Sudan University of Science and Technology

College of Graduate Studies

Design and Modification of Family Size Dryer for Vegetables and Fruits using Hot Water

Thesis Submitted in Fulfillment of the Requirements for the Degree of Ph.D in Agricultural Engineering

By

Khalid Osman Elmussaad Alnour

B.Sc (Honours) Sudan University of Science and Technology 2000

M.Sc in Layers Performance AS Affected by Some Envirpmental Factors - University of Khartoum 2007

Supervisor

Dr. Elnougomi Abd Elgadir Omer

Co-Supervisors

Prof. Dr. Hatim Makki

Dr. Yosrri Bayomi

2015

الآية

قال تعالي:

َال(َقْرعُ ونَ َسْبَع ِسن ِينَ َدَأبً ا فَما َحَصدتُّْم فَذُروهُ فِ ي ُسنب ُل ِه إِلاَّ قَل ِيلاً ِّمَّا
تَأْكُلُونَ(٤٧) ثُمَّ ي َأْتِ ي ِمن َبْعِد ذَل ِكَ َسْبٌع ِشَدادٌ ي َأْ كُلْنَ َما قَدَّْمتُْم لَُهنَّ
إِلاَّ قَل ِيلاً ِّمَّا تُْحِصنُ ونَ (٤٨)).

صدق الله العظيم

سورة يوسف

Dedication

To my family

ACKNOWLEDGEMENTS

I would like to express my gratitude to my supervisor. **Dr. Elnougomi Abd Elgadir Omer** for providing this research opportunity to me, for his supervision of the project and for his helpful guidance .His leadership and friendly attitude were a great help to me.

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LIST OF CONTENTS

Title **Page No.**

LIST OF FIGURES

LIST OF PLATES

Title **Page No.**

LIST OF APPENDICES

Abstract

The experimental study was conducted in the Department of Agricultural Engineering, Faculty of Agriculture, University of Cairo, Egypt. The experiment include design of two dryers, hot water and electric candles dryers, . The source of energy is the only difference between their components. Three varieties of horticulture products, bananas, potatoes and onions were selected to test the dryers performance.

Three different methods of drying were applied based on the location of fan used inside the drying chamber. (top, bottom or both).

The dried products were subjected to many tests. These tests includes drying rate, moisture content, Physical properties (bulk density, water solubility index, rehydration ratio, water absorption index, yield and dehydration ratio) and organoleptic evaluation (color, taste, flavor, general appearance and overall quality).

Electric candles dryer gave faster drying rate (5.5 hours) when using both fans or bottom fan only for banana. For potatoes drying rate; electric candles dryer using top fan gave the faster drying time (4 hours). Electric candle dryer gave faster drying rate when bottom fan was used for onion dried product .

The lowest figure scored for potatoes moisture content with electric candles and hot water dryers when bottom fan used 3.25% and 3.33% respectively, while electric candles with both fans gave the highest value for banana 9.89%

System of electric candles drying for potato to measure bulk density using top and bottom fans obtained the highest value 1.250 (g/ml).

The result of water solubility index measured for different crops showed that, electric candles dryer using bottom fan gave the highest value 71.06(g/100gSM) for banana sample.

The tested rehydration ratio of three dried crops; electric candles dryer gave highest value for onion with both fans 6.50. Hot water dryer using top fan gave the highest value 5.55(g.gel/g DM) for potato when water absorption index measured .

The best result obtained with hot water dryer using top fan 19.93% for onion yield. The dehydration ratio result of banana indicated that, the hot water dryer using two fans gave the highest value 5.77.

When the crops subjected to color evaluation; hot water dryer with two fans had a lowest value 1.29 for potatoes. Onion taste dried by hot water dryer using bottom fan gave the lowest and best value 2.13 among three crops. Onion flavor evaluation gave the best result 2.19 when electric candles dryer with two fans was used. Potatoes general appearance recorded the best result among the tested crops with hot water dryer using both fans 2.24. Overall quality evaluation showed that, hot water dryer using both fans gave the best result 2.18 for potatoes more than banana and onion . The general conclusion for the previous parameters results (bulk density of banana, dehydration ratio of banana, color of potatoes, onion taste, general appearance of potatoes and overall quality of potatoes) indicated that, hot water dryer with top and bottom fans ranking as superior than candles dryer.

ملخص البحث

أجريت هذه التجربة في قسم الهندسة الزراعية، كلية الزراعة، جامعة القاهرة، مصر. شملت التجربة تصميم مجففين: مجفف الماء الساخن و مجفف الشمعات الكهربائية .مصدر الطاقة هو الفرق الوحيد بين مكونات المجففين. وقد تم اختيار ثلاثة أنواع من المنتجات البستانية وهى الموز، البطاطس و البصل لاختبار أداء المجففين.

طبقت ثلاث طرق لإجراء عملية التجفيف استنادا إلى استخدام موقع المروحة داخل غرفة التجفيف. (أعلى ، أسفل أو كليهما).

تعرضت المنتجات المجففة للكثير من الاختباراتز شملت هذه الاختبارات معدل التجفيف، المحتوى الرطوبى، الخصائص الفيزيائية (الكثافة الظاهرية، مؤشر للذوبان في الماء، نسبة التشرب، مؤشر امتصاص الماء، الإنتاجية ونسبة الجفاف) والتقييم الحسي (اللون ،الطعم ،النكهة، ،المظهر العام والجودة الشاملة).

اعطى مجفف الشمعات الكهربية اسرع معدل تجفيف (٥,٥ ساعة) للموز عند استخدام المروحتين معا او استخدام مروحة من اسفل فقط . اظهرت نتائج معدل تجفيف البطاطس ان مجفف الشمعات الكهربية اعطى اسرع وقت (٤ ساعات) عند استخدام المروحة العلوية فقط. بالنسبة للبصل نجد ان مجفف الشمعات الكهربية اعطى اسرع معدل تجفيف (٤ ساعات) عند استخدام مروحة من اسفل فقط.

بالنسبة إلى المحتوى الرطوبي في المنتجات المختلفة، أظهرت البطاطس انه ليست هناك فرق معنوي بين المجففين.وسجل أدنى مستوى مع مجفف الشمعات الكهربائية ومجفف الماء الساخن عندما استخدمت مروحة أسفل ٣.٢٥٪ و ٣.٣٣٪ على التوالي، في حين اعطى مجفف الشمعات الكهربائية مع كل من المروحتين أعلى قيمة ٩.٨٩٪ فى الموز.

أشارت النتائج التي تم الحصول عليها على الكثافة الظاهرية للموز أن مجفف الماء الساخن مع المروحتين معا أعطى أقل قيمة ٠.٧٩٣٠ (جم / مل). بينما اعطى نظام مجفف الشمعات الكهربائية أعلى قيمة ١.٢٥٠ (جم / مل) للبطاطس باستخدام المروحتين كليهما .

أظهرت نتيجة مؤشر الذوبان في الماء للموز بواسطة مجفف الشمعات الكهربائية باستخدام مروحة أسفل أعطى أعلى قيمة ٧١.٠٦ (جم. صلب ذائب / ١٠٠جم مادة صلبة). في حين أن مجفف الشمعات الكهربائية للبطاطس باستخدام المروحتين أعطى أقل قيمة ٩.١٠ (جم .صلب ذائب/ ١٠٠جم مادة صلبة) وأظهرت نتيجة نسبة التشرب للعينة المجففة للموزان مجفف الماء الساخن باستخدام كل من المروحتين اعطى أدنى قيمة ٢.١٦ في حين أن أعلى قيمة لنسبة التشرب تم الحصول عليها للبصل بواسطة مجفف الشمعات الكهربائية مع كل من المروحتين ٦.٥٠.

اوضحت نتيجة مؤشر امتصاص المياه ان الموز حقق أدنى قيمة هى١.٣٥ (جم. جل / جم مادة صلبة) عن طريق مجفف الشمعات الكهربائية باستخدام المروحتين معا. من جهة أخرى نجد أن مؤشر امتصاص الماء للبطاطس أعطى أعلى قيمة ٥.٥٥ (جم. جل / جم مادة صلبة) هع مجفف الماء الساخن باستخدام المروحة العلوية.

أشارت نتائج الدراسة أن إنتاجية الموز في مجفف الماء الساخن باستخدام المروحتين معا أعطى أقل قيمة ١٧.٣١٪. في حين أن أفضل انتاجية تم الحصول عليها مع مجفف الماء الساخن باستخدام مروحة من اعلى فقط ١٩.٩٣٪ لمحصول البصل.

أشارت نتيجة تقدير نسبة الجفاف لمحصول الموز أن مجفف الماء الساخن باستخدام اثنين من المراوح أعطى أعلى قيمة ٥.٧٧ بينما نجد أن مجفف الماء الساخن باستخدام مروحة من أعلى سجل أدنى قيمة ٥.٠٢ للبصل.

أظهرت بيانات التقييم الحسي للون البطاطس أن مجفف الماء الساخن مع اثنين من المراوح كان له أدنى قيمة ١.٢٩، وبالتالي تعتبر هي النتيجة الأفضل. في حين أن أعلى قيمة تم الحصول عليها عن طريق مجفف الشمعات الكهربائية باستخدام مروحة من أعلى ٣.٥٠ لمنتج الموز. أعطى طعم البصل المجفف عن طريق مجفف الماء الساخن باستخدام مروحة من أسفل أفضل و أدنى قيمة ٢.١٣ بينما طعم الموز نتيجة مجفف الشمعات الكهربائية باستخدام مروحة امن اسفل اعطت أعلى قيمة ٢.٧٢. أعطى البصل أفضل نكهة لمجفف الشمعات الكهربائية مع اثنين من المراوح ٢.١٩. سجلت البطاطس لمعيار المظهر

العام أفضل نتيجة مع مجفف الماء الساخن باستخدام كل من المروحتين ٢.٢٤ بينما سجل تقييم المظهر العام للموز لمجفف الماء الساخن باستخدام أعلى مروحة أعلى قيمة ٣.٢٢. أظهر تقييم الجودة الشاملة ان مجفف الماء الساخن باستخدام كل من المروحتين أعطى أفضل نتيجة ٢.١٨ للبطاطس في حين سجل أعلى قيمة لمجفف الشمعات الكهربائية عند استخدام مروحة من أعلى ٣.٢٥ للمنتج البصل.

أشار الاستنتاج العام لنتائج العوامل السابقة   (الكثافة النوعية للموز، نسبة الجفاف للموز، لون البطاطس، طعم البصل ،المظهر العام للبطاطس و الجودة الشاملة للبطاطس) أن مجفف الماء الساخن كان الأفضل وذلك باستخدام المروحتين معا.

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CHAPTER ONE

INTRODUCTION

The influence of food water content on perish ability has been known since ancient times. Between 15,000 and 10,000 BC our ancestors began to preserve excess fish, meat and fruit by drying in the wind and sun (Ray, 1992). Around 8,000 BC, many innovations in preservation techniques were introduced. To ensure a steady supply of food, grains and fruits were stabilized by natural drying and excess meat and fish preserved by smoking and dry salting. In 1795, Masson and Challet applied artificial drying to vegetables in a hot air room. In the 20th century, innovations have included artificial drying of liquids by drum or spray drying, and freeze drying (Zeuthen and Sùrensen, 2003).

So dehydration is the oldest method of food preservation practiced by man. For thousands of years he has dried and/or smoked meat, fish, fruits and vegetables, to sustain him during off season periods in the year (Brennan, 2006). The first known record of drying involved vegetables appeared in the 18^{th} century. Thereafter development of drying industry was closely related to war scenarios around the world. British troops the Crima (1954-1956) received dried vegetable from home land. Canda dried vegetables were shipped to South Africa during the Bore War (1899-1902) and around 4500 tons of dehydrated vegetables were shipped from U S during World War 1. (Canovas *et.al* ,2001).

Today the dehydration section of the food industry is large and extends to all countries of the globe. Drying facilities range from simple sun or hot air driers to high capacity, sophisticated spray drying or freeze drying installations. A very large range of dehydrated foods is available and makes a significant contribution to the convenience food market. The terms dehydration and drying are used interchangeably to describe the removal of most of the water, normally present in a foodstuff, by evaporation or sublimation, as a result of the application of heat. The main reason for drying a food is to extend its shelf life beyond that of the fresh material without the need for refrigerated transport and storage. This goal is achieved by reducing the available moisture, or water activity to a level which inhibits the growth and development of spoilage and pathogenic microorganisms, reducing the activity of enzymes and the rate at which undesirable chemical changes occur. Appropriate packaging is necessary to maintain the low water activity during storage and handling.

Drying also reduces the weight of the food product. Shrinkage, which occurs often during drying, reduces the volume of the product. These changes in weight and volume can lead to substantial savings in transport and storage costs and, in some cases, the costs of packaging. However, dehydration is an energy intensive process and the cost of supplying this energy can be relatively high compared to other methods of preservation (Brennan, 2006).

Alamu *et.al,* (2010) stated that, the energy input for drying is less than what is needed to freeze or can, and the storage space is minimal compared with that needed for canning jars and freezer containers. It was further stated that the nutritional value of food is only minimally affected by drying. Changes detrimental to the quality of the food may also occur during drying. In the case of solid food pieces, shrinkage can alter the size and shape of the pieces. Changes in color may also occur. When the food pieces are rehydrated, their color and texture may be significantly inferior to those of the fresh material.

Dry powders may be slow to rehydrate. Changes in flavor may occur during drying solid or liquid foods, as a result of losing volatile flavor compounds and/or the development of cooked flavors. A reduction in the nutritional value of foods can result from dehydration. In particular, loss of vitamins C and A may be greater during drying than in canning or freezing.

Drying is usually described as a simultaneous heat and mass transfer operation. Sensible and latent heat must be transferred to the food to cause the water to evaporate. Placing the food in a current of hot air is the most widely used method of supplying heat. The heat is transferred by convection from the air to the surface of the food and by conduction within the food. Alternatively, the food may be placed in contact with a heated surface. The heat is transferred by conduction to the surface of the food in contact with the heated surface and within the food. There is limited use of radiant, microwave and radio frequency energy in dehydration. Freeze drying involves freezing the food and removal of the ice by sublimation. This is usually achieved by applying heat, by conduction or radiation, in a very low pressure environment. In osmotic drying food pieces are immersed in a hypertonic solution. Water moves from the food into the solution under the influence of osmotic pressure (Brennan, 2006)**.** (Srivastava and Kumar (2003) mentioned that, the processing should be done in such a way that the food value, natural flavor and characteristic cooking quality of the fresh material are retained after drying. Fruits are considered to be dry when they show no signs of moisture or stickiness when held firmly in the hand. Vegetables are considered to be dry when they become brittle. At this stage, they should be removed from the dryer. The residual moisture in the vegetables should not be more than 6-8 per cent and in fruits 10-20 per cent. Dried fruits can be used as such or after soaking, while dried vegetables are usually soaked in water overnight and then cooked. Patil *et.al*, (2012) stated that, a number of drying technique has been developed over year and year such as conduction, convection, and radiation. The simplest and economic method for dehydration of foods is hot air-drying in conventional tray, cabinet or vacuum dryers but these dehydrated products have fewer acceptances since the products quality is considerably reduced.

Ehiem *et.al*, (2009) stated that, dryers are one of the most important equipment in food processing industries. Many dryers have been developed and used to dry agricultural products in order to improve their storage conditions. Most of the dryers use either expensive source of energy such as electricity or a combination of solar energy and other forms of energy. The most common dryers for vegetables are continuous tunnel dryers, vacuum dryers or solar dryers. (Ehiem *et.al*, 2009 and Huber and Menners 1996) estimated that, out of over 200 different types of dryers that have found different applications in industry, only about 20 basic types and their variants are commonly used in practice. This wide range is as a result of different physical forms of the products to be dried, desired rate of drying and quality constraints of the dried products. Ehiem *et.al*, (2009) mentioned that, most of food dryers are only seen in tertiary institution laboratories while the vegetable farmer's do not have access to these dryers. Hence, these farmers suffer a lot of losses during peak periods of production. Many farmers usually abandon their vegetables in the farm due to low price, which is much less than the cost of production. Besides, vegetable traders also suffer a lot of losses due to poor storage facilities for their unsold vegetables. Direct sun-drying and the use of solar driers depend on the intensity of the sun energy to heat up the air and effect drying. Most vegetables are usually at the peak of their yield when the rain has fully set. This period is characterized by low sun energy and high relative humidity. This condition prolongs drying time which results to deterioration due to mould growth on the product.

In the Sudan the total production of vegetables and fruits in 2003 was 3021.6000 tons and 1913.6000 tons respectively. This production increased in 2013 to 3992, 4 tons and 2754, 1 tons for vegetables and fruits respectively. The production of

onion in the Sudan was estimated to be 971000 tons in 2003 and 1136000 tons in 2013 and the production of potato rise from 44000 tons in 2003 to 336000 tons in 2013 also there was increase in production of banana from 41.3000 tons in 2003 to 900,000 tons in 2013. (Horticulture Sector Administration Sudan, 2014).
Green, (2001) reported that, food losses in the developing world are thought to be 50% of the fruits and vegetables grown and 25% of harvested food grain. Ehiem *et.al*, (2009) stated that, as much as 25 % of some vegetables are wasted during peak production period. Drying represents a highly effective, practical means of reducing post-harvest losses in fruits and vegetables.

Such losses are due to the lack of proper processing or to inadequate storage and can reach between 30 and 40% in developing countries in the tropics and subtropics. In addition, the demand for the year-round availability of seasonal food commodities has increased. There is thus a pressing need to match increased production with suitable, simple, inexpensive and effective post-harvest preservation techniques to minimize loss and guarantee the supply and availability of nutrients (Grades, 2008). Elbashir and Imam (2010) stated that, in Sudan the losses of banana and potatoes is 35% and 30% respectively.

Hence, the study will be of great benefit to vegetable farmers especially in the rural areas and help solve food security problems especially in developing countries such as Sudan. Besides it can also be profitable to food processing industries for the production of dried tomatoes, okra onions, pepper and carrots. This work is therefore aimed at reducing fruits and vegetables wastage and improving their storage conditions under ambient temperature after drying process.

Objectives of the study:

1. To design and construct a new family size cabinet dryer.

2. To evaluation of the performance of the design dryer.

CHAPTER TWO

LITERATURE REVIEW

2.1 Fundamentals of drying

2.1.1 Drying Definition

Brennan (2006) stated that, the terms dehydration and drying are used interchangeably to describe the removal of most of the water, normally present in a foodstuff, by evaporation or sublimation, as a result of the application of heat. In general, *dried* refers to all dried products, regardless of the method of drying, and *dehydrated* refers to products that use mechanical equipment and artificial heating methods (as opposed to natural drying methods) to dry the product**.** Ramos *et.al*, (2000) stated that, many authors use the word ‘‘drying’’ to describe the natural process of water removal by exposure to the sun and ‘‘dehydration’’ as the artificial drying under controlled conditions.

Fellows (2000) defined dehydration or(drying) as the application of heat under controlled conditions to remove the majority of the water normally present in a food by evaporation’ (or in the case of freeze drying by sublimation). This definition excludes other unit operations which remove water from foods (for example mechanical separations and membrane concentration, evaporation and baking as these normally remove much less water than dehydration.

2.1.2 Mechanism of drying

Ramsway and Marcotte,(2005) notted that, drying is a process in which the latent heat of vaporization is supplied to the liquid water present in the food, and the resulting vapor is removed from the food. Therefore, the process involves the simultaneous application of heat and removal of moisture. In other word, it is simultaneous heat and mass transfer process of removing moisture to yield a solid dry product.

Drying is carried out by passing warm dry air over the product. The air provides the latent heat for moisture evaporation in the product, and the moisture transferred from the product is carried away by movement. There is an exchange of heat and moisture between the food and the air. The drying process can be subdivided into two processes: first, the transfer of energy (mostly as heat) from the surrounding environment to evaporate the surface moisture characterized as the active drying. The removal of water as vapor from the humid material depends on the external conditions of temperature, air humidity, air flow, area of exposed and pressure. Second, the transfer of internal moisture to the surface of the solid and its subsequent evaporation according to the process. The movement of moisture internally within the solid is function of the physical nature of the solid, the temperature and its moisture content. (Ramasway and Marcotte, 2005).

Mulet *et.al,* (2010) mentioned that**,** during drying, there is water transfer from a dense phase to a light phase. The dense phase being the food and the light phase the drying medium, usually referred as internal and external medium. (Lewicki and Michaluk, 2004). Stated that, the slow kinetics of these processes increases the economic costs not only by the energy consumption but also by the needs of labour and facilities to be carried out. (Mujumdar and Devahastin, 2000) reported that, in drying heat may be supplied from the drying medium to the drying product by convection (direct dryers), conduction (contact or indirect dryers) and radiation or volumetrically by placing the wet material in a microwave or radio frequency electromagnetic field.

2.1.3 Drying rate Factors

Srivastava and Kumar (2010) mentioned that, the factors that affect the rate of drying include the following:

1. Composition of raw material.
2. Size, shape and arrangement of staking of the product.
3. Temperature as well as humidity and velocity of air.
4. Pressure (barometric or under vacuum).
5. Heat transfer to the surface (conductive, convective or radiative).

In addition to the privious factors (Singh 2007) stated that, generally the fruits and vegetables to be dehydrated are cut into small pieces or thin layers to speed heat and mass transfer. Subdivision speeds drying for two reasons:

1. Large surface areas provide more surfaces in contact with the heating medium (air) and more surface from which moisture can escape.
2. Smaller particles or thinner layers reduce the distance through which heat must travel to the centre of the food and reduce the distance through which moisture in the centre of the food must travel to reach the surface and escape.

2.1.4 Mechanism of water transfer from interior to the surface of the food to be dry

Fellows, (2000) stated that, water moves from the interior of the food to the surface by the following mechanisms:

1. Liquid movement by capillary forces, particularly in porous foods.

2. Diffusion of liquids, caused by differences in the concentration of solutes at the surface and in the interior of the food.

3. Diffusion of liquids which are adsorbed in layers at the surfaces of solid components of the food.

2.1.5 Drying Kinetics and drying curve

Drying kinetics as described by (Methakhup 2003) is the changes of moisture content of material during drying. It can be expressed as a drying curve or drying rate curve. Drying curve (Figure 2.1 a) can be obtained experimentally by plotting the free moisture content versus drying time. This plot can be converted into a drying rate curve (Figure 2.2 b) by calculating the derivative of the curve over time. From these two types of curve it is seen that drying is divided into two distinct portions. The first is the constant rate period, in which unbound water is removed (line BC). Water evaporates as if there is no solid present, and its rate of evaporation is not dependent on the material to be dried. In this stage of drying the rate-controlling step is the diffusion of the water vapor across the air-moisture interface. This period continues until water from the interior is no longer available at the surface of food material. Point C distinguishes the constant rate period from the subsequent falling rate period and is called the critical moisture content. The surface of the solid is no longer wet. The water that is being removed from the center of the solid moves to the surfaces as a vapor. Although the amount of water removed in the falling rate period is relatively small, it can take considerably longer time than in the constant rate period. The heat transmission now consists of heat transfer to the surface and heat conduction in the product.

The drying rate in the falling rate period is controlled by diffusion of moisture from the inside to the surface and then mass transfer from the surface. During this stage some of the moisture bound by sorption is being removed. As the moisture concentration is lowered by drying, the rate of internal movement of moisture decreases. The rate of drying falls even more rapidly than before and continues to drop until the moisture content falls down to the equilibrium value for the prevailing air humidity and then drying stops.

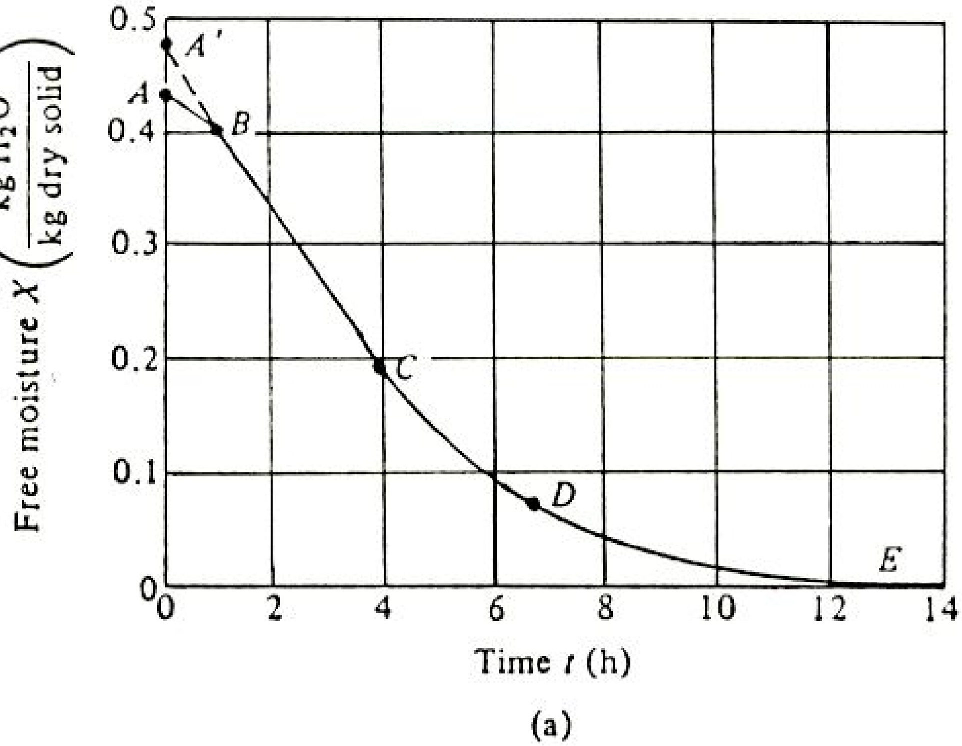


Fig 2. 1: Drying curve

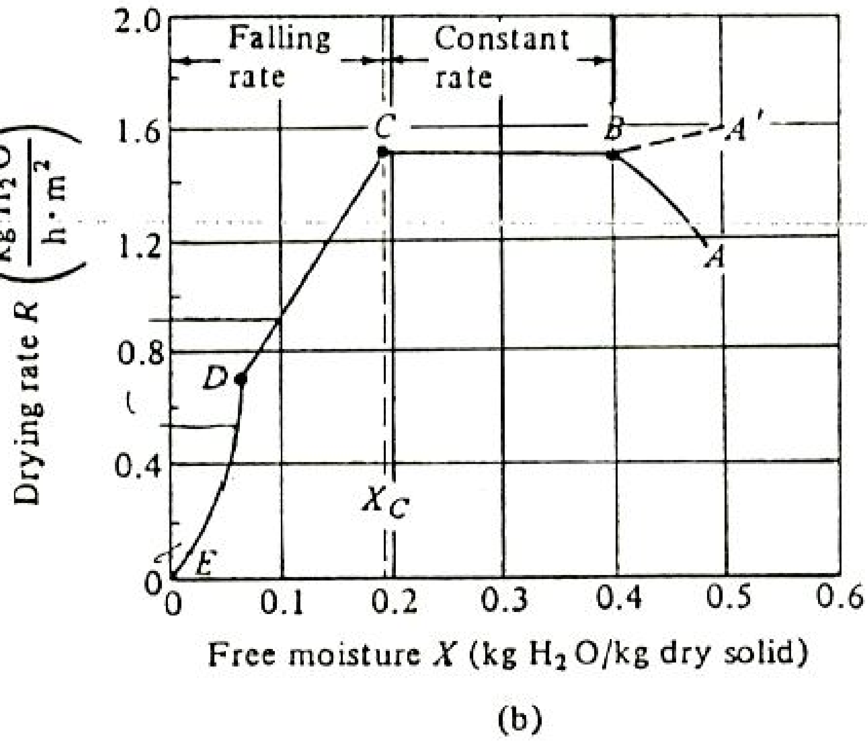


Fig 2. 2: Drying rate curve.

Akintunde and Afon(2009) reported that, drying kinetics of food crops are generally affected by factors which include drying temperature, pretreatment method, relative humidity, and product sizes.

2.1.6 Dehydration techniques and mass transfer mechanisms

Ibarz and Barbosa-Canovas, (2003) stated that, dehydration is one of the most important unit operations in food science. The terms dehydration and drying are generally used as synonymous but they are not exactly the same. Dehydrated vegetables are considered to have a mass fraction of water lower than 2.5%; instead dried vegetables may contain more than the 2.5%. A complete and correct analysis of dehydration or drying technologies is a hard work.

Traditionally, conventional and innovative dehydration techniques are the two most important classes considered in scientific literature. In the first group sun dehydration, hot air dehydration, spray drying, osmotic dehydration, freeze drying, fluidized bed drying, are the most important; instead, microwave drying, infrared drying, ultrasonic dehydration, electric and magnetic field dewatering, solar drying, are among the most studied innovative techniques. Another usual classification is based on the analysis of dryer plant. Okos *et al,* (2007) analyzed several different drying techniques on the basis of a classification of dryer design. However, since many dehydration techniques may be combined and/or several methods to increase the dehydration rate may be used, the number of drying technologies available or in development stage is very high. For instance, Chua and Chou (2005) well reviewed new hybrid drying technologies classifying them in three groups: 1. Combined drying technology; 2. Multiple-stage drying; 3. Multiple-process drying. Moreover, the use of new methods to increase the mass transfer of the above technologies, may promote new dehydration techniques. This is the case in which the use of vacuum pressure was combined with osmotic dehydration giving two innovative techniques: vacuum osmotic dehydration (VOD) and pulsed osmotic dehydration (PVOD). Moreover, some of these possibilities may occur simultaneously or also they could change during drying. In addition, if water evaporates from the surface or inside vegetables, the heating method should be taken into account because it has a great influence on the mass transfer mechanisms inside vegetables.

2.2 Advantages of drying

Drying is the one of the easiest and most efficient methods of food preservation. Food is exposed to heat and air in order to remove moisture. Lacking moisture, bacteria and micro-organisms are inhibited. So dehydrated foods can be preserved for long periods without refrigeration and they have far less weight and bulk (Ronco, 2009).

Brennan (2006) mentioned that, the main reason for drying a food is to extend its shelf life beyond that of the fresh material without the need for refrigerated transport and storage. Drying also reduces the weight and the volume of the product. These changes in weight and volume can lead to substantial savings in transport and storage costs and, in some cases, the costs of packaging.

Wamy and Marcotte, (2005) reported that, among processing technologies(e.g canning, freezing and dehydration etc.) that have been used on industrial scale to preserve food , dehydration one of the oldest methods, offers a cost effective and very practical means of preservation.

Srivastava and Kumar, (2010), stated that, the advantage of dehydration over sun drying as follows:

1. The process of dehydration is much rapid than sun drying.
2. Dehydration requires less floor area and fewer trays.
3. Dehydration is done under very hygienic conditions.
4. Sun drying is not possible in cloudy weather or during rains.

The colour of dehydrated or mechanically dried fruits and vegetables remain uniform due to uniform drying temperature.

2.3 Disadvantages of drying

Abbasi *et al*, (2011) stated that, hot air-drying is the most commonly employed commercial technique for drying of biological products. Drying is a complex process involving simultaneous heat and mass transfer and it can result in significant changes in the chemical composition, structure, and physical properties of food material.

Patil *et al*, (2011) mentioned that, the simplest and most economic method for dehydration of foods is air-drying; although certain problems such as the considerable shrinkage caused by cell collapse following the loss of water, the poor re-hydration characteristics of dried products and unfavorable changes in colour, texture, flavor and nutritive value may occur.

2.4 Drying Models

Modeling the drying process is important for characterizing the processes with different drying methods and conditions. Two models, the exponential and Page models, they have been widely used in drying modeling.

2.4.1 Exponential model

Afzal and Abe (1997) stated that, one of the most basic models used to describe moisture loss during the drying process is a simple exponential model equation (2. 1):

$$d\,M = \alpha \frac{(M - Me)}{dt} \qquad (2.1)$$

This can further be integrated to the following equation (2. 2):

$$MR = \frac{M - M_e}{M_o - M_e} = exp[-kt] \qquad (2.2)$$

where MR is the moisture ratio; M is the moisture content (% db) at any given time during drying; M_o is the initial moisture content; Me is the equilibrium moisture content; k is the drying constant (hr-1); and t is time in hours. This model assumes negligible internal resistance and considers only the resistance concentrated at the surface of the material. The exponential model, equation

(2.1), is a simple lumped model often used to describe mass transfer in thin layer drying (Wang, 2002). This model was used because of its simplicity, high correlation to most drying data, and common use in literature. Drying constant, k (h-1), can be calculated by using the model. MR was plotted on semi-logarithmic axis versus the time (hr) and the slope of the fitting line was the constant k.

2.4.2 Page equation

Page (1949) modified the exponential model to include and additional exponent equation (2.3):

$$MR = \frac{M - M_e}{M_o - M_e} = exp[-kt^N] \quad (2.3)$$

Where K is an empirical drying constant (hr-1); and N is an empirical drying exponent. It has been used extensively in many thin-layer drying applications (Afzal and Abe, 1997).

The Page equation can be adapted from equation (2.4) as follows:

$$ln\left[\frac{M - M_e}{M_o - M_e}\right] = -kt^N \quad y(t) \quad (2.4)$$

This may then be rearranged to read:

$$ln[-y(t)] = ln(K) + N\,ln(t) \quad (2.5)$$

The slope of linear curve of a plot of ln[-y(t)] versus ln(t) was the value N and the exponential of the y intercept as the value of K (Singh and Erdogdu, 2004) and (Pan *et. al*, 2005).

2.5 Water activity (*aw*)

Singh (2007) stated that, water activity or *aw* is a property of solutions and is the ratio of vapor pressure of the solution compared to the vapor pressure of pure water at the same temperature. Under equilibrium conditions water activity equals:

$$aw = RH/l00 \qquad (2.6)$$

Micro-organisms in a healthy growing state may contain in excess of 80% water. They get this water from the food in which they grow. If the water is removed from the food it also will transfer out of the bacterial cell and multiplication will stop. Partial drying will be less effective than total drying, though for some micro-organisms partial drying may be quite sufficient to arrest bacterial growth and multiplication. When stated that, moisture requirements of microorganisms really mean water activity in their immediate environment, whether this be in solution, in a particle of food or at a surface in contact with the atmosphere. At the usual temperatures permitting microbial growth, most bacteria require a water activity in the range of about 0.90 to 1.00.

2.6 Expression of moisture content

Moisture content can be expressed by two ways; (Sodha *et.al.*, 1987), on a wet weight basis, moisture is calculated as

$$Mw = \frac{\text{mass of water}}{\text{Mass of sample}} \times 100 \qquad (2.7)$$

Where mass of sample can be made up of water and dry matter or solids. Hence

$$Mw = \frac{\text{mass of water}}{\text{Mass of water + solids}} \times 100 \qquad (2.8)$$

On a dry weight basis, moisture is calculated as

$$Md = \frac{\text{mass of water}}{\text{Mass of solids}} \quad (2.9)$$

This can sometimes be expressed on a percentage dry weight basis, i.e. 100 multiplied by the moisture. It can be shown by eliminating the mass of solids

$$Mw = \frac{100\,Md}{1+Md} \quad \text{or} \quad Md = \frac{Mw}{100\,(1-\frac{Mw}{100})} \quad (2.10)$$

Moisture content (wet basis) is most often used in food composition tables, whereas moisture content (dry basis) is more often encountered with isotherm and drying curve. The amount of water in a food is most easily determined by taking a representative sample of the food and drying it in an oven to constant mass. During dehydration processes considerable moisture gradients will established within the food.

Fellows (1990) mentioned that during the constant rate period which exists for materials having free surface-wet moisture evaporation is taking from the surface of the solid, and so long as this remains, surface-wet is independent of internal mechanisms within the solid. The rate of drying is essentially that of the evaporation of the fluid component as though no solid were present under the condition of temperature and air flow obtaining the test. The temperature of the fluid film and that of the adjacent solid surface will remain substantially constant and will approximate to the wet-bulb temperature of the moving air at the test temperature assuming radiation effect is negligible. On an operating convection drying plant, these two effects are unlikely to be wholly absent and will result in higher surface temperature than the wet-bulb temperature and will produce a higher constant drying rate.

For the constant-rate drying period, the following general expression would apply:

The rate of heat transfer will be

$$\frac{dQ}{dt} = h_c A (T_a - T_w) \quad (2.11)$$

The rate of mass transfer will be

$$\frac{dm}{dt} = K_m A(H_w - H_a) \quad (2.12)$$

Since, during the constant rate period, equilibrium exists between the rate of heat transfer to the food and the rate of mass transfer in the form of moisture loss from the food, these rates are related by:

$$\left(\frac{dM}{dt}\right) = \frac{h_c A (T_a - T_w)}{h_L} = K_m A (H_w - H_a) \quad (2.13)$$

Where:

$\frac{dQ}{dt}$ the rate of heat transfer , (J/s).

$\frac{dM}{dt}$ the rate of mass transfer, (Kg/s).

$\left(\frac{dM}{dt}\right)_c$ rate of water loss at constant rate period, (Kg_{water}/S).

K_m mass transfer coefficient, (Kg/m^2 /S).

A water surface area. (m^2)

H_w absolute humidity at wet-bulb conditions, (Kg_{water}/($Kg_{dry\ air}$).

H_a absolute humidity of air (Kg_{water}/($Kg_{dry\ air}$).

h_c convection heat transfer coefficient, (W/m^2. °c).

T_a average dry-bulb temperature of dry air. (°c).

T_w average wet-bulb temperature of drying air, (°c).

H_L latest heat of evaporation at the wet-bulb temperature,(J/Kg).

Hall (1980) reported that the magnitude of the rate of drying during constant rate period is dependent upon: area exposed difference in humidity between air stream and wet surface, the coefficient of mass transfer and velocity of the drying air.

The variables are related according to equation (2.14)

$$\left(\frac{dM}{dt}\right)_c = f_v\, A\, (P_w - P_a) = \frac{h_c\, A\,(T_a - T_W)}{h_L} \qquad (2.14)$$

Where:

F_v water vapor transfer coefficient, (Kg/s.m^2.P_a).

P_w saturated vapor pressure at wet bulb temperature, (Kg/m^2).

P_a water vapor pressure in the air, (Kg/m^2).

For a tray food, in which water evaporates only from the upper surface, a heat balance on the drying operation will yield the expression:

$$\left(\frac{dM^*}{dt}\right) = \frac{h_c\,(T_a - T_W)}{p d h_L} \qquad (2.15)$$

Where :

$\left(\frac{dM^*}{dt}\right)$ drying rate, at constant rate period, (Kg_{water}/h/$Kg_{dry\ solid}$).

P bulk density of food, (Kg/m^3).

D thickness of food bed, (m).

The above expression assumes that evaporation is taking place from one surface of a layer of material supported on a solid tray. If evaporation is taking place from both surface as in the case of wire-mesh trays (d = half the total bed thickness).

The drying time in the constant rate period can be obtained by the integration of equation (2.16):

$$t_c = = \frac{p\ d\ h_L\ (Md_o - Md_c)}{h_c\ (T_a - T_W)} \qquad (2.16)$$

Where:

T_c time for constant-rate period, (sec).

Md_o initial moisture content, percent dry basis, $(Kg_{water} / Kg_{dry\ solid})$.

Md_c moisture content at end of constant rate period, percent dry basis, $(Kg_{water} / Kg_{dry\ solid})$.

In the falling rate periods, the rate of drying is mainly influenced by the rate of movement of moisture within the solid and the effects of external factors, in particular air velocity, are reduced, especially in the latter stage. Usually the falling rate periods represent the major proportion of overall drying time. The falling-rate period of drying can be often being expressed with reasonable accuracy by an equation of Lewis (1921) to be analogous to Newton's law of cooling. In this equation, it is assumed that the rate of moisture loss from the product is directly proportional to the difference between the moisture content of the product and the equilibrium value under the given condition of humidity and temperature can be obtained by equation (2.17).

$$\left(\frac{dM}{dt}\right) = -K\,(Md_c - Md_e) \qquad (2.17)$$

Where:

K a constant is related to the constant rate period.

Md_c moisture content at any time of drying, percent dry basis, (Kg_{water} / $Kg_{dry\ solid}$).

Md_e equilibrium moisture content, per cant dry basis, (Kg_{water} / $Kg_{dry\ solid}$).

Thus:

$$K = -\frac{(dM/dt)\ c}{(M_o - M_e)} \qquad (2.18)$$

Combining equations (2-15),(2-17) and (2-18) gives:

$$\left(\frac{dM}{dt}\right)_f = -\frac{h_c\,(T_a - T_w)(M_c - M_e)}{p\ d\ h_L\,(Md_c - Md_e)} \qquad (2.19)$$

The above equation can be integrated to determine the time for falling rate period:

$$t_f = \frac{p\ d\ h_L\,(Md_c - Md_e)}{h_c\,(T_a - T_w)}\ \text{In}\ \frac{(Md_c - Md_e)}{(Md_c - Md_e)} \qquad (2.\ 20)$$

Where:

t_f time for falling-rate period, (sec).

van Arsdel and Copley (1963) mentioned that, (Perry, 1950) found the following equation to express the falling rate period for slab-shaped solids, drying from one large face only, where liquid diffusion controls the internal movement of moisture:

$$\left(\frac{dM}{dt}\right)_f = - \frac{\pi^2 D_{cof}}{4 d^2} (Md_c - Md_e) \qquad (2.21)$$

Where:

$\left(\frac{dM}{dt}\right)_f$ rate of water loss at falling rate period, (Kg_{water}/S)

D_{cof} diffusion coefficient, (m^2/min).

2.7 Drying rate

Tavakolipour and Zirjani (2014) stated that, the drying rate was calculated by dividing difference of two consecutive moisture content by time intervals and plotted against moisture content based on dry basis. Results of hot air drying experiments showed that with increasing of hot air temperature increased drying rate. Ibrahim (1994) mentioned that, there are many factors affecting the drying rate of the agricultural products. The most affecting factors related to the drying air are the drying air temperature, the drying air relative humidity and the drying air velocity as well as the product initial moisture content.

2.8 Determination of moisture content of vegetables and fruits

Determination of fruits or vegetables moisture content and therefore drying rate could be done by weighting the drying tray with its load of product at successive periods. The original moisture content wet basis, Mw_o was determined by the oven drying method at 105 ^oC (AOAC, 1998). The weight loss was evaluated separately and its value correlated with drying air temperature and velocity.

(Ranganna, 1986) mentioned that, the moisture content could be determination as follow:

$$M.C.(w.b.)\ \% = \frac{(W_1 - W_2)}{W_1} \times 100 \qquad (2.22)$$

$$M.C.(d.b.)\ \% = \frac{(W_1 - W_2)}{W_2} \times 100 \qquad (2.23)$$

Where, W1= weight of sample before drying, gram

W2= weight of bone dried sample, gram

2.9 Bulk density:

Ramos *et al* (2002) sated that, bulk density (some times called apparent density) is defined as the particle mass divided by the particle volume, including the volume of all pores. During drying and as food loses water, the bulk density increases (the value of bulk density varies between the density of pure water approximately and the bulk Density of dry solid) Fig (3)

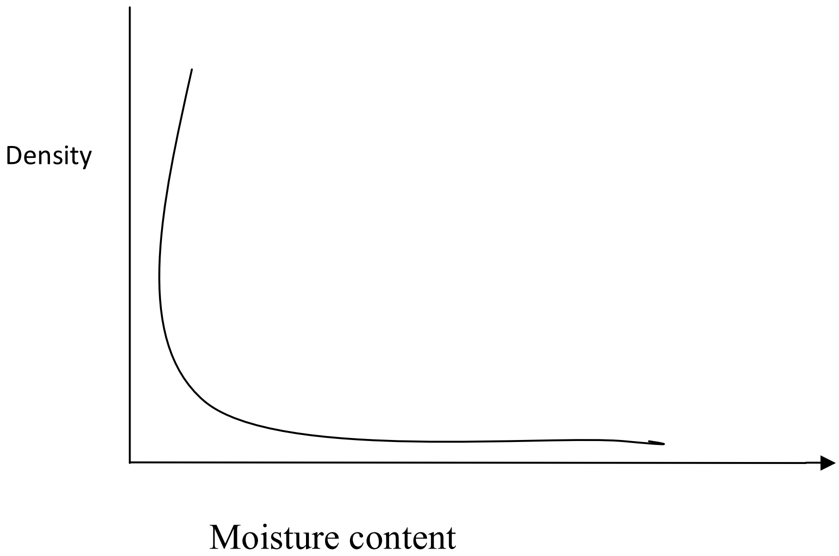


Fig 2.3: Typical variation of density with water content

This tendency was observed by (Krokida and Maroulis, 1997) dealing with drying of carrot, pear, banana, potato, sweet potato and garlic. In some cases, and similarly to particle density, at low water content values a pronounced decrease of bulk density was detected. Zogzas *et al*. (1994b) explained this behavior through the development of product porosity along the drying process. Wang and Brennan (1995) explained it as consequence of a decrease of shrinkage in the final stages of drying**.** Karathanos *et al*. (1996) observed an almost constant bulk density of carrots, not varying with water content.

Krokida and Maroulis,(1997) studied the effect of drying on particle density and correlated this parameter with water content of diversified fruits and vegetables including banana, potato. It was observed that, as water content decreases, the particle density increase. In those situations, after a critical low water content value is reached, the particle density shows a sharp decrease, as water content tends to zero.

2.10 Water absorption WAI and water solubility WSI indices:

Altan *et al* (2009) mentioned that, the WAI is the weight of gel obtained per gram of dry ground sample ,while the WSI is the weight of dry solids in the supernatant expressed as a percentage of the original weight of sample on dry basis .Water absorption has been generally attributed to the dispersion of starch in excess water, and the dispersion is increased by the degree of starch damage. Water solubility index, often used as an indicator of degradation of molecular components, measures the degree of starch conversion during extrusion, which is the amount of soluble polysaccharide released from the starch component after extrusion. Nikjooy and Jahanshahi (2014) reported that, the effect of raising temperature on increasing solubility has a direct relationship with the way of removing moisture from sample tissue and also moisture percent of it. Singhanat and Sertwasana (2010) mentioned that, the instant properties of a powder involve the ability of a powder to dissolve in water. Most powdered foods are intended for rehydration. Hence the ideal powder would wet quickly and thoroughly, sink rather than float and disperse/dissolve without lumps. Water solubility index increased with increasing malt dextrin and liquid glucose up to 96%.

Krzysztof *et al*, (2013) mentioned that, The water absorption capacity gives information about the ability of the material to absorb water with respect to the water loss during dehydration and varies in the range 0≤WAC≤1. The more the water absorption capacity is lost during dehydration the smaller the index.

2.11 Rehydration ratio

Rehydration is a process of moistening dry material. (Femenia *et al* 2000). García-Pascual *et al* (2005) reported that ,rehydration is usually carried out by soaking the dry material in large amounts of water, although, instead of this, some authors have used air with high relative humidity, either statically or in a drying chamber with air circulation**.** Ansari *et al* (2015) reported that, in the rehydration process, the dried products come into contact with water or other liquids such as fruit juices, sucrose, glucose or glycerol Solutions. Velić *et al*. (2004) mentioned that, rehydration characteristic was used as a quality index of a dried product**.** Lee *et al*, (2006) stated that, this process is complex and is aimed at restoring the properties of the fresh products. Three main steps which occur simultaneously during rehydration are: absorption of water into the dry material, swelling, and loss of soluble materials. Ansari *et al*(2015) recorded that, during the initial stages of rehydration, a higher rate of water absorption occurs and there are several factors affect the rehydration process, grouped as intrinsic factors (product chemical composition, drying pre-treatments, product formulation, drying techniques, etc.) and extrinsic factors (composition of immersion media, temperature and hydrodynamic conditions), with immersion temperature being the most important factor influencing rehydration**.**

Maldonado *et al* (2010) stated that, the rehydration temperature markedly affects the increase in volume: moisture content (for the same processing time) increases with an increase in temperature. This has been observed for temperatures in the range of 40–80 ^{o}C for many fruits and vegetables, including bananas, carrots, apples, potatoes, tomatoes, and yellow, red, and green peppers.
Moreira *et al* (2008) mentioned that, three main processes take place simultaneously during rehydration: the imbibitions of water into the dried material , the swelling and the leaching of soluble.

2.12 Drying yields

Brennand (1994) stated that, because drying removes moisture, the food shrinks and decreases in size and weight, thus requiring less space for storage. When water is added to the dried product, it returns to its original size. Yields of dried products are directly related to how much water is in the original product. Twenty-five pounds of apples will yield about 4 pounds of dried apples. Twenty-five pounds of onions will yield about 3 pounds of dried onions. Loesecke (2012) mentioned that, the yield of dried banana, potato and onion were 13,16 and 11 per cent respectively.

2.13. Drying ratio

Quinn and Benchait (1975) stated that, the drying ratio widely depending on the variety, growing conditions ,the time of harvest , the degree of the raw material and loss during setup. And it must be based on the drying process that monitors the drying rate as a basis for the process of drying.

2.14 Food drying Methods

Green (2001) divided the food drying methods into six general categories based on the heated techniques as follows:

1- Open-Air: Food is exposed to the sun and wind in trays, on racks or on ground. Food is rarely protected from predators and the weather.

2- Direct Sun: Food is enclosed in a container with a clear lid allowing sun to shine directly on the food. Vent holes allow for air circulation.

3- Indirect Sun: Fresh air is heated in a solar heat collector and then passed through food in the drier chamber. In this method the food is not exposed to direct sunlight.

4- Mixed Mode: Combines the direct and indirect types: a separate collector preheats air and direct sunlight ads heat to food and air.

5- Hybrid: Combines solar heat with another source such as fossil fuel or biomass.

6- Fueled: Uses electricity or fossil fuel as a source of heat and ventilation.

In addition to what mentioned above, drying of foodstuff can be divided into traditional and artificial methods.

2.14.1 Traditional methods

This method further be subdivided into sun and solar drying.

2.14.1.1 Sun drying

Forson *et al* (2007) reported that, the open sun drying is a traditional method practiced widely in tropical climates for drying agricultural products. Considerable savings can be made with this type of drying since the source of energy is free and sustainable. However, this method of drying is extremely weather dependent and has the problems of contamination, infestation, microbial attacks etc., thus affecting the product quality. Additionally, the drying time required for a given commodity can be quite long and result in post-harvest losses. Covering the food with glass or a transparent plastic material can reduce these problems .Fig (2.4) show simple sun dryer.

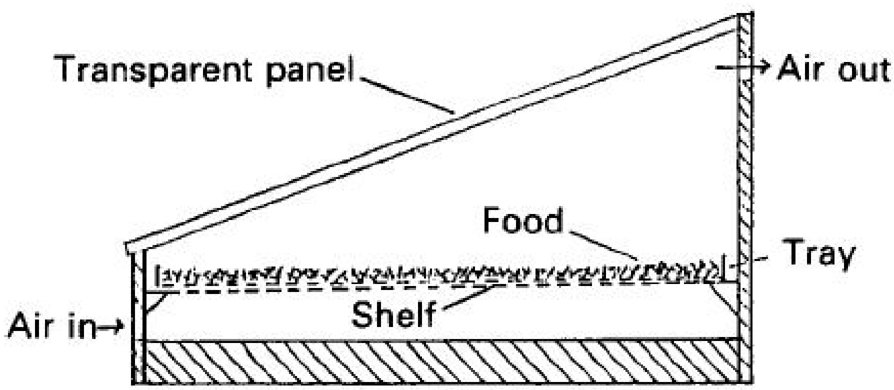


Fig 2. 4: Simple sun dryer.

2.14.1.2 Solar drying

Ezekwe, (1995) stated that, solar drying as a means of food preservation seems to be the most promising and modest approach for preservation of various agricultural products. In solar drying, solar energy is used as either the sole source of the required heat or as a supplemental source. The air flow can be generated by either natural or forced convection. Solar drying offers the following advantages over sun drying: faster drying rate, minimizing damage from rain, protection against infection and also some advantages over the conventional drying with respect to cost and adaptability to small scale farmers. Some of the crops commonly grown in developing countries may be better suited to solar drying than to fossil fuel drying systems because case –hardening and other damages are likely to be less at low temperature characteristics of solar dryers.

2. 14.1.2.1 Direct solar dryers

Forson, *et al* (2007) mentioned that, the natural convection solar crop dryers designs include: direct, indirect and mixed-mode solar-dryers. Sreekumar *et.al,* (2008) mentioned three types of direct solar dryers, a forced circulation cabinet solar timber dryer, in which the material absorbs solar radiation directly (Fig 2.5). Other active solar cabinet dryers reported in the literature were a transparent roof solar barn (Fig. 2.6) and some small scale forced convection dryers. In all these dryers, the products to be dried were directly exposed to solar radiation, and the product itself acts as an absorber.

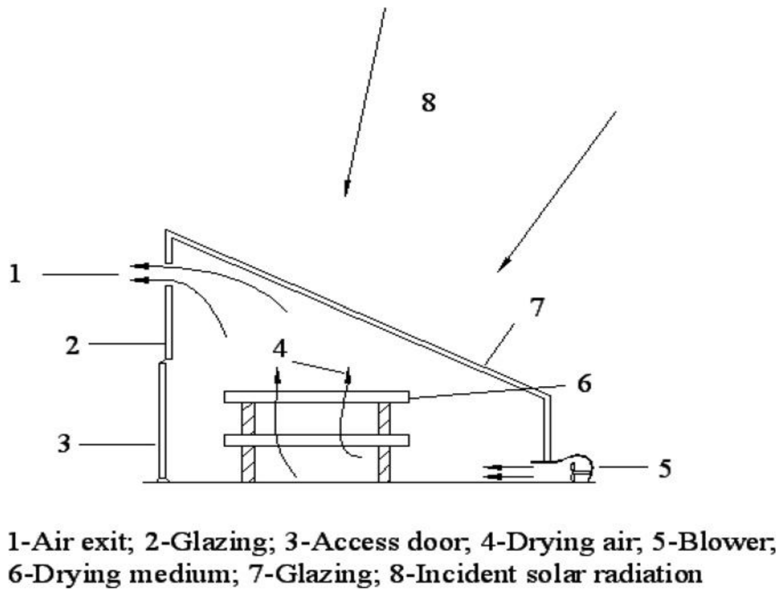
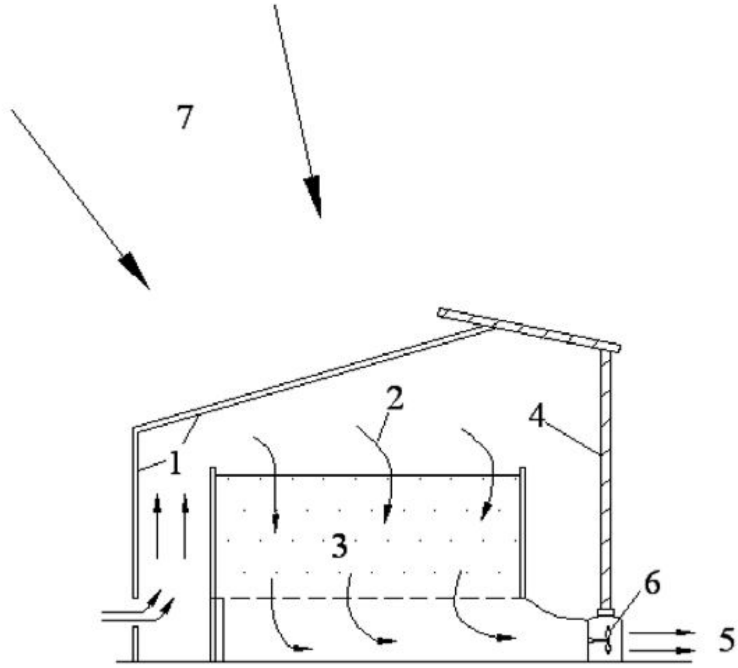


Fig 2. 5: A forced convection greenhouse dryer.



1-Glazing; 2-Drying air; 3-Drying medium; 4-Drying wall; 5-Air exit; 6-Fan; 7-Incident solar radiation

Fig 2. 6: A forced convection transparent roof solar barn.

2. 14.1.2.2 Indirect type conventional solar dryer

Jairaj *et.al* ,(2009) mention that, this type of solar dryer has a solar collector for heating air and a drying chamber to accommodate trays .(Fig 2.7). The solar collector uses a transparent foil cover and a black absorber sheet. The drying chamber is covered by a transparent foil which protects the products from rain and dust. The solar collector collects the solar energy and heats the air entering through an inlet. The maximum temperature recorded in the drying chamber is 50 ^{o}C when the ambient temperature is 30 ^{o}C. Heated air enters the drying chamber from beneath the tray and flows upwards through the product carrying moisture with it. This moist air goes out of the opening provided at the top. Ventilation is provided by natural convection inside the collector and drying chamber. This effect is further enhanced by a sucking effect at the air outlet caused by wind.

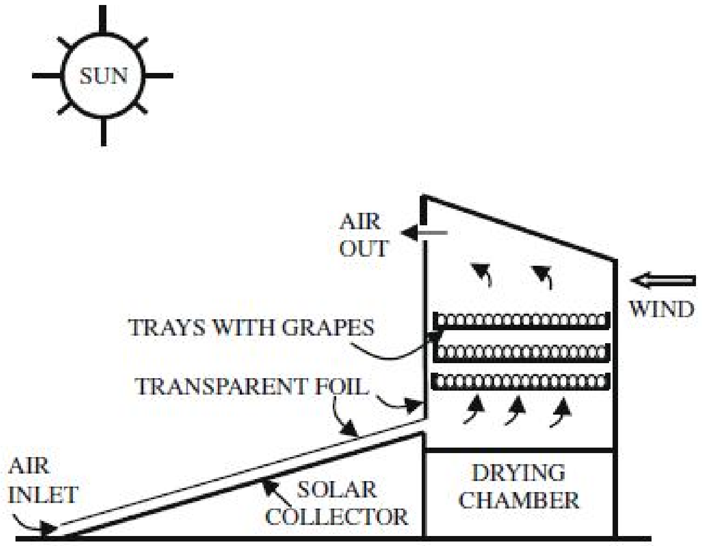


Fig 2. 7: Indirect type conventional solar dryer.

2.14.2 Artificial drying method

Heldman and Hartel (1997) stated that, the development of many different types of methods and equipment in drying technology is due to the diversity of food products. The choice of method and dryer depend on (1) The state and shape (liquid, solid, particulate, etc.) of the food that is being dried. (2) The heat transfer mechanism that is used to provide the energy for drying. Heat can be supplied by: a) convection, where the heating medium, usually hot-air or combustion gases, is in direct contact with the wet material and supplies the thermal energy; b) conduction, where heat is transmitted indirectly by contact of the wet material with a heated surface; c) internal heat generation (dielectric, microwave, radiofrequency); d) freeze drying, where moisture is removed by a solid-vapour transition (sublimation) enhanced by low pressure.

(3) Desired physical form and characteristics of the end product. Chinenye (2009) stated that, artificial drying system consists of mainly a motor, fan and heating element. The fan drives the heated or unheated drying air into the bed. When heat is added to the drying air, the rate of drying increases, depending on the selected drying temperature and air velocity. Therefore proper prediction of the drying time is very important. Knowledge of the drying rate and drying constant in relationship with the drying temperature and air velocity is very important to the scientists and engineers who are involved in the design of the dryers and other post harvest machines.

2.14.2.1 Convectional Hot-Air Drying

Ramaswamy and Marcotte (2006) reported that, the majority of industrial drying installations rely on convectional hot-air drying at atmospheric pressure since it is the simplest and most economical among the various methods. A wide variety of food materials such as fruit, vegetables, herbs and cereal crops has therefore been dried by convectional hot-air dryers. In addition, it is easy to set and control the optimum drying conditions in these dryers, especially in cabinet dryers. Common atmospheric hot-air dryers include kiln, cabinet (tray), tunnel, and belt or conveyor dryers . BARBOSA-CANOVAS and VEGA-MERCADO (1996) mentioned that, the basic configuration of an atmospheric hot-air dryer is an enclosed and heated chamber where food material is placed. It is also equipped with a blower (i.e. fan) and ducts to allow the circulation of hot air around and across the food. When there is no fan the drying takes place under natural convection. The drying process in an atmospheric dryer involves both heating the product and removing water from the product surface .

2.14.2.2 Microwave drying

Inchuen *et.al*, (2008) stated that, microwave drying is an alternative drying method which offers a considerable reduction of drying time. Microwave application has been reported to improve product properties resulting in a better aroma and faster and better rehydration with considerable saving in energy. Microwave drying technique effectively improves the final quality of agricultural products such as grains, vegetables and fruits. However, it may result in a poor-quality product if not properly applied. Beaudry *et.al*, (2003) stated that, microwave drying can reduce drying time but may reduce product quality. Also Prakash *et.al*, (2004), reported that, application of microwave heating to industrial drying is of increasing interest, particularly because of the increased energy and operational efficiency it affords. Microwave drying is more suited to products having high moisture content like carrots, mushroom and cabbage because of the dielectric properties of water that quickly absorb the microwave energy.

2.14.2.3 Osmotic dehydration

Sutar and Gupta (2007) stated that, osmotic dehydration is the process of water removal by immersion of water containing cellular solid in a concentrated aqueous solution during which simultaneous solid gain also takes place. The driving force for water removal is set up because of a difference in osmotic pressure between the food and its surrounding solution. Osmotic dehydration of fruits and vegetables is gaining attention due to its important role in food processing industry because osmotic pretreatment prior to other drying methods improves the colour, flavor and texture of the final product; also it is less energy intensive process as no phase change takes place. Bernan (2006) stated that, when pieces of fresh fruits or vegetables are immersed in a sugar or salt solution, which has a higher osmotic pressure than the food, water passes from the food into the solution under the influence of the osmotic pressure gradient; and the water activity of the food is lowered. This method of removing moisture from food is known as osmotic dehydration (drying). This term is misleading as the end product is seldom stable and further processing is necessary to extend its shelf life. Beaudry (2001) stated that, Osmotic dehydration is the incomplete removal of water from a food product by means of an osmotic agent (usually either sugar or salt solution). Sunjka and Raghavan (2004) reported that, osmotic dehydration is a preservation method that offers a high quality product by means of water removal without phase change.

2.14.2.4 Radio frequency drying

As stated by **(**Devki 2006), in a radio frequency drying system, the radio frequency generator creates an alternating electric field between two electrodes. The material to be dried is conveyed between the electrodes, where the alternating energy causes polar molecules in the water to continuously re-orient themselves to face opposite poles- much in the same way magnets move in an alternating magnetic field. The friction of this movement causes the water in the material to rapidly heat throughout the material's entire mass.

2.14.2.5. Freeze drying

This method of drying foods was first used in industry in the 1950s. The process involves three stages: (a) freezing the food material, (b) subliming the ice (primary drying) and (c) removal of the small amount of water bound to the solids (secondary drying or desorption) Brennan, (2006). Yang and Atallah (1985) mentioned that, freeze drying, provided the highest quality of all dryers tested (freeze drying, convective air, vacuum oven, and micro-convection). Grabowski *et.al,* (2002) comparing numerous dryers (i.e. vacuum, fluid bed, pulsed fluid bed, vibrated fluid bed, and freeze dryer), freeze drying rendered the best product quality (cranberries) quantified in terms of color, taste and rehydration capacity.

Zhongli Pan *et.al* (2008) mentioned that, Freeze-drying (FD) has been used as a single process or in combination with other techniques to minimize the adverse quality changes associated with dried products..(Mohammadzadeh, and Hatamipour, 2010 **)** reported that, freeze drying as a new technology is suitable for obtaining dried matter with high quality.

2.14.2.6 Vacuum drying

Brown *et.al* (1964) reported that, in vacuum drying, the boiling point of water is lowered below 100◦C by reducing the pressure. The degree of vacuum and the temperature for drying depend on the sensitivity of the material ,drying rate and temperatures. At constant temperature and pressure and the drying time varies; depending on the kind of fruit, initial moisture and size. (Sokhansanj and Jayas, 1995) mentioned that, vacuum drying is one of the most expensive methods of drying. The moisture content of high moisture food is reduced to 20-25% by a conventional method, such as hot air drying and then vacuum is applied to bring the moisture down to 1-3%.

2.15 Design of different dryers

According to Brennan (2006) the dries can be classified into:

2.15.1 Cabinet (Tray) drier

This is a multipurpose, batch-operated hot air drier. It consists of an insulated cabinet, equipped with a fan, an air heater and a space occupied by trays of food (Fig 2.8). It can vary in size from a bench-scale unit holding one or two small trays of food to a large unit taking stacks of large trays. The air may be directed by baffles to flow across the surface of the trays of food or through perforated trays and the layers of food, or both ways. The moist air is partly exhausted from the cabinet and partly recycled by means of dampers. Small cabinet driers are used in laboratories, while larger units are used as industrial driers.

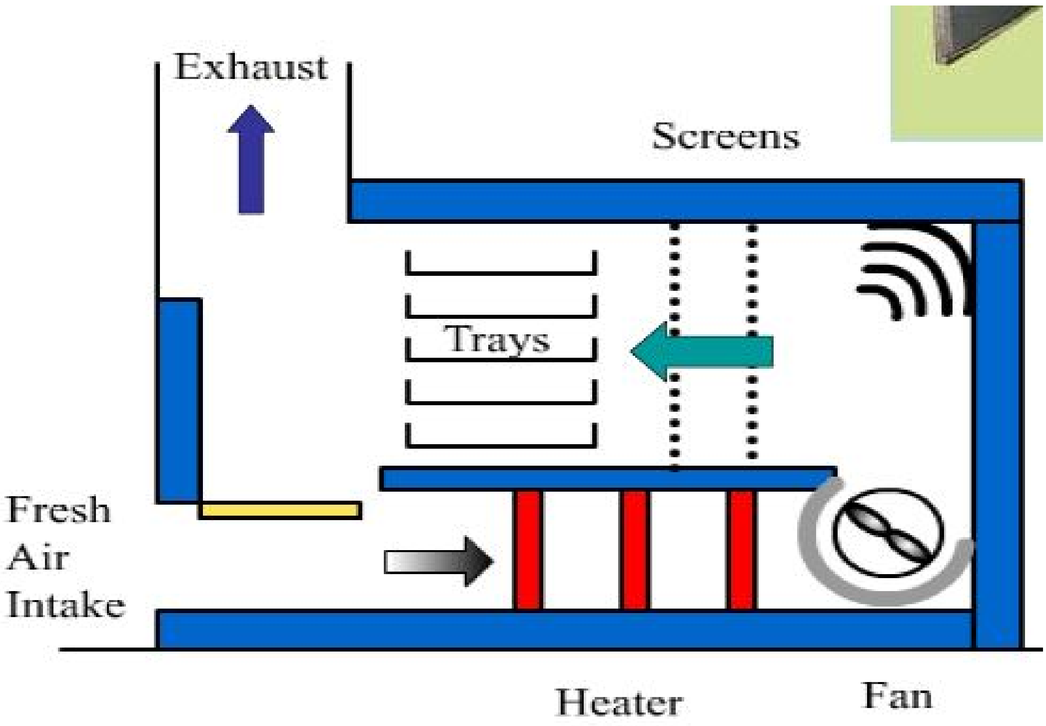


Fig 2. 8: Cabinet tray or dryer.

2.15.2 Tunnel Drier

This type of drier consists of a long insulated tunnel. Tray loads of the wet material are assembled on trolleys which enter the tunnel at one end. The trolleys travel the length of the tunnel and exit at the other end. Heated air also flows through the tunnel, passing between the trays of food and/or through perforated trays and the layers of food. The air may flow parallel to and in the same direction as the trolleys, as shown in Fig (2.9).

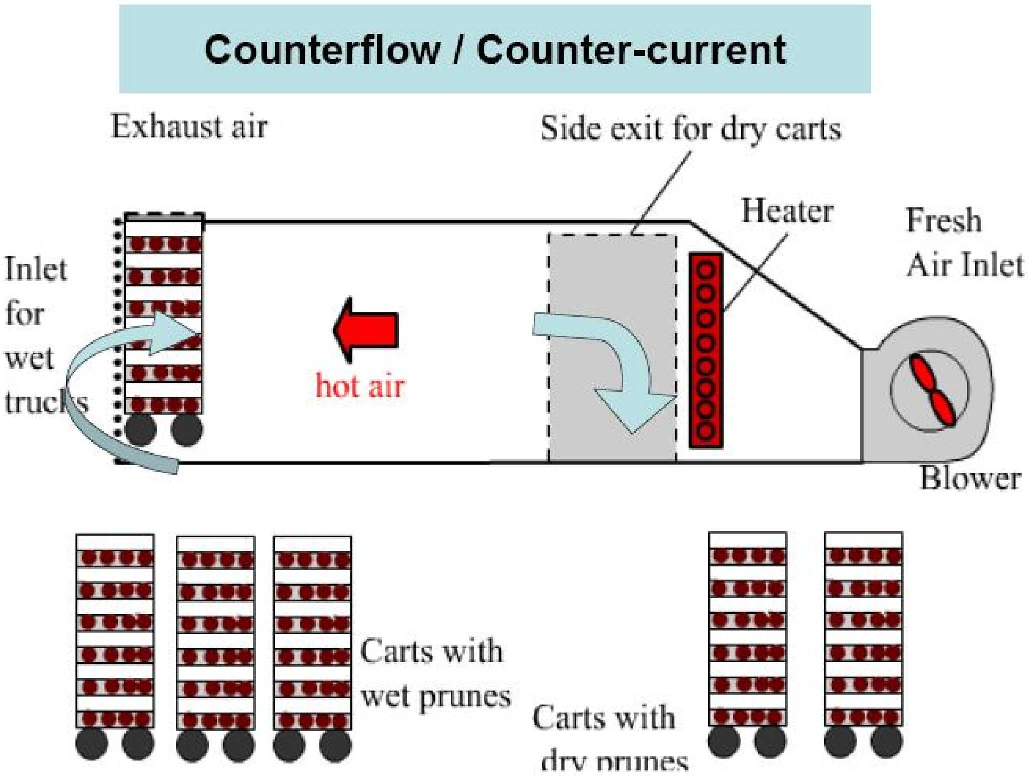


Fig 2. 9: Tunnel dryer.

2.15.3 Conveyor (Belt) Drier

In this type of drier the food material is conveyed through the drying tunnel on a perforated conveyor, made of hinged, perforated metal plates or wire or plastic mesh. The heated air usually flows through the belt and the layer of food, upward in the early stages of drying and downward in the later stages. The feed is applied to the belt in a layer of 75–150 mm deep.

2.15.4 Fluidized Bed Dryer

This is another through flow, hot air drier which operates at higher air velocities than the conveyor dryer. In this type of drier heated air is blown up through a perforated plate which supports a bed of solid particles. As the air passes through the bed of particles, a pressure drop develops across the bed. As the velocity of the air increases the pressure drop increases. At a particular air velocity, known as the incipient velocity, the frictional drag on the particles exceeds the weight of the particles. The bed then expands, the particles are suspended in the air and the bed starts to behave like a liquid, with particles circulating within the bed. This is what is meant by the term fluidized bed as shown in Fig (2.10)

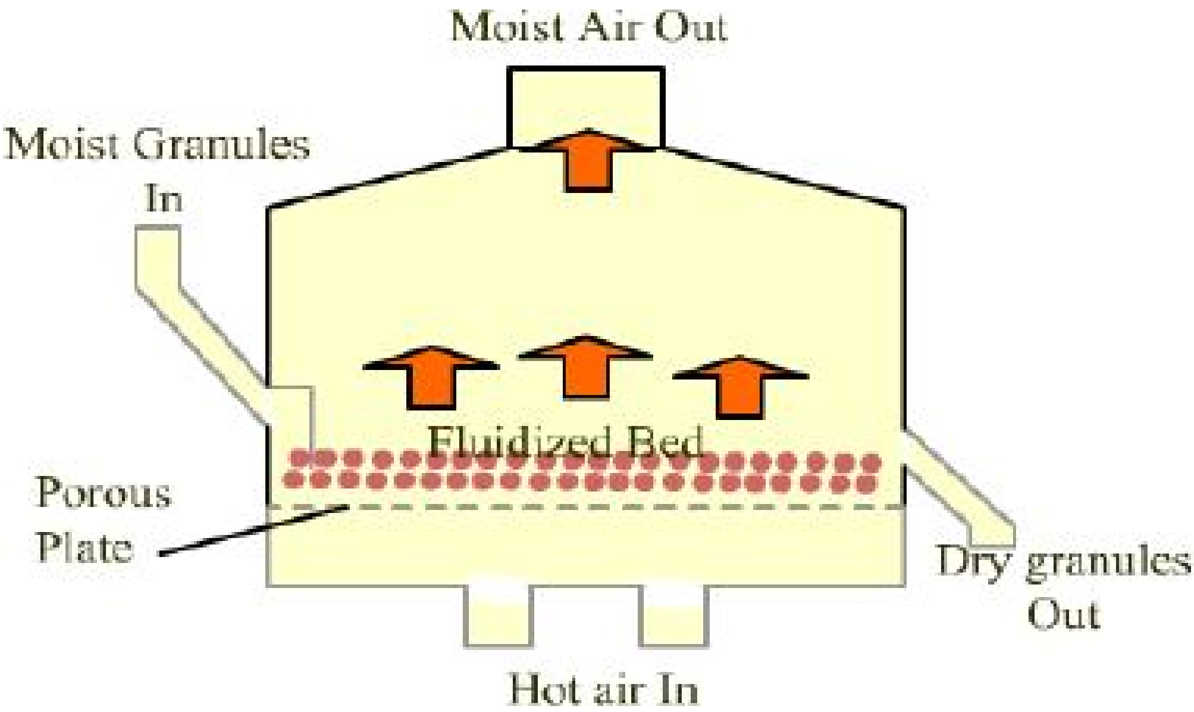


Fig 2. 10: Fluidized-bed dryer.

2.16 Special dryers

2.16.1 Design a dryer for drying sugar beet

Mohammadzadeh, (2010) design a dryer for drying sugar beet root as shown in Fig(2.11)

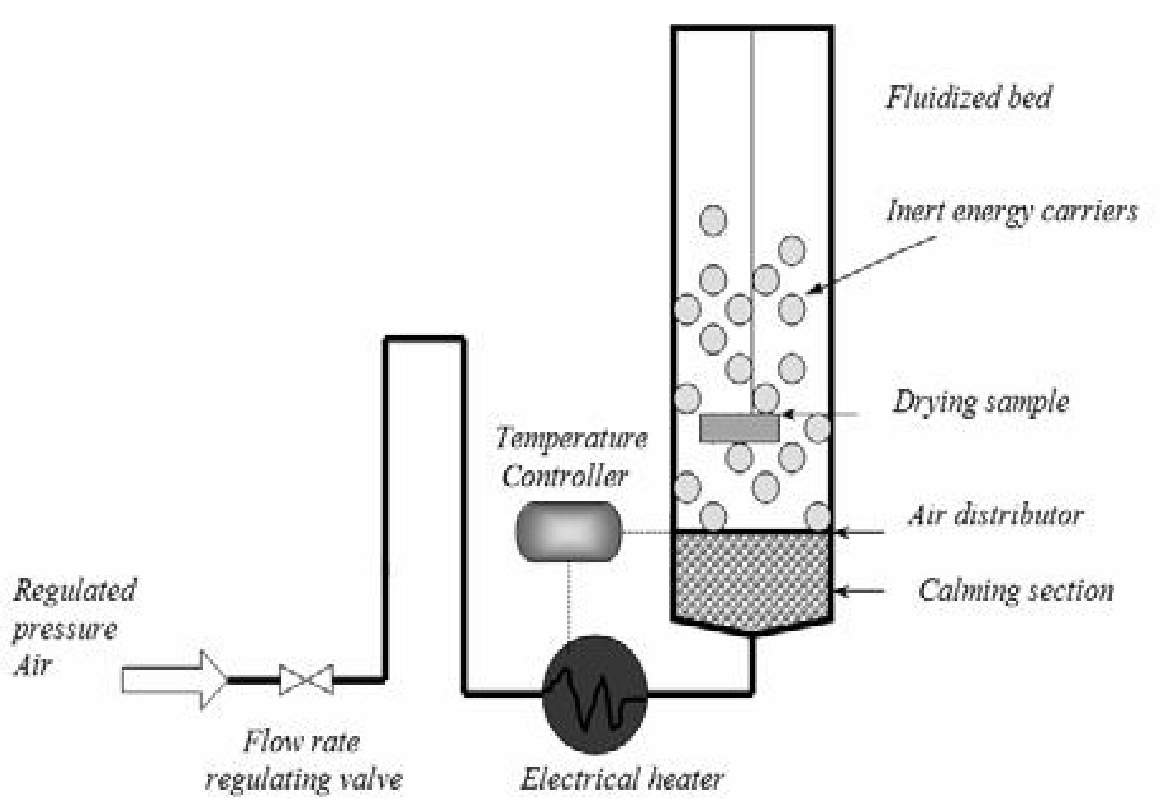


Fig 2. 11: Schematic diagram of the experimental Column for drying sugar beet.

The dryer was a 47 mm diameter and 60 cm length cylindrical pyrex column with a porous plate used in its bottom as the air distributor. Drying air was supplied from a high-pressure air source and a pressure regulator adjusted its pressure. Air was heated by an electrical heater and its temperature was controlled within ±1°C by use of a temperature controller.

2.16.2 Design a dryer for drying Green Table olives

Öngen *et.al (*2005) design a dryer Fig (2.12) in order to dry Green Table Olives using a hot air drying. Olive samples were dehydrated by using the tray dryer. The schematic diagram of the drying equipment is given in Fig. 2. In order to evaluate the effect of air temperature on the drying process, four temperatures (40, 50, 60 and 70 °C) were used. The air velocity was kept constant at 1 m/s and the relative humidity was maintained at 15 %. Every 30 min the samples were taken out, weighed and returned to the dryer. Drying was stopped when the mass of the samples reached a constant value.

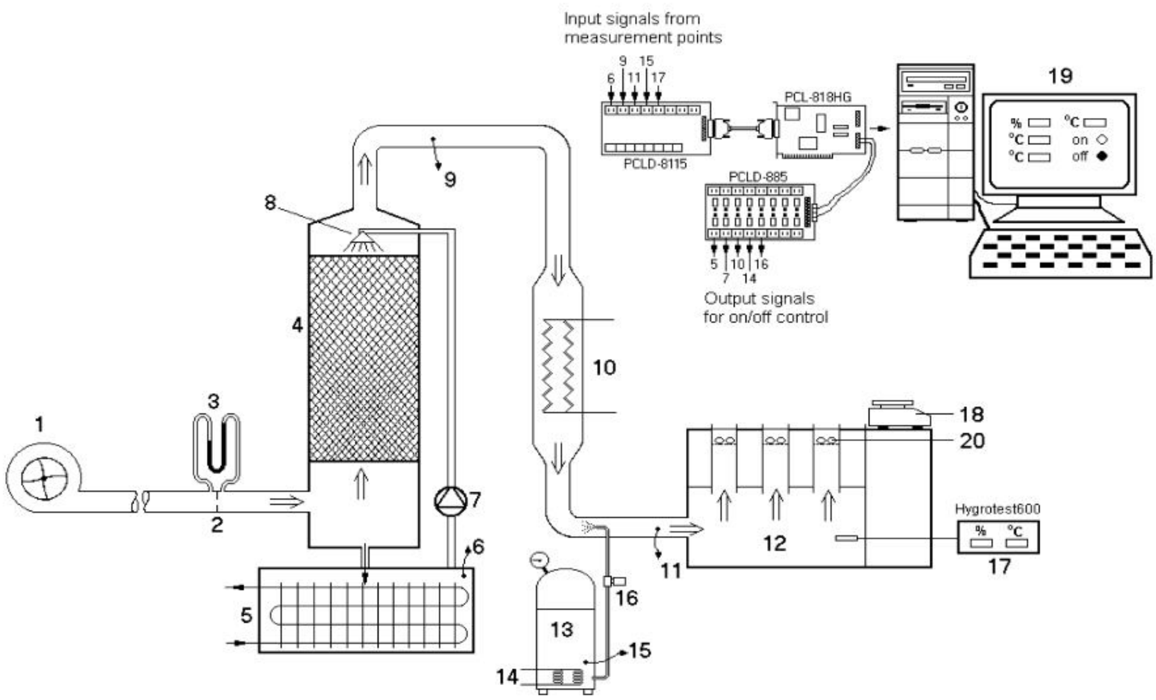


Fig 2. 12: Schematic diagram of the drying equipment.

1, centrifugal fan; 2, orifice plate; 3, differential manometer; 4, cooling and saturating tower; 5, cold water tank and evaporator; 6, 9, 11 and 15, thermocouples (T type); 7, circulation pump; 8, cold water shower; 10, electric heaters; 12, mixing chamber and air channels; 13, steam tank; 14, electric water heater; 16, injector and solenoid valve; 17, temperature and humidity sensor; 18, balance; 19, computer with data acquisition and control cards; 20, olives.

2.16.3 Design of the cabinet solar dryer

Eze (2010) design and construction of the cabinet solar dryer Fig (2.13), the length of the cabinet was chosen to be between 2.5 to 3.0 cm times the width to minimize shading effect from the side panels. The dryer is essentially a single chamber cabinet iron frame covered with Perspex (colorless glass which provides substantial screening effect against ultraviolet light, thus reducing photo degradation of the produce being dried). Its bottom and door are insulated with plywood for reduction in heat losses and together with the roof blackened for effective absorption and retention of solar radiation.

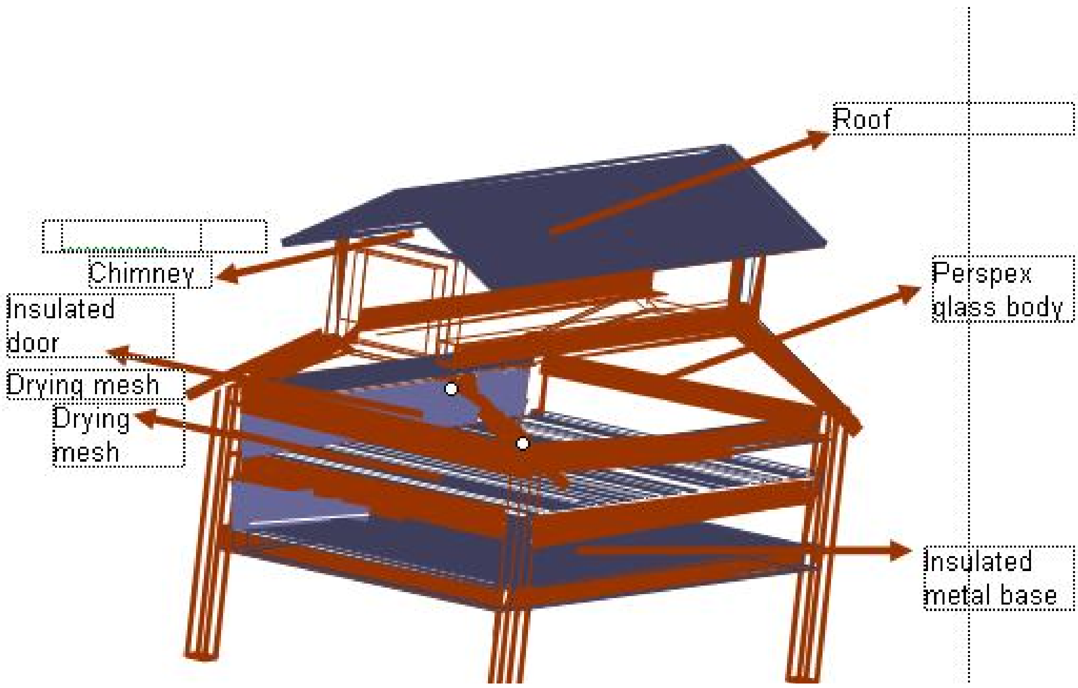


Fig 2. 13: Design of solar cabinet dryer.

2.16.4 Design of mixed-mode natural convection solar dryer

Forson *et.al,*(2007), design of mixed-mode natural convection solar dryer Fig (2.14) used for drying cassava and other crops. Three main components of the dryer can be identified: *An air-heater* (primary collector), through which the drying air is heated as it flows over and under an absorber plate that is heated in turn by direct absorption of incident radiation; a drying chamber, in which the crop to be dried is placed; and a chimney, through which the moist air flows and escapes into the surrounding. Solar energy is incident on the planes of the primary collector and the drying chamber.

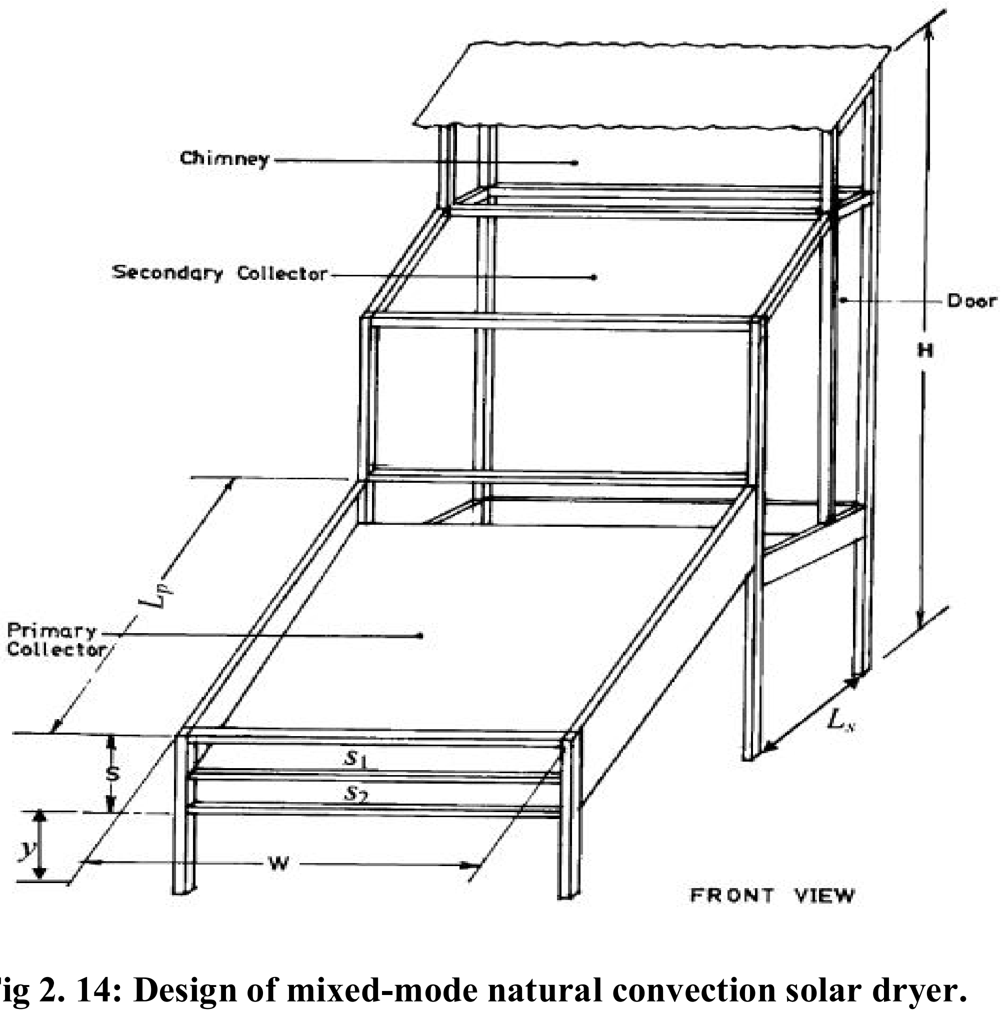


Fig 2. 14: Design of mixed-mode natural convection solar dryer.

2.16.5 Design a cold air dryer

Kilic (2009) design a cold air dryer in order to dry fish Fig (2.15). The experimental set-up for the cold air drying process of the fish samples consists of a cyclone- type dryer, a compressor of the cooling system, a cold air evaporator and a circulatory radial fan.

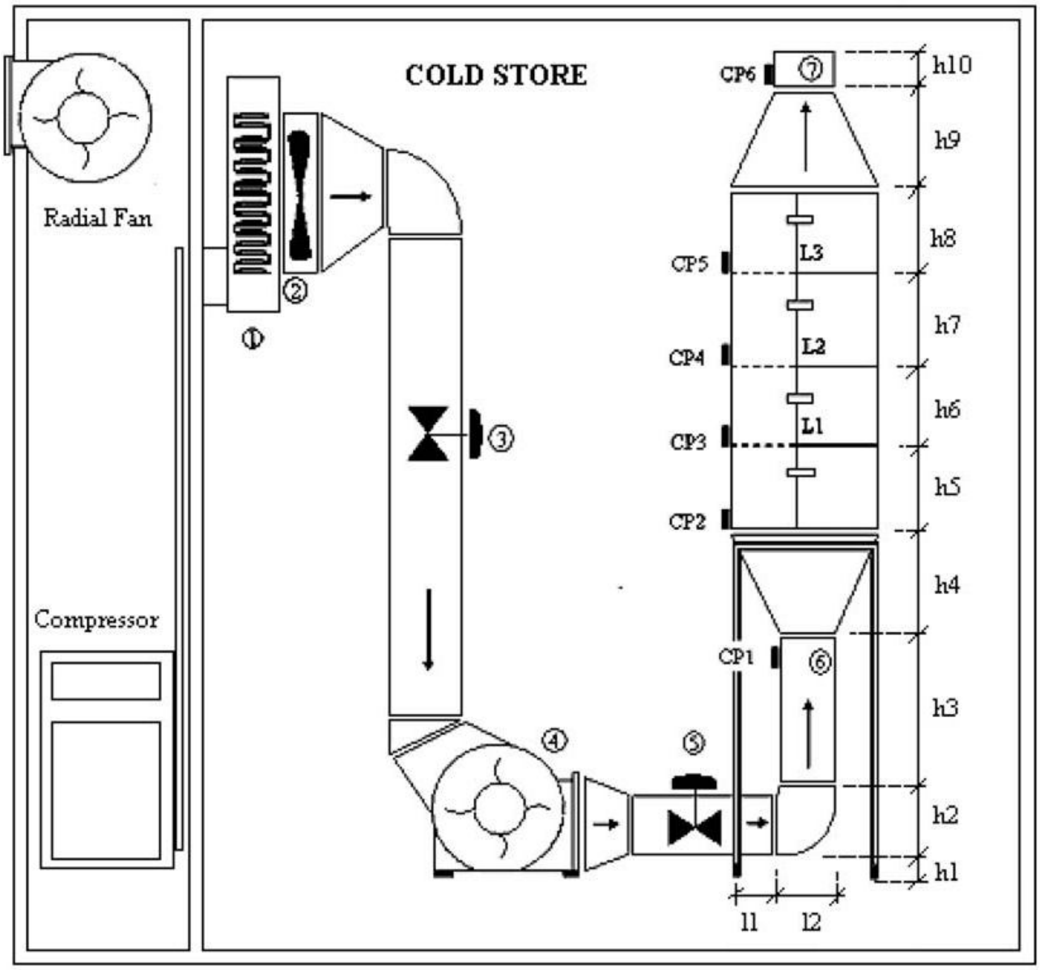


Fig 2. 15: Cold air drying system.

1. Evaporator, 2. Fan, 3. Cold-air Velocity Balance Valve, 4. Radial Fan, 5. Velocity Balance Valve, 6. Cold Air Inlet, 7. Cold Air Outlet. CP: control point, L: Layer (h (height); h1 = 10 cm, h2 = 20 cm, h3 = 100 cm, h4 = h9 = 30 cm, h5 = h6 = h7 = h8 = 30 cm, h10 = 10 cm, l1 = l2 = 20 cm).

2.16.6 A new low-temperature food drying system

Nagaya *et.al,*(2005), design a new low-temperature food drying system with controlled airflow and temperature is designed to dry food such as vegetables. The designs consist of Dehumidifier and drying chamber.

2.16.7 Design of low-pressure superheated steam dryer

Panyawong and Devahastin (2007) design a dryer of low-pressure superheated steam dryer and associated units to find a simple way to describe the deformation of a food product undergoing drying more precisely. Vacuum drying and LPSSD were chosen as the representative drying techniques and carrot cube was chosen as the representative product. The so-called Heywood shape factor, or the volume shape factor, was chosen to represent the shape of the drying product in this study. The dryer Fig (2.16) consists of a stainless steel drying chamber, insulated carefully with rock wool, with an inner dimension of 45 · 45 · 45 cm3; a steam reservoir, which received the steam from the boiler and maintained its pressure at around 200 kPa (gage); and a liquid ring vacuum pump (model ET32030, Nash, Trumbull, CT), which was used to maintain the vacuum in the drying chamber. Steam trap was installed to reduce the excess steam condensation in the reservoir.

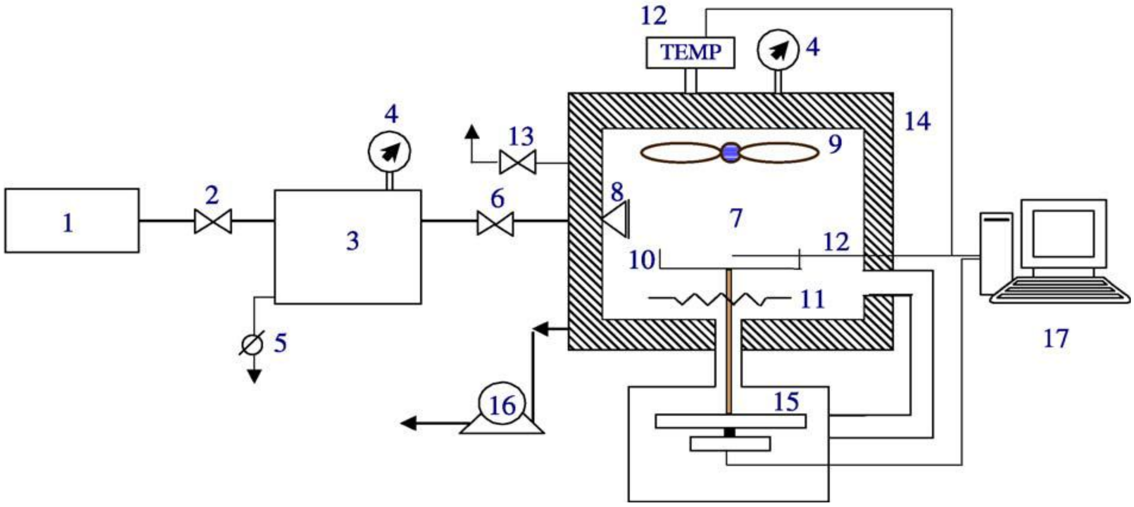


Fig 2. 16: A schematic diagram of low-pressure superheated steam dryer and associated units.

(1) Boiler; (2) steam valve; (3) steam reservoir; (4) pressure gauge; (5) steam trap; (6) steam regulator; (7) drying chamber; (8) steam inlet and distributor; (9) electric fan; (10) sample holder; (11) electric heater; (12) on-line temperature sensor and logger; (13) vacuum break-up valve; (14) insulator; (15) on-line weight indicator and logger; (16) vacuum pump; (17) PC with installed data acquisition card.

2.16.8 A biomass dryer to dry chili peppers

Waewsa *et.al,*(2006) investigate a biomass dryer to dry chili peppers, lemon grass and leech lime leaves at different air temperature and air velocity. The drying experiments were carried out using a biomass dryer which consists of a blower, a combustion chamber, a drying chamber and a ducting system with air recycling as shown in Fig (2.17).

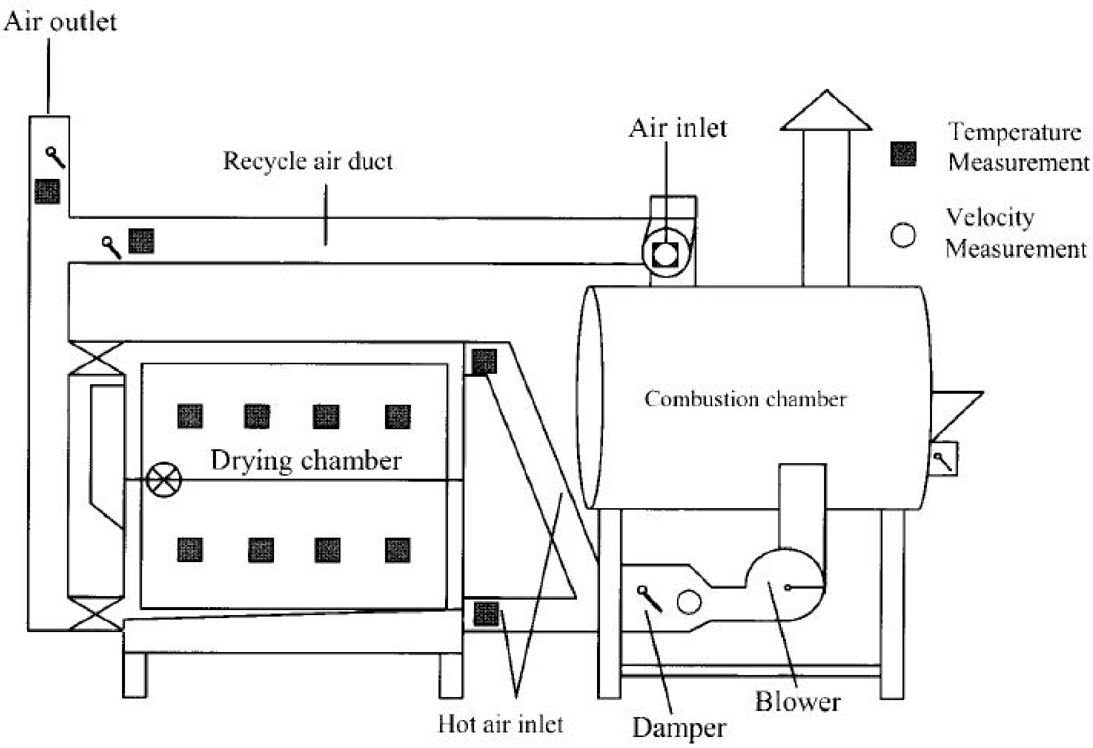


Fig 2. 17: Conventional biomass dryer.

2.16.9 Design of convection drying dryer

Jokić *et.al,* (2009) determine the influence of the process parameters and pre-treatment methods on the quality and drying kinetics of apple samples using convection drying equipment. The dryer operates on the thermo gravimetric principle. The dryer Fig (2.18) was equipped with the temperature and airflow velocity controllers. Air was drawn into the duct through a diffuser by a motor driven axial flow fan impeller. In the tunnel of the dryer were carriers for trays with samples, which were connected to a balance. The balance was placed outside the dryer, continuously determining and displaying the sample weight. A digital anemometer measured the airflow velocity at the end of the tunnel.

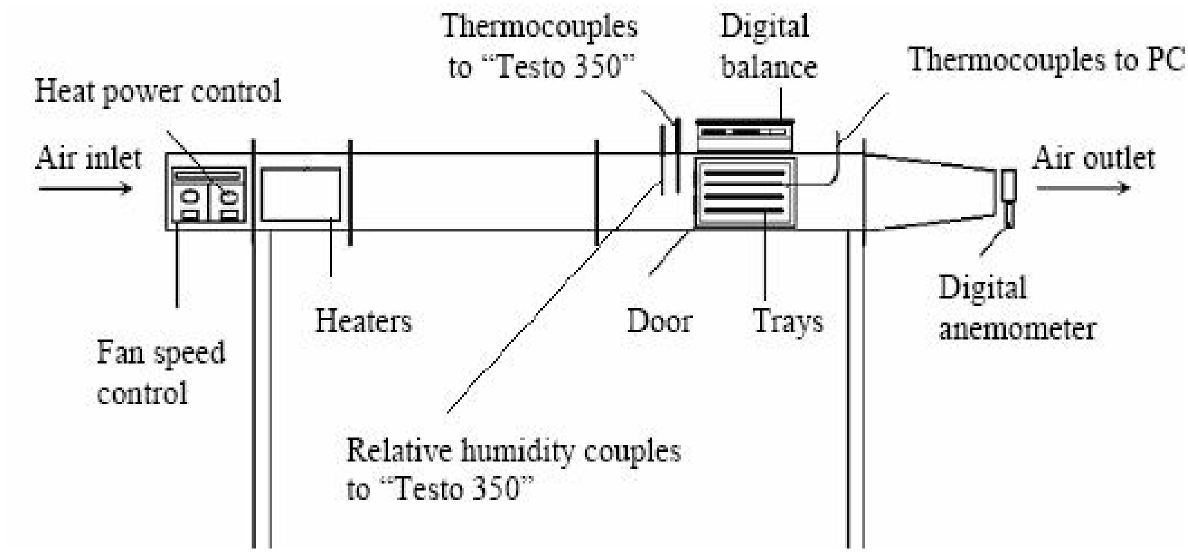
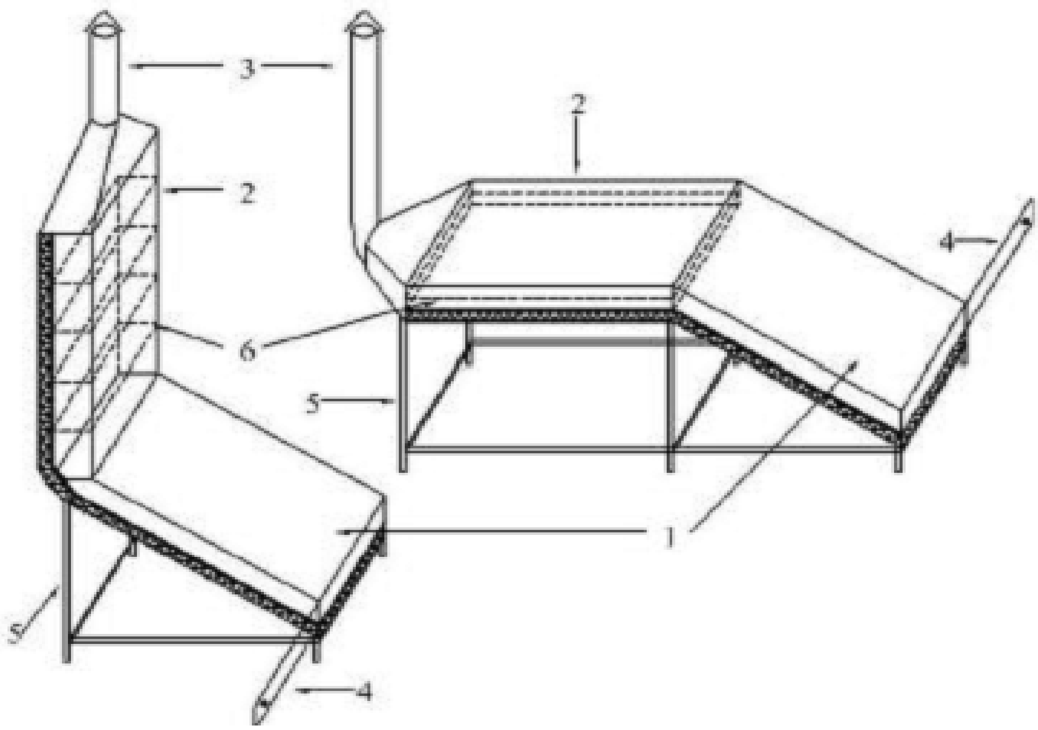


Fig 2. 18: Schematic diagram of the convection drying equipment.

2.16.10 Solar dryer mechanism for drying banana

Solar dryer mechanism was mounted and investigated for drying banana by Hassanain, (2009). The dryer composes three main components: a solar air collector, where the drying air is heated, drying chamber either horizontal or vertical and flow enhancement apparatus as shown in Fig. (2.19).



1=Air type solar collector; 2= Drying chamber; 3= Solar chimney; 4= Shutter;
5= Frame support; 6= Drying shelf

Fig 2. 19: Solar drying systems for drying banana.

The skeleton and frames of the solar collector and the dryer cabinet was fabricated from 5cm thick wood. Solar collector of 1m long, 0.5m width and 0.1m height was mounted fixed at 30° inclined with the horizontal datum. Flexible movable drying chamber of 1 m long, 0.5 m width and 0.15 cm height were used. Polyethylene foam of 5cm thick was used as insulation material underneath the 1mm thick Aluminum absorbing metal material. Aluminum sheet of 1mm thick with dimensions of 1m x 0.5m was used as absorbing material. Matt black paint was applied to the absorber plate paint. One absorbing plate was used for the solar air collector and another one with the same dimensions and material was used for the drying cabinet.

A glass pane of 4mm thick with dimensions of 0.5 x 1.0m was used as a transparent cover; another pane with the same dimensions and thick was used for the cabinet cover to intensify the incident solar flux on the drying product.

2.16.11 A hybrid solar dryer using direct solar energy and heat exchanger for drying banana

A hybrid solar dryer was designed and constructed using direct solar energy and a heat exchanger by (Amer *et.al*, 2010) Fig (2.20). The dryer consists of solar collector, reflector, heat exchanger cum heat storage unit and drying chamber. The drying chamber was located under the collector. The dryer was operated during normal sunny days as a solar dryer, and during cloudy day as a hybrid solar dryer. Drying was also carried out at night with stored heat energy in water which was collected during the time of sun-shine and with electric heaters located at water tank. The efficiency of the solar dryer was raised by recycling about 65% of the drying air in the solar dryer and exhausting a small amount of it outside the dryer.

The capacity of the dryer was to dry about 30 kg of banana slices in 8 h in sunny day from an initial moisture content of 82% to the final moisture content of 18% (wb). In the same time it reduced to only 62% (wb) moisture content in open sun drying method. The colour, aroma and texture of the solar dried products were better than the sun drying products.

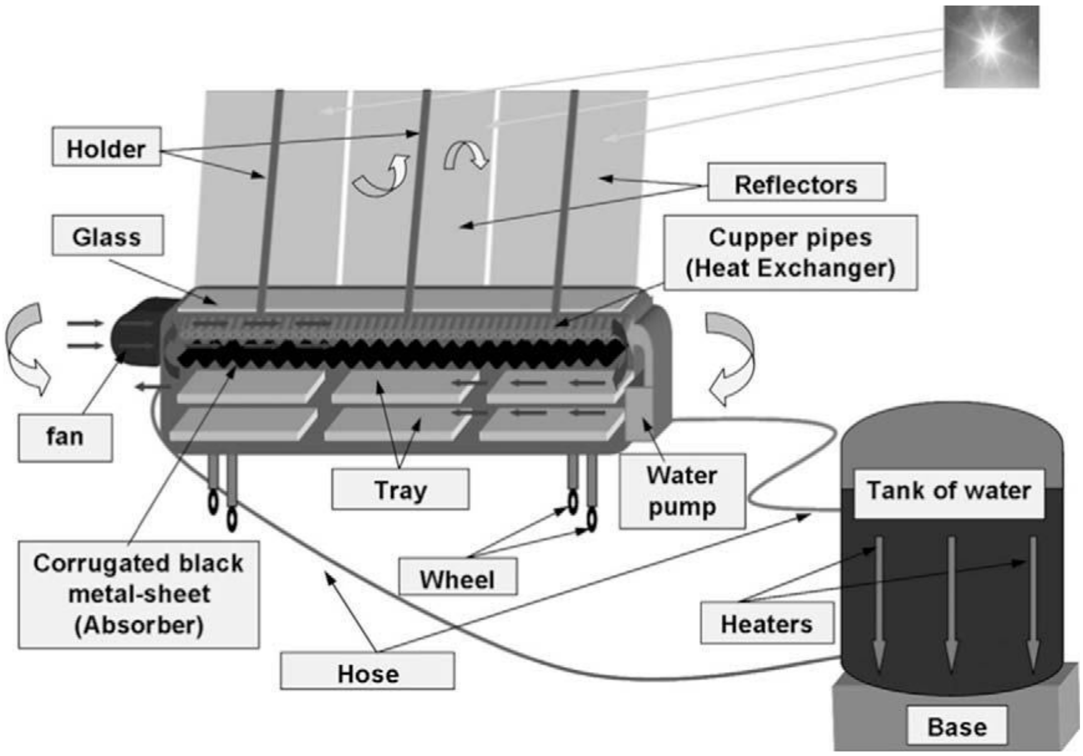


Fig 2. 20: Schematic diagram of a solar hybrid dryer

2.16.12 Spouted bed dryer for drying banana

Bezerra *et.al,* (2013) design a dryer (Spouted bed dryer) for dying banana as shown in Fig (2.21). The dryer consists of a conical base with an internal angle of 60◦ and an inlet orifice diameter of 50 mm. A cylindrical column with a diameter of 200 mm and a height of 300 mm is connected to the conical base of the dryer. The upper part of the equipment is composed of another cone and a cyclone. The operation started with the introduction of 1036 g of inert material into the equipment. Spouting occurred when air was injected at the base of the bed. When the spout was established the inlet air was heated to the desired temperature. The working temperatures in the dryer were 80 and 90 ◦C, and drying air flow rate was fixed at 50 m3/h. Polyethylene pellets were used as the inert material with a diameter of 3.60 mm (±0.02 mm), a density of 905.23 kg/m^3 (±3.82 kg/m^3) and a sphericity of 0.850. The results show that the rheological behavior of flour with peel showed the highest values of viscosities but both flour showed high tendency to retro gradation. The swelling power and solubility were also similar for all flour samples, with low solubility under cold and high solubility under hot conditions.

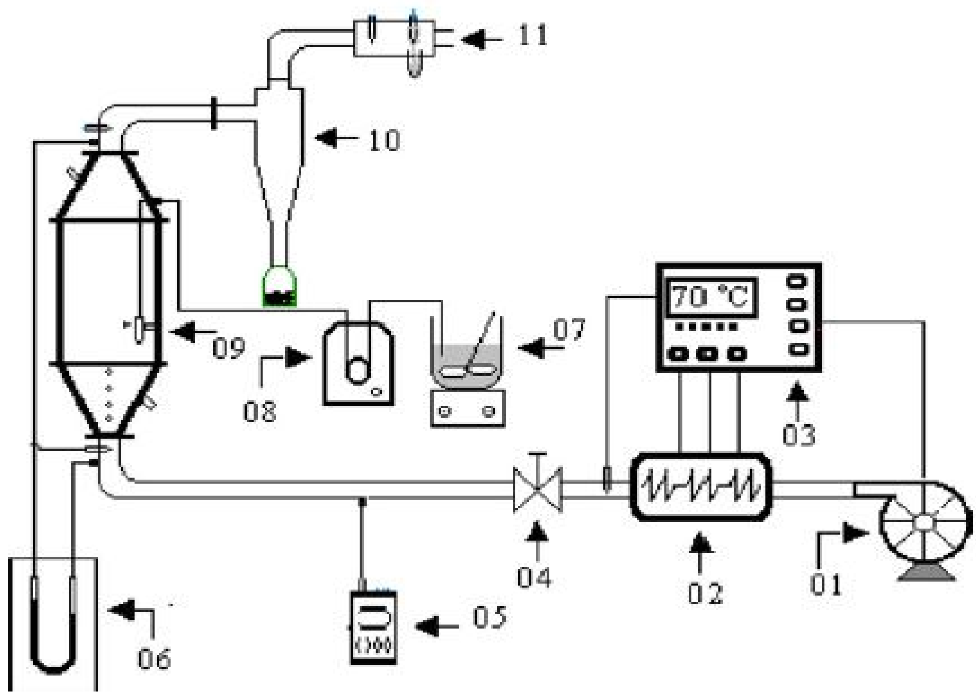


Fig 2. 21: Spouted bed dryer for drying banana.

Blower (01); air heater (02); controller of electrical current (03); valve to regulation of the inlet air (04), flow rate indicator (05); differential pressure indicator (06); suspension (07); peristaltic pump (08); spouted bed (09); cyclone (10) and psychrometer (11).

2.16.13 Experimental apparatus to dry banana

Hadrich and Kechaou (2009) conduct the experimental apparatus to dry banana as shown in Fig (2.22), which was designed to perform hot air drying experiments under the following conditions: air temperature ranging from 50 to 70 °C, air velocity between 3 to4.5m/s and relative humidity ranging from 3.5 to 11.5%. In the drying chamber, a single banana sample was laid on a perforated tray placed over an analytical balance (METTLER) with a precision of ±0.01 g. Periodic weighing was performed throughout the drying experiments at constant time intervals (10 s). The calculated drying curves were compared to the experimental ones in order to determine apparent moisture diffusivity. An empirical equation was suggested, describing the apparent moisture diffusivity within the banana versus product temperature and local moisture content. A good agreement was found between experimental and calculated drying kinetics.

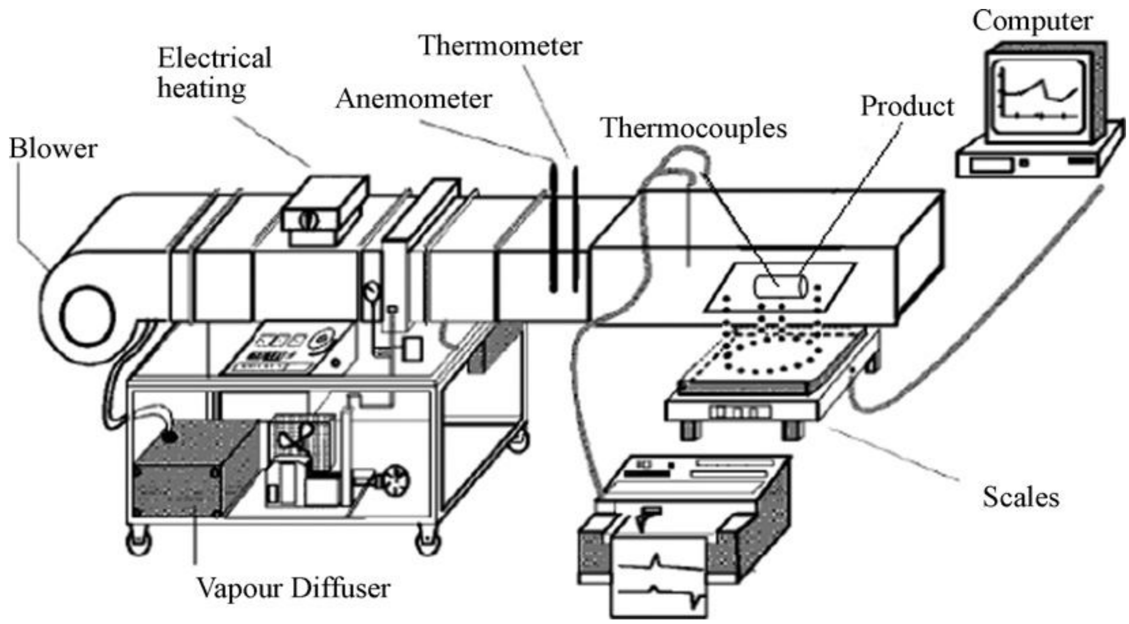


Fig 2. 22: Experimental drying apparatus for drying banana.

2.16.14 A laboratory- scale system dryer for drying banana

Air-drying of banana slabs has been investigated and the influence of experimental parameters such as temperature, relative humidity and slab thickness has been studied using a laboratory- scale system dryer Fig (2.23) by (Nguyen and Price 2007). The dryer consisted of a dehydration unit and an online data-logging data system. The drying chamber was equipped with heating, ventilation, and a humidifying system. The humidifying system was used to control the humidity during drying. The fluctuation in RH% that occurred during the experiments was better than ±5%. Fruit was placed on a stainless steel mesh tray, which was suspended from an electronic balance. The balance output to a computer based data acquisition system recorded automatically the mass change, temperature, and humidity of surrounding air as a function of drying time. In this system air-drying of banana slabs has been investigated and the influence of experimental parameters such as temperature, relative humidity and slab thickness has been studied.

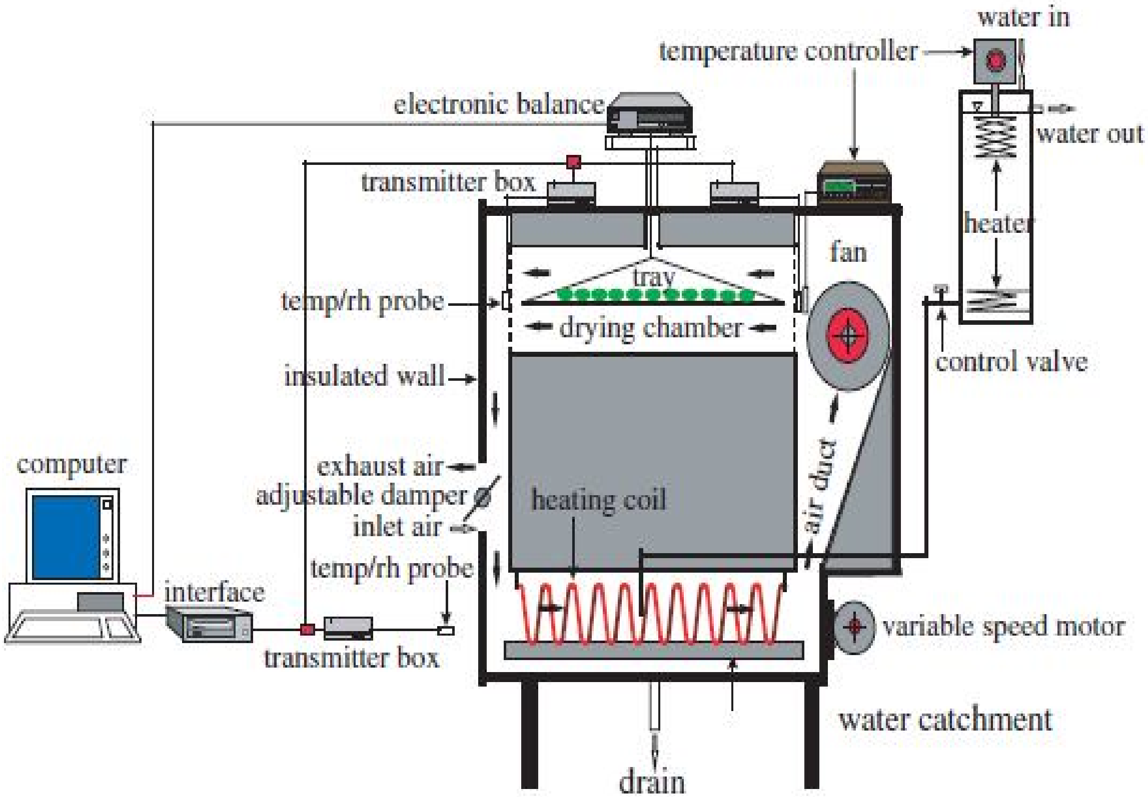


Fig 2. 23: Schematic diagram of the dehydration system.

2.16.15 Infrared radiation assisted with hot air for drying onion slices

Kumar et al (2006) dried onion slices under different processing condition using infrared radiation assisted with hot air as shown in Fig (2.24). The continuous dryer with overall dimensions of (5.5 (L) _0.9 (B) _1.4 (H) has a capacity of 16 kg/h of raw vegetables. The dryer consists of three numbers of insulated chambers, fitted with mid-infrared (MIR) heaters on either side of the wire mesh conveyor. Through flow hot air heating system was provided for convective heating. The experiments were carried out in batch mode with a loading density of 15 kg/m2. The experiments were carried out at different drying temperatures (60, 70 and 80 1C), slice thickness (2, 4 and 6 mm), inlet air temperatures (30, 40 and 50 1C) and air velocities (0.8, 1.4, and 2.0 m/s). The temperatures were controlled by means of thermostats while the air velocity was regulated by flow control valves. During experimentation, one of the above processing conditions was varied, while maintaining the other conditions constant. The samples were drawn at regular intervals for moisture analysis. The final moisture content in the product was 8–9% (w.b).

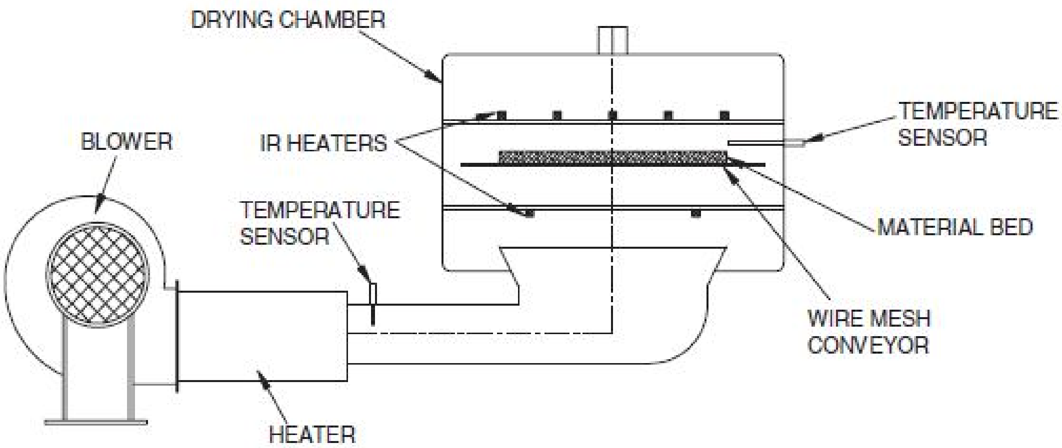


Fig 2.24: Schematic diagram of combined infrared and hot air-drying system for onion drying

2.16.16 A laboratory scale vacuum dryer for drying onion slices

Onion slices were dried in a single layer of thickness varying from 1 to 5mm in the temperature range of 50–70 ◦C in a laboratory scale vacuum dryer by (Mitra *et.al* 2011). The effect of pretreatment, drying temperature and slice thickness on the drying kinetics of onion slices was studied. The schematic view of the dryer is shown in Fig. (2.25). The dryer consisted of a water tank, a heater, drying chamber, the three drying chamber plates termed as header plates, hot water circulation pump, a vacuum pump and a chilled water circulation unit. The dryer was provided with an arrangement for circulating hot water into the header plates through pipelines to maintain the desired drying temperature.

Stainless steel trays were used for placing the onion slices in a single layer for drying. A water ring vacuum pump was used to create the desired vacuum of 710±5mm Hg inside the drying chamber. There was a thermostat type temperature controller attached to the system. The dryer was also equipped with a vacuum gauge and indicators for showing the temperatures of product as well as vapor.

The drying temperature and slice thickness had a significant effect on drying behavior of onion slice. The increase in temperature and decrease in thickness resulted in a decrease in drying time. As the thickness of the slices increased, time required to dry the sample to the safe level of moisture content also increased because moisture had to travel relatively a longer path in case of thick sample to come to the surface from the inside of the slice. As the drying proceeded, the surface moisture receded gradually and the moisture inside the product tried to diffuse to the surface.

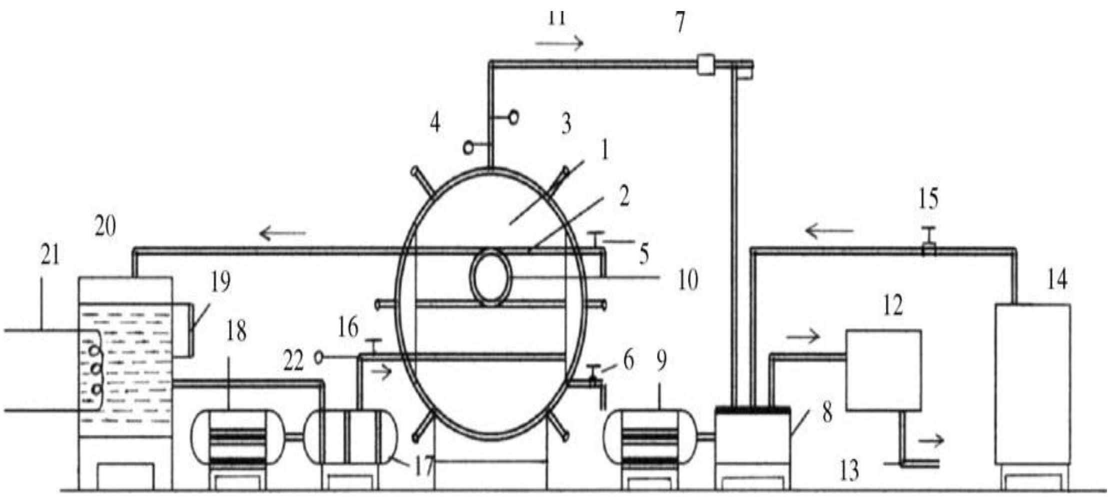


Fig 2.25: Schematic diagram of the vacuum dryer system

(1) Drying chamber, (2) Drying chamber plate, termed as header plate, (3) Vacuum gauge, (4) Vapour temperature gauge, (5) Water drain valve from header, (6) Vacuum break valve, (7) Non-return valve in the vacuum line, (8) Water ring vacuum pump, (9) Motor for vacuum pump, (10) Watch glass, (11) Vacuum suction line, (12) Silencer, (13) Water and vapour outlet, (14) Water chiller to circulate cool water to vacuum pump, (15) One way valve connecting chiller and vacuum pump, (16) One way valve to flow hot water from tank to the header plate, (17) Hot water supply pump, (18) Motor for hot water pump, (19)

Water level gauge, (20) Hot water storage tank, (21) Electric heater, and (22) Water temperature gauge.

2.16.17 Catalytic infrared heating for drying onion

High-solids onions sliced to 2.5mm thick were dehydrated under three conditions by (Talati and Shah 2009) using catalytic infrared (CIR) as shown in Fig (2.26) heating with and without air recirculation, and forced air convection (FAC) heating. The drying and quality characteristics of the onion slices were studied at three drying temperatures 60, 70 and 80°C for each drying condition. The drying temperatures were product temperature for CIR drying and air temperature for FAC drying. Loading rate was kept constant at 2.5 kg/m2, and air velocity for the FAC and CIR-recirculation was set at 0.5 m/s. The drying and quality characteristics of CIR and FAC dried onions were compared.

It was found that CIR drying, both with and without air recirculation, had a higher maximum drying rate, shorter drying time to reach required moisture, and greater drying constants than FAC drying.

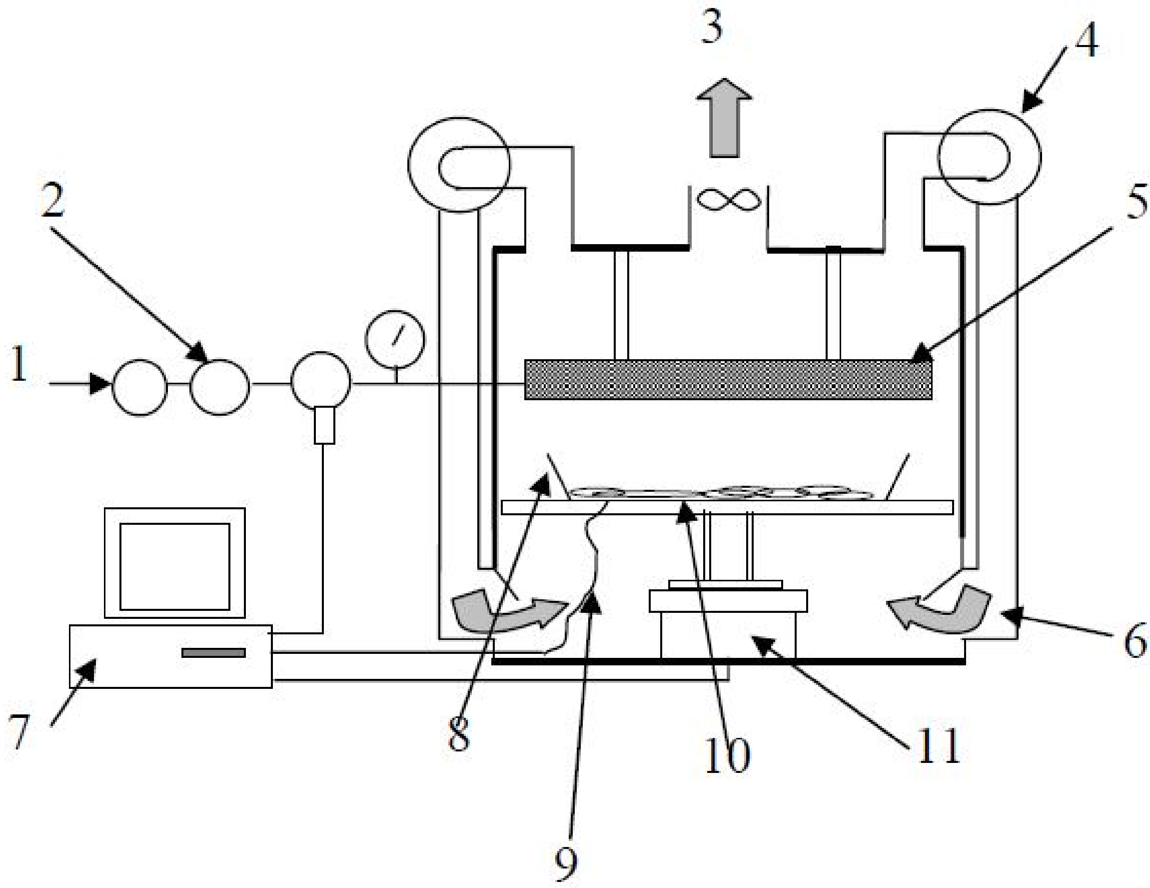


Fig 2.26: CIR Dryer

1- Natural Gas; 2-Gas Flow Control; 3-Exhaust; 4-Blower; 5-CIR Emitter;

6-Recirculation Air; 7-Computer Controller; 8-Wave Guide; 9-Thermocouple, 10-Onion Sample; 11-Balance.

2.16.18 A laboratory scale natural convection mixed-mode solar dryer for drying potatoes

A laboratory scale natural convection mixed-mode solar dryer was designed and fabricated by Tripathy and Kumar (2009) to perform the drying experiments on potatoes samples Fig (2.27). It consisted of an inclined flat-plate solar collector connected in series to a drying chamber in which the food product to be dried is placed on wire mesh tray. The collector-dryer assembly was made of matt black painted 22 gauge (0.64 mm thickness) aluminum sheet used as solar radiation absorber surface with 3 mm thick transparent glass cover on the top to allow solar radiation. Rubber gasket was also used beneath the glass cover for making the system air leak-proof. The fiber glass insulation of thickness 50 mm was provided at the bottom and sides of the assembly to minimize the thermal losses through conduction. The whole assembly was encased in a thick wooden frame with an outer aluminum foil cover to protect it from weather conditions. Two rectangular openings of size 0.305 × 0.05 m at the collector inlet and dryer outlet were made for natural circulation of air by the buoyancy effect due to temperature difference between hot air inside and ambient air outside of the dryer.

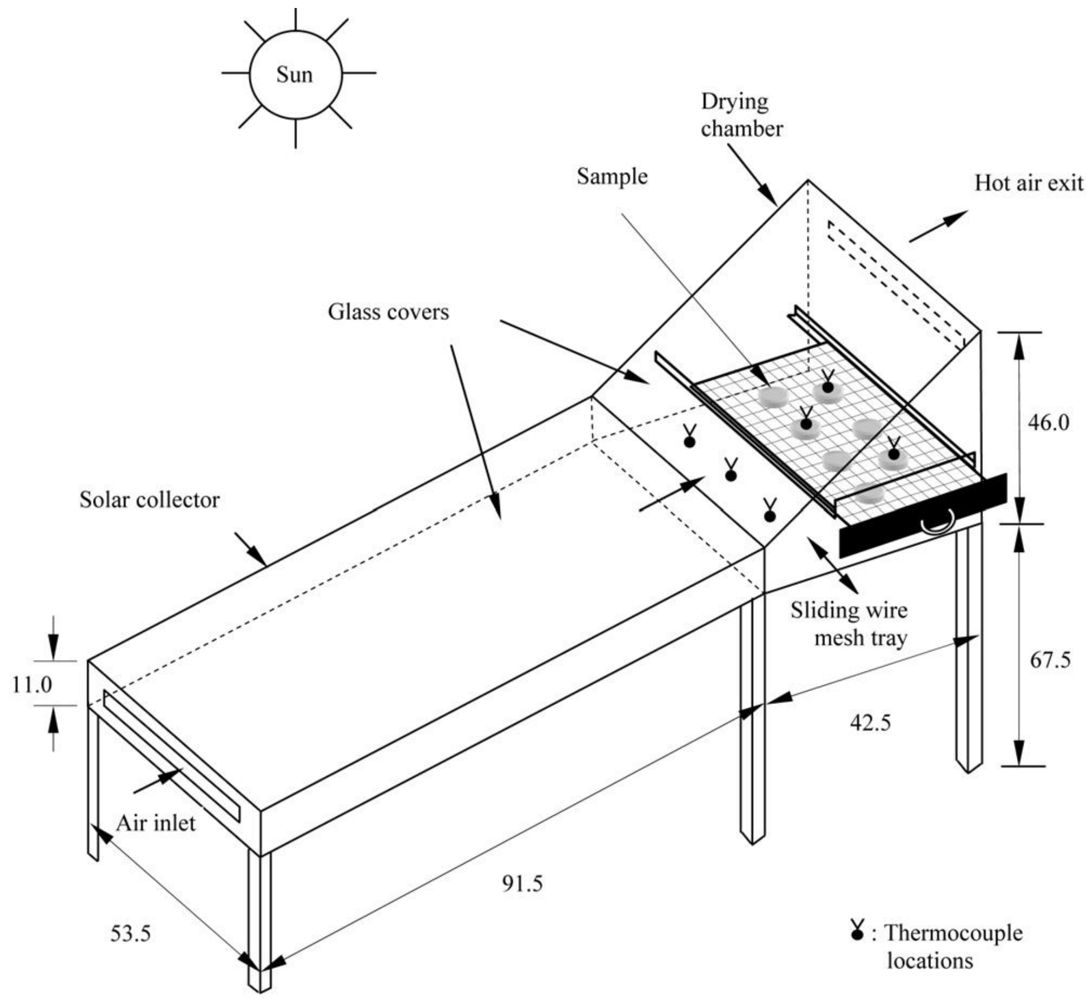


Fig 2. 27: Natural convection mixed-mode solar dryer

2.17 Drying vegetables and fruits

During the past decade, many advances in drying technologies have emerged with the goal of minimizing degradation of various quality attributes of food products during drying. Among an enormous number of foods that need to be dried, fruits and vegetables have received much attention as it has repeatedly been reported that these materials contain a wide array of phytochemicals, which are claimed to exert many health benefits, including antioxidant activity. In some cases where extraction of bioactive compounds cannot be performed on fresh fruits and vegetables, drying is a necessary step that needs to be conducted to keep the materials for later use (Devahastin and Niamnuy2010). Ehiem *et.al*, (2009) reported that, fruits and vegetables are agricultural products that are known for their rich vitamins, high concentration of moisture and low fats. They are highly perishable due to excess moisture present in them especially at harvest. Fruits and vegetables are seasonal crops and are mostly available during the production season. The demand for vegetables by the growing population has not been met despite the increase. This is as a result of wastes that result from biological and biochemical activities taking place in the fresh product and unfavorable storage conditions, inefficient handling, transportation, inadequate post harvest infrastructure and poor market outlets. Fruits and vegetable can be successfully preserved by reducing their moisture content to a level that will discourage the activities of micro-organisms and fungi from deteriorating them. Microbial activities are not active when the moisture content of a product is below 10%. Apart from exposing the product to direct sun energy (traditional method of drying), there are indirect methods of achieving better quality dried products that are free from inefficiencies of sun drying that is characterized by the problems of losses, contaminations, rewetting and uncontrolled drying rate. This results to loss of flavor, color, taste, and case hardening, heat stress and contamination by birds, flies and animal droppings. Etienne and Serge (1983) states that vegetable drying is facilitated by slicing and spreading out the product to increase their surface area to hot air; adopting a reliable heat medium; increasing the circulation of air around the product; insulating the areas that are not exposed to the same source of heat to avoid heat loss; avoiding direct heating since this affects the quality and appearance of the product; and protecting the dried products against contamination, re-absorption of moisture from the environment and harmful effect of sunlight.

2.18 Pre-treatment of fruits and vegetables

Sunjka and Raghavan (2004) reported that, drying of fruits and vegetables is one of the most time and energy consuming processes in the modern food industry. To reduce the processing time, thus facilitating and accelerating the dehydration process, a number of obstacles must be overcome.

(Karim, 2005) stated that, different pre-treatment methods have been developed for fruit drying, among which are lemon juice, salt solution, honey dip, ascorbic acid, sulfuring, osmotic pretreatment, and blanching. Susan and Williams (1993) reported that, no pre-treatment is done; the fruits will continue to darken after they are dried. For long-term storage of dried fruits, sulfuring or using a sulfite dip are the best pre-treatments.

Beaudry (2001) tested different concentrations and time periods of dipping for cranberries and concluded that these have no significant influence on subsequent osmotic dehydration. Doymaz, (2004) stated that, prior to drying process, chemical dipping such as methyl and ethyl ester emulsions or alkaline pre-treatment in aqueous solutions of sodium hydroxide, sodium chloride, potassium carbonate and calcium chloride has been used to overcome the wax barrier on fruits or vegetables. Doymaz, (2007) investigated the drying characteristics of tomatoes. Prior to drying, tomatoes were subjected to dipping in alkaline ethyl oleate solution. It has been found that pre-treatment and air temperature affect the course and rate of drying.

Abano and Amoah,(2011) investigate different pretreatments on the drying characteristics of ripe Gros Michel banana slices. 5 and 7 mm thick slices of bananas were pretreated with four different pretreatments such as ascorbic acid, lemon juice, salt solution, honey dip and a control for 10 minutes. Pretreated banana slices were dried in a cabinet oven dryer using a completely randomized design at 60°C and 70°C and their drying characteristics such as rate of drying, moisture diffusivity, re-hydration ratio, and coefficient of re-hydration were studied. The result show that, minimum re-hydration ratio of 1.215 was obtained for 7 mm thick slices treated with ascorbic acid and the maximum re-hydration ratio of 1.716 was obtained for lemon juice samples. Taiwo and Adeyemi, (2009),study the influence of blanching as pretreatment on the drying and rehydration of banana slices and they found that, blanching improved moisture loss compared to untreated samples. And also improved mass and heat transfer as well as product characteristics (colour, texture, vitamin retention, etc) of various fruits – carrots, apple, kiwifruit, red and green peppers, etc**.** Sousa and Marsaioli (2004) stated that, whole ripe bananas of the variety "nanicão" *Musa acuminata*, subgroup *Cavendish*), with 3 kg water/kg dry matter, were dried to 0.16-0.23 kg water/kg dry matter, using a domestic microwave oven adapted for a bench scale drying operation. The dried samples were sensory evaluated by determining overall product acceptance, the purchasing intention and the degree of ideality of the color, sweetness and texture. The fruit treated with a 4 % citric acid solution for 10 min. The result shows that, overall consumer acceptance tests of the product showed good scores, varying between 5.46 and 7.23, for a hedonic scale from 1 to 9. The purchasing intention rates were also good, varying from 2.20 to 3.06 on a 0 to 4 scale. The color, sweetness and texture of the samples were close to the accepted ideal.

Sunjka and Raghavan (2004) reported that, Mechanical pretreatment might replace or complement chemical pretreatment, mainly because consumers hesitate to buy chemically treated fruits, and it has a profound effect on the later drying process. Beaudry (2001) examined different skin pretreatment techniques on cranberries, cutting into halves, abrading the surface of the skin and puncturing of the skin by a needle, and demonstrated that cutting in half is the best possible method to attain moisture loss. Bezerra *et.a*l,(2013) reported that, to reduce the enzymatic browning, in drying of green banana the fruit should dipped in 0.5% (w/v) citric acid solution for 10 min and drained.

Sharma (2006) stated that, blanching as heat treatment given to fruits and vegetables to inactivate the enzymes and cause cessation of browning to occur. Fruits and vegetable are immersed in boiling water for some time and then immediately cooled by dipping them in cold water. The method however has many limitation. The enzyme is heat stable and for its complete denaturing a temperature of 100 $^{\circ}$C for 2-10 minutes is required. Since this is practically impossible to achieve while cooking as such long- duration heating at high temperature will cause deterioration in taste, texture and flavor of product. Thus the browning can be reduced to a certain extend by lowering or raising the temperature from the optimum range (43°C-50 $^{\circ}$C). Since proteins coagulate during blanching, the enzymes (which are the proteins) are inactivated

Jokić *et.al,* (2009) stated that, blanching in hot water resulted in a higher drying rate and higher rehydration ratio, but also in unacceptable changes in the color appearance of the apple samples. The quality of the dried product is sometimes enhanced by pre-treatment such as blanching prior the drying process. Blanching is carried out prior to dehydration to inactivate the enzyme peroxides, which may otherwise lead to formation of unacceptable colors and flavors. Blanching has added advantages such as removal of intercellular air from tissue, modification of texture, retention of flavor during storage (Femando *et.al,* 2010). Cunningh *et.al,* (2008**)** stated that, blanching give better rehydration ratio. Akissoe *et.al,* (2003) reported that, thermal blanching is carried out by exposing samples to water either at high temperature for a short time (HTST) or to low temperature for a long time (LTLT). The process of HTST blanching is carried out at temperatures close to boiling point of water and lasts for few minutes. Blanching avoids enzymes to be active at least during the drying process. They also mentioned that, blanching has been reported to lead to shorter drying time and increased drying rates of certain materials

2.19 Effect of drying on nutrient value of food

Morris *et.al* (2006) mentioned that nutritional losses during drying are more due to the application of heat than to the removal of moisture. Generally, except for thiamine (vitamin B1), removal of moisture results in increased concentration of nutrients. Losses during the drying process will depend on preparation procedures before drying, e.g. slicing, blanching, drying temperature, drying time and storage conditions. (Methakhup, 2003) reported that, the added heat and exposure times of the product at elevated temperatures affect three quality degradations of the food products. These three qualities are in terms of chemical quality such as browning reaction, lipid oxidation, and color loss; physical quality such as rehydration, solubility, and texture; and nutritional quality such as vitamin loss, protein loss and microbial survival.

Clemente *et.al,* (2011) reported that, according to the food composition, the material is more or less prone to nutrient degradation. The drying temperatures could affect also the textural properties resulting in the collapse of the raw structure. High air velocities could also affect the structure of some food products. For example, in the drying of meat to produce dry-cured ham, air velocities higher than 2 m/s produce the case hardening phenomenon.

2.20 Product quality attributes

Jangam *et al* (2010) reported that, the quality attributes of a dried food product can be classified into physical, chemical, biological and nutritional. The specification of dried food products also largely depends on these quality attributes. In general, improper processing conditions results in higher nutritional loss and poorer product quality **.**

2.20.1 Effect of drying on physical properties of foods

2.20.1.1 Effect of drying on food color

Color is perhaps the most important attribute, apart from product appearance, that will determine the level of acceptance by consumers. Color pigments, Maillard reactions and enzymatic browning play significant roles in the color changes of the product during drying (Jangam *et al* 2010 and Marty and Rocha, 1999).

Roig *et. al*, (1999) reported that, color is an important quality attribute of foods to most consumers. It is an index of the inherent good quality of foods and the association of color with the acceptability of food is universal. Maskan (2001) stated that, browning in foods is of two types: enzymatic and non enzymatic. For enzymatic browning in fruits and vegetables, enzyme poly phenol oxides (PPO) can be inactivated at temperatures above 60oC. Moreover, in citrus fruits the ascorbic acid and its isomers and derivatives act as inhibitors of enzymatic browning. Non enzymatic browning consists of three types, also known as Maillard reaction, caramelization and ascorbic acid degradation.

The color measurement is normally done in an indirect way to estimate the color changes of foods since it is simpler and faster than the chemical analysis (Maskan, 2001).

2.20.1.2 Effect of drying on food Flavor

Flavor is the primary concern to consumers irrespective of the texture, shape and color of a dried product. Flavor of food consists of various food aroma compounds that constitute the taste and odor of the food. Some flavor compounds are volatile and these are carried away during moisture removal process. The change in shape and texture influence the microstructure of the food product and controls the release of flavor during processing and consumption. Flavor properties of a food product can be analyzed via chemical analyses (e.g. by chromatography method) or sensory evaluation. Chemical evaluation is able to provide the quantitative details of the aroma compounds but no indicative on the acceptance in terms of taste as perceived by human beings. Therefore, sensory evaluation plays an ultimate role in deciding the final acceptability of the food product. This is done by comparing the test product to a reference sample and rating is given during evaluation (Jangam *et al* 2010) and Perera 2005).

2.20.1.3 Effect of drying on rehydration ratio

Femenia *et al* (2000) stated that, Rehydration is a process of moistening dry material. Gornicki *et al* (2013) mentioned that, rehydration is usually carried out by soaking the dry material in large amounts of water, although, instead of this, some authors have used air with high relative humidity, either statically or in a drying chamber with air circulation . More over, rehydration is influenced by several factors, grouped as intrinsic factors (product chemical composition, pre-drying treatment, drying techniques and conditions, post-drying procedure, etc.) and extrinsic factors (composition of immersion media, temperature, hydrodynamic conditions). Puttongsiri *et al*, (20 12) mentioned that, drying temperature and drying time did not have an interaction on rehydration ratio of instant mashed potato. However, it was found that increase drying temperature and drying time resulted in instant mashed potato with decreased rehydration ratio. Moreover higher drying temperatures led to products with higher rehydration ratios.

2.21 Effect of air temperature on dried food

One of the key factors affecting the rate of moisture removal is the drying temperature. The greater the temperature difference between the drying air and the food, the greater will be the heat transfer into the food. This results in a higher driving force (water vapor pressure gradient and/or water concentration gradient between the food surface and the drying air) for moisture removal, which shortens the overall drying time. Increased air temperature improves drying by affecting both external (constant rate period) and internal processes (falling rate periods). However, extremely high temperatures may cause quality loss, especially regarding color.

Demirel and Turhan (2003) have investigated air-drying behavior of Dwarf Cavendish and Gros Michel of banana slices with increasing temperatures from 40 ˚C to 70 ˚C. They have observed that, the effective moisture diffusivity increased with increasing temperature from 40 ˚C to 70 ˚C and decreased at 70 ˚C.

Sankat *et.al,* (1996) have found that, drying of fresh and somatically dehydrated banana slices occurred mainly in the falling rate period. It has also been observed that increase of the drying air temperature leads to significant increase of the drying rate until 80 ˚C after which the drying rates tend to fall.

Nagaya *et .al*, (2005) reported that, Low-temperature drying allows foods such as vegetables to be dried without losing the original color and texture. The performance evaluation studies indicated that, combination drying of carrot and potato at 80 °C with air at a velocity of 1 m/s and temperature of 40 °C reduced the drying time by 48. They also reported that, undesired food flavor, color, vitamin degradation and the loss of essential amino acids may be produced at higher temperature. However, these properties of fresh food can be maintained if drying can be performed at low temperature**.** Ibrahim *et.al*, (2009) reported that, increase in the drying air temperature increased the drying process and decreased the Equilibrium Moisture Content (EMC) of Lemon grass. Vega *et.al,* (2007) used air temperatures of between 50-80oC to dry chilli. It has been found that, the higher temperatures resulted in reduced drying time and an increase in the effective moisture diffusivity. However, using high temperatures for drying produces a low quality of chilli, with losses of volatile compounds, nutrients and color. Manzocco *et. al*, (2001) stated that, non enzymatic reactions increase in rate at higher temperatures and at intermediate levels of moisture content in the fruit. Krokida *et.al*,(2003) studied the effect of air temperature, air humidity and air velocity on the drying kinetics of several vegetables such as green, yellow and red peppers, pumpkin, green peas, carrots, tomatoes, corn, garlic, mushrooms, spinaches, onions, celery and leek. As expected. The results show that, air temperature is directly correlated with drying rate and that is the most important external variables. Senadeera *et.al,* (2003) showed, an increase of rate constant as temperature increased from 30°C to 40°C and 50°C during air dehydration of green beans, potatoes and peas.

The drying characteristics of tomatoes were investigated by (Doymaz, 2007) at 55, 60, 65 and 70 _^{o}C with air flow rate of 1.5 m/s.. The increase in the air temperature in the range 55–70 _^{o}C markedly increased the drying rate of tomatoes.

The chemical characterization in fresh and dried onions at different temperatures (varying from 30 ◦C to 70 ^{o}C) was analyses, to evaluate the effect of drying and drying temperature on the chemical composition of the product. In this way, the analyses of moisture content, sugar content, crude protein, ash, fat, crude fibre, acidity and vitamin C. From the results obtained it was verified that some chemical components of the onions are not affected by drying (ash, fat, protein and fibre) whereas some others are considerably influenced by drying (sugars, acidity and vitamin C) (Mota *et.al,* 2010).

(Pan *et.al,* 2005) stated that, when drying onion at temperatures of 60°C and 70°C the pungency degradations were similar for both the drying methods. But private content in 80°C CIR-dried onion was reduced rapidly near the end of drying. To have a product with white color using CIR drying it is recommended to dry the product at a mild temperature, such as 70°C, to take advantage of higher drying rate than 60°C drying and lower browning than 80°C drying.

Chinenye (2009) study effect of air temperature and air velocity on Cocoa Bean.. Three levels of temperatures (55, 70 and 81 °C) and three air velocity levels (1.3, 2.51 and 3.7 m/s) were used in the study. The moisture content of the cocoa bean 79.6 (db). %and it decreased to 6 % (db), in 4-6 h of continuous drying at the above mentioned temperature range. The drying rate increased with increase in temperature and air velocity but decreased with time. The dryer can remove an average of 4.66 kg of water per day at 55-81 °C and air velocity of 1.3 m/s while at 2.51 m/s it can remove an average of 5.3 kg of water per day under the same drying conditions.

Inchuen and Narkrugsa (2010) compared drying Thai red curry pastes by two different drying methods: microwave and hot-air drying. The microwave drying was carried out in a microwave oven with output powers of 180, 360 and 540 W and the hot-air drying was carried out at air temperatures of 60, 70 and 80°C. The quality attributes of Thai red curry powder were evaluated for proximate composition, color antioxidant properties .The drying methods showed no significant effects on the chemical compositions of the red curry powder, whereas color and antioxidant properties were all affected by the two methods to different extents. Microwave drying resulted in darker and less yellow color than the hot-air drying. Almost all red curry powder in the microwave-dried samples had a greater phenolic content and antioxidant activity than hot-air dried samples.

2.22 Drying time

Arnau (2007) stated that, drying is the limiting step of the process in terms of time. A shortening of the drying period would result in a reduction of the drying facilities, capital and labor, and would increase the profit margin and the product competitiveness while reducing some safety concerns, such as mould growth, lipid oxidation and mite infestation.

Kendall and J. Sofos (2003) reported that, the length of time needed to dry fruits will depend on the size of the pieces being dried, humidity and the amount of air circulation in the dehydrator or oven.

According to Flores, (2007) drying time varies widely depending on the method selected and the size and amount of moisture in food pieces. Sun drying requires the most time; an electric dehydrator requires the least. Vegetables take from 4 to 12 hours to dry; fruit take 6–20 hours. Meats require about 12 hours. Making raisins from grapes may require days or weeks when drying is done outside. Generally, you can figure on drying times of 6 to 36 hours for fruit and 3 to 16 hours for vegetables, which take less time due to their lower sugar contents.PNW 397 (2003).

Orgen (2003), mentioned that, there are many factors affect drying time, including type of food, size and moisture content of the food pieces, pretreatment method, dryer type, dryer temperature, relative humidity of the air, and amount of air movement in the dryer and in the surroundings. With so many factors at work, it's impossible to give precise drying times.

2.23. Banana drying

Bananas (*Musa* ssp.) are the fourth most important crop after rice, wheat and corn. It contains appreciable amounts of vitamins B and C, as well as minerals like potassium and calcium. In its green stage it has high levels of starch, mainly in the form of resistant type 2 (Bezerra *et.al,* 2013). The ripe banana contains many of the necessary elements that are essential for a balanced diet. Banana contains fat, natural sugars, protein, potassium and vitamins A, B complex and C.

Due to high moisture content in banana, it is wounded and contaminated during handling and transportation and quality is deteriorated at high temperature and relative humidity. The postharvest losses can be minimized by drying the ripe banana. Therefore, there is a scope of drying of banana in the tropical and subtropical countries (Amer *et.al,* 2010).

Ebrahim *et al* (2012) mentioned that, World production of banana has been increased from 22 million tons in1961 to 96 million tons in 2009.

Abano and Amoah (2011) reported that, ripe bananas have been part of humans' diets for many years. Production and consumption of ripe banana have come to stay with many people around the globe. However, ripe bananas contain about 80% moisture and therefore very susceptible to post-harvest losses and considerable weight loss during transportation and storage.

Sousa and Marsaioli (2004) stated that, dried bananas are mostly consumed on the internal market and are generally produced by small manufacturing establishments located near the banana growing areas, although the sensory quality desired by the consumers has yet to be attained, currently being characterized by hardness, dark color, bitter taste and smoky aroma.

Azoubel *et.al*,(2010) conducted experiment for drying banana using two temperature (50, 70 c) to study the effect of ultrasound on banana and to describe the moisture transfer and the effective diffusivities of water. The result show that, the diffusivities increased with increasing temperature and with the application of ultrasound, while the process time reduced, which can represent an economy of energy, since air drying is cost intensive**.**

(Singh 2007) reported that, banana varieties which give smooth pulp without serum separation must be used for this purpose. Ripe, suitable fruit is selected. The hand-peeled fruits are soaked in 0.3 per cent citric acid solution for about 10 minutes (lime or lemon juice can replace citric acid). The drained fruit are pulped to obtain smooth pulp. At the end of the drying operation, when moisture content is between 15 and 20%, the pieces of suitable shape and size are wrapped in cellophane paper, packed in cartons and stored at ambient air temperature.

Demirel and Turhan (2003) investigated, drying behavior of untreated, and sodium bisulphite and ascorbic/citric acid treated Dwarf Cavendish and Gros Michel banana slices using air temperature between 40 and 70 $^{\circ}$C**.** Pretreatments and increasing temperature decreased the browning, and the color change in the untreated samples was acceptable. Pretreatments and temperature did not affect the shrinkage. The effective moisture diffusivity (D) increased with increasing temperature between 40 and 70 $^{\circ}$C in the untreated samples. It increased between 40 and 60 $^{\circ}$C, and decreased at 70 $^{\circ}$C in the pretreated samples probably due to case hardening and starch gelatinization above 60 $^{\circ}$C. They also stated that, drying of banana was carried out passing air over the sample lying on a supporting tray.

Schirmer *et.al,* (1996) developed and tested a multi-purpose solar tunnel dryer for drying of banana under hot and humid weather conditions. The drying temperature was 40–65 _C. They reported that solar dried banana was high quality products in terms of flavor, color and texture.

Phoungchandang and Woods (2000) found that, the drying time by use solar dryers for banana takes some days and it needs to reduce. In addition, the quality of the dried bananas by the recent solar dryers is not high depends on the non-stability for the drying air temperature during the drying process which causes by the variation of the solar intensity during the period of sun-shine. Krokida and Maroulis (1999) examined the effect of microwave and microwave- vacuum on increased product porosity and color changes. They showed that microwave drying increases elasticity and decreases viscosity of product**.** Krokida, *et al* (1998) studied the effect of freeze-drying conditions on shrinkage and porosity of banana, potato, carrot, and apple. They found that final porosity decreased as sample temperature increases. Krokida, *et al*,(1998) also examined the effect of drying conditions on color change during conventional and vacuum drying those fruits. Rate of color changes was found to increase as temperature increased and air humidity decreased.

Hassanain, (2009) stated that**,** Banana is dried at 105°C, with final moisture content of 2-5% and average drying ratio (fresh to dried weight) of 13:1.

2.24 Onion drying

Onion (*Allium cepa*) has been widely used even in ancient times as seasonings, foods and for medical uses. In current times, onion is an important vegetable to serve as ingredients in dishes, as toppings on burgers, in seasonings, as chip coatings etc. Onion finds widespread usage in both fresh and dried forms. Dried onions are a product of considerable importance in world trade and are made in several forms: flaked, minced, chopped and powdered. It is used as flavor additives in a wide variety of food formulations such as comminuted meats, sauces, soups, salad dressings and pickle relishes (Arslan and Özcan 2010). Onion ranks third highest in production in the world among seven major vegetables, namely onion, garlic, cauliflower, green peas, cabbage, tomato and green beans (Kumar and Tiwari 2007). The world production of onion was 64.48 million tons from 3.45 million ha area (FAO, 2009). Patil *et.al*, (2012) stated that a global review of area and production of onion shows that it is grown in 126 countries over an area of 2.3 million hectares producing 40.0 million tones of dry onion. Sixty-two percent of the world's production is from Asiatic countries. (Sagar, 2001) stated that, onions are dried from initial moisture content of about 82 percent or less sufficient for storage and processing

Sutar and Gupta (2007) study on osmotic dehydration of onion slices was carried out in order to remove the moisture prior to the further mechanical drying. Three salt concentration levels (5%, 12.5% and 20%), three temperature levels of osmotic solution (28 _C, 43 _C and 58 _C) and the observations on weight loss and solid gain were taken at an interval of 5 min up to first half an hour followed by interval of 10 min for next 1 h. The sample to solution ratio of 1:5, agitation of 100 shakes per minute, sample thickness of 4 mm and 0.2% potassium metabisulphite mixed with osmotic solution were used for the study.

An advanced and alternative method to the traditional techniques is greenhouse drying (GHD) studied by (Condorı´ and Luis, 1998), in which the product is placed in trays receiving solar radiation through the plastic cover, while moisture is removed by natural convection or forced air flow. Kumar and Tiwari (2007) conducted two experiments for drying onion in open sun and greenhouse to study the effect of mass on convective mass transfer coefficient. The results show that, there is a significant effect of mass on convective mass transfer coefficient for open sun as well as greenhouse drying. It is also observed that the rate of moisture evaporation in case of greenhouse drying is more than that in open sun drying during the off sunshine hours due to the stored energy inside the greenhouse.

The effect of air drying temperature on shrinkage, rehydration ratio and microstructure of dried onion slices (3±0.2 mm thickness and 30 mm diameter) was studied by (Abbasi *et.al* 2011). The different drying conditions led to distinctive structural changes in the samples, affecting the shrinkage and rehydration ratio. Experiments showed that the intensity of structural changes depends on temperature and drying times. A higher temperature and time caused greater damage to the microstructure of onion slices, resulting in the formation of a highly porous structure. The results also indicated that increasing time and temperature increased the shrinkage and rehydration ratio of samples.

Talati and Shah (2009) stated that, onion dehydration plants are firewood, groundnut shell or diesel oil for hot air generation. These dehydration plants use tray dryers for drying the onion flakes. The drying is done using hot air at 55 to 70‘C. Onion is dehydrated in the form of sliced, large, standard and small chopped; mince granulated, kibbled, 6MM dices and ground or onion powder.

Arslan and Özcan (2010) study sun, oven (50 and 70 _C) and microwave oven (210 and 700 W) drying of onion slices to monitor the drying kinetics and quality degradation of the product. They reported that, the highest mineral values were determined in oven dried samples. Sun and microwave oven drying (210 W) revealed better color values in the dried products.

Patil *et.al*, (2012) study OSMO-Convective Drying of Onion Slices and they found that, the drying temperature and pretreatment as osmotic dehydration had a significant effect on the rehydration ratio and colour. The drying times of un-osmoses and osmoses onion slices by convective drying at 40 and 60 per cent drying temperature were 12, 10 and 8 and 6 hrs respectively. Quality of dried product in respect to colour and rehydration was superior. The osmo-convective dehydrated samples were found more acceptable than convective dried ones.

2.25 Potato dehydration

Aghbashlo *et. al*, (2009) stated that, Potatoes *(Solanum tuberosum L.)* are the fourth most important vegetable crop for human nutrition in the world and approximately 12% are dehydrated products. A potato is semi-perishable in nature because it contains about 80% water. Therefore post-production management is as important as production management. . Srivastara and Kumar, (2010) stated that, under tropical and subtropical conditions, 40-50% losses occur due to poor handling and storage. Therefore, it is of utmost importance, to minimize post-harvest losses

Leeratanarak *et.al,* (2006) reported that, many works have been performed to study hot air drying of potato pieces of various shapes. Generally, it is found that hot air drying causes much quality degradation (in terms of nutritional values, color, shrinkage and other organoleptic properties)

Leeratanarak et.al, (2006) conducted experimental to study drying of potato slices using both low-pressure superheated steam drying (LPSSD) and hot air drying. Prior of drying, the samples were blanched in hot water at 90 ± 2 °C for 0, 1, 3, and 5 min with the ratio of potato to water of 0.015 g/g. The effects of blanching as well as the drying temperature on the drying kinetics as well as various quality attributes of potato slices viz. color, texture, and brown pigment accumulation were also investigated. It was found that LPSSD took shorter time to dry the product to the final desired moisture content than that required by hot air drying when the drying temperatures were higher than 80 °C. Longer blanching time and lower drying temperature resulted in better color retention and led to chips of lower browning index. Blanching also reduced the hardness and shrinkage of the product; however, the use of different blanching periods did not significantly affect the product hardness. Drying methods had no obvious effect on the product quality except the browning index.

Puttongsiri *et a l*, (2012) study effect of drying temperature and drying time on moisture content and physical properties of instant mashed potato. Instant mashed potato was prepared by drying at 60, 70 and 80oC and drying times of 5, 6.5 and 8 hr. After that, moisture content, water absorption, water solubility index and rehydration ratio of the dried product were determined. It was found that drying time and drying temperature at the studied condition did not affect water absorption and water solubility of the final product. However, increase drying temperature and drying time resulted in instant mashed potato with decrease moisture content and rehydration ratio. Instant mashed potato had moisture content of 4.5 to 8.5% (db) depend on the drying conditions. In addition, higher drying temperature resulted in starch granules with more damage and then decreases rehydration ability to the product.

Srivastara and Kumar, (2010) fabricated a home-dryer for drying fruits and vegetables (including potatoes) they stated that, the best dried product was obtained when the potatoes were peeled, slices and blanched for 3-5 nim at 81-100c. The slices could be dried in 9-11 hrs. The dehydrated slices could be rehydrated to normal shape, appearance and flavor if they were soaked for 24 hr in water. Peeling and trimming losses were lower in new potatoes but yield of dried product (22-29) was higher in old potatoes.

Loeseck, (2012) stated that, both tunnel dryer and conveyor dryer are used with a dry bulb temperature of 160f. Dehydrated is finished in bin dryer to final moisture content of 7% and the drying time in the tunnel is about 3 hours and from 3-4 hours in the bins. He also mentioned that the average yield of about 16% based on the weight of the fresh tuber. The effects of drying conditions on shrinkage of potato slices were studied by (Yadollahinia and Jahangiri 2009). A thin-layer dryer with machine vision system and image processing software was used. Potato slices were dried at temperatures of 60, 70, 80 °C and air velocities of 0.5 and 1.0 m/s. Changes in area, perimeter, major and minor diameters, diameters parallel and perpendicular to airflow, roundness and elongation of the slice were measured continuously during drying. Shrinkage showed almost linear relation with moisture content. It was found that airflow direction had significant effect on shrinkage of parallel and perpendicular diameters in 60 and 70 °C and no significant effect at 80 °C. Drying took place entirely in the falling rate period. Air velocity had no significant effect on drying time and shrinkage in the rage tested. Slices dried in 80 °C showed more circularity than slices dried in 60 and 70 °C. Krokida *et.al,*(1998) and **(**McMinn and Magee 1996) study the effect of hot air drying on potatoes pieces of various shapes. Generally, it is found that hot air drying causes much quality degradation (in terms of nutritional values, color, shrinkage and other organoleptic properties). Krokida *et al*, (2001) investigated the effects of drying methods on the color of dried potato and found that the conventional air drying caused extensive browning with a significant drop of the lightness and an increase in the redness and yellowness of dried potato**.** Khraisheh, *et al* (2004) studied the quality and structural changes (in terms of vitamin C destruction, shrinkage and rehydration) of potato during microwave and convective drying. They reported that, air drying led to higher vitamin C destruction than in the case of microwave drying. The rehydration potential of the air-dried sample was also lower than that of microwave-dried sample. Moreover, case hardening of the surface developed in the case of air-dried sample at higher temperatures and thus reduced the degree of shrinkage.

Caixeta, Moreira, and Castell-Perez (2002) studied the effects of impinging superheated steam temperature and convective heat transfer coefficient on the drying rate and quality attributes of potato chips. They found that, the samples dried at higher steam temperatures and high convective heat transfer coefficients had less shrinkage, higher porosity, darker color, and lower vitamin C content. Unlike superheated steam drying (SSD) hot air drying produced less shrinkage because the air-dried samples developed hardened surfaces that increased the resistance to volume change. However, hot air drying led to chips of lower porosity, darker color, and lower vitamin C content. Superheated steam and hot air impingement drying for tortilla and potato chips studied by Moreira (2001). The results show that, impingement drying with superheated steam could produce potato chips with less color deterioration and less vitamin C losses than drying with hot air. Puttongsiri eta l (2012). Found that, Potato dried at 60, 70 and 80^{o}C and drying time of 5 hr had moisture contents of 8.5, 6.5 and 5.2% respectively. Iyota, *et al* (2001) study the changes of potato slices color using atmospheric-pressure SSD and hot air drying. The results show that, the samples dried by superheated steam were more glossy and there were no starch granules remain on the surface. On the other hand, starch gelatinization of the samples dried by hot air occurred more slowly than in the case of SSD. Non-gelatinized starch granules still remained on the surface of the product after the hot air drying process was completed.

Puttongsiri eta l (2012) found that, water absorption and water solubility ranges of the dried potato a t temperature range from 69-80 ◦C were 6.13-7.11 g/g and 8.57-10.48%, respectively. Drying temperature and drying time did not have an interaction on water absorption and water solubility index of the instant mashed potato (not shown). Moreover, it was found that drying temperature at the study conditions did not affect water absorption and water solubility. Result was in the same trend as in the case of drying time

CHAPTER THREE

MATERIALS AND METHODS

Due to the clear effect of ambient drying air and also sun or solar drying on the final dried product, thus this work was intended for the determination of moisture content and the drying rate of the fruits and vegetables and at the same time preserves final product quality.

Thus the experimental work was concentrated on determination of the effect of three systems with drying air flow direction under control conditions of constant air temperature, relative humidity and air velocity and hence continuously changing moisture content of chosen fruits or vegetables to be dried.

3.1 Materials selection

The materials used for the construction of the driers are easily maintained and repaired, and can be obtained locally at cheaper costs. The physical and chemical properties of the materials are strong enough to withstand heat, vibration, humid air, fatigue and stress without failure during operation.

3.2 Design of the dryers

This study includes two components:

1- Design and fabrication of two different types of dryers.

2- Performance test of the designed dryers.

The experiment include design of two dryers, the first one is hot water dryer, and the second is electric candles dryer, the components of the two dryers are the same, while source of energy is the only difference between them. It was design that the hot water was source of energy for the water dryer and candles are used for the electric candles dryer. The design was conducted at the Department of Agricultural Engineering, faculty of Agricultural, University of Cairo Egypt. After confirming the safety of the bodies of refrigerators, the refrigerators were photographed plate (3.1).One of them was selected to use as a frame to the hot water dryer and the other to the electric candles dryer.

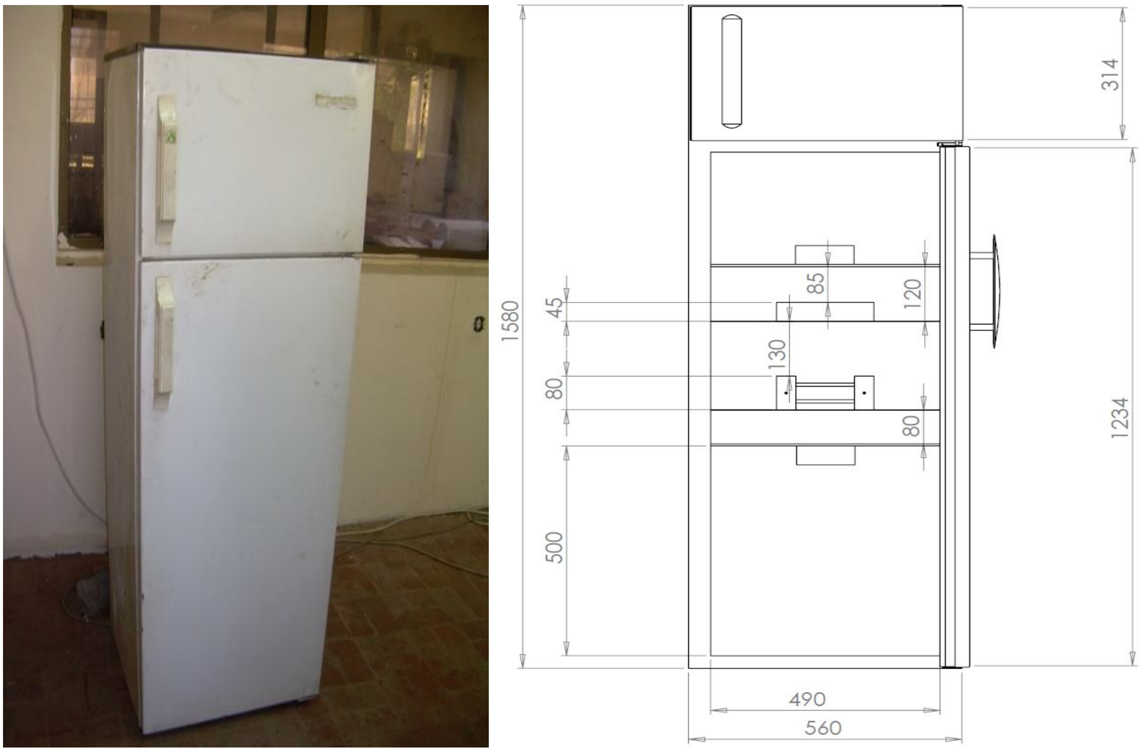


Plate 3. 1: Old refrigerator body and its dimension

3.3 Design and Development Considerations

During designing and developing of the dryers, the following points should be considered:

- The construction materials must be locally and easily available.

- The operating technique of the dryer must be known to the local farmers or craftsmen.
- The device should be batch dryer and can be operated by one person.

The main component parts of the two dryers are:

(a) Heat-exchanger.

(b) Water tank.

(c) Hot water circulation pump.

(d) Heating candles.

(e) Drying cabinet.

(f) Trays.

(g) Fans.

(h) Thermostat.

(k) Water Hoses

3.4 Design of water dryer

Refrigerator frame was used as a frame to the designed dryer. It consist of heat exchanger, drying chamber, water tank, hot water circulation pump, trays, fans, water heater, thermostat, inlet and outlet opening and shelves. plate (3.2) show the general view of the dryer components. The dryer had the dimensions of 158 cm× 56 cm ×46 cm height, length and width respectively. The thickness of the dryer body consist of three layers. The out side layer was made up of high-grade plastic and inside layer was lined with aluminum sheet while the gap of about 2.7cm between two previous layers was filed with insulation of cork. The details of dryer component as follows:

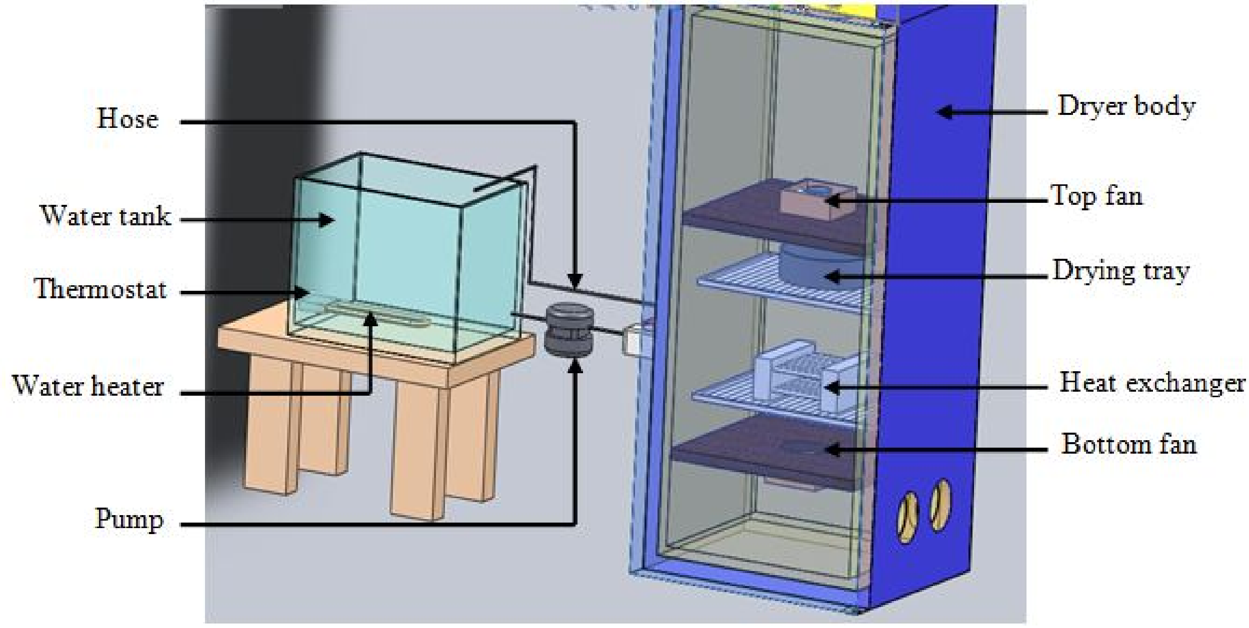


Plate 3. 2: General view design of water dryer.

3.4.1 Heat exchanger

Heat exchanger is device used to exchange heat with a surrounding media. It consists of two stainless steel water tanks with size of 4 cm*8 cm for each, this tanks were joint together with several 18copper tubes, each tube is 12 cm length with 8 mm diameter. The two tanks of Heat exchanger are fixed together by a metal holder of stainless steel also. The two tanks work as hot water storage as showing in plate (3.3).

Plate 3. 3: Heat exchanger.

3.4.2 The drying chamber

The dimensions of the drying chamber were 49 cm×43 cm ×30 cm in length, width and height respectively. The inside surface lined with aluminum sheet in order to increase reflect of heat to the cabinet and to decrease the corrosion. There is a two fans inside the drying chamber will be fixed in the top and bottom through a plywood. There were two shelves on which the drying tray and heat exchanger could be put on it as showing in plate (3.4).

Plate 3. 4: The drying chamber.

3.4.3 Water tank

The main function of the water tank is to store a hot water which was used as a source of heat. Water tank was constructed externally adjacent to the main dryer body. The frame of it made of mild steel with size of 30 cm ×30 cm × 40 cm . A heater was located inside the water tank for heating water. This device type was **Thermowatt R.T 1000 Watt** plate (3.5).

Plate 3. 5: Water tank.

3.4.4 Hot water circulation pump

This pump was **DAB pump performance EVO SERIES** plate (3.6). The pump was connecting beside the water tank and adjusted to discharge the required volume of hot water from the water tank to the heat exchanger.

Plate 3. 6: Hot water circulation pump.

3.4.5 Drying tray

A mild steel tray was used. A metal mesh is fixed in the frame of the tray. This design facilitates the hot air to move across the tray to dry raw materials and drive the humidity outside the chamber through the outlet opening**.** Dimensions of the tray were 20 cm in diameter and 5.5 cm in depth plate (3.7).

Plate 3. 7: Drying tray.

3.4.6 The fans

The function of the fans to supply required amount of air with the optimum velocity towards the heat exchanger. The specifications of two fans were used in experiments was Ac fan model **MTM 12038 Ac**. Plate (3.8). Two plywood's held frames were designed to be placed in the upper and lower position of drying chamber with 11cm diameter of circular hole for fixing the fans. The dimensions of the plywood's frame were: 47 cm in length, 32 cm in width and 0. 5 cm in thickness.

Plate 3. 8: The fan.

3.4.7 Water Hoses

The dryer provided with a hot water insulated hoses which are used to connect the water tank to the heat exchanger. Both the inlet and out let hoses length is 50 cm with diameter of 0.5cm.

3.4.8 The thermostat

The thermostat device model **Tu.F ST 30-110C** was used. A thermostat device is fixed near the water tank to control the water temperature plate (3.9).

Plate 3. 9: The thermostat.

3.5 Design of electric candles dryer

The electric candles dryer plate (3.10) consist of the following components:

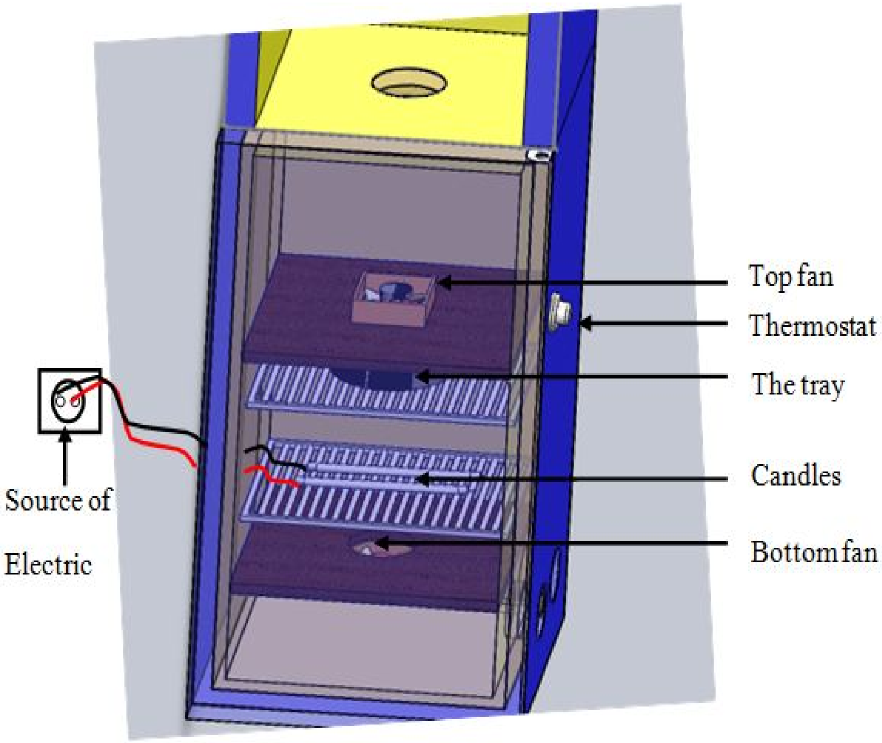


Plate 3. 10: General view design of electric candles dryer

(a) Heating candles.

(b) Drying cabinet.

(c) Trays.

(d) Fans.

(e) Thermostat.

All details and specifications were mentioned above as joint components with water dryer, while only the detail of electric candles as shown blow. In addition to that, the sensor position of the thermostat device was change from water tank to the drying chamber.

3.5.1 Electric candles:

Three glass electric candles were used in this dryer as shown in plate (3.11) . The specifications of these candles includes 25cm length, 22o voltage and 400 watts as power.

Plate 3. 11: Electric candles.

3.6 Adjustment of drying conditions inside the dryer

Temperature measuring device was used to measuring dry and wet temperature and relative humidity first inside the laboratory ,secondly in drying chamber and finally in the point at which the air leave the dryer. The drying process start when the temperature of the air inside the drying chamber reached the 63 $^{\circ}$C in case of onion or potatoes and 55 C^{o} in case of banana. The air velocity was measured directly before and after top or bottom fan.

3.7 The measuring instruments

3.7.1 Temperature and relative humidity measurement device

The temperature of ambient and internal air either dry or wet were measured using **(Elmemo) Model: 2290.8 Thermohyomometer** as shown in plate(3.12). Also the above device used for measuring relative humidity.

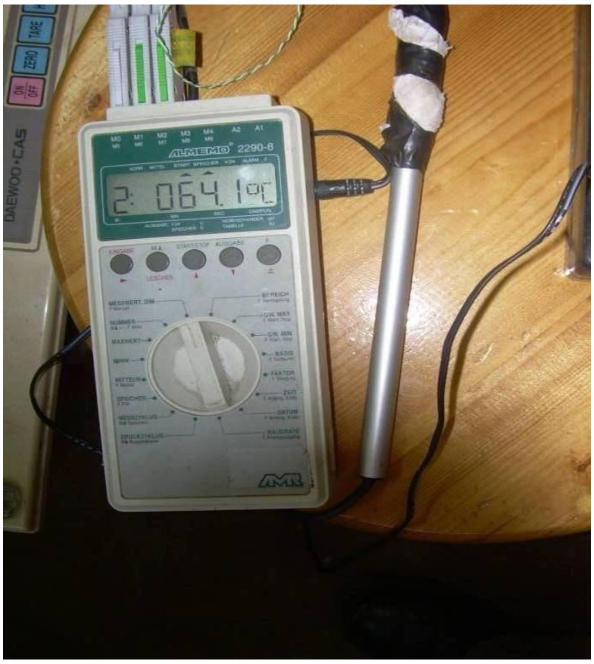


Plate 3. 12: Thermohyomometer device.

3.7.2 Air speed measurement device

The plate (3.13) shown **Hot Wire Thermo-Anenomeses Model: 407123.** This device used to measure air speed**.**

Plate 3. 13: Wire Thermo-Anenomeses Device.

3.7.3 Weighting device

The **Digital Computing Scale Model No 5D** device used to weight the product as shown in plate (3.14)**.**

Plate 3. 14: Digital Computing Scale Device.

3.7. 4 Moisture content measurement device

The device used to determine moisture content was **Oven Drying SL Shell Lab Model 1375 FX** plate (3.15).

Plate 3. 15: Oven Drying SL Shell Lab device.

3.8 The initial tests of the experiments apparatuses:

Some tests were carried out before starting the actual experiments to achieve the following point:

- To check the accuracy and efficiency of the measuring instruments .
- To eliminate any systematic errors may occur during the drying process.
- To determine the best method attained the targeted goals of the experiments.
- To ensure that there is no loss in the heat or air flow thorough the connecting device materials to the drying chamber.
- To check the ability of the dryers performance without loading raw materials.

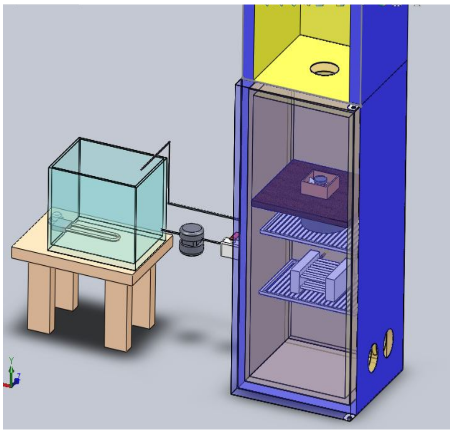
3.9 Operation mechanism

In order to get the best results, three different drying methods were applied in the drying system based on the fan location inside the drying chamber, these include:-

1. Air suction method (one fan at the top of drying chamber).
2. Air intake method (one fan at the bottom of drying chamber).
3. A combination of air suction and intake methods (using in the same time two fans which located at top and bottom of drying chamber).

3.9.1 Air suction method (one fan at the top) Plate (3.16) (A) and (B)

In this system the only one fan in the top slot of the drying chamber has been used to move the air. When the air suction occurred, it passes through the water heat exchanger or the candles in order to increase air temperature and then continued moving through the product on the drying tray in the form of single layer. The result of that heat exchange occurred and then stream of hot wet air get out of the dyer through top suction fan at the top position of the dryer.


(A)

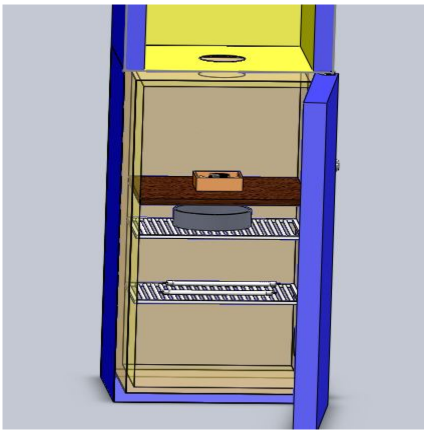
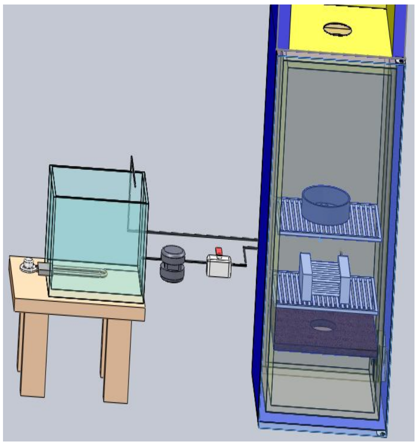
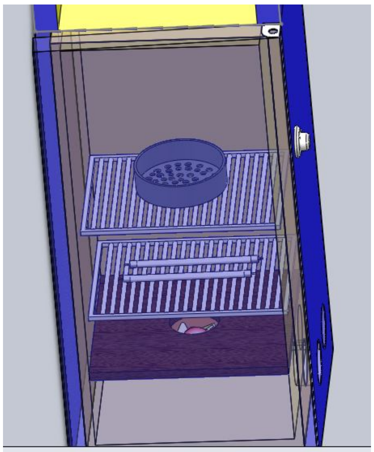

(B)

Plate 3. 16: Air suction method (the fan at the top).
Where(A) water dryer and (B) candles dryer

3.9.2 Air intake method (one fan at the bottom) plate (3.17) (A) and (B)

This method identically the air suction method, except that the air flow came by intake fan , which fixed in the bottom position of the drying chamber system. The suction air comes across the heat exchanger and then passed through the raw material in the drying trays.





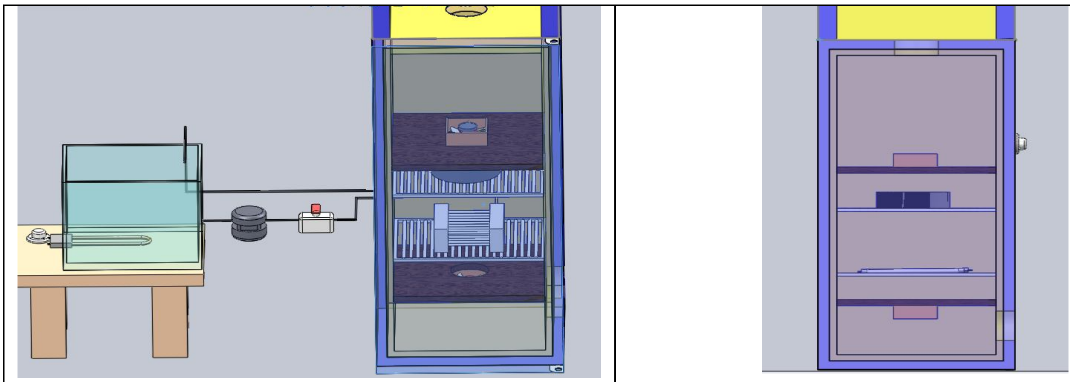
(A) (B)

Plate 3.17: Air intake method (the fan at the bottom)

Where (A) water dryer and (B) candles dryer

3.9.3 A combined method (using two fans at the top and at the bottom) plate. (3.18) (A)and (B)

This method joined between air intake and air suction methods, where the air flow in through bottom fan and get out by the top fan , hence the materials can be subjected to high rates of flow in order to minimizing the drying time of the raw materials.



(A) (B)

Plate 3. 18: A combined method (using two fans at the top and at the bottom).

Where (A) water dryer and (B) candles dryer

3.10 Preparation dryer to work

3.10.1 Water dryer

The water heater which located in the bottom of water pan was connected to an electrical circuit and then wait until the water reaches temperature of 90 ^{o}C in the case of drying onions and potatoes in 20 minutes while 75 ^{o}C in the case of drying bananas in 15 minutes . The temperature of water measuring using thermometer device. Although fans and water pump were operated to raise the temperature of the drying chamber for onion and potatoes to 63 ^{o}C, this expend 20 minutes and for banana to 55 ^{o}C at 15 minutes . In this status the drying is started and the products were introduced inside the dryer. Then the air is moving by the one of the methods mentioned previously. Due to the exchange between air and water, water loss some temperature. Then lower temperature water retain back to the water pan to be heated again and then flow again through the pump to the heat exchanger and so on.

3.10.2 Electric candle dryer

The electric candles which located at the center of drying chamber were operated by connected to an electrical energy source and then wait until the air reaches temperature of 63 ^{o}C. This often takes about 10 minutes in the case of drying onions and potatoes or about 7 minutes in the case of drying bananas for air to reach temperature 55^{o} C. After that, fans operated to push air through the candles. Then the air is moving by one methods mentioned previously.

3.11 Performance test to the dryers

The performance test of the dryers includes three stages as follows:

1- Pretreatments of the products to be dried.

2- The drying process.

3- Products dried tests.

Three varieties of agricultural products namely bananas, potatoes and onions were selected to test the dryers performances. The drying processes carried out at temperature of 63 C^{o} and relative humidity of 13% with air velocity of 1.5 m.s for potatoes and onions and temperature of 55 C^{o} and relative humidity of 16% with previous air velocity for banana.

3.12 Pretreatment of the products

3.12.1 Banana pretreatment

Banana was purchased from Geza market. Yellow bananas plate (3.19) was used to carry out drying experiment.

Plate 3. 19: Bananas sample before treatment.

The moisture contents of bananas used for drying measured and found 83.7% . Primary processes such as cleaning, washing, peeling, and cutting were done. The peeled bananas were sliced into 6 mm thicknesses and 30 mm n diameter with a sharp knife manually prior to pretreatment. Samples of the sliced bananas was soaked into lemon juice for 5 minutes. Slices were rinsed in distilled water for 30 s, wiped with tissue paper, and brought to the experiment.

3.12.2 Potatoes pretreatments

A sample of good quality of potato purchased from the local market in Giza plate (3.20).

Plate 3. 20: Potato sample before treatment.

Before drying process, the moisture contents of potato was measured and found 82.7% . All potatoes washed and then selected amount were peeled off, hence circular shape slices with of 6 mm in thickness and 50 mm in diameter were prepared .This function was achieved by a food slicer. The potato slices sample putted into a vegetable basket and immersed into the boiling water, result of that the temperature of water decreased so, the potato will remain for awhile until the water to return back to a boiling status .Blanching time was achieved within 5 of minutes. And then the potatoes putted immediately into r cold water and let them stay there for 15 minutes. Finally, the blanched potato slices were spread in a single layer between paper towels to drying.

3.12.3 Onion pretreatment

A sample of good quality of white onions was bought from the local market in Giza Cairo Egypt plate (3.20) . The moisture content of onion was measured and found 81.3 %.

Plate 3. 21: Onion sample before treatment.

Before the drying process has to be start the outer shell and appendages at the top and bottom of the onion bulb removed. Then the sample of onions was chopping by cutter into circular 40 mm diameter slices with 5 mm thickness. The diameter and thickness measured using Venire Caliper. The measuring repeated three times in the three different positions through the onion slices and then the average calculate. The circular slices were putted in sodium chloride solution of 5% concentrate for a quarter of an hour after that the solution is filtered and the samples putted on dishes paper for three minutes to remove the access water due to the pretreatment. Then the drying tray has been weighted on the balance and recorded, then 50grams of onion slices added on a tray and then reweighing again, hence the onion sample was ready for drying process.

3.13 Drying process

3.13.1 Banana Drying

The experiments were carried out at constant air velocity (1.5 m/s), air temperatures of 55 ^{o}C which corresponded respectively to air humidity of 15%.The pre-treated bananas were putted on drying   tray and placed inside drying chamber. The 6 mm thick slices were dried at temperatures of 55 C till the constant mass was observed. After e sample putted in to the drying chamber, the beginning of the drying time was recorded and continuing for 20 minutes after that sample is reweighed by using sensitive balance and anew weight recorded. This process expend of time not exceeding ten sec. The weight of the drying bananas were determined every 20 min at first hour and every 30 min after that until drying was completed. Drying was completed when the moisture content a value reached 6.39% dry basis. After that, the samples were allowed to cool and keep inside a transparent tightly zipped bag and labeled for further analysis. Each experiment was replicate three times.

3.13.2 Potato drying

The experiments were carried out at constant conditions (air velocity 1.5 m/s and air temperatures of 63, which corresponded respectively to air humidity of 13.2**%).** Potato slices placed on drying tray which have been prepared with vegetable oil spray without overlapping so, air is allowed to circulate between them. After that the processes go on as mentioned in case of banana**.**

3.13.3 Onion drying

The experiments were carried out at constant conditions (air velocity 1.5 m/s and air temperature of 63^{o} C, which corresponded to air humidity of 13.2%) using thin layers of onion slices. After e sample putted in to the drying chamber, the beginning of the drying time was recorded and continuing for 20 minutes after that sample is reweighed by the sensitive balance and anew weight recorded. This process expend of time not exceeding ten sec and then the process was repeated. . After the weight stability the sample is placed inside disekater for 10 minutes to recool and then put and kept in plastic bags.

3.14 Products dried tests

These tests include the following:

1. Drying rate

2 Moisture content property.

4. Physical properties (bulk density, water absorption index, water solubility index, rehydration ratio, dehydration ratio and yield).

5. Organoleptic evaluation properties (color, taste, flavor, general appearance and overall quality).

3.14.1 Drying rate

Drying rate was calculated in gram of moisture loss per kg of initial weight of product sample per minute (g/kg initial weight *min) (Pan *et al* 2005). Only MC data at every minute increment was used for the calculation of drying rate. Difference in weight (g) over difference in time (min) was calculated using equation (3.1).

$$\textbf{Drying rate} = \frac{\Delta W}{\Delta t} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (3.1)$$

3.14.2 Vegetables or fruits moisture content determination

Determination of fruits and vegetables moisture content and therefore drying rate could be done by weighting the drying tray with its load of product at successive periods. The original moisture content wet basis, Mw_o was determined by the oven drying method at 105^{o}C (AOAC, 1998). The weight loss was evaluated in each of these experiments separately and its value correlated with drying air temperature and velocity. The moisture content wet basis of the fresh product was expressed using equation (3.2):

$$Mw_o = \frac{W_o - W_d}{W_O} \times 100 \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (3.2)$$

For the determination of the moisture content wet basis at any time t_i " during drying process, the following equation (3.3) could be used:

$$Mw_o = \frac{W_o - W_d}{W_O} \times 100 \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (3.3)$$

Where:

Mw_o moisture content, wet basis of the fresh fruit.

W_o weight of fresh sample,(kg).

W_d weight of dried sample,(kg).

W_i weight of fruit at time $t_{i,}$ (kg)

The average dry matter content (*w*db), expressed in percents, was calculated using the following equation:

$w\text{db}\ (\%) = (m2/m1) \times 100$ (1)

Where:

*m*1 – mass of the sample before drying (g)

*m*2 – mass of the sample after drying (g)

3.14.3 Bulk density

The bulk density of onion instant product was measured following the method of Wang and Kinsella (1976).

Principle: The measurement of bulk density is mainly based on loosely filling of a sample in graduated cylinder. After taping of the cylinder on bench top from a reasonable high, the bulk density is expressed as sample weight per unit volume occupied.

Procedure: A sample of 20g ± 1mg was transferred into a graduated cylinder (25ml) and gently backed by tapping the cylinder on a bench top (10 times) from a reasonable high (5-8 cm). The final volume of the sample was recorded and the bulk density is expressed as gram sample per milliliters volume occupied.

3.14.4 Water absorption and water solubility indices

Water absorption index (WAI) and water solubility index (WSI) were determined by the centrifugal method of Anderson, *et.al*, (1969) with some modifications.

Principle: The water absorption index is the weight of gel that is obtained per gram of dry sample after centrifugation of the sample suspension, whereas the water solubility index is amount of soluble solids, which is remained after drying of the supernatant and expressed as a percentage of total dry solids of the sample.

Procedure: A sample of 1g± 1mg was weighted in pre-weighted centrifuge tube (12ml). To each tube, 10ml distilled water were added and mixed for 30 min. in a shaking water bath **(Type SBK25. Salvis, Germany**) at 30 C◦. Instantly, the sample was centrifuged on ultracentrifuge **(Type L7, Beckman, USA)** At 11400 min for 20 min. at 4C◦ and the clear supernatant was oven dried at 105 C until a constant weight was obtained. Meanwhile, the weight of precipitate (gel) was achieved by subtracting the weight of the centrifuged tube from the total weight of the tube plus the precipitate. Then, the water absorption and the water solubility indices were expressed as gram of gel per gram of dry matter and gram of soluble solid per 100g of dry matter (DM),equations (3.4) and (3.5) respectively.

$$[WAI] = \frac{\text{gel weight (g)} - \text{sample weight(g DM)}}{\text{sample weight (g DM)}} \quad \ldots\ldots\ldots\ldots(3.4)$$

$$[WSI] = \frac{\text{weight of the supernatant after drying} \times 100}{\text{Sample weight (g DM)}} \quad \ldots\ldots\ldots (3.5)$$

Where:

[WAI] = water absorption index (g gel/g DM)

[WSI] = water solubility index (g. soluble solids/ 100g DM)

3.14.5 Rehydration ratio

The rehydration measurement was calculated in all samples according to Ragnna (1977).

Procedure: A sample of 10 g from the dry material was placed into 500 ml beakers, then 150 ml of distilled a water was added and the sample was covered with a watch glass and boiled on an electric heater for 5 minutes. After that, the sample was removed from the heater and filtered through a filter paper **(Watman No.4)** with **Buchner Funnel** (7.5 cm) under gentle suction. When the drip from the funnel was almost stooped, the sample was removed from the funnel and weighed with in a covered porcelain dish.

Calculation: Rehydration ratio could be calculation using equation (3.6)

$$\text{Rehydration ratio} = \frac{Wr}{Wd} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (3.6)$$

where:

Wr – drained weight (g) of the rehydrated sample

Wd – weight of the dry sample used for rehydration (g)

3.14.6 Calculation of dehydration ratio and the yield of dried products:

Dehydration ratio and yield can be calculated by using equations (3.7) and (3.8) respectively Quinn and Benchait (1975).

$$\text{Dehydration ratio} = \frac{T_o + 1}{T_f + 1} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (3.7)$$

$$\text{Yield} = \frac{T_f + 1}{T_o + 1} \times 100 \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (3.8)$$

Where:

F_o = mass of water in the product before introduced the dryer(kg water /kg dry matter).

T_f = mass of water in the product after drying (kg water /kg dry matter).

3.14.7 Organoleptic evaluation properties method

In this method, 20 trained panelists from the Food Science and Technology Department in the College of Agricultural Studies in Sudan University of Science and Technology according to Sidel and Stane (1976) were asked to evaluate the three dried products (Banana, Potato and Onion) with regard to their color, taste, flavor, general appearance and overall quality using the following Hedonic Scale: 1= excellent, 2 = v. good, 3 = good, 4 = acceptable and 5 = un acceptable. After that, two factors RCD statistical analysis was performed to analysis the data.

CHAPTER FOUR

RESULTS AND DISCUSSION

The performance tests experiments were done to evaluate the designed dryer and the results obtained on the qualities of the dried banana, potato and onion products includes and handling the following:

1. Drying rate.
2. Moisture content properties
3. Physical properties (bulk density, water solubility index, rehydration ratio, water absorption index, yield and dehydration ratio).
4. Organoleptic evaluation properties (color, taste, flavor, general appearance and overall quality.

4.1 Drying rate

4.1.1 Banana drying rate

The result of experiment to measure the drying rate to banana Fig (4.1) gave only (5.5 hours) as shorten times with electric candle dryer in case using both fans or bottom fan only . The above time scored when the moisture content for two systems 7.90% and 7.10% respectively. And at the same time hot water dryer with top fan gave the longest time (8.5hours) with moisture content of about 6.42%. When compared the moisture content value for two dryers found that, hot water dryer has less value than the candle dryer. Hence using hot water dyer was best than candle dryer. Also the result showed there was a highly significant difference ($p > 0.05$) between the treatments.

4.1.2 Potato drying rate

The result of study for measuring drying rate of potato Fig (4.2) showed that, electric candle system of candle dryer using top fan gave the shorten time (4 hours) to achieve moisture content of about 3.86%. While hot water dryer with top fan gave the longest time (5.5 hours) with moisture content of about 3.57%. Also the result showed there was highly significant difference ($p > 0.05$) between the treatments.

4.1.3 Onion drying rate

Fig (4.3) represented drying time for onion. The electric candle dryer using bottom fan gave the shorten time (4 hours) and moisture content of about 4.91%. At the same time hot water system with bottom fan gave the longest time (7.5 hours) with moisture content of about 5.74%. Also the result showed there were highly significant differences ($p > 0.05$) between the treatments.

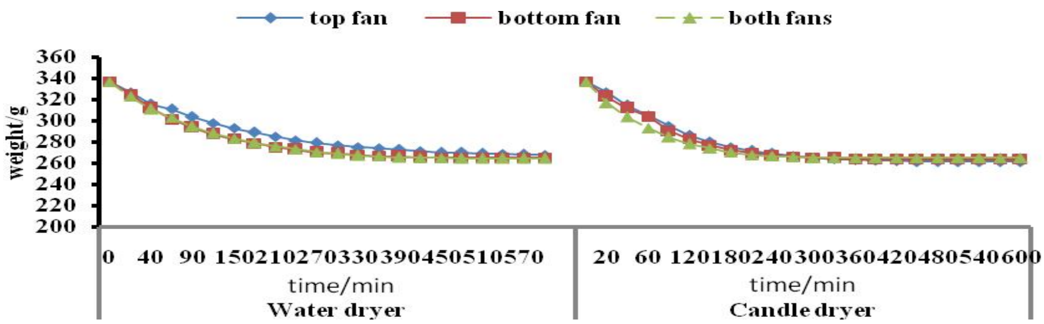


Fig 4. 1: Drying rate of banana.

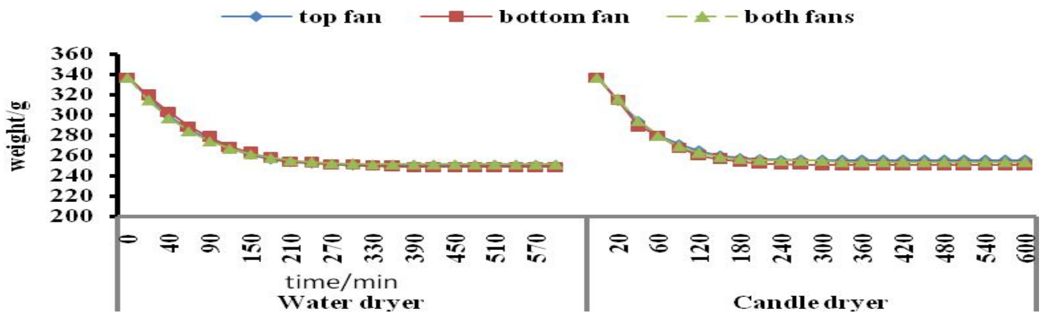


Fig 4. 2: Drying rate of potatoes.

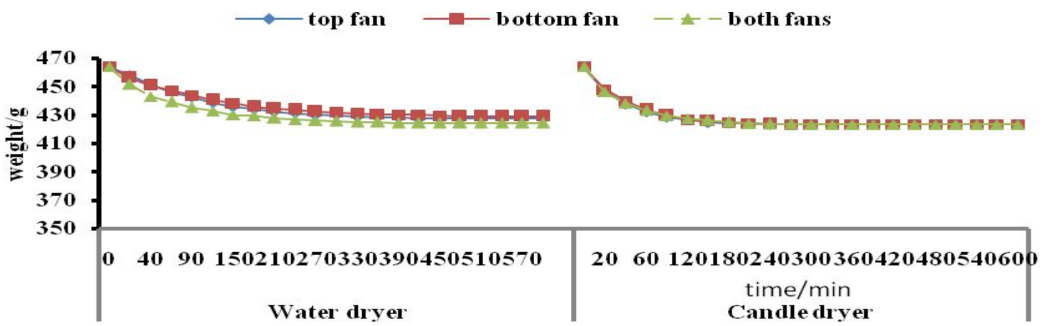


Fig 4. 3: Drying rate of onion.

4.2 Moisture content of dried products (banana, potato and onion) dehydrated by using hot water and electric candles techniques

4.2.1 Banana moisture content

Data of moisture content of banana represent in Fig (4.4).The results showed highly significant difference ($p > 0.05$) between the treatment of electric candle system with top and bottom fans and the other treatments. It is also observed that, hot water system with top and bottom fans gave the lowest value 5.86 % which can evaluated as the best result followed by hot water system (top fan only) 6.42 %.On the other hand electric candle system using top and bottom fans gave the highest value 9.89 %.This result may be due to heat moment created inside of drying chamber and the result agreement with findings research conducted by Pan *etal* (2008).

4.2.2 Potato moisture content

Statistical analysis data of moisture content of dried potato sample showed significant differences ($p > 0.05$) between the treatments of two dryers Fig (4.5). It is also conducted that, electric candle system (one fan on the bottom) gave the lowest value 3.25% followed by hot water system (fan on the bottom) 3.33% although, there were not significant difference between the two systems . The highest value obtained by electric candle (fan on the top) 3.91% .This result according to a proper pretreatment applicator before drying and agreement with findings research investigated by Loeseck,(2012) and Srivastava and Kumar (2002) Ali (2008).

4.2.3 Onion moisture content

The data present in Fig (4.6) represent moisture content of onion dried sample. The result indicated that, there were significant differences ($p > 0.05$) among treatments. They also observed that, electric candle system (one fan on the bottom) gave the lowest value 4.91% followed by electric candle system(two fans on the top and bottom) 5.20 %.The result also showed that, hot water system (fan on the top) gave the highest value 6.16% . This above results agreement with findings research investigated by Kumar *et.al,* 2006 and FAO 2014.

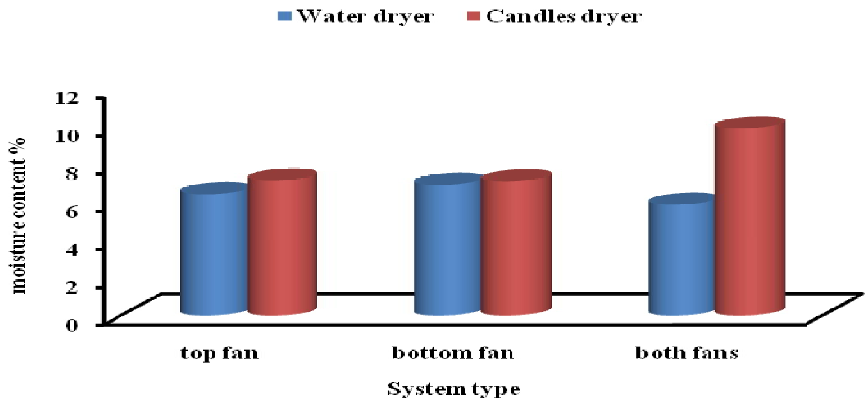


Fig 4. 4: Moisture content of banana.

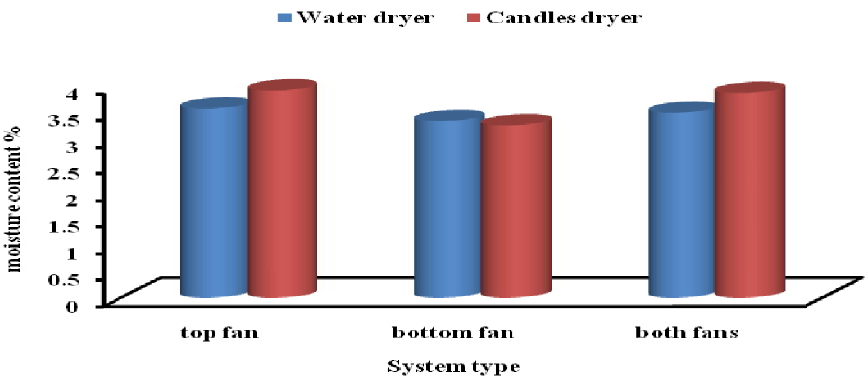


Fig 4. 5: Moisture content of potato

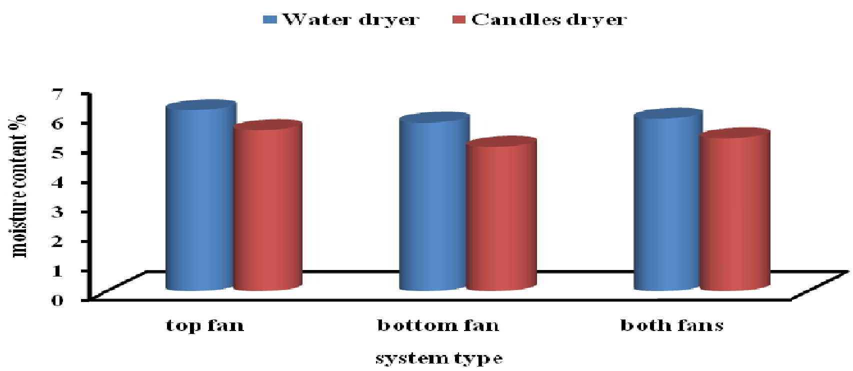


Fig 4. 6: Moisture content of onion.

4.3 Products physical properties

The result for the physical properties which includes bulk density, water solubility index, rehydration ratio, water absorption index, yield, dehydration ratio were mention and discussed in the following:

4.3.1 Bulk density

4.3.1.1 Banana bulk density

Results obtained on bulk density of dehydrated banana as presented in Fig (4.7) showed significant difference ($p > 0.05$) between the treatments. The results indicated that, the packaged of hot water system and the two fans was together gave the lowest value 0.7930 (g/ml) ,while the system of electric candle of drying technique using top and bottom fans gave the highest value 0.9389 (g/ml) . The result for some extend agreement with findings research conducted by Lozano *et.al,* 1980, 1983; Vagenas *et.al,* 1990; Zogzas *et.al,* 1994; Karathanos *et.al,* 1996; Krokida and Maroulis, 1997) and Ronco (2009**)**.

4.3.1.2 Potato bulk density

Potato bulk density results showed that, Fig (4.8) hot water system using top and bottom fans gave the lowest value 1.111(g/.ml). On the other hand the system of electric candle using top and bottom fans gave the highest value 1.250(g/ml). It was noticed that, the treatment hot water system with top fan showed non significant difference($p < 0.05$) with electric candle system using also top fan, but all the other treatments showed significant difference ($p > 0.05$). These showed the effect of which for some extend agreement with findings research conducted by Brenan (2006), FAO (2012) **.**

4.3.1.3 Onion bulk density

The experiment results for bulk density of dried onion Fig (4.9) noticed that, the hot water system with bottom fan gave the lowest value 0.8142(g/ml). The highest figure 0.9632(g/ml) obtained by candle dryer with bottom fan Also the previous treatment showed significant differences ($p > 0.05$) with all other treatments. The previous results for some extend agreement with findings research conducted by Ronco (2009), FAO (2012) and Ali (2008).

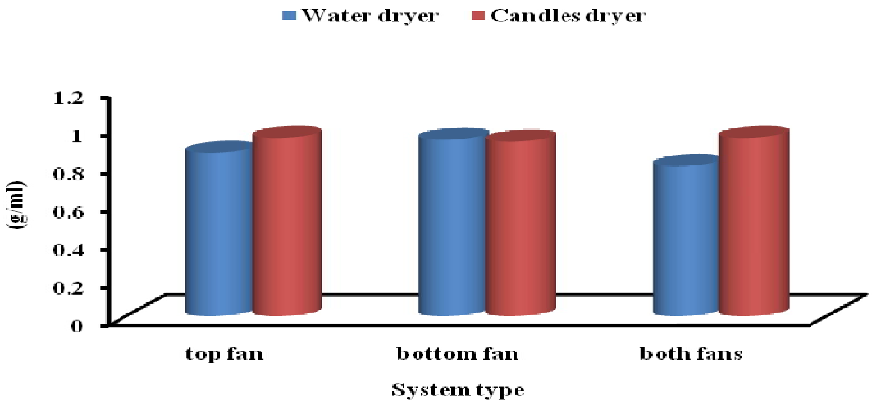


Fig 4. 7: Bulk density of banana.

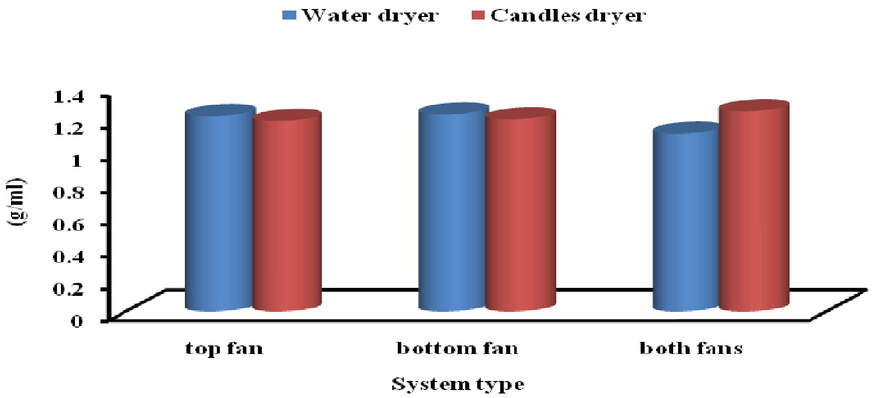


Fig 4. 8: Bulk density of potato.

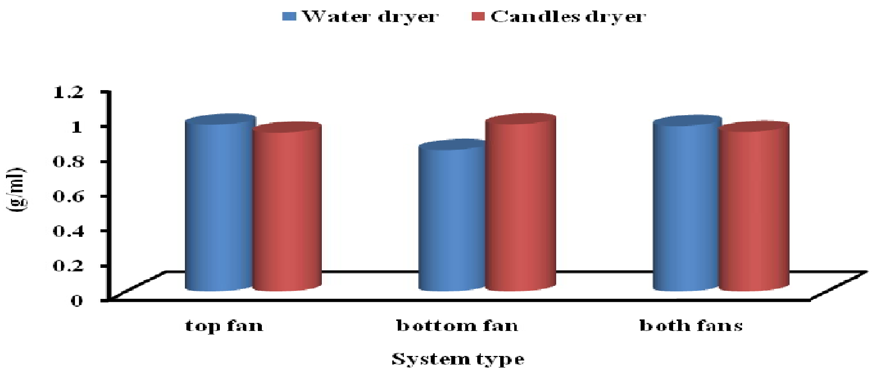


Fig 4. 9: Bulk density of onion.

4.3.2 Water solubility index

4.3.2.1 Banana water solubility index

The result of water solubility index of dried banana sample conducted that Fig(410) , electric candle system with bottom fan gave the highest value 71.06(g/100gSM).On the other hand hot water system with top fan gave the lowest value 54.37(g/100gSM). The result also showed that there were a significant difference ($p > 0.05$) between the hot water system (fan at the top) and electric candle systems (fan at the bottom) only. The result agreement with findings research conducted by Ronco (2009), (Bezerra *et.al*, 2013) and FAO (2012).

4.3.2.2 Potato water solubility index

The study of water solubility index of potato drying sample showed that, there are significant differences ($p > 0.05$) between the treatments Fig (4.11). System of hot water using two fans at top and bottom give the highest value 20.99(g/100gSM). On the other hand electric candle system using two fans at top and bottom gave the lowest value 9.10(g/100gSM). The results disagree with finding research by Ali (2008).

4.3.2.3 Onion water solubility index

For onion solubility index the result showed that, there were highly significant differences ($p > 0.05$) between the treatments Fig (4.12). Hot water system (the fan located at the top) of water dryer gave the high value 66.12(g/100g DM), and electric candle system in which one fan located at the top gave the lowest value 34.12(g/100g DM).

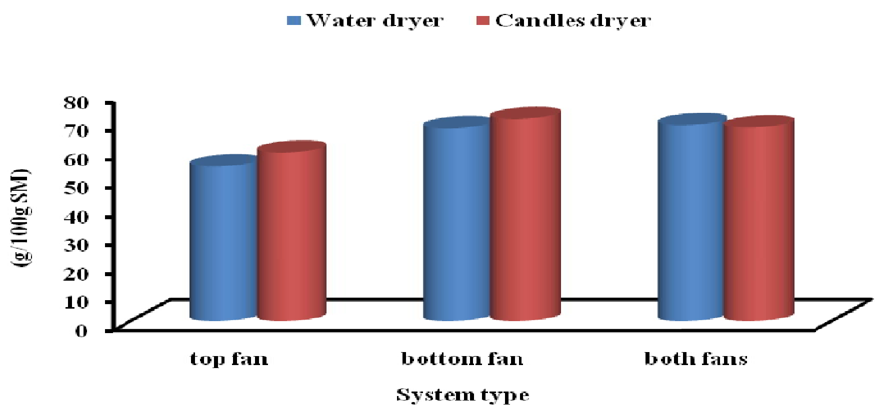


Fig 4. 10: Water solubility of banana.

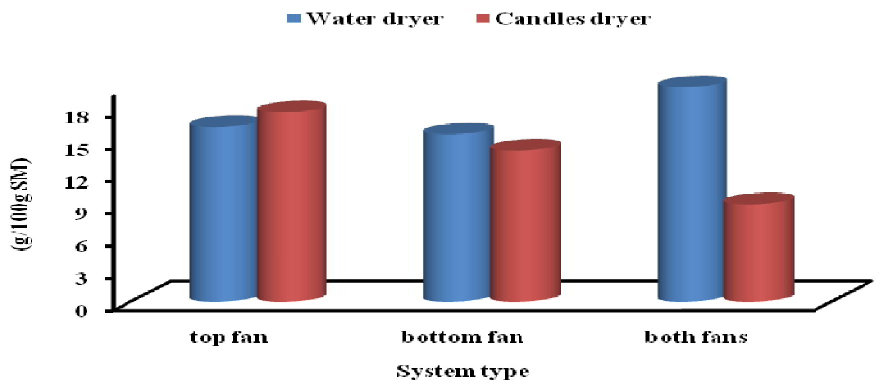


Fig 4. 11: Water solubility of potato.

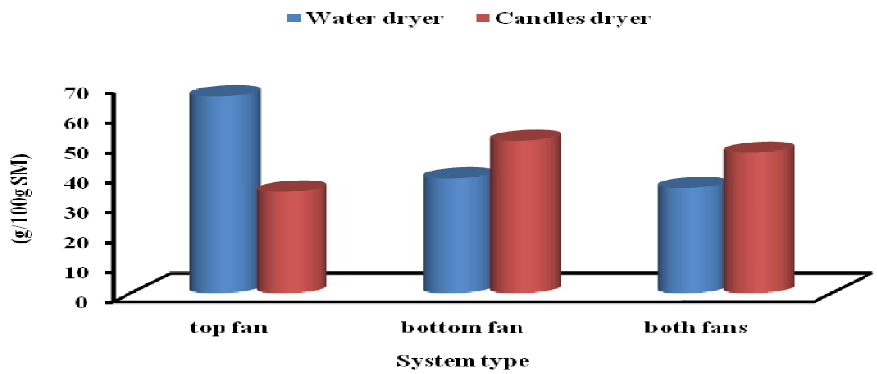


Fig 4. 12: Water solubility of onion

4.3.3 Rehydration ratio

4.3.3.1 Banana rehydration ratio

The result obtained from the experiment for rehydration ratio of banana dried sample showed there were significant differences ($p > 0.05$) between the treatments Fig (4.13). The electric candle system using two fans were located at the top and the bottom of drying chamber gave the highest value 2.83, and at the same time hot water system (one fan at the bottom) gave the lowest value 2.16. The results agreement with finding research by Abano and Amoah (2011) and Sous and Marsaiobi (2004).

4.3.3.2 Potato rehydration ratio

Potato rehydration test Fig (4.14) the results showed that, here were significant difference ($p < 0.05$) between the treatments. The electric candle system of candle dryer where the fan was located at the top of drying chamber gave the highest value 3.16, and at the same time hot water system (using two fan at the top and bottom) gave the lowest value 2.50. The results for some extend agreement with findings research conducted by Srivastara and kumar (2010).

4.3.3.3 Onion rehydration ratio

The highest value for rehydration ratio of onion rehydrated sample obtained from the electric candle system in which two fans located at the top and bottom were used gave the highest value 6.50 Fig(4.15). On the other hand hot water system in which two fans located at the top and bottom gave the lowest value 4.08. The result also showed non significant differences between the treatments ($p < 0.05$). The results for some extend agreement with findings research conducted by Abbasi *et.al,* (2011).

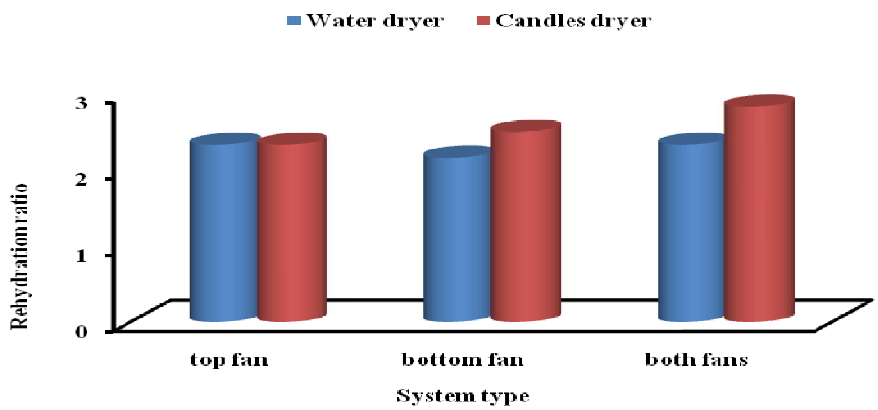


Fig 4. 13: Rehydration ratio of banana.

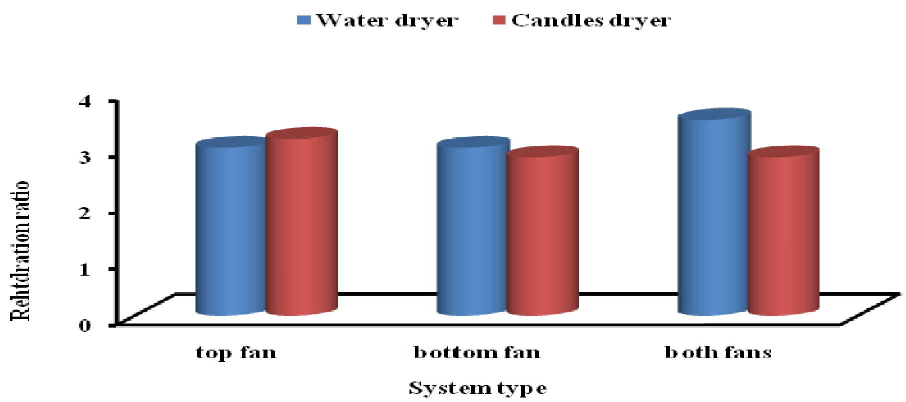


Fig 4. 14: Rehydration ratio of potato.

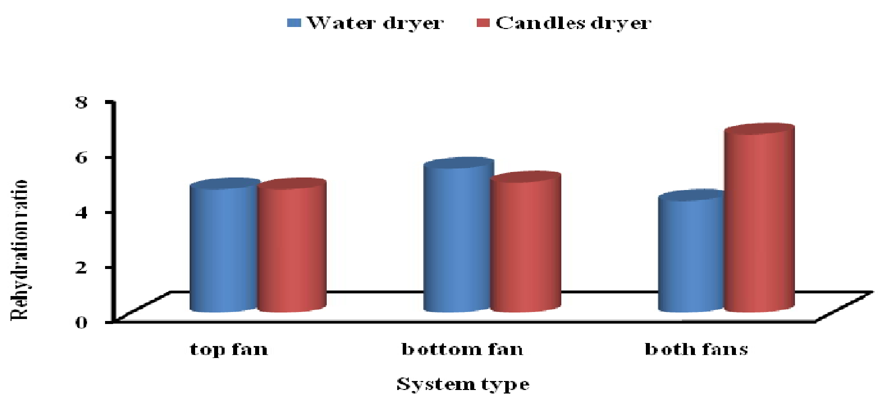


Fig 4. 15: Rehydration ratio of onion.

4.3.4 Water absorption index (g. gel/g DM)

4.3.4.1 Determine of Banana Water Absorption index (g. gel/g DM)

The result found for banana dried sample Fig (4.16) indicated that, the hot water system with one fan at the top of drying chamber gave the highest value 1.93(g. gel/g DM). The lowest value 1.35(g. gel/g DM) obtained from the system of electric candle using top and bottom fan. Also the result indicated that, there are not significant differences among all treatments of the two dryers ($p < 0.05$). This results may be due to the same drying condition which the product exposure to them.

4.3.4.2 Determine of Potato water absorption index (g. gel/g DM)

For water absorption index of potato dried sample the result showed that, Fig(4.17) hot water system of drying technique using top fan only gave the highest value 5.55(g.gel/g DM). On the other hand the electric candle system of drying technique using also top fan only gave the lowest value 4.10(g.gel/g DM).Also the result indicated that, there are not significant differences among all treatments ($p < 0.05$). These may be due to the nature of the product and external conditions of drying.

4.3.4.3 Determine of Onion water absorption index (g. gel/g DM)

The result of water absorption index for dried onion sample showed that, hot water system using upper and lower fan of drying technique gave the highest value 4.20(g.gel/g DM), and the hot water system using lower fan only of the same dryer gave the lowest value 3.63(g.gel/g DM) Fig (2.18). The treatment of hot water system(one fan at lower position) showed significant differences ($p > 0.05$) with hot water system(using upper and lower fan) The value of this treatments were 3.63(g.gel/g DM) and 4.20(g.gel/g DM) respectively.

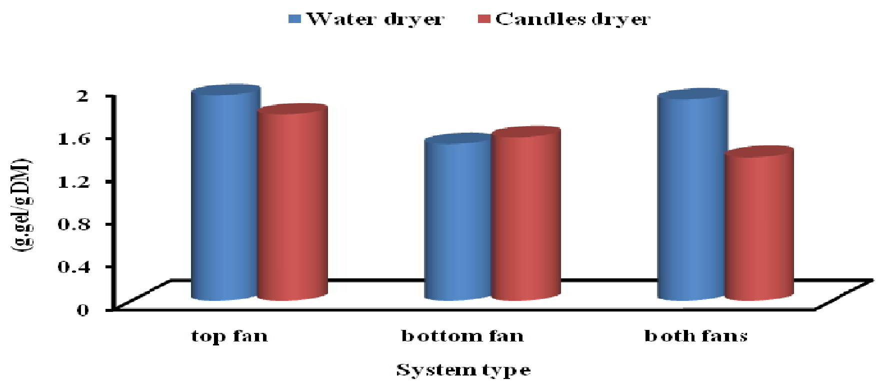


Fig 4. 16: Water absorption index of banana.

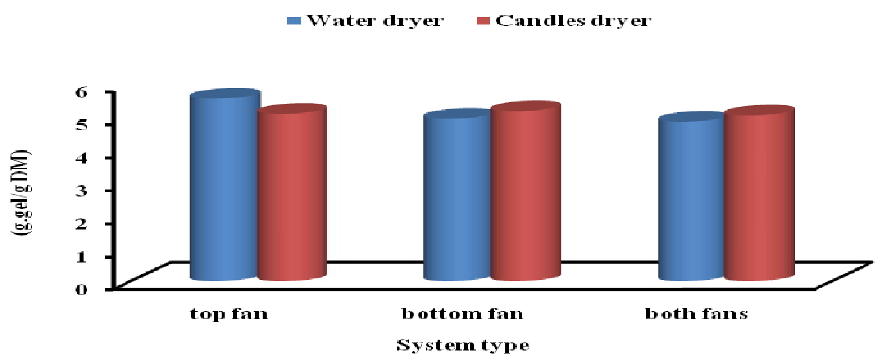


Fig 4. 17: Water absorption index of potato.

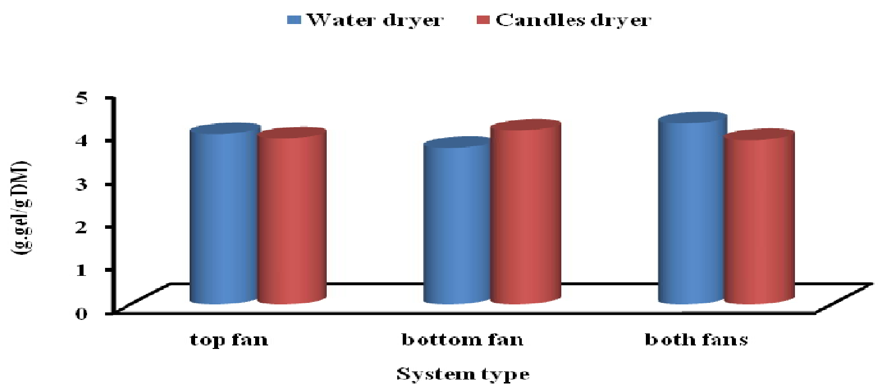


Fig 4. 18: Water absorption index of onion.

4.3.5 Yield of dried products

4.3.5.1 Determination of yield of dehydrated banana %

The study of yield of dehydrated banana sample the result Fig (4.19) indicated that, electric candle system of candle dryer using top and bottom fan gave the high value 17.70% , and at the same time hot water system with two fans gave the lowest value 17.31%. Also the result showed there were significant differences ($p > 0.05$) between the treatments. Loesecke, (2012) dried banana in cabinet dryer and found the yield of about 12%. The previous results show the effect of degree of ripening.

4.3.5.2 Determination of yield of dehydrated Potato %

The study for yield of dehydrated sample of potato Fig(4.20) showed that, the highest value of yield obtained from the system of hot water using upper and lower fan was18.10% and the lowest value obtained from electric candle system using bottom fan only was 17.88%. The result also appears a significant difference ($p > 0.05$) between the treatments. The results for are in line with Loesek (2012) and Srivastara and Kumar (2010).

4.3.5.3 Determination of yield for dehydrated Onion %

The data of yield of dehydrated onion sample found in Fig (4.21).The statistical analysis showed that, there were no significant differences ($p > 0.05$) between the treatments. Although, the best result obtained with hot water system using one fan located at the top19.93% and at the same time the lowest value observed with electric candle system with one fan located at the bottom of drying chamber 19.67%.This may be due to application of the same drying conditions.

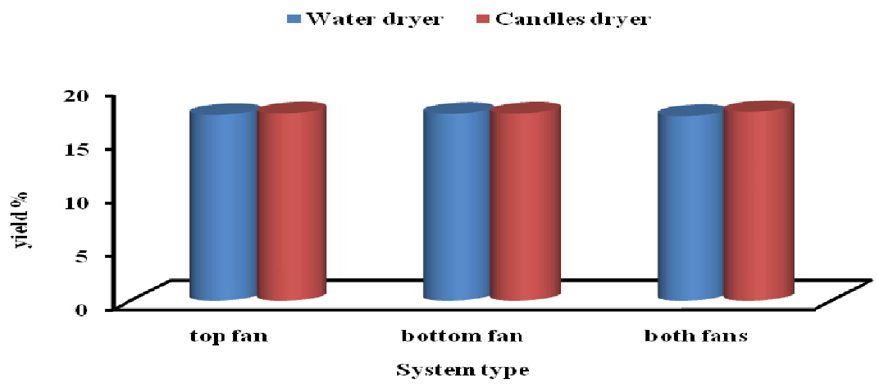


Fig 4. 19: Yield of banana.

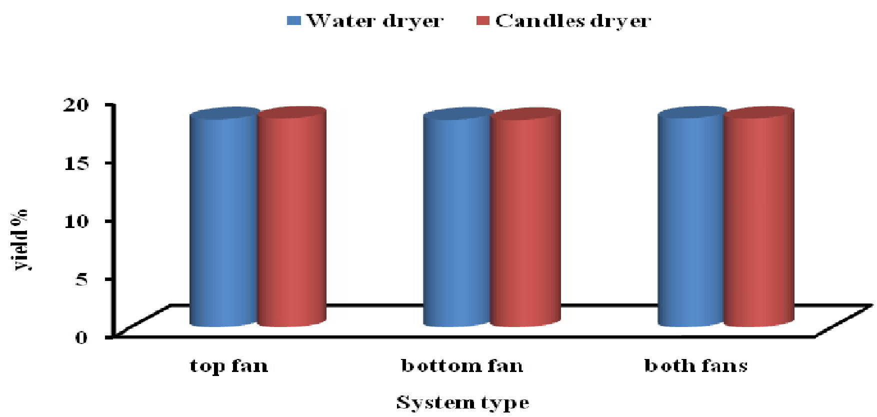


Fig 4. 20: Yield of potato.

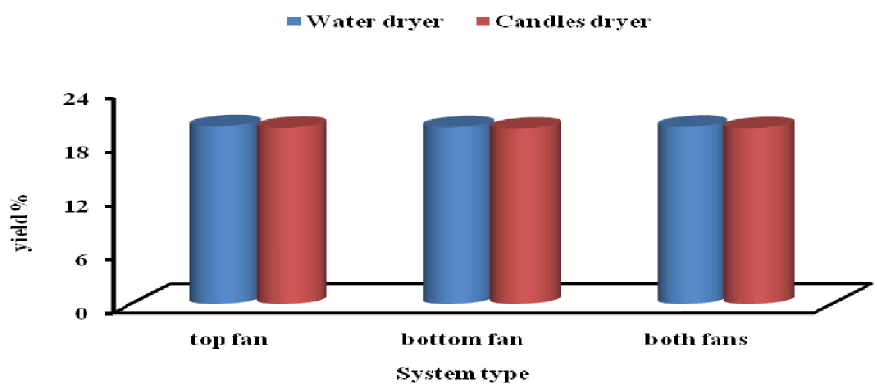


Fig 4. 21: Yield of onion.

4.3.6 Calculation of dehydration ratio of dried products

4.3.6.1 Dehydration ratio of dried banana

The data of dehydration ratio of dried banana sample present in Fig (4.22) .The results indicate significant differences between treatments ($p > 0.05$). However, the hot water system using two fans (at top and bottom) gave the highest value 5.775, and electric candles system using two fans (at top and bottom) gave the lowest value 5.649.these results disagree with that finding research conducted by Hassanain (2009).

4.3.6.2 Dehydration ratio of dried potato

For dehydration ratio of potato sample, the data are present in Fig (4.23). The statistical analysis revealed that, there were significant differences between all treatments ($p > 0.05$). It has been well documented that, electric candle system with one fan located at the bottom gave the highest value 5.592 and at the same time hot water system using two fans gave the lowest value 5.

4.3.6.3 Dehydration ratio of dried onion

The data of dehydration ratio of onion sample found in Fig (4.24).The statistical analysis indicated that, there were a significant differences between all treatments ($p > 0.05$). The result also showed that electric candle system using fan located at the bottom gave the highest value 5.085± 0,02 .On the other hand hot water system using one fan at the top of drying chamber gave the lowest value 5.018.

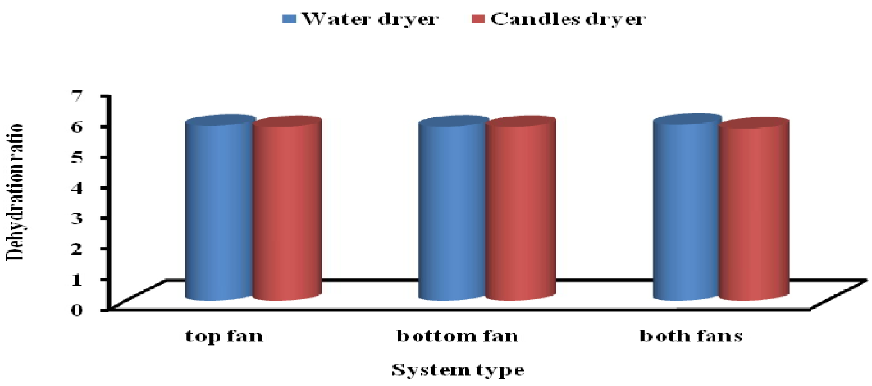


Fig 4. 22: Dehydration ratio of banana.

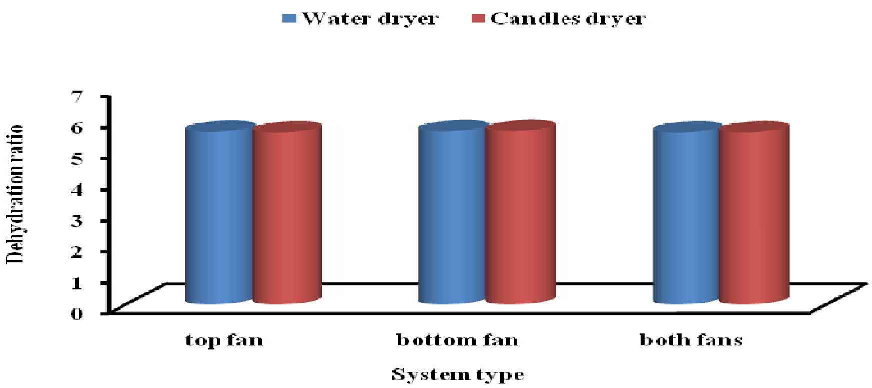


Fig 4. 23: Dehydration ratio of potato.

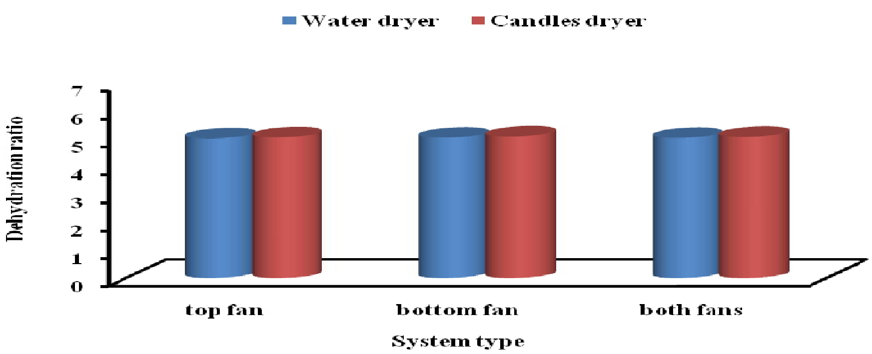


Fig 4. 24: Dehydration ratio of onion.

4.4 Organoleptic evaluation properties

4.4.1 Color evaluation

4.4.1.1Color evaluation of banana

The data of color evaluation of banana dried products present in Fig (4.25).The result of color evaluation of banana dried product showed significant differences ($p > 0.05$) between the treatments. However, the best value (low figure) was observed with hot water system using one fan located at the lower position of drying chamber 2.17 followed hot waters system using two fan (at the top and bottom) 2.22. On the other hand the highest figure obtained by electric candle system with one fan located at the top 3.50. These results may be due to indirect exposure to the heat as mention by Kenddal *et.al*, (2004) (Demirel and Turhan 2003).

4.4.1.2 Color evaluation of potato

For color evaluation of potato dried sample, the result showed significant difference ($p > 0.05$) between the treatments Fig (4.25). The lowest value figure (best result) obtained by hot water system two fans at the top and bottom 1.29 followed by hot water system using one fan at the top 1.47.The highest value figure obtained by electric candle system with one fan at the bottom 2.35. The previous results agree with Nagaya *et .al*, (2006), Kenddal *et.al*,(2004) and Leeratanarak (2006).This may be due to using blanch as pretreatment before drying.

4.4.1.3 Color evaluation of onion

The statistical analysis of color evaluation of onion dried sample Fig (4.26) revealed that, there were a significant differences among the treatments ($p > 0.05$). It has been observed that, both hot water with system one fan at the top and hot water system using one fan at the bottom gave the lowest value (best result) 2.00 for each. The highest value (large figure) obtained by electric candle system using fan at the top 3.38. The results agreement with findings research conducted by Ronco (2009). Nagaya *et,al*, (2006 Kenddal *et.al*,(2004) and Arslam and Ozcan (2010) Patil *et.al,* (20012). And this result may be due to a proper temperature and a proper pretreatment. Generally for color evaluation for three products the results showed that, the water dryer was superior of candle dryer.

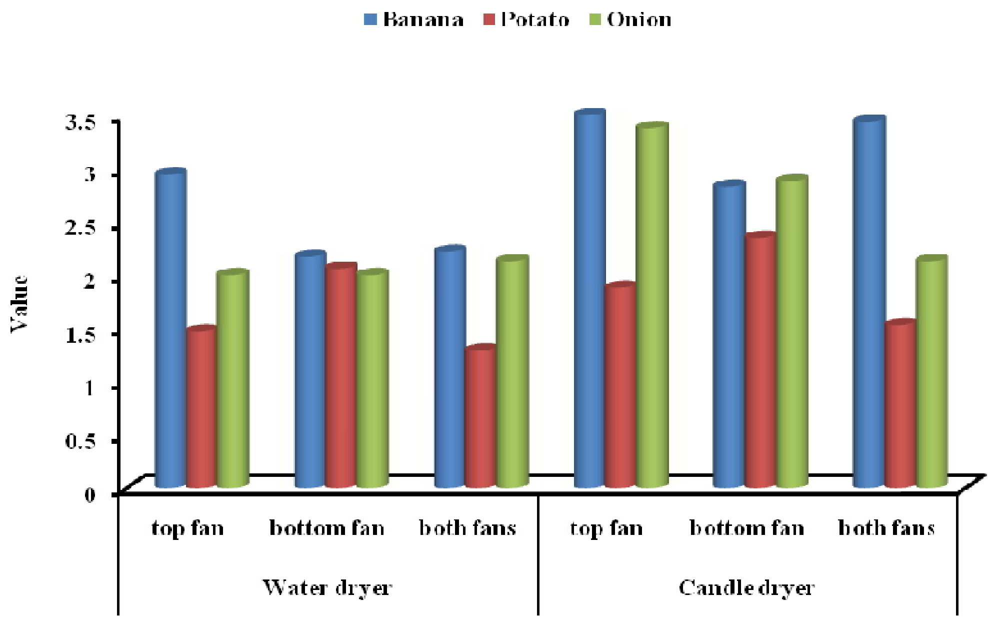


Fig 4. 25: Color evaluation of banana, potato and onion.

4.4.2 Taste evaluation

4.4.2.1 Taste evaluation of banana

Data of the evaluation of banana taste showed in Fig (4.26).The results obtained from statistical analysis indicate no significant differences ($p < 0.05$) between all treatments but the hot water system using two fans located at the top and bottom gave the lowest number (the best result)2.17 followed by hot water system using one fan at the bottom. At the same time electric candle system using one fan at the lower gave the highest figure 2.72. The result agreement with findings research conducted by Sous and Marsaiobi (2004).

4.4.2.2 Taste evaluation of potato

Although the results of taste evaluation of potato dried sample Fig (4.26) showed no significant differences ($p < 0.05$) between all treatments, the hot water system with two fans gave the lowest number 2.18 , and at the same time the hot water system (one fan at the lower position) gave the highest figure 2.65.

4.4.2.3 Taste evaluation of onion

Evaluation of onion taste, Fig (4.26) the result indicated that, there were not significant differences ($p < 0.05$) between all treatments. However, hot water system using one fan at the bottom of drying chamber gave the lowest figure 2.13 followed by hot water system when using one fan at the top of drying chamber 2.25. At the same time electric candle system (using one fan at the top) gave the highest figure 2.69. Also results showed that, the water dryer was superior to candle dryer.

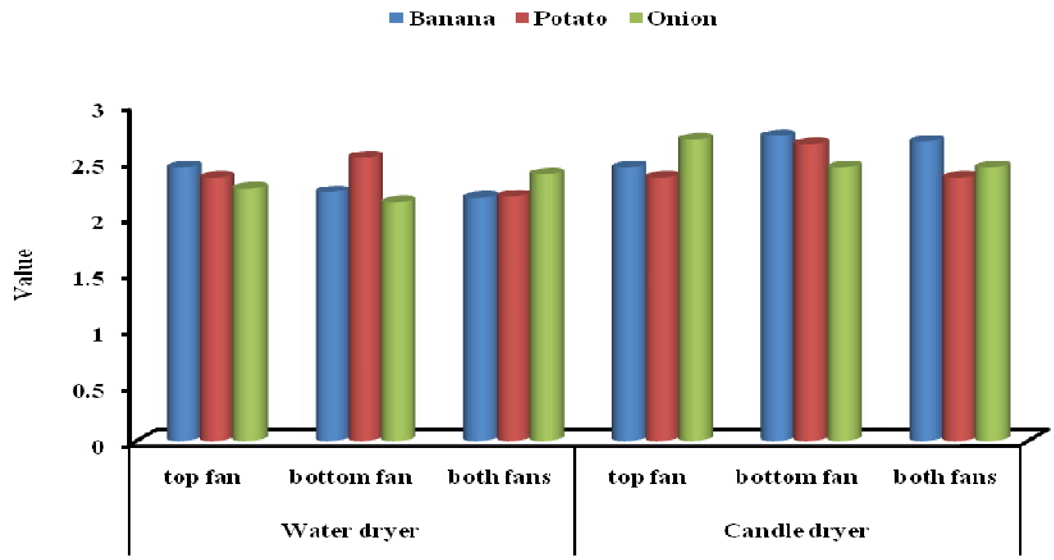


Fig 4. 26: Taste evaluation of banana, potato and onion.

4.4.3 Flavor evaluation

4.4.3.1 Flavor evaluation of banana

The data of flavor evaluation of banana , dried products present in Fig (4.27).The result showed significant differences (p > 0.05) between the treatments meanly hot water system using top and bottom fans and electric candle also using top and bottom fan . The best value (low figure) was observed with hot water system using top and bottom fans 2.39 .followed hot water system using top fan and hot water system using lower fan which they gave the same results 2.56 for each. On the other hand the highest figure obtained by electric candle system using top and bottom fan 3.93. The result for some extends agreement with findings research conducted by Kenddal *et.al,* (2008).

4.4.3.2 Flavor evaluation of potato

Although the results of flavor e evaluation of potato dried samples showed no significant differences ($p < 0.05$) between all treatments, Fig (4.27). The hot water system using one fan at the top ,and two fans and electric candles using two fans scored the same figure result 2.53. On the other hand electric candles with lower fan gave the highest figure 2.65. The results for some extend agreement with findings research conducted by Kenddal *et.al,* (2008), Cunz *et.al,* (2008) and agreement with Srivastara and Kumar (2010).

4.4.3.3 Flavor evaluation of onion

The statistical analysis of flavor evaluation of onion dried sample showed no significant differences ($p < 0.05$) between the treatments ,Fig (4.27) but electric candles system with two fans gave the best result 2.19 followed by electric candles system with one fan at the bottom 2.44. On the other hand hot water system (one fan at the top) gave the highest figure 2.81. Generally water dryer was superior to candle dryer except in case of onion product.

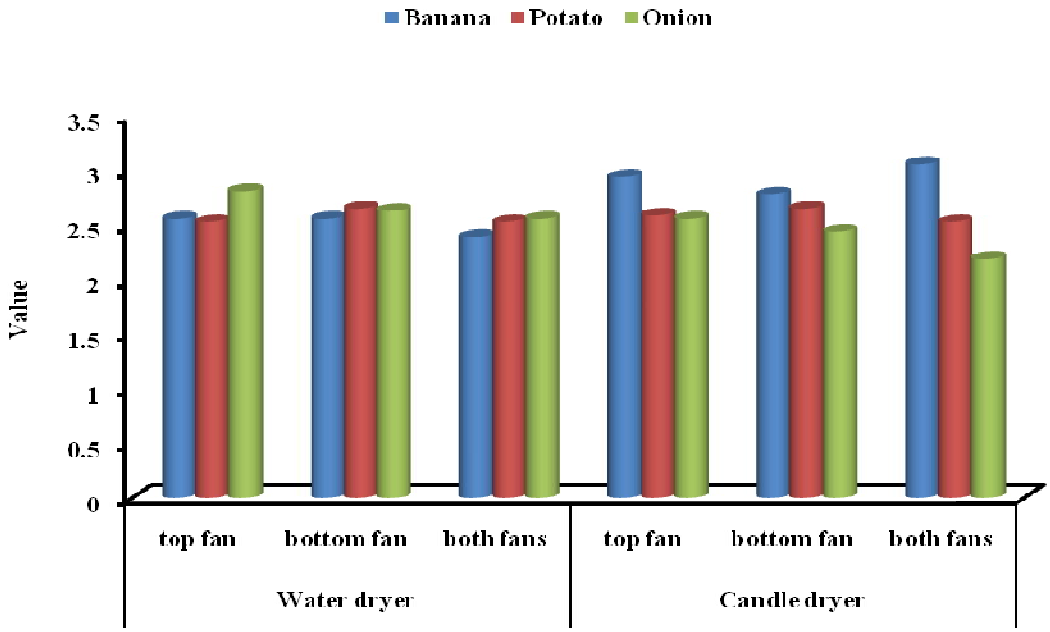


Fig 4. 27: Flavor evaluation of banana, potato and onion.

4.4.4 General appearance evaluation

4.4.4.1 General appearance evaluation of banana

The data of general appearance evaluation of banana dried sample present in Fig (4.28). Banana results indicate significant differences ($p > 0.05$) between the treatments. Although, hot water system using lower fan gave the best result 2.44 followed by hot water system using top and bottom fan 2.72. At the same time the highest figure obtained by hot water system using top fan suct3.22.

4.4.4.2 General appearance evaluation of potato

For potato general appearance, the result indicated that, there were no significant differences ($p < 0.05$) between all treatments Fig (4.28). The best result was observed with hot water system using top and lower fan 2.24 followed by hot water system using one fan at the top of drying chamber and electric candles system using two fans (top and bottom) which they gave the same results 2.35 for each. On the other hand the highest figure obtained by electric candle system using one fan at the lower position of drying chamber 2 .65. The result agreement with findings research conducted by Srivastara and Kumar (2010).

4.4.4.3 General appearance evaluation of onion

The statistical analysis data of general appearance of onion dried sample Fig (4.28) showed that, there were no significant differences($p < 0.05$) between the treatments .The results also indicated that, hot water system using upper fan gave the best result 2.44 followed by hot water system using two fan (top and bottom) 2.56. The highest figure obtained by electric candle system using one fan located at the bottom of drying chamber 2.88. The results for some extend agreement with findings research by Exienne and Serge (1983). As general results the water dryer found to be superior to candle dryer.

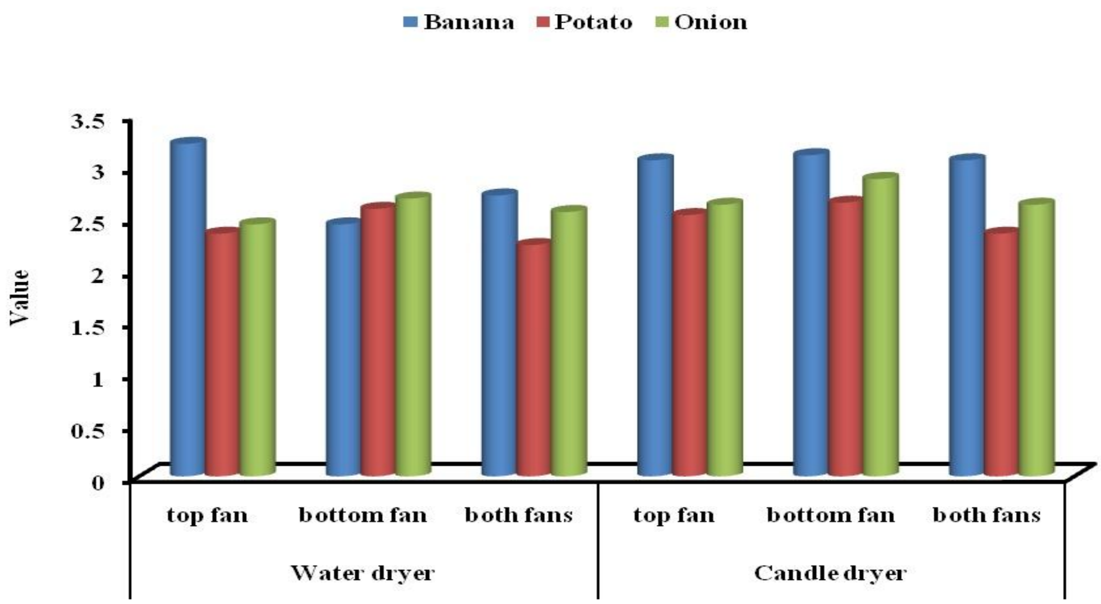


Fig 4. 28: General appearance of banana, potato and onion.

4.4.5 Overall quality evaluation

4.4.5.1 Overall quality evaluation of banana

The data of overall quality evaluation of banana, dried sample data present in Fig (4.29). The statistical analysis data of overall quality of banana dried sample showed that, there were a significant differences($p > 0.05$) between the treatments .The results also indicated that, hot water system using one fan at lower position gave the best result 2.39 followed by hot water system using two fans (top and bottom) 2.44. The highest number obtained by electric candle system using upper fan only 3.11. The result agreement with findings research conducted by Sous and Marsaiobi (2004).

4.4.5.2 Overall quality evaluation of potato

Potato evaluation dried sample the result observed that, Fig (4.29) there were no significant differences($p < 0.05$) between the treatments .The results also conducted that, hot water system using two fans (top and bottom) gave the best result 2.18 followed by electric candle system using two fan(top and bottom) 2.24. The highest number obtained by hot water system when one lower fan was used 2.65.

4.4.5.3 Overall quality evaluation of onion

Onion evaluation dried sample the result observed that, Fig (4.29) there were a significant differences ($p > 0.05$) between the treatments. Also the results showed that, hot water system using one fan at the top gave the best result 2.44 followed by electric candle system with one fan located at the lower position of drying chamber 2.50. The highest number obtained by electric candle system using one fan located at upper position of drying chamber 3.25.From the result the study showed that, water dryer was superior to candle dryer.

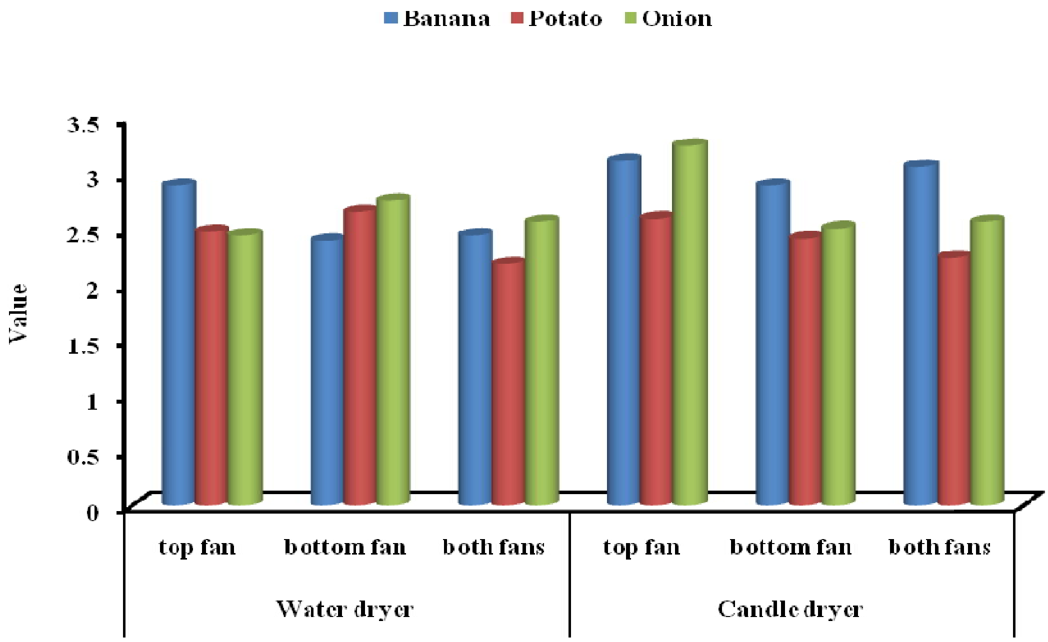


Fig 4. 29: Overall quality evaluation of banana, potato and onion


Plate 4. 1: Banana feature using hot water dryer (Top fan system)


Plate 4. 2: Banana feature using hot water dryer (Bottom fan system)


Plate 4. 3: Banana feature using hot water dryer (Both fans system)


Plate 4. 4: Banana feature using candles dryer (Top fan system)


Plate 4. 5: Banana feature using candles dryer (Bottom fan system)


Plate 4. 6: Banana feature using candles dryer (Both fans system)

Plate 4. 7: Potatoes feature using hot water dryer (Top fan system)

Plate 4. 8: Potatoes feature using hot water dryer (Bottom fan system)

Plate 4. 9: Potatoes feature using hot water dryer (Both fans system)

Plate 4. 10: Potatoes feature using candles dryer (Top fan system)

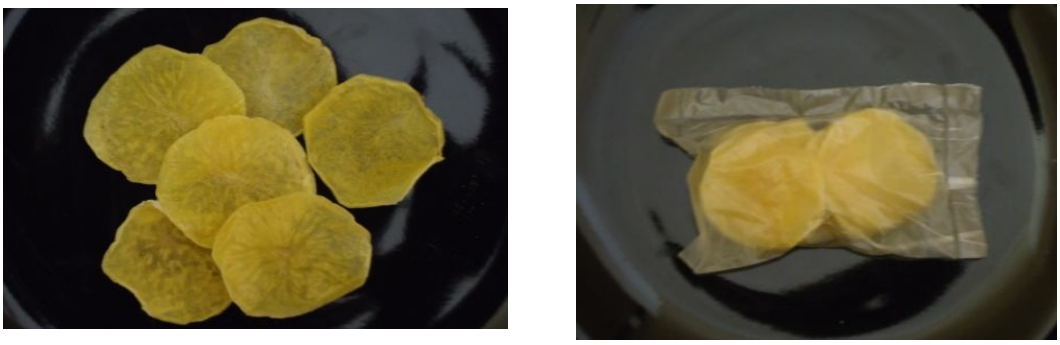


Plate 4. 11: Potatoes feature using candles dryer (Bottom fan system)

Plate 4. 12: Potatoes feature using candles dryer (Both fans system)


Plate 4. 13: Onion feature using hot water dryer (Top fan system)


Plate 4. 14: Onion feature using hot water dryer (Bottom fan system)


Plate 4. 15: Onion feature using hot water dryer (Both fans system)

Plate 4. 16: Onion feature using candles dryer (Top fan system)

Plate 4. 17: Onion feature using candles dryer (Bottom fan system)

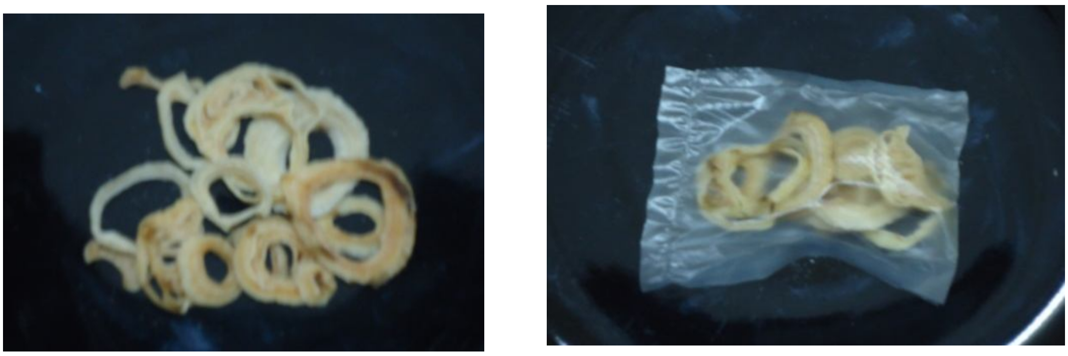


Plate 4. 18: Onion feature using candles dryer (Both fans system)

CHAPTER FIVE

CONCLUSION AND RECOMMENDATIONS

5.1 Conclusion

1. Hot water dryer can be used to dry some fruits and vegetables.
2. The water dryer gave lowest moisture content of dried banana and potatoes compared to candle dryer.
3. The water dryer scored best results of buck density of banana, water absorption index of potatoes, yield of onion and dehydration ratio of banana when compared to candle dryer.
4. The water dryer recorded best color of the three dried products.
5. The water dryer gave best taste.
6. The water dryer achieve best general appearance.
7. The water dryer gave best overall quality.
8. Water dryer with both fans is the best system.

5.2 Recommendations

1. The study support that, use old refrigerators as a dryer was a good idea, hence recommended that it may commercially produced.
2. A cause to the lack of facilities and instrumentation an old refrigerator with it specific dimensions was use to make back bone for the dryer.
3. Adoption of idea by production family.

4. Dried excessive vegetables mainly onion, potatoes okra and banana for later usage.
5. Support of applied research in the field of dehydration of fruits and vegetables through financial, training of personal and support fund from government.
6. Collaboration between the different researchs institutions in the area of dehydration.
7. Establishment of technical committees for development of agriculture and use of dehydration technology.

REFERENCES

Abano E. E. and L. K. Sam-Amoah (2011). Effects Of Different Pretreatments on Drying Characteristics of Banana Slices Journal Of Engineering And Applied Sciences Vol. 6, No. 3, 1819-6608 .

Abbasi. S ,S. M. Mousavi and M. Mohebbi (2011). Investigation of Changes in Physical Properties and Microstructure and Mathematical Modeling of Shrinkage of Onion during Hot Air Drying. Iranian Food Science and Technology Research Journal Vol. 7, No. 1, 2011, p. 92-98.

Afzal, T. M. and T. Abe. (1997). Modeling far infrared drying of rough rice. Journal of Microwave Power and Electromagnetic Energy 32(2): 80-86.

Akissoe. N, J. Hounhouigan, C. Mestres and M. Nago (2003). How blanching and drying affect the colour and functional characteristics of yam (Dioscorea cayenensis rotundata) flour. Food Chemistry, 82 pp. 257–264.

Akpinar E.K., A. Midilli and Y. Bicer. (2003). Single layer drying behavior of potato slices in a convective cyclone dryer and mathematical modeling. Energy Conversion Manag. 44: 1689-1705

Alamu O. J. l, N. N. Collins And A. Olayinka (2010). Design and Construction of a Domestic Passive Solar Food Dryer. Leonardo Journal of Sciences, Issue 16 p. 71-82.

Altan. A, KL. McCarthy and M. Maskan (2009).Effect of extraction cooking on functional properties and into starch digestibility of Barley-based extrudates from fruit and vegetable by- products. Journal of food science 74 (2), E77-E86.

Amer. B.M.A., M.A. Hossain and K. Gottschalk. (2010). Design and performance evaluation of a new hybrid solar dryer for banana. Energy Conversion and Management 51, 813–820.

Anderson. R.A, Conway. H.F ,Pfieffer,V.F and . E.l. Guiffin.(1969). Gelatinization of corn by roll and extrution –cooking .Cereal Science, Today, 14:4-12.

Ansari1.S, N. Maftoon-Azad, E. Hosseini, A. Farahnaky, and Gh. Asadi (2015). Modeling Rehydration Behavior of Dried Figs. J. Agr. Sci. Tech.) Vol. 17: 133-144.

Arnau .J , X. Serra, J. Comaposada, P. Gou and M. Garriga (2007) Technologies to shorten the drying period of dry-cured meat products. Meat science ,Voluem 77, Issue 1, pp 81-89.

Arslan .D, and Mehmet Musa Özcan (2010). Study the effect of sun, oven and microwave drying on quality of onion slices. LWT - Food Science and Technology 43 1121e1127.

Association of Official Analytical Chemista (AOAC) (1990). Official Method of Analysis, 15th ed., The Association of Official Agricultural Chemists, Virginia.

Audrey Morris, Audia Barnett and Olive-Jean Burrowsa (2004) Effect of Processing on Nutrient Content of Foods. cajarticlesno3c Vol. 37, No.3,pp 160-164.

Azoubela P. M, Maria do Amparo Melo Baima, Mariana da Rocha Amorim and Sofia Sorelly Belém Oliveira. (2010). Effect of ultrasound on banana cv Pacovan drying kinetics. Journal of Food Engineering 97 194–198.

Azuara. E, Cortes. R, H. S. Garcia. and C. I. Beristain. (1992). Kinetic model for osmotic dehydration and its relationship with Fick's second law. International Journal of Food Science and Technology, 27, 239−242

Baini. R. and T.A.G. Langrish (2007). Choosing an appropriate drying model for intermittent and continuous drying of bananas. Journal of Food Engineering 79 330–343.

Barbosa-Canovas. G. V and H. Vega-mercado. (1996). Dehydration of Foods. New York: International Thomas Publishing.

Barbosa-Cánovas. G.V,M.M. Góngora Nieto and H. Vega-M. (2001). Dehydration of Foods: Review and Update. In: The 7th Conference of Food Engineering. K. Mallikarjunan and G.V. Barbosa-Cánovas, Eds. AIChE, Dallas. pp 469-479.

Barnwal, P and G.N. Tiwari. (2008). Grape drying by using hybrid photovoltaic-thermal (PV/T) greenhouse dryer: an experimental study. Solar Energy 82 (12), 1131–1144..

Beaudry, C. (2001). Evaluation of drying methods on osmotically dehydrated cranberries. Unpublished M.Sc. thesis. Montreal, QC: Department of Agricultural and Biosystems Engineering, McGill University.

Bezerra .C .V, E. R. Amante, D. Oliveira, A. M.C. Rodriguesa and L. H. M. da Silva. (2013). Green banana (Musa cavendishii) flour obtained in spouted bed – Effect of drying on physico-chemical, functional and morphological characteristics of the starch. Industrial Crops and Products 41 , 241– 249.

Brennan. J. G. (2006). Food Processing Handbook . 16 Benning Way Wokingham Berks RG40 1 XX UK.

Brennand. Ch. P. (1994). Home Drying of Food. Extension Food Science Specialist. Utah State University cooperation Extension.

Brown, A.H., Van Arsdel, W.B. and E. Lowe. (1964). Drying Methods and Driers, In Food Dehydration Vol. 2 Product &Technology, Van Arsdel, W.B. and Copley, M.J. (Eds.), AVI Publishing, Inc., Westport, pp. 28-131.

Caixeta.A.T., R. Moreira and M.E. Castell-Perez. (2002) Impingement drying of potato chips Journal of Food Process Engineering, 25, pp. 63‑90 .

Cajarticlesnoc qxp Articles continued.(2004). Effect of Processing on Nutrient Content of Foods aMs. Audrey Morris is CFNI's Food Safety Specialist, Dr. Audia Barnett is Director, Scientific Researh Council, Jamaica and Ms. Olive-Jean Burrows is Consultant, Kingston, Jamaica. Audrey Morris, Audia Barnett and Olive-Jean Burrowsa Vol. (37), No. (3).

Chinenye. N. M. (2009). Effect of Drying Temperature and Drying Air Velocity on the Drying Rate and Drying Constant of Cocoa Bean. : the CIGR Ejournal. Manuscript 1091. Vol. XI.

Chua, J. K., and K. S. Chou. (2005). A comparative study between intermittent microwave and infrared drying of bioproducts. International Journal of Food Science and Technology, 40, 23–39

Chua, K. J; Hawlader, M. N. A.; CHOU, S. K.; HO, J. C. (2002).On the Study of Time- Varying Temperature Drying-Effect on Drying Kinetics and Product Quality. Drying Technology 20(8): 1559-1577

Chua, K.J., and Chou, S.K. (2005). New Hybrid Technologies. In: Emerging technologies for food processing., 535 – 551..

Clemente. G, J. Bon, N .Sanjuán and A.Mulet. (2011). Drying modelling of defrosted pork meat under forced convection conditions. Meat Science, 88, 374-378.

Condorı´, M., and S. Luis. (1998). The performance of forced convection greenhouse driers. Renewable Energy, 13(4), 453–469.

Cunningham. S.E, W.A.M. Mcminn, T.R.A. Magee and P.S. Richardson. (2008). Experimental study of rehydration kinetics of potato cylinders. Transactions of IChemE, Part C, Food and Bio-products Processing, 86, pp. 15‑24.

Demirel. D, and M .Turhan. (2003). Air-drying behavior of Dwarf Cavendish and Gros Michel banana slices. Journal of Food Engineering, 59, 1.11.

Devahastin1.Sakamon and Chalida Niamnuy. (2010). Modelling quality changes of fruits and vegetables during drying: a review. International Journal of Food Science and Technology, 45, 1755–1767.

Devki Energy Consultancy. (2006). Pvt. Ltd. 405, Ivory Terrace, R.C. Dutt Road, Vadodara – 390007, India.

Di Scala, K. C., & Crapiste, G. H. (2008). Drying kinetics and quality changes during drying of red pepper. LWT: Food Science and Technology, 41(5), 789–795.

Dissa A.O., H. Desmorieux , J. Bathiebo , J. Koulidiati. (2008). Convective drying characteristics of Amelie mango (Mangifera Indica L. cv. 'Amelie') with correction for shrinkage . Journal of Food Engineering 88 429–437

Doymaz, I, (2006). Drying kinetics of black grapes treated with different solutions. Journal of Food Engineering 76, 212–217.

Doymaz, I. (2004). Effect of pre-treatments using potassium metabisulphide and alkaline ethyl oleate on the drying kinetics of apricots. Biosystems Engineering, 89, 281–287.

Doymaz, I. (2007). Air-drying characteristics of tomatoes .Journal of Food Engineering 78 1291–1297

Drouzas, A.E. and Schubert, H. (1996). Microwave Application in Vacuum Drying of Fruits, Journal of Food Engineering, Vol. 28, pp. 203-209.

Ebrahimi. M.A, S.S. Mohtasebi, Sh. Rafiee and S. Hosseinpour. (20012). Investigation of banana slices shrinkage using image processing technique. AJCS 6(5):938-945 .

Ehiem. J.C S.V. Irtwange and S.E. Obetta (2009).Design and Development of An Industrial Fruit and Vegetable Dryer. Research Journal of Applied Sciences, Engineering and Technology 1(2): 44-53.

Elbashir . A. H and Imam.A. Mohamed. (2010). Status report on fruits and vegetables production and processing industry in Sudan. AARDO Workshop on Technology on Reducing Post-harvest and Maintaining Quality of Fruits and Vegetables.168-179.

Etienne, E. and M. Serge, (1983). Sun drying Techniques in Africa: Sudan, Kenya, Zaire and Upper Volta.

Eze .J.I. (2010) Evaluation of the efficacy of a family sized solar cabinet dryer in food preservation. American Journal of Scientific and Industrial Research 1(3): pp 610-617

Ezekwe, C. I. (1995). Introduction to Solar Drying. National Center for Energy Research and Development Journal .pp 2-8.

F.A.O. (2005). Available from http://www.fao.org, accessed 30 .

Fellows. P. (2000).FOOD PROCESSING TECHNOLOGY Principles and Practice Second Edition Director, Midway Technology and Visiting Fellow in Food Technology at Oxford Brookes University

Fellows. P.J. (1990) Food Processing Technology: Principles and Practice. West Sussex, England. Ellis Horwood limited 35: 197-208..

Femenia A, Bestard M. J, Sanjuán N, Rosselló C, and Mulet A.(2000) Effect of Rehydration Temperature on the Cell Wall Components of Broccoli (Brassica oleracea L. Var. italica) Plant Tissues. Journal of Food Engineering 46(3) 157-163.

Fernando. W.J.N, A.L. Ahmad and M.R. Othman. (2011) Convective drying rates of thermally blanched slices of potato (Solamum tuberosum):

Parameters for the estimation of drying rates. Food and Bioproducts Processing .Volume 89, Issue 4,pp 514‑519.

Fernando. W.J.N, A.L. Ahmad, S.R. Abd. Shukor and Y.H. Lok .(2008). A model for constant temperature drying rates of case hardened slices of papaya and garlic. Journal of Food Engineering Vol 88 PP. 229–238.

Flores. N. C. (2007) . Drying Foods. Extension Food and Technology Specialist, Department of Extension Famil and Consumer Sciences, New Mexico State University.

Food and Agricultural Organization, (2009). www.F.A.O.org. Area and production data.

Forson, F.K, M.A.A. Nazha,.and H. Rajakaruna, (2007) . Modelling and experimental studies on a mixed-mode natural convection solar cropdryer. REP Solar Energy 81, 346–35.

Forson. F.K., M.A.A. Nazha , F.O. Akuffo, and H. Rajakaruna. (2007). Design of mixed natural convection solar crop dryers: Application of principles and rules of thumb. Renewable Energy 32 2306-2319

García-Pascual P, Sanjuán N, Bon J, Carreres JE, Mulet A. (2005)Rehydration Process of Boletus edulis Mushroom: Characteristics and Modelling. Journal of the Science of Food and Agriculture;85(8) 1397-1404, ISSN 0022-5142.

Ghbashlo .M. A , M. H. Kianmehr and A. Arabhosseini. (2009) Modeling of thin-layer drying of potato slices in length of continuous band dryer Energy Conversion and Management Volume 50, Issue 5, May 2009, Pages 1348‑1355.

Górnicki. K, A. Kaleta, R. Winiczenko, A. Chojnacka and M. Janaszek. (2013). Some Remarks on Modelling of Mass Transfer Kinetics During Rehydration of Dried Fruits and Vegetables. Faculty of Production Engineering, Warsaw University of Life Sciences, Poland.

Grabowski, S, M. Marcotte, M. Poirier, and T. Kudra. (2002). Drying characteristics of osmotically pretreated cranberries: Energy and quality aspects.

URL: http://cetcvarennes nrcan.gc.ca/eng/publication/r2002083e.html .

Green. M. G. and D .Schwarz. (2001). Solar Drying Technology for Food Preservation (GTZ-GATE), Investigations into the High-Temperature Air Drying of Tomato Pieces Inaugural.

Hadrich, B.and Nabil Kechaou. (2009). Mathematical modeling and simulation of shrunk cylindrical material's drying kinetics—Approximation and application to banana. Food and bioproducts processing 8 7 96–101.

HALL. C. W. (1980). Drying and Storage of Agricultural Crops Westport: The AVI Publishing Company, Inc.

Hassan. M .K, W.A. Shipton, R .Coventry and C. Gardiner.(2005). Extension of banana shelf life. Aust. Plant Pathology 33(2):305–8.

Hassanain. A.A. (2009). Simple solar drying system for banana fruit. World J. Agric. Sci., 5: 446-455

Hebbar, H. U, K.. H. Vishwanathan and M. N. Ramesh,. (2004). Development of combined infrared and hot air dryer for vegetables. Journal of Food Engineering, 65, 557e563.

Heldman. D and R. Hartel. (1997). Principles of Food Processing. New York: International Thomson Publishing.

Huber. S, and M. Menners, (1996). A new laboratory dryer for analyzing the deterioration kinetics of biomaterials. Proceedings of I.S.E.S. Solar World Congress Hungary. II (2): 10-15

Ibarz .A and G. Barbosa-Canovas. (2003). Unit Operations in Food Engineering.CRC Press LLC P 15. Book.

Ibrahim. H. I. K. (1994). Thermal process evaluation of heat dehydration of some fruits and vegetables. Ph. D. Thesis, Food Sci. Dept., Faculty of Agric., Ain Shams Univ., Egypt.

Ibrahim. M, K. Sopian and, W. R. W. Daud. (2009). Study of the Drying Kinetics of Lemon Grass. American Journal of Applied Sciences, 6 (6):1070-1075.

Inchuen, S, W. Narkrugsa, P. Pornchaloempong, P. Chanasinchana and T. Swing.(2008). Microwave and hot-air drying of Thai red curry paste. Mj Int J. Sci. Tech. 1(Special Issue): 38-49.

Inchuen. S, W. Narkrugsa and P. Pornchaloempong. (2010). Effect of Drying Methods on Chemical Composition, Color and Antioxidant Properties of Thai Red Curry Powder. Kasetsart J. (Nat. Sci.) 44 : 142 – 151.

Islam. M. S, M. A. Haque and M. N. Islam. (2012). Effects of Drying Parameters on Dehydration of Green Banana (*Musa sepientum*) and its Use in Potato (*Solanum tuberosum*) Chips Formulation. A Scientific Journal of Krishi Foundation .The Agriculturists 10 (1): 87-97.

Jairaj K.S, S.P. Singh and K. Srikant. (2009) A review of solar dryers developed for grape drying Available online at www.sciencedirect.com Solar Energy 83 1698–1712.

Jangam. S.V., C.L. Law. and A..S. Mujumdar . (2010) Drying of Foods, Vegetables and Fruits. Volume 1, ISBN: 978-981-08-6759-1.

Jaya, S., Das, H. (2003). A vaccum drying model of mango pulp. Drying Technology 21 (7), 1215–1234.

Jokić .S, Darko Velić, Mate Bilić, Jasmina Lukinac, Mirela Planinić and Ana Bucić-Kojić. (2009). Influence of Process Parameters and Pre-treatments on Quality and Drying Kinetics of Apple Samples Vol. 27, , No. 2: 88–94 Czech J. Food Sci .

Jompob .W. (2006) A Mathematical Modeling Study of Hot Air Drying for Some Agricultural Products. ThammasaItn t. J. Sc.T ech..V ol. I l. No. l

Karathanos V.T, N.K. Kanellopoulos. And V.G. Belessiotis. (1996). Development of porous structure during air drying of agricultural plant products. Journal of Food Engineering 29: 167–183.

Karim O.R. (2005). Effect of Pre-treatment on Drying Kinetics and Quality Attributes of Air - Dehydrated Pineapple Slices. PhD. Thesis. University of Agriculture, Abeokuta, Ogun State, Nigeria.

Kendall P. and L. Allen. (1998). Drying Vegetables: Food and Nutrition Series-Preparation. Colorado State University Cooperative Extension Service Publication 10 / 1998

Kendall. P, P. DiPersio and J. Sofos (2003). COLORADO STATE UNIVERSITY COOPERATIVE EXTENTION. Drying Vegetables no. 9.308.

Khraisheh. M.A.M, W.A.M. McMinn and T.R.A. Magee. (2004). Quality and structural changes in starchy foods during microwave and convective drying. Food Research International, 37 pp. 497–503.

Kilic. A. (2009). Low temperature and high velocity (LTHV) application in drying: Characteristics and effects on the fish quality Contents . Journal of Food Engineering91 173–182.

Krokid .A, M. K, D. Marinos-Kouris. (2003). Rehydration Kinetics of Dehydrated Products. Journal of Food Engineering 57: 1-7.

Krokida .M.K., Z.B. Maroulis and G.D. Saravacos. (2001) The effect of the method of drying on the colour of dehydrated products . International Journal of Food Science and Technology, 36, pp. 53–59 .

Krokida MK, and Marolis ZB. (2001). Structural Properties of Dehydrated Products During RehydrationInternational Journal of Food Science and Technology,36(5) 529-538

Krokida, M. K and Z. B. Maroulis. (1997) Effect of drying method on shrinkage and porosity. Drying Technologies, 15, , pp. 2441–2458.

Krokida, M. K., & Maroulis, Z. B. (1999). Effect of microwave drying on some quality properties of dehydrated products. Drying Technology, 17(3), 449–466.

Krokida, M. K., Karathanos, V. T., and Z. B. Maroulis, (1998). Effect of freeze-drying conditions on shrinkage and porosity of dehydrated agricultural products. Journal of Food Engineering, 35(4), 369–380.

Krokida, M. K., Tsami, E., and Maroulis, Z. B. (1998). Kinetics of color change during drying of some fruits and vegetables. Drying Technology, 16(3–5), 667–685

Krokida, M.K., Karathanos VT. and Maroulis ZB. (2000). Effect of osmotic dehydration on colour and sorption characteristics of apple and banana. Drying Technology, 18 pp 4-5.

Krokida, M.K., Karathanos, V.T. and Maroulis, Z.B.,(2003), Drying kinetics of some vegetables. Journal of Food Engineering, 59(4): 391–403.

Krokida. M.K and Z.B. Maroulis. (1997). Effect of drying methods on shrinkage and porosity. Journal of Drying technology, Volume .15, Issue 10. Pp 2441-2458.

Kumar. A, G.N. Tiwari. (2007). Effect of mass on convective mass transfer coefficient during open sun and greenhouse drying of onion flakes. Journal of Food Engineering 79 1337–1350.

Kumar. D.G. P , H. Umesh Hebbar_, M.N. Ramesh. (2006). Suitability of thin layer models for infrared–hot air-drying of onion slices. LWT 39 700–705

Leeratanarak. N , S. Devahastin and N. Chiewchan. (2006). Drying kinetics and quality of potato chips undergoing different drying techniques Journal of Food Engineering Volume 77, Issue 3, Pp 635‑643.

Lewicki, P.P., Michaluk, E. (2004). Drying of tomato pretreated with calcium. Drying Technology, 22, 1813-1827.

Loesecke ..H.W .V. (2012). Drying and dehydration of foods.(book text) AGROBios (INDIA) pp 106 -109.

Magdalini . K. Krokida, Zacharias B. Maroulis and George D. Saravacos. (2008). The effect of the method of drying on the colour of dehydrated products, International Journal of Food Science and Technology Volume 36, Issue 1, pp 53–59.

Manzocco, L., Calligaris, S., Mastrocola, D., Nicoli, M., & Lerici, C. (2001). Review of non-enzymatic browning and antioxidant capacity in processed foods. Trends in Food Science and Technology, 11, 340–346

Miranda .Margarita, H. Maureira, K. Rodriguez and A. Vega-Galvez a, (2009). Influence of temperature on the drying kinetics, physicochemical properties, and antioxidant capacity of Aloe Vera (Aloe Barbadensis Miller) gel. Journal of Food Engineering 91 297–304.

Markowski, M. and I. Bialobrzewski. (1997). Celery Slice Vacuum Drying Kinetics, In Engineering and Food at ICEF 7 Part 2, Jowitt, R. (Ed.), Sheffield Academic Press, Broston, pp. 93-96.

Maroulis.Z.B and G.D. Saravacos. (2003). Food Process Design. Marcel Dekker, New York, NY, USA.

Maskan. M. (2001). Drying, shrinkage and rehydration characteristics of kiwifruits during hot air and microwave drying. Journal of Food Engineering, 48, 177-182.

Methakhup. M. Siporn. (2003).Effects Of Drying Methods And Conditions On Drying Kinetics And Quality Of Indian Gooseberry Flake.A Special Research Project Submitted In Partial Fulfillment Of The Requirements For The Degree Of Master Of Engineering (Food Engineering) Faculty Of Engineering King Mongkut's University Of Technology Thonburi

Mitra. J, S. L. Shrivastava1 and P. S. Rao. (2015). Non-enzymatic browning and flavour kinetics of vacuum dried onion slices International Agrophysics , Volume 29 , Hssue1

Mitra. J., S.L. Shrivastava, P. Srinivasa Rao. (2011). Vacuum dehydration kinetics of onion slices. food and bioproducts processing 8 9 1–9.

Mohammadzadeh. M., M. S. Hatamipour. (2010). Effect of Drying Conditions on Properties of Dried Sugar Beet. Iranian Journal of Chemical Engineering Vol. (7), No. (3).

Morris. A, Audia. Barnett and Olive-Jean Burrows. (2006).Effect of Processing on Nutrient Content of Foods pp. 160 Vol. 37,(No.3)

Mota. C.L., C. Lucianoa, A. Dias, M.J. Barroca and R.P.F. Guiné. (2 0 1 0). Convective drying of onion: Kinetics and nutritional evaluation. food and bioproducts processing 8 8 115–123.

Mujumdar. A.S and S. Devahastin. (2000). Fundamental principles of drying. In: Mujumdars' Practical Guide to Industrial Drying. Principles, Equipment and New Developments: Exerger Corp., Montreal, Canada.

Mulet, A., Cárcel, J.A., Sanjuán, N and García-Pérez, J.V. (2010). Food dehydration under forced convection conditions. In Current Trends in

Chemical Engineering, J.M.P.Q. Delgado ed. Studium Press, LLC, Houston, USA, 153-177.

Mwithiga. G, and J. O. Olwal. (2004). The drying kinetics of kale (Brassica oleracea) in a convective hot air dryer. Journal of Food Engineering 71(4), 373–378.

Nagaya .K , Ying Li , Zhehong Jin , Masahiro Fukumuro ,Yoshinori Ando and Atsutoshi Akaishi. (2006). Low-temperature desiccant-based food drying system with airflow and temperature control. Journal of Food Engineering 75 71–77.

Nguyen. M and William E. Price (2007). Air-drying of banana: Influence of experimental parameters, slab thickness, banana maturity and harvesting season. Journal of Food Engineering 79 200–207.

Nikjooy .S and S. S. Jahanshahi. (2014). Effect of hot-air drying conditions on the quality of rhubarb (Rheum Ribes L.). Intl J Agri Crop Sci. Vol., 7 (5), 230-236.

Okos, M.R, O. Campanella, G. Narsimhan, R..K Singh and A.C. Weitnauer. (2007). Food Dehydration. In: Handobook of Food Engineering, Second Edition. Edited by Heldman, D.R., and Lund, D.B. CRC press, 601-744.

Öngen. G,S. Sargi, D.Tetik and T, Kose. (2005). Drying of Green Table Olives, Food Technol. Biotechnol. 43 (2) 181–187.

Oregon. I . (2003). Drying fruits and vegetables A Pacific Northwest Extension Publication Washington PNW 397 2nd edition.

Page, G.E. (1949). Factors influencing the maximum rates of air drying shelled corn in thin layers. M. Sc. Thesis, Lafayette: Purdue University.

Pan, Y.K., L.J. Zhao, Y. Zhang. G .Chen and A.S. Mujumdar,. (2003). Osmotic dehydration pretreatment in drying of fruits and vegetables. Drying Technology, 21, 1101–1114.

Pan. Z, M. Gabel, S. Amaratunga and J.F. Thompsonb. (2005). Onion Drying Using Catalytic Infrared Dryer . Progress Report #2, Award No. MR-03-07.

Panagiotou N.M., V.T. Karathanos and Z.B. Maroulis. (1998). Mass transfer modeling of the osmotic dehydration of some fruits. International Journal of Food Science and Technology. 33(3): 267-284.

Panyawong. S and S. Devahastin. (2007). Determination of deformation of a food product undergoing different drying methods and conditions via evolution of a shape factor. Journal of Food Engineering 78 151–161.

Patil M.M., Kalse S.B. and Jain S.K. (2012) OSMO-Convective Drying of Onion Slices. Research Journal of Recent Sciences. Vol. 1(1),pp 51-59.

Perera.C.O., (2005). Selected Quality Attributes of Dried Foods, Drying Technology, 23, pp. 717-730.

Phoungchandang. S and J.L. Woods. (2000). Solar drying of banana: mathematical model, laboratory simulation, and field data compared. Journal of Food Science 65, 990–996.

Puttongsir.T, N. Choosakul and D. Sakulwilaingam. (2012). Moisture Content and Physical Properties of Instant Mashed Potato. International

Conference on Nutrition and Food Sciences IPCBEE vol. 39 IACSIT Press, Singapore.

Rakish.S. P. , S.K. Jha b and N. Datta. (2004). Performance evaluation of blanched carrots dried by three different driers. Journal of Food Engineering 62 305–313.

Ramaswamy. H and M. Marcotte. (2006). Food Processing - Principles and Applications. London: Taylor and Francis Group.

Ramos I.N., Silva C.L.M, Sereno A.M. and Aguilera J.M.. (2002). Kinetic studyon microstructural changes during convective air drying of grapes. In: Proceedings of the 13th International Drying Symposium (IDS), Beijing, China.

Ramos, I. N, T. R. S. Brandao and C. L. M .SILVA. (2000). Structural Changes during Air Drying of Fruits and Vegetables. Food Science Technology International 9 (3). 201-206

Ranganna, S. (1977). Manual of analysis of fruit and vegetable products. Published by Tata-McGraw-Hill compony limited, New Delhi,India.

Ranganna, S. (1986). Handbook of analysis and quality control for fruit and vegetable products. New Delhi: Tata McGraw-Hill Publishing Company Limited.

Ray .B. (1992).The need for food biopreservation .In: Food Biopreservatives Orgin, eds. B.Ray and M.Daeschel pp.1-24. Boca Raton, F L . CRC press.

Reynolds. S. (1998). Drying Prepared Fruit, University of Florida Cooperative Extension Service Institute of Food and Agricultural Sciences .

Roig, M.G., Bello, J.F., Rivera, Z.S. and Kennedy, J.F. (1999). “Studies on the Occurrence of Non-enzyamtic Browning during Storage of Citrus Juice”, Food Research International, Vol.32, pp. 609-619.

Ronco. (2009). Ronco Acquisition Corporation. Food Dehydrator. P.O. Box 1000 Peck Slip Station New York, NY 10272-1000 (800) 486-1806 www.Ronco.com.

Sablani, S.S. (2006). Drying of fruits and vegetable: retention of nutritional ⁄ functional quality. Drying Technology, 24, 123–135.

Sagar, V. R. (2001). Preparation of onion powder by means of osmotic dehydration and its packaging and storage. Journal of Food Science and Technology, 38(5), 525–528.

Sankat, C.K., Castaigne, F., Maharaj, R. (1996). The air drying behavior of fresh and osmotically dehydrated banana slices. International Journal of Food Science and Technology, vol. 31, pp. 123-135.

Scanlin. D. (1997). The Design, Construction, and Use of an Indirect, Through-Pass, Solar Food Dryer. Homebrew.

Schirmer.P, S. Janjia , A. Esper and R. Smitabhindu. (1996). Experimental investigation of the performance of the solar drier for drying bananas. Renewable Energy ,7(2):119-129.

Senadeera. W, Bhandari. B. R, Young. G And Wijesinghe. B. (2003). Influence of Shapes of Selected Vegetable Materials on Drying Kinetics during Fluidized Bed Drying. Journal of Food Engineering 58 (3): 277-283.

Sharma, H.K., B. Kaur, B.C. Sarkar,. and C. Singh. (2006). Thermal behavior of pure rice bran oil, sunflower oil and their model blends during deep fat frying. Grasas Y Aceites, 57 4: 376-381

Sigge, G.O., Hansmann, C.F and Joubert, E., (1988). Effect of temperature and relative humidity on the drying rates and drying times of green bell peppers. Drying Technology 16 (8), 1703–1714.

Singh .U., S.K. Jain, A. Doshi, K.H. Jain and K.V. Chahar. (2008). Effects of Pretreatments on Drying Characteristics of Button Mushroom. International Journal of Food Engineering, The Berkeley Electronic Press. 4(4).

Singh RP, Heldman DR (2008). Introduction to food engineering, 4th ed. Academic Press.

Singh U., S.K. Jain, A. Doshi, K.H. Jain and K.V. Chahar. (2008). Effects of Pretreatments on Drying Characteristics of Button Mushroom. International Journal of Food Engineering, The Berkeley Electronic Press. 4(4).

Singh, R.P and F. Erdogdu.(2004). Virtual Experiment in Food Engineering. Davis, CA: RAR Press.

Singh. N. P. (2007). Fruit and Vegetable Preservation . Oxford Book Company 267, 10-B-Scheme, Opp. Narayan Niwas, Book

Singhanat. Ph and A. Sertwasana (2010) Spray-drying of ginger juice and physicochemical properties of ginger powders. ScienceAsia 36 pp 40–45.

Sodha. M.S, N.K. Bansal, A. Kumar, P.K .Bansal and M.A.S Malik. (1987). Solar crop drying, vol. 1. Boca Raton, Florida, USA: CRC Press;

Sokhansanj, S. and S.D. Jayas. (1995). Drying of Foodstuffs, In Handbook of Industrial Drying, Mujumdar, A.S. (Ed.), 2nd ed., Vol. 1, Marcel Dekker, New York,pp. 589-623.

Sousa, W. A., and Marsaioli Jr. A. (2004). Drying of bananas assisted by microwave energy. In Proceedings of the 14th international drying symposium, Sao Paulo Brazil, 22–25 August, vol C (pp. 1946– 1954).

Sreekumar. A, P.E. Manikantan, and K.P. Vijayakumar. (2008) Performance of indirect solar cabinet dryer Energy Conversion and Management 49 1388–1395.

Srivastava. R.P and Kumar S. (1993). Fruits and Vegetable preservation Methods and practices. Lucknow: International Book Distribution Co.

Srivastava. R.P and S. Kumar. (2003). Fruits and vegetable preservation – principles and practices, International Book Distributing Co., India, pp.360.

Srivastava. R.P and S. Kumar. (2010). Fruits and vegetable preservation – principles and practices. Sex Reprint. International Book Distributing Co., India, pp.127, 128 and 275.

Sudathip . I, W. Narkrugsa, P. Pornchaloempong, P .Chanasinchan and T .Swing. (2008). Microwave and hot-air drying of Thai red curry paste. Mj. Int. J. Sci. Tech., 1(Special Issue), 38-49.

Sunjka, P.S. and Raghavan. G.S.V .(2004). Assessment of pretreatment methods and osmotic dehydration for cranberries. Canadian Biosystems Engineering/Le génie des biosystèmes au Canada 46: 3.35-3.40.

Susan R. and P. Williams. (1993). So Easy To Preserve. Cooperative Extension Service, the University of Georgia. Revised By Judy Harrison.

Sutar, P.P, and D.K. Gupta. (2007). Mathematical modeling of mass transfer in osmotic dehydration of onion slices. Journal of Food Engineering, 78, 90-97.

Taiwo K. A. and O. Adeyemi. (2009) Influence of blanching on the drying and rehydration on banana slices. African Journal of Food Science Vol. 3(10) pp. 307-315.

Talati Smt. S, and P. Shah. (2009). Nutritional Studies On Fresh And Dehydrated Onion (Allium Cepa Linn) International Research Journal)—Issn-0974-2832 Vol. Ii, Issue-5.

Tavakolipour .H and L. Zirjani. (2014). Banana Chips Production by Hot Air and Microwave Dehydration Methods: A Comparative Study. Middle-East Journal of Scientific Research 21 (10): 1828-1836.

Tripathy . P.P and S. Kumar. (2009). Neural network approach for food temperature prediction during solar drying. International Journal of Thermal Sciences 48 1452–1459.

Tripathy . P.P., S. Kumar. (2009) A methodology for determination of temperature dependent mass transfer coefficients from drying kinetics: Application to solar drying. Journal of Food Engineering 90 ,212–218.

Tulasidas, T.N., G.S.V. Raghavan, T. Kudra, Y. Gariepy and C. Akyel. (1994). Microwave drying of grapes in a single mode resonant cavity with pulsed power. ASAE Paper No 94- 6547. St. Jospeh, MI: ASAE.

Tunde-A. T.Y1. and A.A. Afon. (2009) Modelling of Hot-Air Drying of Pretreated Cassava Chips. Agricultural Engineering International: the CIGR Ejournal. Manuscript 1493 Vol.

.

Vega-Galvez. A, E. Uribe, R. Lemus and M. Miranda. (2007) .Hot air drying characteristics of aloe vera (Aloe barbadensis Miller) and influence of temperature on kinetic parameters. Lebensm.- Wiss. Technol. 40, 1698-1707.

Velić .D, M. Planinić, S. Tomas and M. Bilić. (2004): Influence of airflow velocity on kinetics of convection apple drying. Journal of Food Engineering, 64: 97–102.

Venkatachalapathy, K. (1998). Combined osmotic and microwave drying of strawberries and blueberries. Unpublished Ph. D. Thesis. Montreal, QC: Department of Agricultural and Biosystems Engineering, McGill University.

Waewsa . J, S. Chindaruksa and Ch. Punlek. (2006) A Mathematical Modeling Study of Hot Air Drying for Some Agricultural Products. ThammasaItn t. J. Sc.T ech..V ol. I l. No. l.

Wakayama, T., (1995). “Polyphenol Oxidase Activity in Japanese Apples”, In Enzymatic Browning and Its Prevention, American Chemical Society, Washington DC, pp. 251-266

Wang Z., Sun J., Liao X., Chen F., Zhao G., Wu J. and X. Hu. (2007). Mathematical modeling on hot air drying of thin layer apple pomace. Food Research International. 40: 39-46.

Wang. N., and J.G. Brennan. (1995). Changes in structure, density and porosity of potato during dehydration. Journal of Food Engineering, 24 (pp. 61‑76.

Wang. J.C and Kinsella,J.E . (1976) .Functional properties of novel protein: alfalfa leaf protein. Journal of food science, 41:286

Yadollahinia . A and M. Jahangiri. (2009) Shrinkage of potato slice during drying . Journal of food engineering Volume 94, Issue 1, Pp 52‑58.

Yang. C. S. T, and W. A. Atallah. (1985). Effect of four drying methods on the quality of intermediate moisture lowbush blueberries. Journal of Food Science, 50, 1233–1237.

Zanoni, B., Peri, C., Nani, R. and Lavelli, V. (1999). Oxidative heat damage of Tomato halves as Affected by Drying, Food Research International, Vol. 31, No. 5, pp. 395- 401.

Zeuthen. P. and Leif B-Sùrensen. (2003). Food preservation techniques Woodhead Publishing Cambrige England.

Zhongli Pan, S. b. Connie, T.H. McHugh and H. Edward. (2008). Study of banana dehydration using sequential infrared radiation heating and freeze-drying .Available LWT - Food Science and Technology 41 PP 1944-1951.

Zhongli Pan, M. Gabel , S. Amaratunga and James F. Thompsonb. (2005). Onion Drying Using Catalytic Infrared Dryer USDA ARS WRRC University of California, Davis Submitted toCalifornia Institute for Energy and Environment and California.

Zhongli. P,b, Michael Gabel b, Sanath Amaratunga b and James F. Thompsonb. (2006) Onion Drying Using Catalytic Infrared Dryer . Progress Report #2, Award No. MR-03-07, Page 2-2.

Zogzas.N.P, Z.B. Maroulis and D. Marinos-Kouris. (1994b). Densities Shrinkage and Porosity of Some Vegetables During Air Drying, Drying Technology, 12(7) pp. 1653-1666.

APPENDICES

Appendix. 1: Drying rate of banana.

Time (min)	Type of dryer					
	Water			Candle		
	System					
	Suction	Intake	Suction + intake	Suction	Intake	Suction + intake
0	337.00[a] (±0.00)	337.00[a] (±0.00)	337.00[a] (±0.00)	337.00[a] (±0.00)	337.00[a] (±0.00)	337.00[a] (±0.00)
20	326.67[b] (±2.89)	325.00[b] (±2.00)	323.00[bc] (±5.57)	326.67[b] (±3.21)	322.67[bc] (±3.51)	316.67[c] (±7.77)
40	315.67[c]	312.00[d]	311.00[d]	314.67[cd]	311.67[d]	303.67[ef]

	(±3.06)	(±4.00)	(±4.58)	(±3.21)	(±4.93)	(±6.81)
60	311.00^{d} (±8.00)	301.33^{f} (±2.08)	303.00^{ef} (±3.51)	305.00^{e} (±3.21)	304.00^{e} (±5.29)	293.33^{gh} (±5.51)
90	303.67^{ef} (±9.07)	293.67^{gh} (±2.31)	294.67^{g} (±3.51)	295.00^{g} (±5.29)	290.67^{h} (±5.13)	284.67^{i} (±4.93)
120	297.67^{f} (±9.71)	287.33^{hi} (±1.53)	288.33^{hi} (±2.89)	286.67^{i} (±7.64)	283.00^{ij} (±4.58)	278.33^{k} (±4.73)
150	293.00^{gh} (±9.85)	283.00^{ij} (±1.00)	283.33^{ij} (±2.89)	280.33^{j} (±8.08)	277.00^{k} (±5.00)	274.00^{l} (±4.58)
180	289.00^{h} (±9.64)	278.67^{k} (±1.53)	279.00^{k} (±2.64)	275.33^{l} (±9.07)	272.33^{lm} (±5.51)	270.33^{m} (±4.04)
210	285.33^{i} (±9.29)	275.33^{l} (±2.08)	276.00^{kl} (±3.00)	272.00^{lm} (±10.15)	269.67^{n} (±4.51)	267.67^{no} (±4.16)
240	281.67^{j} (±10.41)	272.67^{lm} (±2.31)	273.33^{lm} (±2.52)	269.00^{n} (±10.15)	267.67^{no} (±4.04)	266.67^{o} (±4.16)
270	279.33^{k} (±10.26)	270.00^{m} (±1.53)	270.67^{m} (±2.08)	267.00^{no} (±9.85)	266.00^{o} (±3.61)	266.00^{o} (±3.610)
300	277..00^{kl} (±9.85)	269.00^{n} (±1.73)	269.00^{n} (±1.73)	265.00^{o} (±9.17)	265.33^{o} (±3.21)	265.33^{o} (±3.79)
330	275.33^{l} (±9.29)	267.67^{no} (±1.53)	267.33^{no} (±1.53)	264.00^{op} (±8.18)	264.67^{op} (±3.79)	265.33^{o} (±3.79)
360	274..00^{l} (±9.17)	266.67^{o} (±1.53)	266.67^{o} (±2.08)	263.33^{p} (±7.77)	264..00^{op} (±3.64)	265.00^{o} (±4.36)
390	272.67^{lm} (±9.07)	266.33^{o} (±1.15)	265.67^{o} (±1.15)	262.67^{p} (±7.37)	264..00^{op} (±3.64)	265.00^{o} (±4.36)
420	271.67^{lm} (±8.50)	265.67^{o} (±1.53)	265.00^{o} (±1.73)	262.33^{op} (±6.81)	264..00^{op} (±3.64)	265.00^{o} (±4.36)
450	270.00^{m} (±8.50)	265.33^{o} (±1.15)	265.00^{o} (±1.73)	261.67^{po} (±6.43)	264..00^{op} (±3.64)	265.00^{o} (±4.36)

480	270.00^{m} (±8.00)	265.00^{o} (±1.73)	264.67^{op} (±2.08)	261.67^{po} (±6.43)	$264..00^{op}$ (±3.64)	265.00^{o} (±4.36)
510	269.00^{n} (±8.54)	265.00^{o} (±1.73)	264.67^{op} (±2.08)	261.67^{po} (±6.43)	$264..00^{op}$ (±3.64)	265.00^{o} (±4.36)
540	268.67^{n} (±8.62)	265.00^{o} (±1.73)	264.67^{op} (±2.08)	261.67^{po} (±6.43)	$264..00^{op}$ (±3.64)	265.00^{o} (±4.36)
570	268.33^{n} (±8.73)	265.00^{o} (±1.73)	264.67^{op} (±2.08)	261.67^{po} (±6.43)	$264..00^{op}$ (±3.64)	265.00^{o} (±4.36)
600	267.67^{no} (±9.07)	265.00^{o} (±1.73)	264.67^{op} (±2.08)	261.67^{po} (±6.43)	$264..00^{op}$ (±3.64)	265.00^{o} (±4.36)
$Lsd_{0.05}$	1.025^{**}					
SE±	0.038					

Values are mean±SD.
Any two mean value(s) sharing same superscript letter(s) are not significantly different (P≤0.05).

Appendix. 2: Drying rate of onion.

Time (min)	Type of dryer					
	Water			Candle		
	System					
	Suction	Intake	Suction + intake	Suction	Intake	Suction + intake
0	464.00^{a} (±0.00)	464.00^{a} (±0.00)	464.00^{a} (±0.00)	464.00^{a} (±0.00)	464.00^{a} (±0.00)	464.00^{a} (±0.00)
20	458.00^{b} (±2.65)	456.33^{c} (±4.04)	451.67^{d} (±0.58)	446.67^{bc} (±2.08)	448.00^{e} (±0.2.65)	446.33^{f} (±1.15)
40	451.67^{d} (±3.21)	451.00^{d} (±3.61)	443.00^{g} (±2.00)	437.67^{k} (±2.08)	439.67^{ij} (±2.31)	438.33^{j} (±2.08)
60	446.33^{f} (±4.73)	447.33^{bc} (±3.51)	439.33^{i} (±1.53)	432.33^{mn} (±1.53)	434.00^{lm} (±1.73)	433.33^{m} (±2.08)
90	442.67^{h} (±5.77)	443.67^{g} (±3.06)	435.33^{l} (±1.53)	428.33^{p} (±1.15)	429.67^{op} (±0.58)	429.33^{op} (±1.15)
120	438.67^{j} (±6.81)	440.67^{j} (±2.89)	433.00^{m} (±1.73)	426.67^{pqr} (±0.58)	426.67^{pqr} (±0.58)	427.33^{pq} (±1.15)
150	436.00^{kl} (±6.24)	438.33^{j} (±2.31)	430.00^{o} (±1.53)	424.67^{qr} (±0.58)	425.67^{q} (±0.58)	426.33^{pqr} (±1.15)
180	434.33^{m} (±5.69)	436.00^{kl} (±1.73)	429.33^{op} (±1.53)	424.33^{qr} (±0.58)	424.67^{qr} (±0.58)	425.00^{q} (±1.00)
210	432.67^{mn} (±5.51)	434.67^{m} (±1.15)	427.67^{pq} (±1.53)	424.00^{qr} (±0.00)	424.00^{qr} (±0.00)	424.00^{qr} (±1.00)
240	431.33^{no} (±5.69)	434.00^{m} (±1.00)	426.67^{pqr} (±1.53)	423.33^{r} (±0.58)	423.67^{r} (±0.58)	423.67^{r} (±0.58)
270	430.33^{o} (±5.69)	432.67^{mn} (±0.58)	426.00^{pqr} (±1.00)	423.33^{r} (±0.58)	423.33^{r} (±0.58)	423.67^{r} (±0.58)
300	430.00^{o}	432.00^{mn}	425.67^{q}	423.33^{r}	423.33^{r}	423.33^{r}

	(±5.29)	(±1.00)	(±1.53)	(±0.58)	(±0.58)	(±0.58)
330	428.67^{p} (±5.13)	431.33^{no} (±0.58)	425.00^{q} (±1.00)	423.33^{r} (±0.58)	423.33^{r} (±0.58)	423.33^{r} (±0.58)
360	428.33^{p} (±4.73)	430.67^{o} (±0.58)	425.00^{q} (±1.00)	423.33^{r} (±0.58)	423.33^{r} (±0.58)	423.33^{r} (±0.58)
390	428.00^{p} (±4.58)	430.33^{o} (±0.58)	424.33^{qr} (±0.58)	423.33^{r} (±0.58)	423.33^{r} (±0.58)	423.33^{r} (±0.58)
420	427.33^{pq} (±4.04)	430.33^{o} (±0.58)	424.33^{qr} (±0.58)	423.33^{r} (±0.58)	423.33^{r} (±0.58)	423.33^{r} (±0.58)
450	427.33^{pq} (±4.04)	429.33^{op} (±0.58)	424.33^{qr} (±0.58)	423.33^{r} (±0.58)	423.33^{r} (±0.58)	423.33^{r} (±0.58)
480	427.33^{pq} (±4.04)	429.00^{op} (±1.00)	424.33^{qr} (±0.58)	423.33^{r} (±0.58)	423.33^{r} (±0.58)	423.33^{r} (±0.58)
510	427.33^{pq} (±4.04)	429.00^{op} (±1.00)	424.33^{qr} (±0.58)	423.33^{r} (±0.58)	423.33^{r} (±0.58)	423.33^{r} (±0.58)
540	427.33^{pq} (±4.04)	429.00^{op} (±1.00)	424.33^{qr} (±0.58)	423.33^{r} (±0.58)	423.33^{r} (±0.58)	423.33^{r} (±0.58)
570	427.33^{pq} (±4.04)	429.00^{op} (±1.00)	424.33^{qr} (±0.58)	423.33^{r} (±0.58)	423.33^{r} (±0.58)	423.33^{r} (±0.58)
600	427.33^{pq} (±4.04)	429.00^{op} (±1.00)	424.33^{qr} (±0.58)	423.33^{r} (±0.58)	423.33^{r} (±0.58)	423.33^{r} (±0.58)
$Lsd_{0.05}$	0.8257**					
SE±	0.0162					

Values are mean±SD.
Any two mean value(s) sharing same superscript letter(s) are not significantly different ($P \leq 0.05$).

Appendix. 3: drying rate of potatoes.

Time (min)	Type of dryer					
	Water			Candle		
	System					
	Suction	Intake	Suction + intake	Suction	Intake	Suction + intake
0	337.00^{a} (±0.00)	337.00^{a} (±0.00)	337.00^{a} (±0.00)	337.00^{a} (±0.00)	337.00^{a} (±0.00)	337.00^{a} (±0.00)
20	317.00^{c} (±1.73)	319.00^{b} (±1.00)	314.67^{e} (±3.79)	314.00^{e} (±4.36)	315.00^{d} (±2.65)	315.33^{d} (±6.11)
40	299.00^{g} (±1.00)	303.00^{f} (±2.65)	297.00^{gh} (±4.36)	293.67^{hi} (±3.79)	288.67^{i} (±8.39)	294.00^{h} (±5.20)
60	285.00^{ij} (±1.73)	288.67^{i} (±4.04)	284.00^{ijk} (±4.58)	279.67^{j} (±3.06)	279.67^{j} (±1.53)	279.67^{j} (±5.13)
90	276.00^{k} (±2.00)	278.33^{jk} (±3.79)	274.00^{kl} (±4.58)	271.330^{l} (±1.53)	268.00^{m} (±1.73)	269.00^{lm} (±6.24)
120	267.00^{m} (±2.00)	268.67^{lm} (±4.04)	267.00^{m} (±4.00)	264.67^{mn} (±3.79)	260.33^{nop} (±1.53)	262.67^{n} (±6.11)
150	261.00^{no} (±1.73)	262.67^{n} (±3.21)	261.67^{no} (±3.21)	260.33^{nop} (±1.53)	256.33^{opq} (±2.08)	258.67^{o} (±5.13)
180	256.33^{opq} (±0.58)	257.33^{op} (±2.89)	258.00^{o} (±2.65)	257.67^{op} (±1.53)	254.33^{pq} (±2.08)	256.67^{opq} (±4.16)
210	253.67^{q} (±1.53)	254.33^{pq} (±1.15)	255.33^{p} (±1.53)	256.67^{opq} (±1.53)	252.00^{qr} (±1.73)	255.67^{p} (±4.04)
240	252.33^{qr} (±0.58)	252.67^{qr} (±0.58)	253.67^{q} (±1.15)	256.00^{opq} (±1.73)	251.67^{r} (±2.08)	255.00^{p} (±3.46)
270	251.33^{r} (±1.15)	251.33^{r} (±0.58)	252.33^{qr} (±1.53)	255.67^{p} (±1.53)	251.00^{r} (±1.73)	255.00^{p} (±3.46)
300	250.33^{rs}	251.33^{s}	252.00^{qr}	255.67^{p}	250.67^{rs}	253.67^{q}

	(±0.58)	(±0.58)	(±1.73)	(±1.53)	(±2.08)	(±7.64)
330	250.33^{rs} (±0.58)	250.33^{rs} (±0.58)	251.33^{r} (±1.53)	255.67^{p} (±1.53)	250.67^{rs} (±2.08)	253.67^{q} (±7.64)
360	250.00^{rs} (±1.00)	249.33^{t} (±0.58)	251.33^{r} (±1.53)	255.67^{p} (±1.53)	250.67^{rs} (±2.08)	253.67^{q} (±7.64)
390	250.00^{rs} (±1.00)	249.00^{t} (±1.00)	251.33^{r} (±1.53)	255.67^{p} (±1.53)	250.67^{rs} (±2.08)	253.67^{q} (±7.64)
420	250.00^{rs} (±1.00)	249.00^{t} (±1.00)	251.33^{r} (±1.53)	255.67^{p} (±1.53)	250.67^{rs} (±2.08)	253.67^{q} (±7.64)
450	250.00^{rs} (±1.00)	249.00^{t} (±1.00)	251.33^{r} (±1.53)	255.67^{p} (±1.53)	250.67^{rs} (±2.08)	253.67^{q} (±7.64)
480	250.00^{rs} (±1.00)	249.00^{t} (±1.00)	251.33^{r} (±1.53)	255.67^{p} (±1.53)	250.67^{rs} (±2.08)	253.67^{q} (±7.64)
510	250.00^{rs} (±1.00)	249.00^{t} (±1.00)	251.33^{r} (±1.53)	255.67^{p} (±1.53)	250.67^{rs} (±2.08)	253.67^{q} (±7.64)
540	250.00^{rs} (±1.00)	249.00^{t} (±1.00)	251.33^{r} (±1.53)	255.67^{p} (±1.53)	250.67^{rs} (±2.08)	253.67^{q} (±7.64)
570	250.00^{rs} (±1.00)	249.00^{t} (±1.00)	251.33^{r} (±1.53)	255.67^{p} (±1.53)	250.67^{rs} (±2.08)	253.67^{q} (±7.64)
600	250.00^{rs} (±1.00)	249.00^{t} (±1.00)	251.33^{r} (±1.53)	255.67^{p} (±1.53)	250.67^{rs} (±2.08)	253.67^{q} (±7.64)
$Lsd_{0.05}$	0.9035^{**}					
SE±	00262					

Values are mean±SD.
Any two mean value(s) sharing same superscript letter(s) are not significantly different (P≤0.05).

Appendix. 4: Moisture content (%) of banana dried products by using hot water and electric candle drying techniques.

Location of fan	Dryer techniques		Mean value
	Hot water	Electric candle	
Top fan	$6.42^{b}\pm0.12$	$7.14^{b}\pm0.31$	6.78^{C}
Bottom fan	$6.91^{b}\pm2.24$	$7.10^{b}\pm0.31$	7.01^{B}
Top and Bottom fans	$5.86^{b}\pm0.31$	$9.89^{a}\pm0.06$	7.88^{A}
Mean value	6.40^{B}	8.04^{A}	
$Lsd_{0.05}$	1.661^{**}		
SE±	0.5391		

Values are mean±SD.

Any two mean value(s) sharing same superscript(s) are not significantly different (P≤0.05).

Appendix. 5: Moisture content (%) of potato dried products by using hot water and electric candle drying techniques.

Location of fan	Drying techniques		Mean value
	Hot water	Electric candle	
Top fan	$3.57^{b}\pm0.07$	$3.91^{a}\pm0.14$	3.74^{A}
Bottom fan	$3.33^{cd}\pm0.11$	$3.25^{d}\pm0.13$	3.29^{B}
Top and Bottom fans	$3.49^{bc}\pm0.00$	$3.86^{a}\pm0.12$	3.70^{A}
Mean value	3.46^{B}	3.67^{A}	
$Lsd_{0.05}$	0.1866^{*}		
SE±	0.06055		

Values are mean±SD.

Any two mean value(s) sharing same superscript(s) are not significantly different (P≤0.05).

Appendix. 6: Moisture content (%) of onion dried products by using hot water and electric candle drying techniques.

Location of fan	Drying techniques		Mean value
	Hot water	Electric candle	
Top fan	$6.16^{a}\pm0.14$	$5.48^{d}\pm0.03$	5.82^{A}
Bottom fan	$5.74^{c}\pm0.01$	$4.91^{f}\pm0.02$	5.54^{B}
Top and Bottom fans	$5.87^{b}\pm0.04$	$5.20^{a}\pm0.01$	5.54^{B}
Mean value	5.96^{A}	5.20^{B}	
$Lsd_{0.05}$	0.1125^{*}		
SE±	0.03651		

Values are mean±SD.

Any two mean value(s) sharing same superscript(s) are not significantly different (P≤0.05).

Appendix. 7: Bulk density (g/ml) of banana dried products by using hot water and electric candle drying techniques.

Location of fan	Drying techniques		Mean value
	Hot water	Electric candle	
Top fan	$0.8572^{ab}\pm0.10$	$0.9347^{a}\pm0.02$	0.896^{B}
Bottom fan	$0.9305^{a}\pm0.02$	$0.9234^{a}\pm0.02$	0.927^{A}
Top and Bottom fans	$0.7930^{a}\pm0.02$	$0.9389^{a}\pm0.00$	0.866^{C}
Mean value	0.860^{B}	0.932^{A}	
$Lsd_{0.05}$	0.07956^{*}		
SE±	0.02582		

Values are mean±SD.

Any two mean value(s) sharing same superscript(s) are not significantly different (P≤0.05).

Appendix. 8: Bulk density (g/ml) of potato dried products by using hot water and electric candle drying techniques.

Location of fan	Drying techniques		Mean value
	Hot water	Electric candle	
Top fan	1.219^{c} ±0.02	1.190^{e} ±0.00	1.205^{B}
Bottom fan	1.228^{b} ±0.04	1.198^{d} ±0.01	1.213^{A}
Top and Bottom fans	1.111^{f} ±0.00	1.250^{a} ±0.00	1.181^{C}
Mean value	1.186^{B}	1.213^{A}	
$Lsd_{0.05}$	0.0005626*		
SE±	0.0001826		

Values are mean±SD.

Any two mean value(s) sharing same superscript(s) are not significantly different (P≤0.05).

Appendix. 9: Bulk density (g/ml) of onion dried products by using hot water and electric candle drying techniques.

Location of fan	Drying techniques		Mean value
	Hot water	Electric candle	
Top fan	0.9604^{a} ±0.03	0.9160^{a} ±0.01	0.938^{A}
Bottom fan	0.8142^{b} ±0.04	0.9632^{a} ±0.02	0.889^{B}
Top and Bottom fans	0.9540^{a} ±0.02	0.9204^{a} ±0.02	0.937^{A}
Mean value	0.9160^{B}	0.9330^{A}	
$Lsd_{0.05}$	0.05626*		
SE±	0.01826		

Values are mean±SD.

Any two mean value(s) sharing same superscript(s) are not significantly different (P≤0.05)..

Appendix. 10: Water solubility index (g/100g DM) of banana dried products by using hot water and electric candle drying techniques.

Location of fan	Drying techniques		Mean value
	Hot water	Electric candle	
Top fan	$54.37^{b}\pm7.22$	$59.26^{ab}\pm7.04$	56.82^{B}
Bottom fan	$67.78^{ab}\pm10.89$	$71.06^{a}\pm8.32$	69.42^{A}
Top and Bottom fans	$68.88^{ab}\pm11.11$	$68.07^{ab}\pm1.04$	68.48^{AB}
Mean value	63.68^{B}	66.13^{A}	
$Lsd_{0.05}$	14.78^{**}		
SE±	4.796		

Values are mean±SD.

Any two mean value(s) sharing same superscript(s) are not significantly different (P≤0.05).

Appendix. 11: Water solubility (g/100g DM) index of potato dried products by using hot water and electric candle drying techniques.

Location of fan	Drying techniques		Mean value
	Hot water	Electric candle	
Top fan	$16.31^{ab}\pm4.01$	$17.67^{ab}\pm3.81$	16.99^{A}
Bottom fan	$15.62^{ab}\pm0.03$	$14.11^{bc}\pm3.59$	14.87^{C}
Top and Bottom fans	$20.99^{a}\pm0.90$	$9.10^{c}\pm2.38$	15.04^{B}
Mean value	17.64^{A}	13.62^{B}	
$Lsd_{0.05}$	5.132^{**}		
SE±	1.665		

Values are mean±SD.

Any two mean value(s) sharing same superscript(s) are not significantly different (P≤0.05).

Appendix. 12: Water solubility index (g/100g DM) of onion dried products by using hot water and electric candle drying techniques.

Location of fan	Drying techniques		Mean value
	Hot water	Electric candle	
Top fan	66.12^{a} ±3.36	34.12^{c} ±3.49	50.12^{A}
Bottom fan	38.58^{c} ±1.17	51.24^{b} ±2.50	44.91^{B}
Top and Bottom fans	35.36^{c} ±6.15	47.21^{b} ±0.53	41.29^{C}
Mean value	46.69^{A}	44.19^{B}	
Lsd$_{0.05}$	6.04**		
SE±	1.96		

Values are mean±SD.

Any two mean value(s) sharing same superscript(s) are not significantly different (P≤0.05).

Appendix. 13: Rehydration ratio of banana dried products by using hot water and electric candle drying techniques.

Location of fan	Drying techniques		Mean value
	Hot water	Electric candle	
Top fan	2.33^{bc} ±0.00	2.33^{bc} ±0.00	2.33^{B}
Bottom fan	2.16^{c} ±0.17	2.50^{b} ±0.17	2.33^{B}
Top and Bottom fans	2.33^{bc} ±0.00	2.83^{a} ±0.17	2.58^{A}
Mean value	2.27^{B}	2.55^{A}	
Lsd$_{0.05}$	0.2105*		
SE±	0.6831		

Values are mean±SD.

Any two mean value(s) sharing same superscript(s) are not significantly different (P≤0.05).

Appendix. 14: Rehydration ratio of potato dried products by using hot water and electric candle drying techniques.

Location of fan	Drying techniques		Mean value
	Hot water	Electric candle	
Top fan	$3.00^{ab}\pm0.00$	$3.16^{a}\pm0.17$	3.08^{A}
Bottom fan	$3.00^{ab}\pm0.00$	$2.83^{b}\pm0.17$	2.92^{B}
Top and Bottom fans	$2.50^{c}\pm0.17$	$2.83^{b}\pm0.17$	2.66^{B}
Mean value	2.83^{B}	2.94^{A}	
$Lsd_{0.05}$	0.2452^{*}		
SE±	0.7958		

Values are mean±SD.

Any two mean value(s) sharing same superscript(s) are not significantly different ($P\leq0.05$).

Appendix. 15: Rehydration ratio of onion dried products by using hot water and electric candle drying techniques.

Location of fan	Drying techniques		Mean value
	Hot water	Electric candle	
Top fan	$4.50^{c}\pm0.00$	$4.50^{c}\pm0.00$	4.50^{C}
Bottom fan	$5.25^{b}\pm0.25$	$4.75^{c}\pm0.25$	5.00^{B}
Top and Bottom fans	$4.08^{d}\pm0.38$	$6.50^{a}\pm0.00$	5.29^{A}
Mean value	4.61^{B}	5.25^{A}	
$Lsd_{0.05}$	0.3774^{*}		
SE±	0.1225		

Values are mean±SD.

Any two mean value(s) sharing same superscript(s) are not significantly different ($P\leq0.05$).

Appendix. 16: Water absorption index (g.gel/g DM) of banana dried products by using hot water and electric candle drying techniques.

Location of fan	Drying techniques		Mean value
	Hot water	Electric candle	
Top fan	1.93^{a} ±0.43	1.75^{a} ±0.01	1.84^{A}
Bottom fan	1.47^{a} ±0.05	1.53^{a} ±0.52	1.50^{A}
Top and Bottom fans	1.89^{a} ±0.16	1.35^{a} ±0.86	1.62^{A}
Mean value	1.76^{A}	1.54^{A}	
$Lsd_{0.05}$	1.017^{NS}		
SE±	0.3302		

Values are mean±SD.

Any two mean value(s) sharing same superscript(s) are not significantly different (P≤0.05).

Appendix. 17: Water absorption index (g. gel/g DM) of potato dried products by using hot water and electric candle drying techniques.

Location of fan	Drying techniques		Mean value
	Hot water	Electric candle	
Top fan	5.55^{a} ±0.43	5.09^{a} ±0.74	5.32^{A}
Bottom fan	4.94^{a} ±0.05	5.17^{a} ±0.02	5.06^{A}
Top and Bottom fans	4.85^{a} ±0.16	5.04^{a} ±0.20	4.95^{A}
Mean value	5.11^{A}	5.10^{A}	
$Lsd_{0.05}$	0.6361^{NS}		
SE±	0.2057		

Values are mean±SD.

Any two mean value(s) sharing same superscript(s) are not significantly different (P≤0.05).

Appendix. 18: Water absorption index (g.gel/g DM) of onion dried products by using hot water and electric candle drying techniques.

Location of fan	Drying techniques		Mean value
	Hot water	Electric candle	
Top fan	3.95^{ab} ±0.02	3.85^{ab} ±0.32	3.90^{AB}
Bottom fan	3.63^{b} ±0.13	4.03^{ab} ±0.33	3.83^{B}
Top and Bottom fans	4.20^{a} ±0.29	3.81^{ab} ±0.38	4.01^{A}
Mean value	3.93^{AB}	3.99^{A}	
$Lsd_{0.05}$	0.50^{*}		
SE±	0.1623		

Values are mean±SD.

Any two mean value(s) sharing same superscript(s) are not significantly different (P≤0.05).

Appendix. 19: Yield (%) of banana dried products by using hot water and electric candle drying techniques.

Location of fan	Drying techniques		Mean value
	Hot water	Electric candle	
Upper fan	17.42^{c} ±0.06	17.55^{b} ±0.02	17.49^{AB}
Lower fan	17.51^{b} ±0.01	17.54^{b} ±0.03	17.53^{A}
Upper and lower fans	17.31^{d} ±0.06	17.70^{a} ±0.05	17.51^{A}
Mean value	$17.41A^{B}$	17.60^{A}	
$Lsd_{0.05}$	0.07956^{*}		
SE±	0.02582		

Values are mean±SD.

Any two mean value(s) sharing same superscript(s) are not significantly different (P≤0.05).

Appendix. 20: Yield (%) of potato dried products by using hot water and electric candle drying techniques.

Location of fan	Drying techniques		Mean value
	Hot water	Electric candle	
Top fan	$17.93^{ab}\pm0.16$	$18.00^{a}\pm0.03$	17.97^{AB}
Bottom fan	$17.90^{ab}\pm0.02$	$17.88^{b}\pm0.02$	17.89^{B}
Top and Bottom fans	$18.10^{a}\pm0.00$	$17.99^{a}\pm0.02$	18.04^{A}
Mean value	17.98^{A}	17.96^{B}	
$Lsd_{0.05}$	0.1257^{*}		
SE±	0.04083		

Values are mean±SD.

Any two mean value(s) sharing same superscript(s) are not significantly different (P≤0.05).

Appendix. 21: Yield (%) of onion dried products by using hot water and electric candle drying techniques.

Location of fan	Drying techniques		Mean value
	Hot water	Electric candle	
Top fan	$19.93^{a}\pm0.03$	$19.78^{a}\pm0.01$	19.85^{A}
Bottom fan	$19.83^{a}\pm5.77$	$19.67^{a}\pm0.00$	19.75^{A}
Top and Bottom fans	$19.87^{a}\pm0.01$	$19.72^{a}\pm0.07$	19.80^{A}
Mean value	19.88^{A}	19.72^{A}	
$Lsd_{0.05}$	4.186^{NS}		
SE±	1.359		

Values are mean±SD.

Any two mean value(s) sharing same superscript(s) are not significantly different (P≤0.05).

Appendix. 22: Dehydration ratio of banana dried products by using hot water and electric candle drying techniques.

Location of fan	Drying techniques		Mean value
	Hot water	Electric candle	
Top fan	5.741^{b} ±0.16	5.697^{e} ±0.03	5.719^{A}
Bottom fan	5.711^{c} ±0.02	5.700^{d} ±0.02	5.705^{C}
Top and Bottom fans	5.775^{a} ±0.00	5.649^{f} ±0.02	5.712^{B}
Mean value	5.742^{A}	5.682^{B}	
$Lsd_{0.05}$	0.0005626^{*}		
SE±	0.01826		

Values are mean±SD.

Any two mean value(s) sharing same superscript(s) are not significantly different (P≤0.05).

Appendix. 23:Dehydration ratio of potato dried products by using hot water and electric candle drying techniques.

Location of fan	Drying techniques		Mean value
	Hot water	Electric candle	
Top fan	5.574^{c} ±0.16	5.554^{e} ±0.03	5.564^{B}
Bottom fan	5.588^{b} ±0.02	5.592^{a} ±0.02	5.590^{A}
Top and Bottom fans	5.553^{f} ±0.00	5.557^{d} ±0.02	5.555^{C}
Mean value	5.572^{A}	5.568^{B}	
$Lsd_{0.05}$	0.0005626^{*}		
SE±	0.01826		

Values are mean±SD.

Any two mean value(s) sharing same superscript(s) are not significantly different (P≤0.05).

Appendix. 24: Dehydration ratio of onion dried products by using hot water and electric candle drying techniques.

Location of fan	Drying techniques		Mean value
	Hot water	Electric candle	
Top fan	5.018^{f}±0.16	5.054^{c}±0.03	5.036^{A}
Bottom fan	5.041^{d}±0.02	5.085^{a}±0.02	5.063^{C}
Top and Bottom fans	5.034^{e}±0.00	5.070^{b}±0.02	5.052^{B}
Mean value	5.031^{A}	5.070^{B}	
$Lsd_{0.05}$	0.0005626*		
SE±	0.01826		

Values are mean±SD.

Any two mean value(s) sharing same superscript(s) are not significantly different (P≤0.05).

Appendix. 25: Colour evaluation of banana, potato and anion dried products by using hot water and electric candle drying techniques.

Location of fan in the drying chamber	Banana		Potato		Onion	
	Drying Technique					
	Hot Water	Electric Candle	Hot Water	Electric Candle	Hot Water	Electric Candle
	(Mean Value ±SD)					
Top fan	2.94^{a} ±0.80	3.50^{a} ±0.81	1.47^{bc} ±0.80	1.88^{abc} ±0.86	2.00^{b} ±0.89	3.38^{a}±1.02
Bottom fan	2.17^{b} ±0.92	2.83^{ab} ±0.90	2.06^{ab} ±1.03	2.35^{a} ±1.22	2.00^{b} ±0.73	2.88^{a} ±1.26
Top and Bottom fans	2.22^{b} ±0.94	3.44^{a} ±0.89	1.29^{c} ±0.59	1.53^{bc} ±0.80	2.13^{b} ±0.89	2.13^{b} ±0.81
Mean values	2.44^{B}	3.26^{A}	1.61^{B}	1.92^{A}	2.04^{B}	2.79^{A}
LSD 0.05	0.6545*		0.6162*		0.6664*	
SE ±	0.2333		0.2195		0.2372	

Values are mean±SD.

Mean value(s) sharing same superscript(s) for each product are not significantly different (P≤0.05).

Appendix. 26: Taste evaluation of banana, potato and anion dried products by using hot water and electric candle drying techniques.

Location of fan in the drying chamber	Banana		Potato		Onion	
	Drying Technique					
	Hot Water	Electric Candle	Hot Water	Electric Candle	Hot Water	Electric Candle
	(Mean Value ±SD)					
Top fan	2.44^{a} ±0.92	2.44^{a} ±0.88	2.35^{a} ±0.70	2.35^{a} ±0.86	2.25^{a} ±0.77	2.69^{a} ±1.08
Bottom fan	2.22^{a} ±0.65	2.72^{a} ±0.60	2.53^{a} ±0.72	2.65^{a} ±1.00	2.13^{a} ±1.02	2.44^{a} ±0.96
Top and Bottom fans	2.17^{a} ±0.79	2.67^{a} ±0.71	2.18^{a} ±0.81	2.35^{a} ±0.70	2.38^{a} ±0.96	2.44^{a} ±0.96
Mean values	2.28^{A}	2.61^{A}	2.35^{A}	2.45^{A}	2.25^{A}	2.52^{A}
LSD 0.05	$0.5711^{N.S}$		$0.5481^{N.S}$		$0.6777^{N.S}$	
SE±	0.2036		0.1952		0.2412	

Values are mean±SD.
Mean value(s) sharing same superscript(s) for each product are not significantly different (P≤0.05)

Appendix. 27: Flavor evaluation of banana, potato and anion dried products by using hot water and electric candle drying techniques.

Location of fan in the drying chamber	Banana		Potato		Onion	
	Drying Technique					
	Hot Water	Electric Candle	Hot Water	Electric Candle	Hot Water	Electric Candle
	(Mean Value ±SD)					
Top fan	2.56^{ab} ±0.78	2.94^{ab} ±0.73	2.53^{a} ±1.07	2.59^{a} ±1.12	2.81^{a} ±1.05	2.56^{a} ±1.15
Bottom fan	2.56^{ab} ±0.86	2.78^{ab} ±0.85	2.65^{a} ±0.93	2.65^{a} ±0.86	2.63^{a} ±0.96	2.44^{a} ±1.15
Top and Bottom fans	2.39^{b} ±0.85	3.06^{a} ±0.79	2.53^{a} ±1.18	2.53^{a} ±0.87	2.56^{a} ±1.26	2.19^{a} ±1.05
Mean values	2.50^{B}	2.93^{A}	2.57A	2.59^{A}	2.67^{A}	2.40^{A}
LSD 0.05	0.5787^{*}		$0.69^{N.S}$		$0.778^{N.S}$	
SE ±	0.2063		0.2458		0.2769	

Values are mean±SD.
Mean value(s) sharing same superscript(s) for each product are not significantly different (P≤0.05).

Appendix. 28: General appearance evaluation of banana, potato and anion dried products by using hot water and electric candle drying techniques.

Location of fan in the drying chamber	Banana		Potato		Onion	
	Drying Technique					
	Hot Water	Electric Candle	Hot Water	Electric Candle	Hot Water	Electric Candle
	(Mean Value ±SD)					
Top fan	3.22^{a}±1.06	3.06^{ab}±0.98	2.35^{a}±1.00	2.53^{a}±0.80	2.44^{a}±0.96	2.63^{a}±1.09
Bottom fan	2.44^{b}±0.86	3.11^{a} ±0.84	2.59^{a}±0.87	2.65^{a}±0.93	2.69^{a}±0.95	2.88^{a}±1.09
Top and Bottom fans	2.72^{ab}±0.75	3.06^{ab}±0.71	2.24^{a}±1.09	2.35^{a}±1.22	2.56^{a}±1.09	2.63^{a}±0.81
Mean values	2.80^{B}	3.07^{A}	2.39^{A}	2.51^{A}	2.56^{A}	2.71^{A}
LSD 0.05	0.5884^{*}		$0.6774^{N.S}$		$0.7045^{N.S}$	
SE ±	0.2098		0.2413		0.2507	

Values are mean±SD.

Mean value(s) sharing same superscript(s) for each product are not significantly different (P≤0.05).

Appendix. 29: Overall quality evaluation of banana, potato and anion dried products by using hot water and electric candle drying techniques.

Location of fan in the drying chamber	Banana		Potato		Onion	
	Drying Technique					
	Hot Water	Electric Candle	Hot Water	Electric Candle	Hot Water	Electric Candle
	(Mean Value ±SD)					
Top fan	2.89^{ab}±0.68	3.11^{a}±0.62	2.47^{a}±0.94	2.59^{a}±0.94	2.44^{b}±0.73	3.25^{a}±1.00
Bottom fan	2.39^{b}±0.70	2.89^{ab}±0.65	2.65^{a}±0.70	2.41^{a}±0.87	2.75^{ab}±0.86	2.50^{ab}±1.03
Top and Bottom fans	2.44^{b}±0.92	3.06^{a}±0.81	2.18^{a}±1.01	2.24^{a}±0.90	2.56^{ab}±1.26	2.56^{b}±0.96
Mean values	2.57^{B}	3.02^{A}	2.43^{A}	2.41^{A}	2.58^{B}	2.77^{A}
LSD 0.05	0.5113^{*}		$0.6131^{N.S}$		0.6939^{*}	
SE ±	0.1823		0.2184		0.247	

Values are mean±SD.

Mean value(s) sharing same superscript(s) for each product are not significantly different (P≤0.05).