-38°C for OSD) and relative humidity have been presented in Figures 14 to 16 for treated and untreated banana slices. Generally, drying rates decreased with decreasing moisture contents, and drying occurred in the falling rate period. The drying rate was not constant. It varied for each day of drying. This is because moisture content was different for the different days. These observations are in agreement with previous work on the convective drying of banana by Demirel and Turhan (2003) and plantain by Ayim et al. (2011)

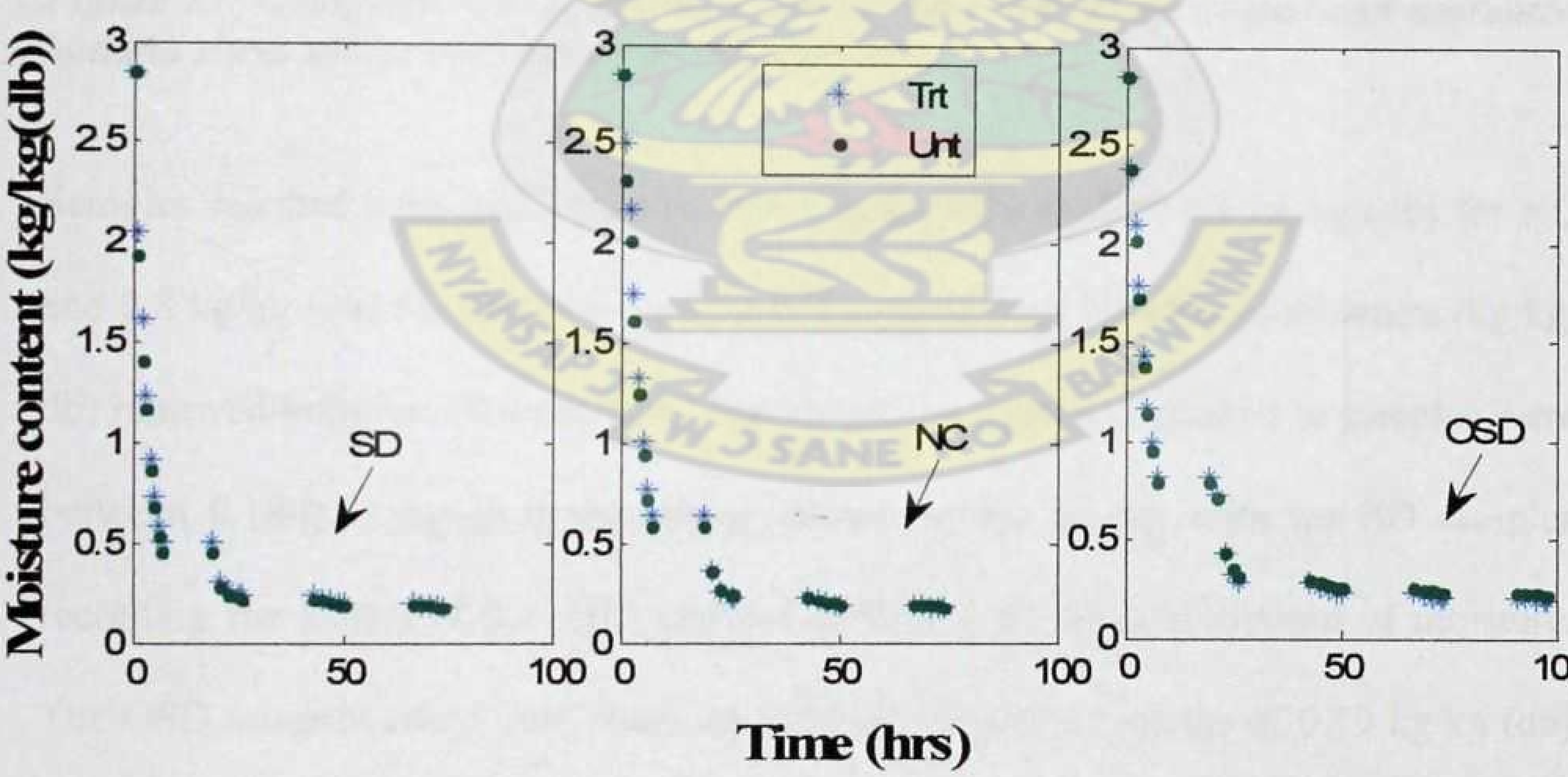


Figure 12: The drying behavior of forced convection (SD), natural convection (NC), and open sun drying (OSD) under variable temperature conditions.

The drying rate decreased steadily with decreased moisture contents. This trend was due to the removal of free moisture near the surface of the banana 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. The drying process took four days in the SD and NC and 5 days for OSD dried samples. Comparison of performance of drying methods is shown in Figure 13.

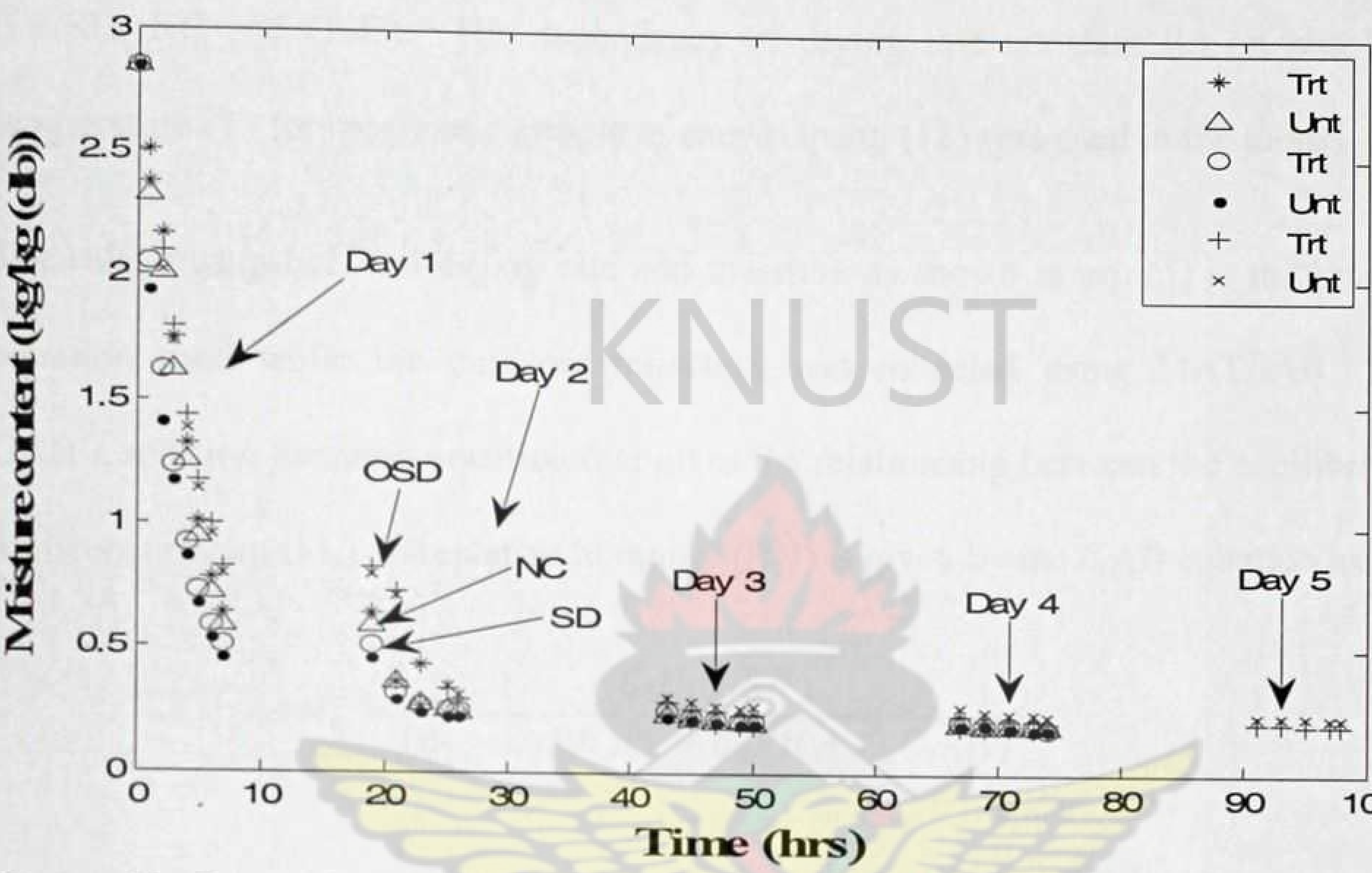


Figure 13: Comparison of performance of drying methods on treated and untreated banana slices under variable solar temperatures

Samples reached a moisture content of 0.5 kg/kg (db) for SD, 0.6 kg/kg (db) for NC and 0.8 kg/kg (db) for OSD on the first day representing 68-84% of moisture (kg/kg, db) removed between 10am to 5pm. The moisture contents contained in samples were between 0.18-0.23 kg/kg at the end of drying on the 3rd day with the SD samples recording the least and the OSD samples recording the highest amount of moisture. The OSD samples could only reach equilibrium moisture contents of 0.19 kg/kg (db) on the fifth day of drying. Ascorbic acid treatment had no effect on the drying behavior of banana slices. From Figure13 it is obvious that drying banana slices in the SD performs better in terms of moisture removal than that for NC followed by OSD dried samples.

4.7 Prediction of drying rate Constants under variable conditions

The parameters obtained in the OV dried samples under constant conditions were used to predict the drying moisture (kg/kg, (db)) trajectory under variable conditions (i.e SD, NC and OSD). The dependency of drying rate constant (k) on absolute temperature (T) for the treated sample as shown in eq. (18) was used in the model.

The relationship between drying rate and moisture as shown in eq. (5) is the kinetic equation used while the moisture trajectory was modeled using MATLAB. The GAB's sorption isotherm equation that gives the relationship between the equilibrium moisture content (M_e) and relative humidity (RH) is given by the GAB equation as:

$$M_e = \frac{(C_1 C_2 C_3 RH)}{(C_1 - C_2 RH)(1 - C_2 RH + C_2 C_3 RH)} \tag{20}$$

Where C_1, C_2 and C_3 are sorption coefficients. Since banana has similar composition as yam the sorption coefficients obtained for yam by Amankwah et al. (2012) were used. These are C_1=9.8375, C_2=0.6795 and C_3=7.3062. Since the rate constant is in practice not constant, k_o is adjusted to fit the moisture trajectory over time as moisture decreases. k_o obtained is presented in Table 5. It was observed that the drying rate constants varied over time and were found to be 1.4 for day one (1), 0.6 for day two (2), 0.1 for days three (3) and four (4) for SD dried samples; 1.1 for day one (1), 0.8 for day two (2) and 0.1 for days three (3) and four (4) for NC whiles OSD recorded 1.45 for day one (1), 1.2 for day two (2), 0.5 for day three (3) and 0.09 for days four (4) and five (5). It is indicative that at low moisture content drying rate hardly varies.

The experimental and predicted moisture trajectory against time (hours) including relationship between relative humidity and air temperature for SD, NC and OSD are shown in Figures 14 to 16. It is observed that for all the drying methods relative humidity varied inversely with temperature. It is also instructive in this experiment that the amount of available heat with corresponding low relative humidity strongly influenced the rate of moisture removal. While temperature and relative humidity ranges were 31-58°C and 20-60% for SD dried samples (Figure 14) those of NC (Figure 15) were 32-64°C and 20-60%. Meanwhile OSD dried samples experienced low temperatures with corresponding high relative humidities. The temperatures ranged from 29-38°C and relative humidity 40-70% (Figure 16).

Table 5: Variation of drying rate constants for different drying methods and days.

	k_o				
Drying Methods	**Day 1**	**Day 2**	**Day 3**	**Day 4**	**Day 5**
SD	1.4	0.6	0.1	0.1	-
NC	1.1	0.8	0.1	0.1	-
OSD	1.45	1.2	0.5	0.09	0.09

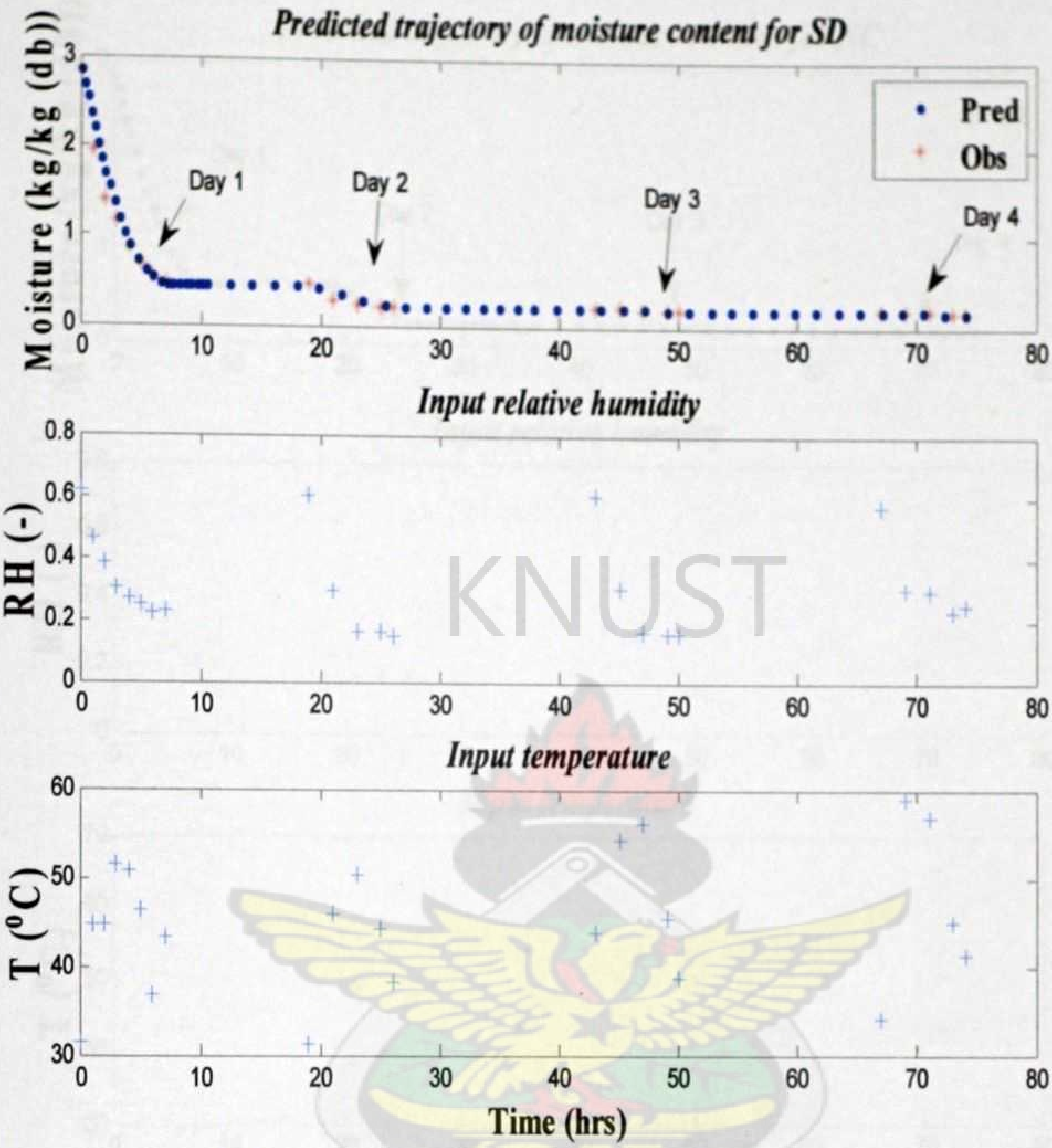


Figure 14: Predicted (Pred) and experimental (Obs) drying data for various temperatures (°C) and relative humidity (RH) for forced convection solar dryer (SD)

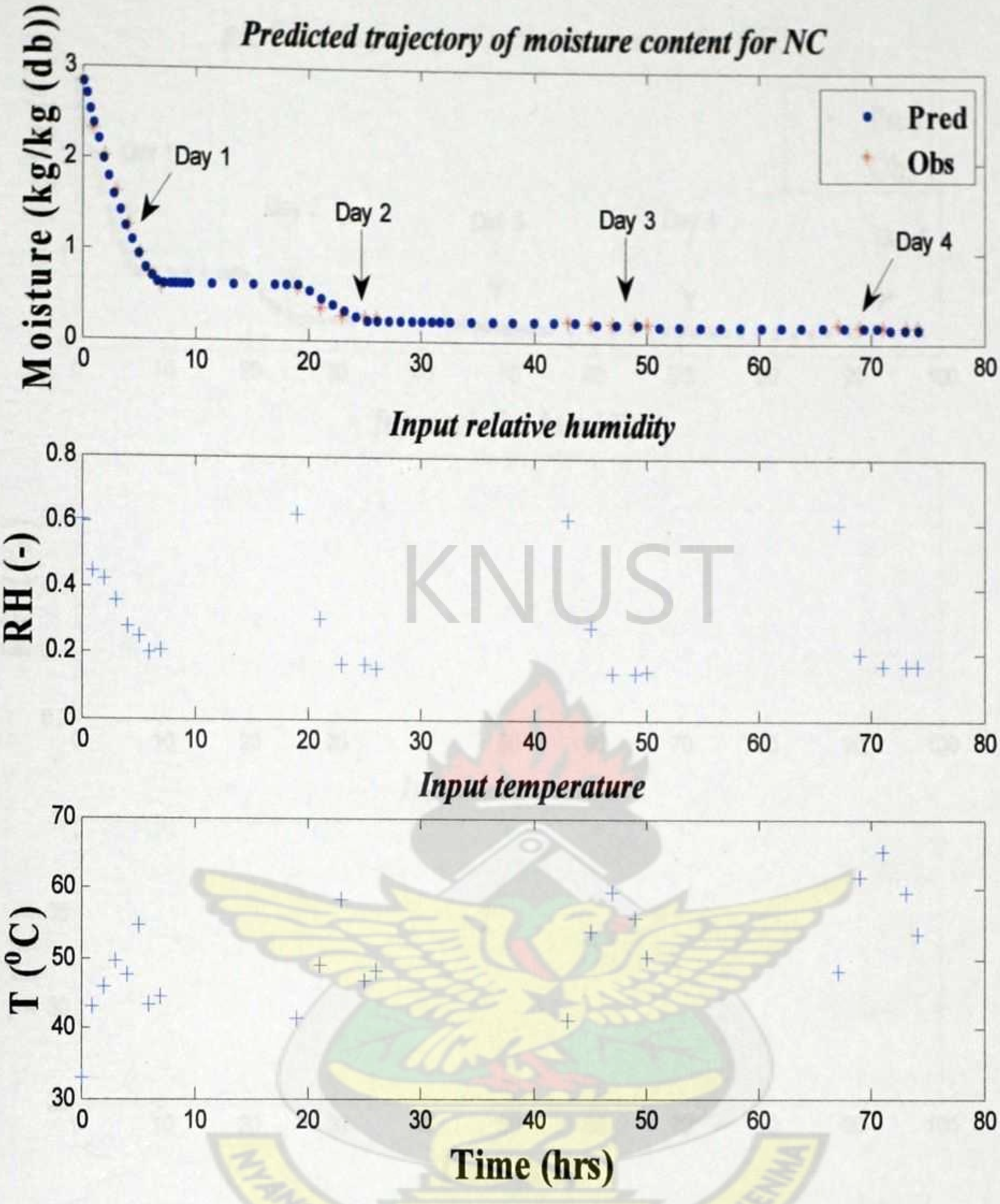


Figure 15: Predicted (Pred) and experimental (Obs) drying data for various temperatures (°C) and relative humidity (RH) for natural convection solar dryer (NC)

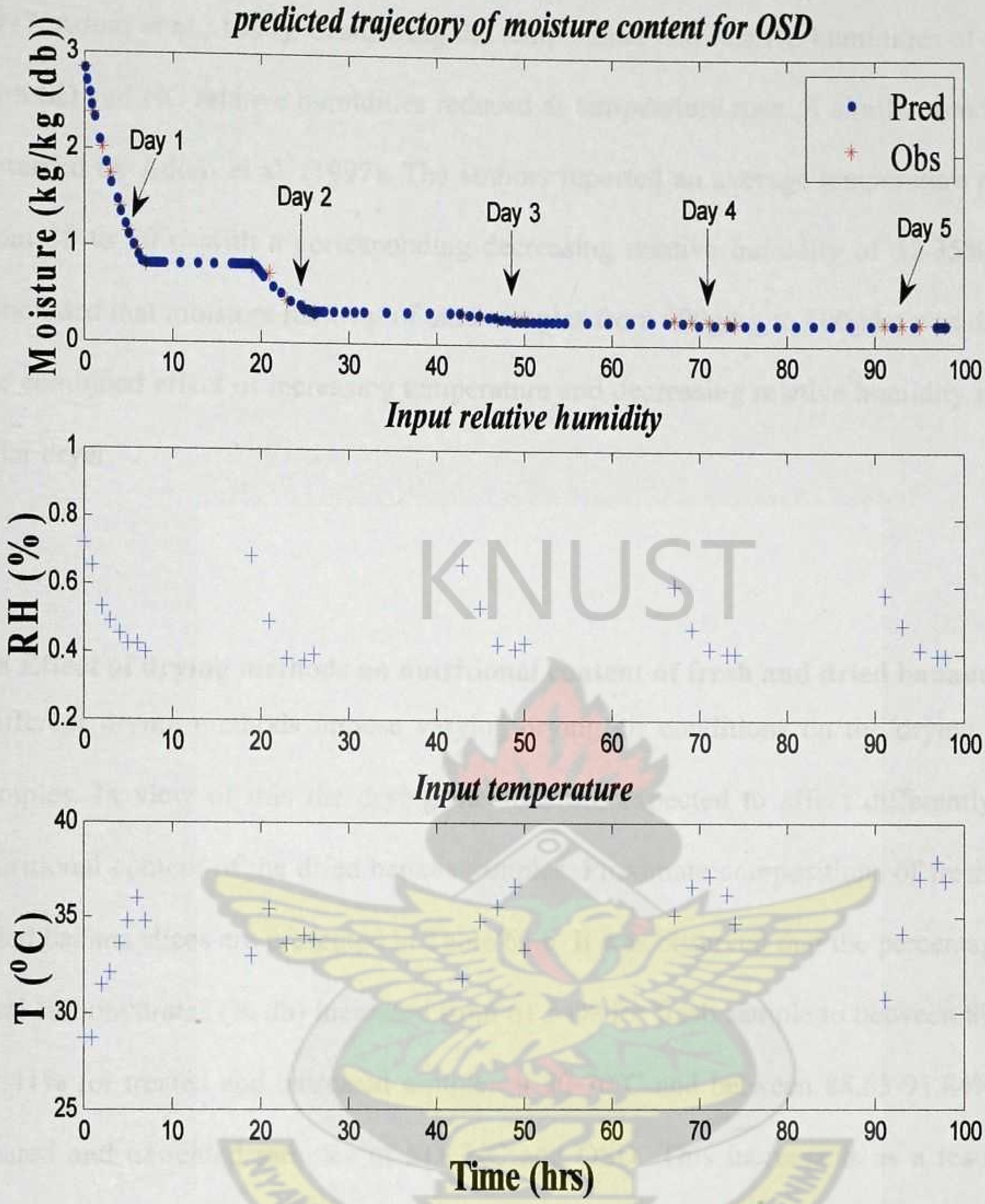


Figure 16: Predicted (Pred) and experimental (Obs) drying data for various temperatures (°C) and relative humidity (RH) for open sun drying (OSD)

Solar dryers have the ability to reduce the relative humidities by 50% or less (Scanlin, 1997, Adom et al., 1997). Comparing the temperature and relative humidities of OSD with SD and NC relative humidities reduced as temperature rose. A similar trend was observed by Adom et al. (1997). The authors reported an average temperature range from 30 to 60°C with a corresponding decreasing relative humidity of 57-35% and concluded that moisture removal of okra samples from 900g/kg to 100g/kg was due to the combined effect of increasing temperature and decreasing relative humidity in the solar dryer.

4.8 Effect of drying methods on nutritional content of fresh and dried banana

Different drying methods impose varying drying air conditions on the drying food samples. In view of this the drying methods are expected to affect differently the nutritional content of the dried banana samples. Proximate compositions of fresh and dried banana slices are presented in Table 6a-b. It was observed that the percentage of total carbohydrates (% db) increased from 61.54% for fresh sample to between 89.76-91.41% for treated and untreated samples at 50-70°C and between 88.63-91.84% for treated and untreated samples of SD, NC and OSD. This increase is as a result of reduction in moisture resulting in higher concentrations of carbohydrate content. Agunbiade et al. (2006) reported a similar increase in carbohydrates content of dehydrated banana and plantain.

Table 6a: Proximate analysis of fresh and dried banana for different drying methods

Method	Moisture (% wb)	Carbohydrates (% wb)	Protein (% wb)
Oven drying			
FRESH	72.8 (267.65)	16.74 (61.54)	3.06(11.25)
70 TRT	12.4 (14.16)	78.99 (90.17)	4.81(5.49)
70 UNT	12.6 (14.42)	79.89 (91.41)	4.81(5.50)
60 TRT	12.6 (14.42)	78.19 (89.46)	4.81(5.50)
60 UNT	13.8 (16.01)	77.52 (89.93)	4.38(5.08)
50 TRT	13.0 (14.94)	78.09 (89.76)	4.81(5.53)
50 UNT	12.6 (14.42)	78.62 (89.95)	4.38(5.01)
Solar drying			
SD TRT	14.6 (17.2)	75.69 (88.63)	4.81(5.63)
SD UNT	14.8 (17.37)	75.99 (89.19)	4.81(5.65)
NC TRT	15.0 (17.65)	78.06 (91.84)	3.94(4.64)
NC UNT	14.8 (17.37)	76.87 (90.22)	4.13(4.85)
OSD TRT	16.8 (20.19)	74.72 (89.81)	4.38(5.26)
OSD UNT	16.6 (19.9)	74.82 (89.71)	4.38(5.25)

Values in bracket are in dry basis (% db)

Protein contents (% db) decreased for all drying methods. The amount of proteins contained in fresh banana was 11% db which was reduced to between 5.65-5.08% db. The results on the proximate (Table 6) indicated that dried banana at different drying methods maintained about 50% of protein content. Again treatment had less significance effect on the proximate properties. Reduction of protein content in banana slices for all the methods can be attributed to inorganic nitrogen which might have been given off during dehydration, there by affecting the protein content of the dehydrated sample.

Table 6b: Proximate analysis of fresh and dried banana for different drying methods

Method	Fiber (%)	Fat (%)	Ash (%)
Oven drying			
FRESH	5.60 (20.6)	1.00 (3.68)	0.80 (2.94)
50 TRT	2.0 (2.4)	0.5 (0.58)	1.60 (1.84)
50 UNT	1.6 (1.72)	0.5 (0.57)	2.40 (2.75)
60 TRT	1.5 (1.72)	0.5 (0.57)	2.40 (2.75)
60 UNT	2.0 (2.32)	0.3 (0.4)	2.00 (2.32)
70 TRT	1.5 (1.7)	0.5 (0.57)	1.80 (2.06)
70 UNT	1.0 (1.14)	0.5 (0.57)	1.20 (1.37)
Solar drying			
SD TRT	2.0 (2.34)	0.5 (0.59)	2.4 (2.81)
SD UNT	1.5 (1.77)	0.5 (0.59)	2.4 (2.82)
NC TRT	1.0 (1.18)	0.5 (0.47)	1.6 (1.88)
NC UNT	1.5 (1.76)	0.5 (0.59)	2.2 (2.58)
OSD TRT	1.0 (1.2)	0.5 (0.6)	2.6 (3.13)
OSD UNT	1.5 (1.8)	0.5 (0.6)	2.2 (2.64)

Values in bracket are in dry basis (% db)

The percentages ***(% db)*** of fiber reduced greatly for all methods and this is attributed to the application of heat and moisture removal. From 20.6% to 1.2% with 50 TRT being the highest and 1.2% OSD TRT being the lowest. The results are comparable to Agundele et al. (2006). They recorded lower fiber content after drying of banana and plantain dehydration. The results are in contrast with what Agoreyo et al. (2011) had for drying of plantain. They recorded a decrease of carbohydrates and fiber content in drying of plantain, yam and cocoyam.

The ash content (% db) which gives an indication of the minerals present in the dried sample decreased for all drying methods. However the decrease was not significant. Fat content (% db) decreased at the end of the drying process for all methods. Fats reduced significantly. Dried banana is a good source of food if less fat is required.

Temperatures affected nutrients by increasing the carbohydrates content, reducing the protein, the ash and fiber content. Results obtained are similar to that obtained in dehydration of plantain and banana slices by Agunbiade et al. (2006).

Table 7: Effects of different drying methods on minerals Phosphorus (P), Potassium (K), and Magnesium (Mg)

METHOD	P(mg/100g)	K(mg/100g)	Mg(mg/100g)
Oven drying			
FRESH	60 (220.6)	158 (5808.8)	58 (2101.5)
50 TRT	90 (103.4)	305 (2620.7)	84 (1793.1)
50 UNT	90 (103.4)	205 (2562.9)	72 (805. 0
60 TRT	130 (148.7)	198 (2265.4)	55 (629.3)
60UNT	90 (104.4)	174 (2018.6)	60 (686.5)
70 TRT	150 (171.2)	250 (3059.4)	84 (958.9)
70 UNT	150 (171.6)	205 (2345.5)	72 (821.9)
Solar drying			
SD TRT	140 (158.1)	285 (3278.7)	77 (901.6)
SD UNT	180 (211.3)	347 (4072.8)	55 (645.5)
NC TRT	60 (70.0)	242 (2847.1)	67 (788.2)
NC UNT	60 (70.0)	220 (2582.2)	65 (762.9)
OSD TRT	90 (108.2)	284 (3413.5)	94 (1130)
OSD UNT	120 (143.9)	328 (3932.9)	82 (983.2)

Values in bracket are in dry basis (% db)

Mineral content in banana slices were higher than what is reported in literature. All drying methods studied showed significant increase in minerals (Tables 7) except NC TRT and NC UNT which recorded the same amount of P in fresh and dried sample as 60 mg/100g.

Comparatively and considering the three solar systems, the SD dried samples recorded the least moisture content. This phenomenon caused the highest concentration effect on the mineral content. This is as result of a combination of forced air and relatively high temperature. For the OV dried samples the higher the temperature the higher the concentration effect. While the SD samples caused thrice as much increase in phosphorous for example, the OV samples at 70 °C caused twice as much increase with respect to the content in the fresh sample. Though there were general increases in potassium and magnesium contents they did not conform to any defined trend. Agoreyo et al. (2011) reported an increase, in the magnesium (Mg) content of plantain and ~~yam and~~ Calcium (Ca) content in dried plantain. This generally corroborates the results obtained for minerals. Increase in minerals corresponded to the increase in ash content of dried samples.

Vitamin C of fresh sample was higher than the values reported by Masamba et al. (2013) for banana as 13 mg/100. The results of vitamin C content for fresh and dried samples are summarized in Tables 8. The content was 33.6 mg/100g (120.7 mg/100 db) for fresh banana. The dried samples had higher vitamin C content than fresh samples regardless of the drying method. There was an increasing trend for the wet basis and a decreasing trend for the dry basis.

Table 8: Effects of different drying methods on Vitamin C

Method	Moisture (% wb)	Vitamin C (mg/100g)
Oven drying		
FRESH	72.6	33.1 (120.7)
50TRT	12.4	61.7 (70.63)
50UNT	12.6	50.7 (58.24)
60TRT	12.6	64.3 (74.56)
60UNT	13.8	60.8 (69.57)
70 TRT	12.6	76.3 (87.26)
70 UNT	12.4	57.1 (65.29)
Solar drying		
SD TRT	14.6	60.7 (71.04)
SD UNT	14.8	57.6 (67.61)
NC TRT	15.0	58.9 (69.33)
NC UNT	14.8	55.7 (65.57)
OSD TRT	16.8	53.7 (64.43)
OSD UNT	16.6	49.7 (59.78)

Values in bracket are in dry basis (mg/100g db)

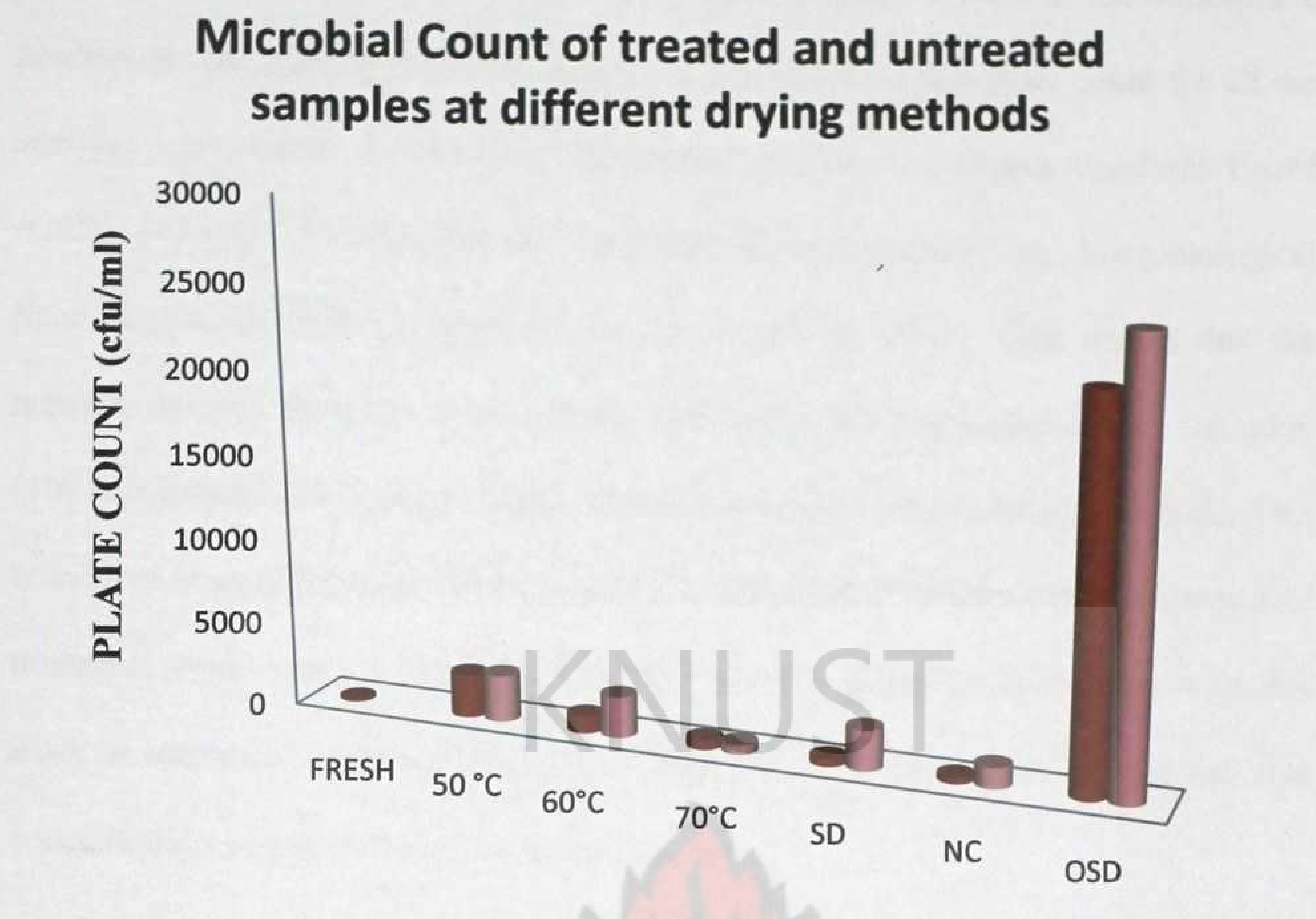
Vitamin C degradation kinetics has been studied by Jin et al. (2011). From the studies as moisture content reduces, rate of vitamin C degradation initially increases until it reaches a peak and then falls after 2 kg/kg db moisture content. This means that from moisture content below 2.0kg/kg db degradation rate decrease corresponding to an increase in vitamin C content.

In the present work the initial moisture content was between 2.50 kg/kg db (OV) – 2.80 kg/kg db (solar energy). Therefore an increase in vitamin C content for all drying methods was no surprise though it contradicted some reported literature. From all methods of drying Vitamin C content increased between 50-130%.

Higher Vitamin C content were recorded for 70°C (TRT) representing about 130% increment and OSD UNT by 50% the lowest. There were significant differences ($p<0.05$) in vitamin C content of samples dried by OSD, SD and NC. Meanwhile ascorbic acid pretreated samples showed an increased vitamin C content on treated samples for all drying methods.

4.9 Bacterial (Plate) Count of Fresh and Dried Banana.

The quality of the final product after drying is paramount. Thus effect of drying methods on the microbiological status of the dried product was investigated. This is presented in Figure 17.



	FRESH	50 °C	60°C	70°C	SD	NC	OSD
UNT (cfu/ml)	137.5	2550.27	1000.45	562	437.5	362.5	22538.5
TRT (cfu/ml)		2746.41	2424.02	562	2415.85	1221.75	25745.6

Figure 17: Plate count of fresh and dried samples of different drying methods.

The microbial load on fresh samples (Figure 17) was found to be 1.375x10^2 cfu/ml . After drying the microbial load on dried samples were 2.550 x10^3 cfu/ml (50 UNT) and 2.746 x10^3 cfu/ml (50 TRT), 1.000 x10^3 cfu/ml (60 UNT) and 2.424 x10^3 cfu/ml (60 TRT) and 5.62 x10^2 cfu/ml (70UNT) and 5.62 x10^2 cfu/ml (70TRT) of OV being the least. This means that temperature significantly influenced the reduction of microbial growth.

The following was also counted to be, 4.375 x10^2 (SD UNT) and 2.415 x10^2 cfu/ml (SD TRT), 3.625 x10^2 (NC UNT) and 1.22175 x10^3 cfu/ml (NC TRT) and finally 2.57456 x10^4 (OSD UNT) and 2.23 x10^4 cfu/ml (OSD TRT) recording the highest values of bacterial counts. It is indicative that exposure of food to the atmosphere predisposes the food to microbial attack. It was observed that plate count for all the samples were within the standard requirements of both the Ghana Standards Board (GSB) ($<1.0x10^4$cfu/ml) and the International Commission on Microbiological Specification (ICMS) ($<1.0x10^6$cfu/ml) (Soyiri et al., 2008). This means that the number isolated from the food sample was within the acceptable range. Scanlin, (1997) indicated that drying at higher temperature reduces bacterial load on food. This is evident in samples from 70 OV and NC. Leigh (2007) indicated that ascorbic acid treatment could prevent microbial load but this was however in contrast with this work as treatment did not affect microbial growth. This may be due to the fact that concentration of ascorbic acid used was low.

CHAPTER FIVE

5.0 CONCLUSION

The effect of different drying methods on nutritional properties of banana *(Musa sapientum*) slices at 5mm thickness was investigated. Increasing air temperature significantly reduced the drying time of the banana slices. The entire drying process occurred in falling rate period. Drying rate decreased with decreasing moisture content. Drying rate were almost the same below 0.2kg/kg db for all temperatures.

There was a strong dependency between drying rate, diffusivity and temperature Activation energy (Ea), was found to be 31.58 kJ/mol for untreated and 25.58 kJ/mol for treated samples. Effective diffusivity and drying rate constant depended strongly on drying air temperature. In predicting the experimental drying data, it was shown that the drying rate constant varied over time and specifically with respect to the days as moisture content dropped.

The Henderson and Pabis model was found to satisfactorily describe the thin-layer drying kinetics of banana slices out of the six drying models. Drying with SD was faster than drying with NC and OSD.

Treatment had no significant effect on the drying characteristics, proximate, minerals but had effect on the Vitamin C content and microbial count on dried banana slices.

Bacterial count was between the acceptable range of the Ghana Standards Board (GSB) (<$1.0x10^4$cfu/ml) and the International Commission on Microbiological Specification (ICMS) (<$1.0x10^6$cfu/ml).

REFERENCES

AOAC, (1996). Moisture in dried fruits. In: Williams S, editor. Official methods of analysis of the Association of Official Analytical Chemists. Arlington, Va.: AOAC. 415.

Abano, E.E. and Sam-Amoah, L.K. (2011). Effects of different pretreatments on drying characterics of banana slices. *ARPN Journal of Engineering science,* 6(3): 120-128.

Adeniji, T. A., Tenkouano, A., Ezurike, J.N., Ariyo, C. O. and Vroh-Bi, I., (2010). Value-adding post-harvest processing of cooking bananas (*Musa* spp. AAB and ABB genome groups). *J. of Biotechnology*, 9 (54): 9135-9141, 29.

Adom, K .K., Dzobefia, V.P. and Ellis, W.O. (1997). Combined effect of drying time and slice thickness on the solar dryng of okra. *J. of the Science of Food and Agriculture*, 73:315-320.

Agoreyo, B.O., Akpiroroh O., Orukpe, O.A. Osaweren, O.R. And Owabor, C.N (2011). The effects of various drying methods on the nutritional composition of Musa paradisica Dioscorea roundata And Colocasia esculenta. *Assian J. Of Biochemistry,* 6(6):458- 464.

Agunbiade, S.O., Olunlokun, J.O. and Oloafe, O.A. (2006). Quality of chips produced from rehydrated dehydrated plantain and banana. *J. of Nutrition,* 5(5): 458-463.

Afzal, T.M. and Abe, T. (1998). Diffusion in potato during far infrared radiation drying. *Journal of Food Engineering,* 37: 353-365.

Aishah, M.S. and Wan Rosli, W.I. (2013). Effect of Different Drying Techniques on the Nutritional Values of Oyster Mushroom. *Sains Malaysiana,* 42(7): 937–941.

Akpinar, E.K. and Bicer, Y. (2006). Mathematical modeling and experimental study on thin layer drying of strawberry. *International Journal of Food Engineering,* 2 (1):5

Al- Zaemey, A.B.S., Falana, I.B. and Thompson, A.K. (1989). Effects of permeable fruit coating on the storage life of plantain and banana. *Aspects of Applied biology*, 20: 74.

Amankwah, E.A., Ayim, I., Dzisi, K.A. and Barimah(2011). Nutritional content and functional properties of French Horn, False Horn and FHIA-21. *American J. of food Tech.*, 6(4):322-328

Amankwah, E.A., Dzisi, K.A., van Straten, G., A.J.B. van Boxtel (2012) Modeling the solar collector for drying agricultural products, *Proceedings of the 18th International Drying Sympozium, China, Xiamen, 11-15th, November, A3.*

Amunugoda, P. N. R. J., Senanayake, N.S., Wijeratnam, R.S. and Kulatunga, K.D. G. (2013). Quality enhancement of dehydrated products through the modification of solar tunnel dryer for continuous operation in rural communities. *J. of Energy Engineering,* 3(1): 7-14.

Axtell, B. and Bush, A., (1991). Try drying it. Case studies in the dissemination of tray drying technology. Intermediate Technology Publications, London.

Ayim, I., Amankwah, E.A. and Dzisi, K.A. (2012). Effect of pretreatment and temperature on the air drying of French and False horn plantain slices. *J. of Animal & Plant Sciences*, 13(2): 1771-1780.

Ayim I. (2011). Drying characteristics of pretreated pulp of triploid and tetraploid plantain varieties. An unpublished thesis submitted to the Biochemistry Department, Kwame Nkrumah University of Science and Technology, Kumasi.

Baini, R. and Langrish, T.A.G. (2007). Choosing an appropriate drying model for intermittent and continuous drying of bananas. *J. of Food Eng., 79 (1): 330 – 343.*

Benderitter M.M.V., Vergely C , Dalloz, F., Briot, F. and Rochette, L. (1998) . Fundamental Clinical Pharm., 12:510-516.

Bolin, H.R., Petrucci, V. and Fuller, G. (1975). Characteristics of mechanically harvested raisins produced by dehydration and field drying. *Journal of Food Science*, 40, 1036-1038.

Cape, J. N. and Percy, E. (1996). The interpretation of leaf-drying curves. Plant cell and environment. Blackwell Science Ltd., 19,356-361.

Ceylan, I., Aktas, M. and Dog˘an, H. (2007). Mathematical modeling of drying characteristics of tropical fruits. *Applied Thermal Engineering* ,27: 1931-1936.

Chia, C.L. and Huggins, C.A. (2003). Bananas Community fact sheet BA-3(A) fruit. Hawaii Cooperative Extension Service, CTAHR, University of Hawaii.

Chayjan, A.A. (2012). Modelling some drying characteristics of high moisture potato slices in fixed, semi fluidized and fluidized bed conditions. *J. Agr. Sci. Tech.,* 14: 1229-1241.

Crank, J. (1975). The mathematics of diffusion (2nd ed.). Oxford: Clarendon Press.

Dadali, G., Apar, D.K. and Ozbek, B. (2007). Estimation of effective moisture diffusivity of Okra for microwave drying. *Drying technology* 25:1445-1450.

Daily Guide, (2012). [online] http://www.dailyguideghana.com/?category_name=business&paged=185 [accessed on 12/10/2012]

Darvishi, H., Farhang, A. and Hazbavi, E. (2012). Mathematical Modeling of Thin - Layer Drying of Shrimp. *Global J. of Science Frontier Research Mathematics & Decision Sciences*, 12(3):1-9.

Das, I., Das, S.K. and Bal, S. (2004). Specific energy and quality aspects of infrared (IR) dried ~~parboiled~~ rice. *J. Food Eng.,* 62: 9-14.

Desrosier, N.W. (1963). The technology of food preservation.Westport, Conn.: Avi Publishing.

Demirel, D. and Turhan, M. (2003). Air-drying behavior of Dwarf Cavendish and Gros Michel banana slices. *J. of Food Engineering,* 1(11):59.

Decuypere, J.D. (2013). Nutrient Chart/Health alternatives http://www.health-alternatives.com/fruit-nutrition-chart.html

Dickson, K.B., and Benneh,G. (1988). A new geography of Ghana. Longman Group UK Limited. Longman House, Burnt mill, Harlow, Essex, England.

Doymaz, I. (2004). Convective air drying characteristics of thin-layer carrots. *J. of Food Eng.*, 61(3), 359-364.

Doymaz, I. (2010). Evaluation of Mathematical Models for Prediction of Thin-Layer Drying of Banana Slices. *International J. of Food Properties*, 13:3, 486-497, DOI: 10.1080.

Dzisi, K.A., Ayim, I. and Amankwah, E.A. (2012). Thin Layer Modeling Of Fhia-21 (Tetraploid Plantain). *ARPN J. Agricultural and Biological Science,* 7(11):947-952

Elkhoreiby, A.M. (2003). Banana production: Egypt and Arabian countries (El-dar, Elarabia), 180.

Essien, A.I., Ebana, R.U.B. and Udo, H.B. (1992). Chemical evaluation of pod and pulp of the fluted pumpkin (Telfairaoccidentalis) fruit. *Food Chem.*, 45:175-178.

Falade, K.O. and Ogunwolu, O.S. (2012). Modeling of Drying Patterns of fresh and osmotically pretreated cooking banana and plantain slices. *J. of Food Processing and Preservation*, 1-16.

FAO, (2001). Contribution of bananas to income, employment and food security in Ghana and Ecuador; Committee on commodity problems [online]. Intergovernmental group on bananas and on tropical fruits. San José, Costa Rica. Available from: www.fao.org/docrep/MEETING/004/Y1871e.HTM. [Accessed on 16th February, 2013].

FAO, (2004). Assessment of food import and food aid against support for Agricultural development: The case of Ghana. Draft report for the Food and Agriculture Organization Regional Office, Accra, Ghana. p55

FAO, (2008). Certification in the value chain for fresh Fruits; The example of the banana industry. Information Division, FAO, Rome, Italy.

Forson, F.K., Nazha, M.A.A., Akuffo, F.O. and Rajakaruna, H. (2006). Design of mixed-mode natural convection solar crop dryers: Application of principles and rules of thumb (online) knust.edu.gh/library/downloads/6/64.pdf.

Guarte R. (1996). Modeling the drying behavior of copra and development of a Natural convection dryer for production of high quality copra in the Philippines. Dissertation. University of Hohenheim.

Gutti, B.,Kiman, S., and Mustafa, B.G. (2012). Design and construction of forced and natural convection solar vegetable dryer with heat storage. *J. of Eng. and Applied Sci.,* 7(10):1213-1218

Islam, M.S., Haque, M.A. and Islam, M.N. (2012). Effects of drying parameters on dehydration of green banana (*Musa sepientum*) and its use in Potato (*Solanum tuberosum*) Chips Formulation. *The Agriculturists,* 10 (1): 87-97 *(2012)*

Hassanian, A.A. (2009). Simple Solar Drying system for Banana fruit. *J of Agricultural Sciences.,* 5(4):446 – 455.

Hanson J.A. and Andress E. L. (1914). Preserving Food (Drying fruits and vegetables). http://nchfp.uga.edu/publications/uga/uga_dry_fruit.pdf

Hill, K.A. and Pyke, N. (1997). Influence of commercial drying on maize grain attributes. *Foundation for arable research (far) arable update no.* 10

Hoy, M.K., EdD, R.D. and Goldman, J.D. (2012). Potassium Intake of the U.S. Population: What we eat in America. Food Surveys Research Group Dietary Data Brief No. 10. Available at: http://ars.usda.gov/Services/docs.htm?docid=19476 [08/04/2013]

Jannot, Y. Talla, A. Nganhou, J. and Puiggali J.R. (2004). Modeling of banana convective drying by the drying characteristic curve (DCC) method. *Drying Technology*, 22:1949-1968.

Jayas, D.S.S., Pabis, C.S. and Muir, W.E. (1991). Review of Thin layer drying and rewetting equations. *Drying Technology,* 9: 551-558

Jha, S.S.N. (1996). Determination of processing conditions of gorgon nut (Euryale ferox). *J. of Agricultural Engineering Research*, vol. 63, 103–112.

Jin X., van der Saman, R.G.M. and van Boxtel, A.J.B. (2011). Evaluation of free volume theory to predict moisture transport and quality changes during Broccoli drying. *Drying technology: An International Journal, 29(16):*1963-1971.

Kolawole, O. F. and Ogunwolu, O.S. (2012). Modeling Of Drying Patterns Of Fresh and osmotically pretreated cooking banana And plantain slices. *J. Of Food Processing and Preservation,* 1-16

Karim, O.R. and Adebowale, A.A. (2009). A dynamic method for kinetic model of ascorbic acid degradation during air dehydration of pretreated pineapple slices. *International Food Research Journal,* 16: 555-560.

Karathanos, V.T. and Belessiotis, V.G. (1999). Application of a thin layer equation to drying data of fresh and semi-dried fruits. *Journal of Agricultural Engineering Research,* 74, 355-361.

Khin, S.O. and Yee, Y.W. (2011). Preparation of Banana Chips and Banana Powder. *Universities Research Journal,* 4(3).

Kotwaliwale, N., Bakane, P. and Verma, A. (2005). Changes in textural and optical properties of oyster mushroom during hot air drying. *Journal of Food Engineering,* 78: 1207-1211.

Korus, A. (2011). Effect of preliminary processing, method of drying and storage temperature on the level of antioxidants in kale (Brassica oleracea L. var. acephala) leaves. *LWT - Food Science and Technology,* 44:1711–1716.

Lee, S.H. and Labuza, T.P. (1975). Destruction a function of ascorbic acid as water activity. *Journal Of Food Science,* 40 :370-373.

Leigh J., (2012).What is proximate analysis.[online] www.wisegeek.com [accessed on

12/12/2012]
Lewis, W.K. 1921. The rate of drying the solids materials. *Industrial Engineering Chemistry* 13: 427.
Maharaj, V. and. Sankat, C.K. (1996). The drying Behaviour of Green Dasheen Leaves as affected by Temperature and Blanching Treatments. ASEAN Food Journal , Vol.11(4): 138-147
Mahendran, T. and Prasannath, K. (2008). Influence of Pre-treatments on Quality of Dehydrated Ripe Banana (*Musaacuminata* cv *Embul). J. of Food and Agriculture*, 1(2) 11-10.
Masamba, K.G., Mkandawire, M., Chiputula, J. and Nyirenda, K.S. (2013). Evaluation of sensory quality attributes and extent of vitamin C degradation in dried pineapple, mango and banana fruit pieces pre –treated with sodium metabisulphite and lemon juice, 3(3):75-80.
McMinn, W.A.M. and Magee, T.R.A. (1997). Physical characteristics of dehydrated potatoes. *Journal of Food Engineering,* 33: 49 – 55.
Mishkin, M.A. (1983). Dynamic modeling, simulation and optimization of quality changes in air-drying of foodstuffs. Ph.D. thesis, Massachusetts Institute of Technology, Cambridge, MA.
Mittal, G. (1999) Mass diffusivity of food products. *Food Review International,* 15(1):19-66.
MoFA, (2006). Agriculture in Ghana: Facts and Figures. Draft Report, Ministry of Food and Agriculture, Accra, Ghana. 55. http://mofa.gov.gh/site/wp-content/uploads/2011/11/GCAP-FINAL-PMP-Safgd-Team-CLEARED.pdf [Assessed on 03/02/2013]
Morris, A., Audia, B. and Olive-Jean, B. (2006). Effect of Processing on Nutrient. *Foods Nutrient,* 37(3):160-165.
Moser, U. and Bendich, A. (1990): Vitamin C. In Handbook of Vitamins. Edited by Machlin LJ. Marcel Dekker, New York:Ch5.
Nelson, S.C., Ploetz, R.C. and Kepler, A.K. (2006). Musa species (Bananas and Plantains), ver. 2.2. In: Elevitch CR (ed.). Species Profiles for Pacific Island Agroforestry. Permanent Agriculture Resources (PAR), Hôlualoa, Hawaii.(http://www.traditionaltree.org).
Ogheneruona, D.E. and Yusuf Momoh, O.L. (2011). Design and Fabrication of a Direct Natural Convection Solar Dryer for Tapioca Leonardo Electronic Journal of Practices & Technologies, 18:95 http://lejpt.academicdirect.org/A18/095_104.tm. [02/05/2013]
Ologhobo, A.D. and Fetuga, B.L. (1983). Investigation on the trypsin inhibitor, hemagglutinin, phytic and tannic acid contents of cowpea Vigna unguiculata. *Food Chem.* 12(4):249-254.
Osunde, Z.D. and Musa Makama, A.L. (2007). Assessment of Changes in Nutritional Values of Locally Sun-Dried Vegetables *AU J.T.* 10(4): 248-253.
Ozbek, B. and Dadali, G. (2007). Thin-layer drying characteristics and modeling of mint leaves undergoing microwave treatment. *Journal of Food Engineering,* 83: 541-549.

Oyewole, O.A. (2012). Microorganisms Associated with Deterioration of Stored Banana Fruits. *Frontiers in Science*, 2(5): 86-91.

Parti, M. (1993). Selection of mathematical model for drying grain in thin-layers. *Journal of Agricultural Engineering Research,* 54: 339-352.

Padovani, M.I. (1989), Banana um mercado crescente para este alimento milenar. 2a ed., ICONE, São Paulo, Brasil.

Padilla, R.Y.C., Limaverde, J.R., and Finzer, J.R.D. (2004). Drying of banana paste in rotary dryer with inert bed *Drying 2004 – Proceedings of the 14th International Drying Symposium (IDS 2004) São Paulo, Brazil, 22-25 August 2004,* vol. B, 876-883.

Pan, Z., Shih, C., McHugh, T.H. and Hirschberg, E. (2008). Study of banana dehydration using sequential infrared radiation heating and freeze-drying. *LWT - Food Science and Technology*, 41:1944 -1951.

Prescott, L.M., John, P.H., Donald, A.K. (2002). *Microbiology*, 4th edition. NY McGraw Publishers, 11-14.

Ponting, J. D. and McBean, D.M. (1970). Temperature and dipping treatment effects on drying rates and drying times of grapes, prunes and other waxy fruits. *Food Technology,* 24: 85-88.

Puupponen-Pimiä, R., Häkkinen, S.T., Aarni, M., Suortti, T., Lampi, A- M. Eurola, M., Piironen, V., Nuutila, A.M. and Oksman- Caldentey, K.M. (2003). Blanching and long-term freezing affect various bioactive compounds of vegetables in different ways. *J. of the Science of Food and Agriculture,* 83(14):1389–1402.

Rahman, M.S., Perera, C.O. and Thebaud, C. (1998). Desorption isotherm and heat pump drying kinetics of peas. *Food Research International*, 30, 485-491.

Ruta, G., Zanda, K. and Karina, R. (2012) .Effect of Pretreatment method on the Content of Phenolic Compounds, Vitamin C and Antioxidant Activity of Dried Dill. *World Academy of Science, Engineering and Technology*, 64:1075-1079.

Sarsavadia, P.N., Sawhney, R.L., Pangavhaned, R. and Singh, S.P. (1999). Drying behaviour of brined onion slices. *J Food Eng,* 40, 219-226.

Scanlin, D. (1997). The Design, Construction, and Use of an Indirect, Through-Pass, Solar Food Dryer[online].1-11 http://www.homepower.com/view/?file=HP57_pg62_Scanlin [accessed 02/09/2012].

Selman, J.D. (1994). Vitamin retention during blanching of vegetables", *Food Chemistry*, 49(2):137–147.

Singh, B., Panesar, P.S. and Nanda, V. (2006). Utilization of Carrot Pomace for the Preparation of a Value Added Product. *World Journal of Dairy and Food Sciences,* 1(1): 22-27.

Soyiri, I.N., Agbogli, H.K. and Dongdem, J.T. (2008). A pilot microbial assessment of beef sold in the Ashaiman market, a suburb of Accra, Ghana. *African J. of Food Agriculture Nutrition and Development, 8(1): 90-103.*

Taiwo, K.A. and Adeyemi, O. (2009). Influence of blanching on the drying and

rehydration of banana slices. *Afr. J. Food Science,* 3(10): 307-315.
Thompson, R.A. and Foster, G.H. (1963). Stress cracks and breakage in artificially dried corn. United States Department of Agriculture. Marketing Res. Report No. 631.24.
Thuwapanichayanam, R., Prackchayawarakorn, S. and Kunwisawa, J. (2011) Determination of effective moisture diffusivity and assessment of quality attributes of banana slices during drying, *Food science and technology,* 44:1502-1510.
Trim, D.S. and Robinson, A.P. (1994). Drying methods in: grain storage techniques, evolution and trends in developing countries. Edited by proctor L.D. food and agricultural organization of United Nations. Agricultural services bulletin no. 109.
Verma, L.R., Bucklin, R.A., Endan, J.B. and Wratten, F.T. (1985). Effects of drying air parameters on rice drying models. *Transactions of the ASAE,* 28, 296-301.
Westerman, P.W., White, G.M. and Ross, I.J. (1973). Relative humidity effect on the high temperature drying of shelled corn. *Transactions of the ASAE,* 16: 1136-1139.
Yagcioglu, A., Degirmencioglu, A. and Cagatay, F. (1999). Drying characteristic of laurel leaves under different conditions. In: A. Bascetincelik (Ed.), *Proceedings of the 7th International Congress on Agricultural Mechanization and Energy,* Adana, Turkey: Faculty of Agriculture, Cukurova University, (565–569).
Yaldiz, O., Ertekin, C. and Uzun, H.I. (2001). Mathematical modelling of thin layer solar drying of Sultana grapes. *Energy,* 26(5), 457–465.

Zogzas, N.P., Maroulis, Z.B., and Marinos-Kouris, D. (1996). Moisture diffusivity data compilation in foodstuffs. *Drying Technology,* 14(10): 2225–2253.

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

Appendix 2: Calibration curve for vitamin C