DESIGN, CONSTRUCTION AND PERFORMANCE EVALUATION OF A POSTHARVEST HEAT STORAGE SOLAR ENERGY CROP DRYER

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A PROJECT RESEARCH STUDY SUBMITTED IN PARTIAL FULFILLMENT FOR THE RQUIREMENT OF THE AWARD OF THE DEGREE OF MASTER OF ENGINEERING (M.ENG) IN THE DEPARTMENT OF AGRICULTURAL AND BIORESOURCES ENGINEERING, FACULTY OF ENGINEERING UNIVERSITY OF NIGERIA, NSUKKA

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CERTIFICATION PAGE

I hereby certify that this Project Research Study described herein is the original work of LIBERTY JACOB TIZHE with Registration Number PG/M.ENG/12/61320 of the Department of Agricultural and Bioresources Engineering, Faculty of Engineering University of Nigeria, Nsukka.

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External Examiner DATE

DEDICATION

This Project is dedicated unreservedly to my Parents, Mr and Mrs Liberty Tizhe for being a Blessing to my Life. May they live to reap the fruits of their Labour.

ACKNOWLEDGEMENT

My greatest appreciation goes to the Only Wise, Gracious and Merciful God for being my Pillar through thick and thin of this study. He is faithful indeed!

Well acknowledged is my Sagacious and Scholarly Supervisor whom despite his tight schedules never failed to give me all the needed attention required to successfully complete this research work.

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ABSTRACT

The present study designed, constructed and undertook the performance evaluation of a post harvest passive solar crop dryer for drying agricultural produce. The solar crop dryer consists of a solar collector with dimensions 110 x 61 x 10cm, a drying chamber measuring 102 x54cm, a movable heat storage unit with the dimensions 40 x 35 x 13cm and drying trays each having an area of 1806cm^2. The performance evaluation was conducted using three crops- tomatoes, pepper and okra which are locally produced. The test performance was done in both rainy and dry seasons to conform to the two major seasons in Nigeria and to determine the functionality of the crop seasonally. Open sun drying of the above crops was undertaken simultaneously as a control measure. Results of the performance evaluation showed that the highest chamber and ambient temperatures without the heat storage system incorporated was 53.3 and 32.8 ^oC respectively during the rainy season while the chamber and ambient temperatures with heat storage unit incorporated were 65.6 and 36.6 ^oC respectively. This indicates that the incorporation of heat storage unit improved the quality of heat output of the dryer temperature which was able to increase the drying process hours after the sun ceased shining. During the dry season (December), there was a little rise in ambient temperature as compared with rainy season. The maximum ambient and chamber temperature obtained during the dry season was 68.2 and 33.2^oC respectively. As a result of the relative rise in temperature during the dry season, the rate of moisture lose was faster than during the raining season. As part of the performance evaluation the physicochemical properties of the crops were evaluated before and after drying. Physicochemical properties evaluated includes: moisture, protein, fat, fibre, ash, carbohydrate and vitamin C, contents. The fresh, open and solar dried samples were analysed for their proximate composition using the recommended method of Association of Official Analytic Chemists (AOAC). Also, statistical analysis of the data was conducted using analysis of variance (ANOVA) using Completely Randomize Design (CRD) and means were separated by Duncan’s New Multiple Range test (DNMRT). Proximate analysis showed that solar dried vegetables had significantly ($P < 0.05$) higher protein, fibre, ash, carbohydrate and vitamin C except for the fat content that was significantly ($P < 0.05$) higher for all the open sun dried samples than the solar dried and fresh products. The nutrient which is highly affected by sun drying is vitamin C. Result indicates that moisture loss in solar dried vegetables was faster than the open dried samples and as such makes the solar dried products of lesser tendency to mould and bacterial growth. The open sun dried samples had to be carried into the sheltered place each time it rains. The observation is that the solar dried produce is of high quality and hygienically good for human consumption. Further processing of the dried crops will involve packaging for commercial purposes. This will also help in making these agricultural produce available in a relatively cheap prices in off season and also avert micronutrient deficiencies in diet especially among the low income groups in Nigeria.

CHAPTER ONE

1.0 INTRODUCTION

1.1: Background of the Study

Vegetables and their products are of great nutritional and health importance since they make significant contribution in supplying essential vitamins, minerals, antioxidants, fibers and carbohydrates that improve the quality of the diet and also contains constituents that have health benefits and anti-disease factors, such as antioxidants and polyphenols. These components are known to scavenge harmful free radicals that are associated with incidence of cancer and heart diseases (Cao *et al.,* 1996; Velioglu *et al.,* 1998).

Unfortunately, fresh fruits and vegetables are not only seasonal but highly perishable since the moisture content is more than 80%, they are classified as highly perishable commodities (Orsat et al., 2006). As a result they deteriote very fast few days after harvesting, losing almost all their required quality attributes and some could likely result to total waste. The post harvest losses in vegetables has been estimated to be about 30-40% due to inadequate post harvest handling, lack of infrastructure, processing, marketing and storage facilities (Karim and Hawlader, 2005). It has been shown that as high as 50% of these produce are lost between rural production and town consumption in the tropical areas. Studies have also recorded that 20 to 40% of harvested vegetables are not eaten because they are made unavailable through some forms of spoilage (Orsat *et al.*, 2006).

FAO (2000) estimated that the world production of fruits and vegetables over a three-year period (1993 – 1995) was 489 million tons for vegetables and 448 million tons for fruits. This trend increased as expected, reaching a global production of 508 million tons for vegetables and 469 tons for fruits in 1996. This trend of production is expected to increase at a rate of 3.2 percent per year for vegetables and 1.6 percent per year for fruits. However, little considerations and attention are given to preservation aspect of these important agricultural produce in Nigeria. The increase in production of these vegetables usually results in gluts at harvest time and very low price, while few months after, scarcity sets in resulting in high prices.

One major means of preservation of vegetables is by drying. Drying is an excellent way to preserve food and solar food dryers are appropriate food preservation technology for sustainable development. Drying was probably the first ever food preserving method used by man, even before cooking. It involves the removal of moisture from agricultural produce so as to provide a product that can be safely stored for longer period of time (Scalin, 1997).

Fruits and vegetables are dried to enhance storage stability, minimize packaging requirement and reduce transport weight. Drying is a suitable alternative for post harvest management especially in developing countries where exist poorly established low temperature distribution and handling facilities. It is noted that over 20% of the world perishable crops are dried to increase shelf-life and promote food security (Grabowski *et al.*, 2003).

Moreover, products with low moisture content can be stored at ambient temperatures for long period of time due to a considerable decrease in the water of the material, reduced microbiological activity and minimized physical and chemical changes (Vlachos *et al.*2002). Dried vegetables are more concentrated than any other preserved form of foodstuffs and are tasty, nutritious, light weight and easy to prepare, store and use (Yaldyz *et al.*2001).

Sun drying is the earliest method of drying farm produce known to man and it involves simply laying the agricultural products in the sun on mats, roofs or drying floors. This has several disadvantages since the farm produce are laid on the open sky and there is greater risk of spoilage due to adverse climate conditions like rain, wind, moist and dust, loss of produce to birds, insects and rodents (pests); totally dependent on good weather and very slow drying rate with danger of mould thereby causing deterioration and decomposition of the produce. The process also requires large area of land, takes time and highly labour intensive (Gujarat Energy Development Agency, GEDA, 2003).

With cultural and industrial development, artificial mechanical drying came into practice, but this process is highly energy intensive and expensive which ultimately increases product cost (GEDA, 2003). Recently, efforts to improve sun drying have led to solar drying.

Solar dryers are specialized devices that control the drying process and protect the agricultural produce from damage by insects, pests, dust and rain. In comparison to natural sun drying solar dryers generate higher temperatures, lower relative humidity, and lower product moisture content and reduce spoilage during the drying process. In addition it takes less time to dry produce and is relatively inexpensive compared to artificial mechanical drying method. Thus, solar drying is a better alternative solution to all the drawbacks of natural drying and artificial mechanical drying (GEDA, 2003).

The Nigerian stored product Research Institute (NSPRI) has developed techniques for the storage of fruits, vegetables and tubers. These methods are not strictly solar dependent, may in some cases require high-energy like refrigeration. It is believed that these inventions cannot be practically transferred to the rural-poor farmers in the society, since they may require financial inputs which are not within their reach.

The revival of solar drying of the more perishable agricultural products (like fruits and vegetables), appears to be a promising method of reducing post-harvest losses, improving rural incomes and contributing to self-sufficiency, even of reducing some imports through substitution products.

However, there is an objection over sun-drying as a preservative method that considerable amount of nutrients are lost during this process due to heat. Therefore, this study is aimed at evaluating the effect of the sun-drying on the nutritive properties of Tomatoes, Pepper and Okra.

1.2: Statement of the Problem

The production of agricultural products such as fruits and vegetables is seasonal in Nigeria. There are periods when there is a glut and others when there is acute shortage. The periods of glut clearly indicate that relatively large quantities of fresh agricultural products are produced in Nigeria. Hence, there exists a possibility of having the product round the year. The obvious acute shortage of agricultural products at some periods of the year in Nigeria is attributed to poor storage facilities. The immediate effect of poor storage facilities is that the farmer is robbed of benefits accruable from his hard labour, as he hurriedly disposes off his product at give-away prices, to save him the situation of helplessly watching his produce rot away. This serious lack of opportunity for adequate economic return reduces the farmer’s incentive and consequently his desire to produce more and as such there is need to device a measurement that could encourage and enhance the preservation and storage of agro-produce at least for some period of time before usage. Solar energy drying technology appears the best option for such measure.

However, the concept of solar drying to mitigate the above challenge is nonetheless without some major problems such as inability to undertake drying process over the night or during off sunshine hours. A solar dryer that could dry agricultural products during the off sunshine periods could have an advantage over an ordinary dryer and will be of great benefits to farmers. Such a solar dryer would incorporate energy storage device for drying purposes when needed for all day round (Okonkwo and Okoye, 2005). There are many methods of solar energy storage materials available (Duffie and Beckman, 1979). One of such method is storage of solar energy as sensible heat using materials such as pebbles (rocks). Pebble is an inexpensive material locally available in Nigeria. Its utilization could pose no burden to farmers.

1.3: Objectives of the Study

The present study is aimed to:

i. Design and construct a solar dryer for drying agricultural produce.
ii. Dry agricultural produce using the post-harvest heat storage solar energy crop dryer with tomato, pepper and okra as test samples.
iii. Evaluate the physicochemical properties of fresh, solar dried and open sun dried tomato, pepper and okra.
iv. Compare the physicochemical properties of the fresh products with the solar and open sun dried produce.

1.4: Justification of the Study

The small-medium scale solar dryer when developed and commercialized, will help the rural farmers by bridging the large scale industrial techniques and the traditional method of drying. The solar dryer can now dry large quantity of tomatoes, pepper and okra with better quality and relatively better efficiency than the traditional method. The solar dried products were of high quality. Further processing of the dried crops will involve packaging for commercial purposes. This will also help in making these agricultural produce available in a relatively cheap prices in off season and also avert micronutrient deficiencies in diet especially among the low income groups in Nigeria.

1.5: Scope and Limitation of the Study

This present research study is limited to the design, construction and performance evaluation of a solar energy crop dryer. Three agricultural produce (crops) – tomatoes, pepper and okra were chosen as the test samples. It also involved the comparative analysis of the solar and open sundried crops. The physicochemical properties evaluated include moisture, ash, fibre, protein, carbohydrate, fat and vitamin C contents of the crops.

The work was initiated at the verge of the end of dry season in 2012. Hence, the drying experiment of the vegetables was carried out mainly during the rainy season of 2013.

CHAPTER TWO

2.0 LITERATURE REVIEW

2.1: Concept of Drying

Drying is an excellent way to preserve food and solar dryers are appropriate food preservation technology for sustainable development. Drying was probably the first ever food preserving method used by man, even before cooking (Alamu *et al.*, 2010). It involves the removal of moisture from agricultural produce so as to provide a product that can be safely stored for longer period of time.

Sun drying is the earliest method of drying farm produce ever known to man and it involves simply laying the agricultural products in the sun on mats, roofs or drying floors. This has several disadvantages since the farm produce are laid in the open sky and there is greater risk of spoilage due to adverse climatic conditions like rain, wind, moist and dust, loss of produce to birds, insects and rodents (pests); sun drying is totally dependent on good weather and very slow drying rate with danger of mould growth thereby causing deterioration and decomposition of the produce. The process also requires large area of land takes time and highly labour intensive. In order to protect the products from above mentioned disadvantages and also to accelerate the time for drying the products, control the final moisture and reduce wastage through bacterial action, different types of solar dryer can be used (Exell, 1980; Fohr and Figueredo, 1987; Ting and Shore, 1983; Yaldyz and Ertekyn, 2001). With cultural and industrial development, artificial mechanical drying came into practice, but this process is highly energy intensive and expensive which ultimately increases product cost. Recently, efforts to improve sun drying have led to solar drying.

Solar dryers are specialized devices that control the drying process and protect agricultural produce from damage by insect pests, dust and rain. In comparison to natural sun drying, solar dryers generate higher temperatures, lower relative humidity, lower product moisture content and reduce spoilage during the drying process. In addition, it takes up less space, takes less time and relatively inexpensive compared to artificial mechanical drying method. Thus, solar drying is a better alternative solution to all the drawbacks of natural drying and artificial mechanical drying (Khalil *et al.*, 2007; Roa and Macedo, 1976).

The solar dryer can be seen as one of the solutions to the world’s food and energy crises. With drying, most agricultural produce can be preserved and this can be achieved more efficiently through the use of solar dryers. Solar dryers are a very useful device for:

- Agricultural crop drying.
- Food processing industries for dehydration of fruits and vegetables.
- Fish and meat drying.
- Dairy industries for production of milk powder.
- Seasoning of wood and timber.
- Textile industries for drying of textile materials, etc.

Thus, solar dryer is one of the many ways of making use of solar energy efficiently in meeting man’s demand for energy and food supply. Total system cost is a most important consideration in designing a solar dryer for agricultural uses. No matter how well a solar system operates, it will not gain widespread use unless it presents an economically feasible alternative to other available energy sources (Ghazanfari and Sokhansanj, 2002; Janjaia *et al.,* 2008).

2.2: Basic Theory of Solar Drying Operation

The main goal of solar drying is to remove moisture from the fruit or vegetable to a level that will prevent microbial growth (≤20%) while maintaining acceptable quality of the product. The drying rate of produce is dependent upon the rate at which the moisture content is evaporated from the surface of the vegetable and how quickly the moist air is removed from the area adjacent to the surface of the produce (Joshi *et al.*, 2004).

The drying rate also depends on the rate of mass transfer of moisture from the interior of the produce to the surface of the produce. During drying, the produce structural changes cause a reduction in moisture transport inside the produce. The latent heat of vaporization required to remove moisture from produce is provided by hot air flowing through a dryer and by direct radiation striking the vegetables in the drying chamber. The air flow in dryer is responsible for carrying away the evaporated moisture from produce. The moisture leaving the produce is equal to the moisture entering the air stream by convection (Simate, 2001).

$$\frac{\rho_f \Delta M}{\Delta t} = -\frac{G \Delta H}{\Delta x} \qquad 2.1$$

Where ρ_f = density of the dried material (kg/m^3)

M = moisture content (d.b.)

t = time (hr)

G = air flux (kg/m^{2}hr),

H= humidity (kg/kg) and

x = depth of the bulk (m)

Air flow through a dryer is an important factor in the drying process and is responsible for moisture transport by enhancing convective transfer of water vapor from the drying food material to the surrounding air. The moist laden air is carried away by the air flow through an exhaust. Humidity and temperature determine the dryness or drying power of the atmosphere (Brown, 2000).

2.3: Drying of Fruits and Vegetables

Fruits and vegetables are the fresh agricultural produce having high moisture content and are perishable in nature. Fruit normally means the fleshy seed-associated structures of certain plants that are sweet and edible in the raw state, such as apples, oranges, grapes, strawberries, juniper berries and bananas. Vegetable usually means an edible plant or part of a plant other than a sweet fruit or seed. This typically means the leaf, stem, or root of a plant. Some vegetables can be consumed raw, some may be eaten, cooked, some must be cooked in order to be edible and some are dried to increase the shelf life.

Inhabitants living close to the Mediterranean Sea and in the Near East traded fruits that had been dried in the open sun. Dried fruit is a delicacy, because of the nutritive value (66– 90% carbohydrate) and the shelf life. Today, the production of dried fruits is widespread. The selection of fruit for drying depends on local circumstances. Fruits can be dried whole, in halves, or as slices, or alternatively can be chopped after drying. The residual moisture content varies from small (3–8%) to large (16–18%) amounts, according to the type of fruit (Josef, 2006).

A wide range of dried fruits and vegetables are available in the market in whole, sliced, or ground form. Reduction in moisture during drying of high-moisture materials, like fruits and vegetables, induces changes in shape, density, and porosity. Product quality plays a major role in food drying operation. Upon rehydration, dried vegetables should exhibit desirable sensory and nutritional quality. Numerous processing techniques have been practiced for drying of vegetables. However, it should be noted that water should be removed in such a way that dehydrated products can easily be rehydrated to regain their structure (Jasim, 2011).

In fruits and vegetables drying, diffusion transport mechanism has a significant role, especially during the falling rate period, which is controlled by the mechanism of liquid and vapor diffusion. This behavior indicates an internal mass transfer-type drying with moisture diffusion as the controlling step. The water diffusion coefficient reflecting the whole complexity of water transport is referred to as an effective coefficient. Generally, it is difficult to predict the effective mass diffusion coefficient values theoretically; therefore, experimental techniques based on sorption/desorption kinetics, moisture content distribution, or porosity can be used (Bialobrzewski and Markowski, 2004). For vegetables with significantly high moisture content, like celery, it is often assumed that mass diffusion is determined by external conditions of mass transfer. The rate of moisture movement during drying is well described by effective diffusivity (D*eff*) value (Jasim, 2011).

The green colour of most vegetables is due to chlorophyll, which is the most widely distributed plant pigment. The most common change that occurs in green vegetables during thermal processing and storage is the conversion of chlorophyll to pheophytins, causing a colour change from bright green to olive-brown, which is undesirable to the consumer (Schwartz and Elbe, 1983). For green vegetables, pretreatment prior to drying can aid the chlorophyll retention during the drying operation. When vegetables are maturing in the field they are changing from day to day. There is a time when the vegetable will be at peak quality from the stand-point of color, texture and flavor. This peak quality is short and may last only for few days. The vegetables can be stored, in some specific natural conditions, in fresh state that is without significant modifications of their initial organoleptic properties. Fresh vegetable storage can be achieved by short term like freezing or by cold storage and long term by drying. In order to assure preservation for long term storage, it is necessary to process them by drying (King and Ann, 1992).

Vegetables are classified according to which part of the plant is consumed. Some of the vegetables may fall into more than one category as more than one part of the same plant is consumed.

2.4: States of Water in Fruits and Vegetables

Water in vegetables is present mainly in two forms, free (or unbound) and bound. Free water behaves as pure water, and bound water, which is physically or chemically bound to food materials, exhibits vapor pressure lower than that of pure water at the same temperature. Free water is the first fraction of moisture adherent to the food surface to be removed. Water remains in the pores and the capillaries. Bound water may exist in different forms: unfreezeable, immobile, monolayer, etc. A fraction of bound water is loosely adsorbed to food materials while higher energy requirement is necessary to remove the trapped water (Jasim, 2011).

Fruit drying involves removing water in different forms (both free and bound) and different amounts. The amount and manner of water removal change the structure of fruit depending on the type of bonding, and also determine the character of the reconstituted dried material. Among the various bonding forms of water, the strongest is the chemical, physicochemical bonding, followed by adsorption, osmotic, micro- and macro-capillary, and, finally, rehydration. During drying, the weakest bound water is removed first; removing moisture by breaking stronger bonds requires energy. Removal of free water does not change the character of the material in either the dried or rehydrated states. Significantly higher energy and special procedures are required to remove bound water, i.e., to decompose the higher bonding energies (Ginzburg, 1968; Ginzburg 1976).

Drying a moist material and decreasing the water activity means evaporation of bound water from inside the solid material into the atmosphere. Breaking water bonds, releasing, and transferring heat connected to phase change require energy. Drying can be done with different types of drying energy: convective (warm air), contact (cooled surface), and radiative (infrared rays), and excitation (microwave) energies. With convective drying, the heated air flow in moisture content meets the wet material and as a result, the moisture moves onto the surface of the material and then into the drying air. Tasks of the warm air are to transfer heat to the material being dried to establish the drying potential and to transfer moisture into the air (Josef, 2006).

Drying technology of fruits and vegetables involves three basic steps

• Preliminary and preparative procedure: cleaning, washing, slicing and pretreatments if necessary

• Drying procedure

• Processing after drying, secondary treatments: packaging and storage

2.5: Pretreatments of Fruits & Vegetables before Drying

Fruits, vegetables and their products in the dried form are good sources of energy, minerals and vitamins. However, during the process of dehydration, there are changes in nutritional quality (Sablani, 2006). Product quality is becoming more and more important for dehydrated fruits and vegetables, which must retain quality attributes (colour, texture) and nutritional quality after dehydration. Improvement of such qualities can be achieved by pretreatments before drying. Suitable pretreatments can improve the drying process by reducing the drying time, yields better-quality products, and energy savings. A more number of vitamins such as A, C and thiamine are heat sensitive and sensitive to oxidative degradation. Sulphuring can destroy thiamine and riboflavin while pre-treatment such as dipping in sulphite solutions reduce the loss of vitamins during drying. As much as 80% decrease in the carotene content of some vegetables may occur if they are dried without enzyme inactivation. However, if the product is adequately blanched then carotene loss can be reduced to 5%. Steam blanching retains higher amounts of vitamin C in spinach compared with hot-water blanching (Ramesh *et al.,* 2001). Blanching in sulphite solution can retain more ascorbic acid in okra (Inyang and Ike, 1998).

Pre-drying treatments such as addition of sugars are needed for vegetable drying in order to avoid damages to tissue structures. Previous work has shown that non-reducing disaccharides such as sucrose and trehalose can protect biological systems from the adverse effects of freezing and drying. Especially trehalose is known to have many advantages. For example, sweetness of a 10% trehalose solution is 45% as that of a 10% sucrose solution. Trehalose is a non-reducing sugar and therefore does not react with amino acids or proteins to cause Maillard browning. Pretreatment with trehalose solution has been claimed to be very effective for producing high quality dried vegetable chips Aktas *et al.,* (2004) found that pretreatment with trehalose solution improved the reconstitutional properties of dried sliced carrot and potato samples compared with the dried products pre-treated with sucrose solution, which is generally used for osmotic dehydration. Osmotic treatment is a simultaneous water and solute diffusion process (Rastogi *et al.,* 2004). Many studies showed that sucrose treatment increases the water loss compared with the other osmotic solutions (Reppa *et al.,* 1998; Khiabani *et al.,* 2002).

Various pretreatment methods may be used in conjunction with the drying process to maintain or even improve the quality of a dried product. Among many methods of pretreatment blanching is one of the most common. Blanching is usually performed prior to drying to inactivate enzymes responsible for various undesirable enzymatic reactions. Blanching also helps with color retention and modification of product texture (Mate *et al.*, 1999; Ahmed *et al.*, 2001).

Moreover, blanching can help increase the drying rate, hence reducing the drying time (Severini *et al.*, 2005). Dipping or soaking a product (especially vegetable) in organic acids such as citric acid, lactic acid or acetic acid (Karapinar and Gonul, 1992; Yu *et al.,* 2001) is an alternative to blanching as these pretreatment methods can help reduce the number of normal flora and pathogenic organisms. Some organic acids such as acetic acid have been noted to reduce the activity of enzymes responsible for browning (Naphaporn *et al.*, 2010). These are the various pretreatments that can be employed prior to solar drying of fruits and vegetable.

2.6: The Theory of Drying

The theory of drying can be divided into two distinct and yet inter-related parts:

(1) Thin-layer and /or single particle drying during which the entire particles are completely exposed to the drying medium.

(2) Deep-bed drying in which the solid phase consists of a number of layers of particles.

During this drying process, there is continuous change in air temperature, humidity and moisture content, all happening simultaneously.

a. Thin layer drying

For the purpose of studying the drying rate and time, it is assumed that the entire particles are completely exposed to the drying medium.

The knowledge of the drying periods enables us to establish the most economic and effective operating conditions for drying agricultural products. It is actually a form of carrying out drying tests on specific materials with various air temperatures, relative humidity and air velocities.

If the rate of drying is plotted against time, three distinct drying periods emerge as shown in fig.1.

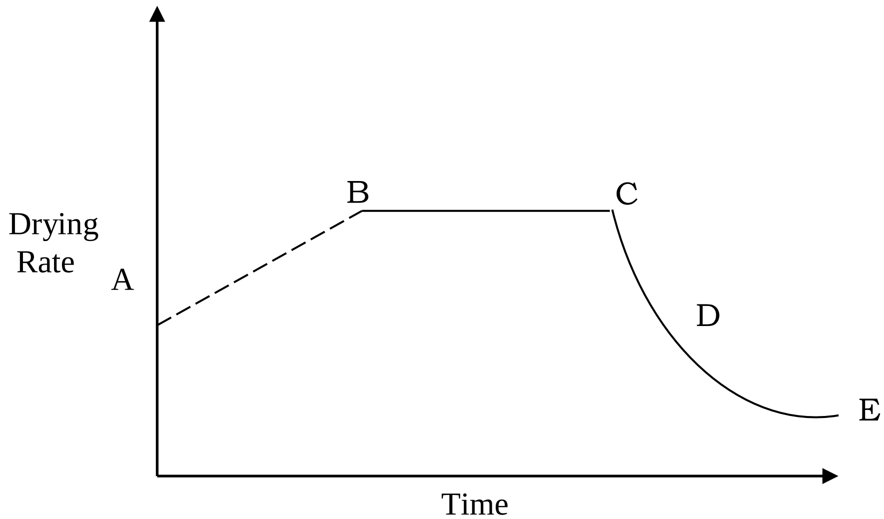

Fig. 1: The Periods of Drying (Source: Dryden, 1976)

(i) Heating-up period (A-B)

Part of the heat input initially goes to heating up the material and progressively increasing the sensible heat of the contained moisture. This then leads to a greater proportion of evaporating water from the material surface which in turn increases the drying rate. It is often a negligible proportion of the overall drying cycle.

(ii) Constant rate period (B-C)

This is the constant rate-drying period. During this period, the surface of the solid remains saturated with liquid water, since the rate of removal of moisture from the surface is counter balanced by the rate of capillary transfer of water to the surface of the solid. The driving force causing vapour movement through the stagnant air film is the water vapour gradient between the drying surface and the main air stream. The rate of mass transfer can be expressed as given by Hall (1970) as,

$$dw/dt = -\,kgA\,(Ps - Pa) \qquad 2.2$$

Where

dw/dt = drying rate kg/hr

Kg = mass transfer coefficient (kg/hr-m^2 atm)

A = drying surface area m^2

Ps = water vapour pressure at surface temperature (atm)

Pa = partial pressure of water in air (atm)

Equation (1) can also be expressed in terms of humidities as

$$\frac{dw}{dt} = -\,kg\;A\,(Hs - Ha) \qquad 2.3$$

Where

Kg^1 = mass transfer coefficient (kg/hr-m^2)

Hs = absolute humidity at surface temperature (kg/kg)

Ha = Humidity of air kg/kg or gm/kg.

The rate of heat transfer to the drying surface is given by Hall (1970) as,

$$\frac{dQ}{dt} = hcA(Ta - Ts) \qquad 2.4$$

Where

$$\frac{dQ}{dt} = Rate\ of\ \ heat\ \ transfer\,(J/hr)$$

hc = convective heat transfer coefficient (J/hr-m^2 ^{0}C).

A = area of heat transfer (m^2)

Ta = Dry bulb temperature of air (^{0}C)

Ts = Temperature of drying surface (wet bulb temperature of air)

Since the rate of mass transfer can be said to be rate of change of moisture content of the drying product, the equation (3) could be written as

$$\frac{dm}{dt} = -\, hc\ A(Ta - Ts) \qquad 2.5$$

Where

$$\frac{dm}{dt} = -\ drying\ rate\ kg/kg\ dry\ solid$$

A =effective drying surface area m^2/kg dry solid

The convective heat transfer coefficient for air blowing parallel to a surface is given by (Charm, 1971) as,

hc = 0.0128 G^{08}

Where

hc = Convective heat transfer c

G= mass velocity of air kg/hr-m^2

For air flowing perpendicular to a surface, the heat transfer coefficient may be given as hc = 0.37$G^{0\ 37}$

The rate of drying during the constant rate period is a function of three external parameters, air velocity, air temperature and relative humidity.

Hall (1970) reported that constant rate drying could only be observed in products for which the internal resistance to moisture transport is much less than external resistance to water vapour removal from the product surface.

(iii) The falling rate period (C-D)

As drying proceeds, a point is reached at which the rate of transfer of moisture within the material to the surface is less than the rate of evaporation from the surface and the surface then starts to dry out. At this point (pt. C) in the graph, the rate of drying begins to fall. The moisture content at this point is known as critical moisture content (Mc), which depends on the characteristics of the solid such as shape, size and also on the drying condition. Often the falling rate periods consists of two period C-D and D-E. In the first phase, the surface is drying out and the drying rate falls. Point E, the plane of evaporation moves into the solid and the drying rate falls further.

A number of physical mechanisms have been proposed to describe the transfer of moisture within the drying product (Araullo *et al*. 1976) as follows:

- Liquid movement due to surface forces (capillary flow.)
- Liquid movement due to moisture concentration difference (liquid diffusion)
- Liquid movement due to diffusion of liquid layers absorbed at solid interface.
- Vapour movement due to temperature difference.
- vapour movement due to moisture concentration gradient (vapour diffusion).
- Liquid and vapour movement due to total pressure differences-hydrodynamic flow. This occurs at temperatures higher than 100^0C.
- A number of approaches have been used to characterize drying at the falling rate period.

Empirical – This is used specifically for a particular material and for a specific range of temperatures. Brooker and Bakker (1974) reported that during the falling rate drying period. The moisture removal rate is inversely proportional to the moisture to be removed such that

$$\frac{dm}{dt} = -k(m - m_e)n \qquad 2.6$$

Separating variables and integrating equation (5) we arrive at the exponential drying equation.

$$\frac{m - m_e}{m_a - m_e} = e - k^1 \qquad 2.7$$

Where

K = drying constant, h^{-1}

n= exponential constant =1

m- me = driving potential force

b. Deep-bed drying

The deep-bed present complex problems due to the multitude of interdependent and continuously changing temperature and moisture profiles generated in both air and grain masses as well as well as inside individual kernels. In an attempt to characterize these phenomena, three distinct approaches have been used namely, analytical, empirical and theoretical.

Brooker and Bakker (1974) reported that drying in deep beds can be accomplished with a number of drying systems e.g. cross-flow dryer operates by passing warm air perpendicular to the direction of grain flow. Continuous flow characteristics are as shown in fig. 2

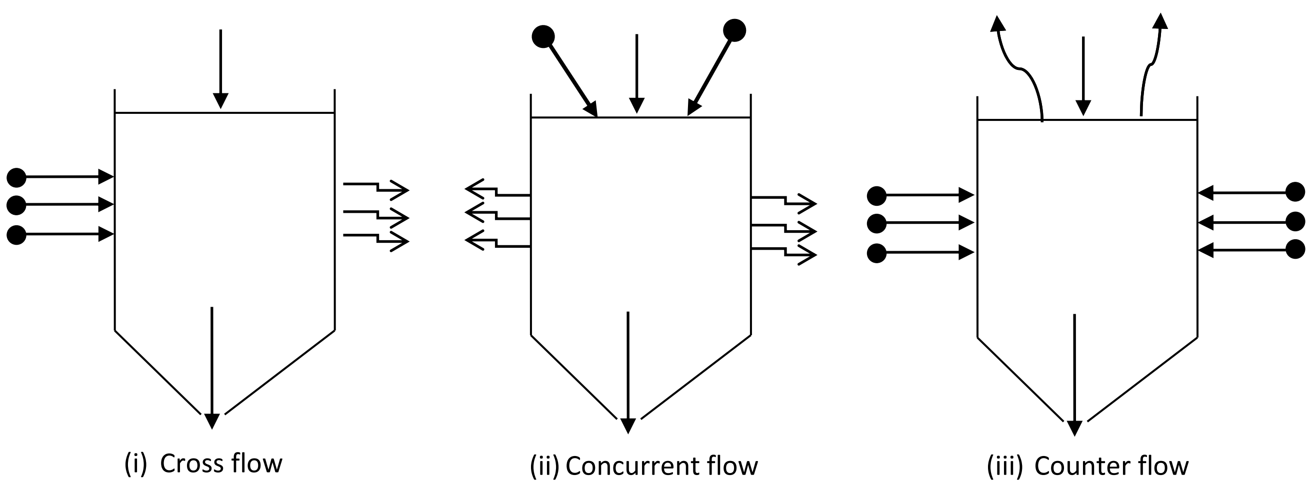

Fig 2: Continuous Airflow Illustrated. (Source: Brooker and Bakker, 1974).

The drying air carries away moisture from the grain. As the air absorb moisture, its temperature fall, and its ability to pick up more moisture decreases. A batch type dryer can be considered to be made up of a group of thin layers of parboiled paddy stacked upon one another with the drying air flowing up through the stacks. Thus the moisture removed from one particle affects the state of the air surrounding other adjacent particles in subsequent layers. The mathematical simulation of such a dryer would lead to complex equations of momentum, heat and mass transfer since each particle is continuously exposed to continuously changing environmental conditions.

Three distinct layers exist within deep-bed drying proceeds as shown in Fig. 3

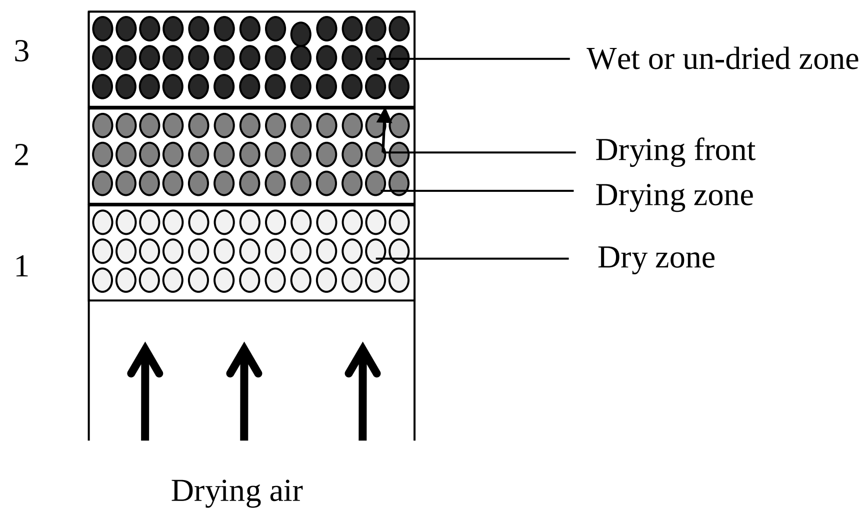

Fig.3: A Sketch of Drying Profile in a Deep-bed Dryer (Source: Carl and Hall, 1980).

The three distinct layers are: the dry zone, the drying zone and the wet or un-dried zone.

These zones form progressively from the bottom of the bed to the top. The rate of movement of the drying front will depend on factors such as grain depth, grain initial moisture, airflow rate, grain temperature, air temperature and relative humidity.

1. The depth of drying bed

According to Carl and Hall, (1977) and Ejie (1981), the major effects of decreasing depth while maintaining temperature at a constant level are:

(a) The medium moisture zone becomes an increasingly larger proportion of the total depth

(b) Grain is over dried to a lesser extent and is exposed to the heated air at a shorter period of time.

(c) Less grain is above 20 % moisture content at the end of the drying period.

(d) The moisture content of the over-dried grain decreases.

Differences in drying time would be mainly due to the difference in the energy available for drying. As the plenum temperature increases, the difference between the inlet and outlet air temperature is initially appreciably high but later decrease as the drying front passes through the bed.

$$\frac{\partial T}{\partial x} = \frac{-ha(T-\theta)}{GaCa + GaCaW} \qquad 2.8$$

Where

$\frac{\partial T}{\partial x} =$ drying air temperature.

Ga = mass flow rate of air

Ca = specific heat capacity of air

T = air temperature

W = moisture content

Ha = heat transfer coefficient

$\theta =$ grain temperature

It is assumed that the change in air temperature with respect to time at any position within the bed is small compared to the change with respect to position $(\frac{\partial T}{\partial x})$

4. Drying rate period

Two drying rate periods are considered for a deep layer. The maximum drying rate period does not occur until the drying front reaches the top of the bed. Capacity of the drying air is given in the following equation

$$\frac{dMa}{d\theta} = \frac{M_1 - M_x}{\theta_1} = \frac{AG(H_S - H_1}{W} \qquad 2.9$$

Where

$$\theta_1 = \frac{W(M_1 - M_X)}{AG(H_S - H_1)} \qquad 2.10$$

As soon as the drying front reaches the top of the bin, the rate of drying starts to decrease and is designated as the decreasing rate of layer drying as given by (Hall 1977) in the equation below:

$$\frac{dm_e}{d\theta} = 2.303 m^1 (m_x - m_e) \qquad 2.11$$

Where;

$$\theta_1 = \frac{1}{M} \log \frac{(M_X - M_e)}{(M_2 - M_1)} \qquad 2.12$$

$$\theta = \theta_1 + \theta_1 \qquad 2.13$$

Where

Ma = average moisture content in bed (db)

M_1= initial moisture content in bed (db)

M_e = equilibrium moisture content in bed (db)

M_2 = final moisture content in bed (db)

M_x = average moisture content in bed at end of maximum drying rate (db)

A = cross sectional area of dryer m^2

G = mass flow rate of air in kg of dry air/m^2

W = weight of grain in bin kg dry matter

H_s = humidity of saturated air in the grain bin kg water/kg dry air.

H_1 = humidity of air entering dryer, kg water/kg dry air

M^1 = rate of drying constant for deep bed/hr ($^2/_3 m^3 = k$).

θ_1 = time of drying during maximum rate period/hr

θ_T = time of drying during decreasing rate period/hr

$\theta =$ total time for drying

The drying time for the product in a deep layer is the sum of time required for the maximum rate of drying and the time required for the decreasing rate of drying. The amount of drying is indicated by the temperature of the exhaust air, which is cooled upon giving up its heat to evaporate moisture from the product.

When thin layer theory is applied to deep bed, it is limited in the following ways:

(i) Thin layer dry uniformly with no apparent gradient.

(ii) Temperature and humidity of the air change continuously as the air passes or progresses through a thick bed, where as these conditions are approximately constant for a thin layer. Consequently, the drying potential will decrease as the top of the bed is approached.

(iii) A further limitation is that in commercial operations, agricultural materials are seldom dried in thin layers but in deep beds.

2.7: Methods of Drying Fruits & Vegetables

Drying is a process of moisture removal from a product whereby the moisture content of the product is reduced to a predetermined value, usually by movement of heated air through the product. Drying may involve any of the following methods:

(a) Natural air drying (b) supplemental and low temperature drying (c) Heated air drying and (d) Forced air drying.

(a) Natural air drying

This method makes use of the solar energy and natural air currents. It is the most popular method of drying in the tropics where maturity of grains and some other crops coincide with the beginning of the dry season and where the level of technology is relatively low at present. This is especially true in Nigeria where the level of agricultural production is largely subsistent and other methods of drying would be highly uneconomical. Hall (1977) reported that the quality, quantity and economic value of the produce would be reduced as follows:

1. Cracking and cleavage formation due to alternate drying and wetting of the grain by sun in the day and wetting in the night over the long time required to dry the grain to the desired moisture content.
2. Moving the grain to and from the open court in the afternoon and night brings about the loss of some of the grain.
3. The labour involved in moving and stirring the grain at intervals is often expensive.
4. The rate of drying and extent of drying are not controlled, since every requirement for this drying method depends on nature

However, the use of natural air drying method may be economical for a small-scale farmer because of the following:

i. It does not involve the use of sophisticated equipment and energy cost is zero. However, the only cost may be that of labour. It is therefore cheap
ii. It requires little supervision
iii. The risk for fire hazard and breakdown of equipment is completely eliminated.

(b) Supplemental heat and low temperature drying

According to Hall (1970) this method involves the addition of a small amount of heat to the drying air raising its temperature before it enters the product. The temperature in most cases ranges from 5-10 % above ambient temperature. This method becomes important especially when the moisture content of the grain to be dried is close to the recommended safe storage moisture content, thus making the humidity of the drying air a very important factor. A small quantity of heat when added onto a natural air-drying system may give the supplemental heat required.

(c) Forced air drying

According to Ihekoronye and Ngoddy (1985), this method consists of a bin for drying of the products, a fan and motor to blow air through the product and an appropriate duct system for uniform distribution of air through the product. In forced air-drying, moisture is evaporated with the help of the atmospheric air or in some cases by heat from a source. The success of forced air drying depends on the proper selection and design of component parts, proper management of the system and favorable atmospheric conditions. The performance of the system is greatly affected by the depth of the material to be dried, unless a special consideration is given to the design to compensate for this. The power of the fan must be adequately chosen to suit the depth being handled.

(d) Heated air drying

This method of drying involves the circulation of heated air of about 15-60^{0}C through the produce by natural convection or by use of mechanical equipment such as a fan. Ejie (1981) observed that the air is heated by any of the following:

(i) Solar energy collector.

(ii) Burning carbon and hydrocarbon fuels e.g. coal, charcoal, rice husk etc

(iii) Utilizing the heat supplied by internal combustion engines

(iv) Electrical resistance heating.

Nwankwo (1980) reported that the drying operation might be completed in a few hours depending on dryer capacity. The dryer fans may be driven by an internal combustion engine or by an electric motor. The air distribution system could be by a lateral duct system, a single central duct or a perforated false floor.

Firing or heating of the circulating air could be done directly or indirectly. In the directly fired dryer, the fuel is burned and the hot gaseous products of combustion are thrown directly into the air stream entering into the air distribution system. Although this system has higher fuel utilization efficiency, there is the danger of grains being contaminated by sooth, un-burnt fuel and foul smelling fumes from the fuel. Meiregn *et al.* (1961) reported on hydrocarbon contamination of dried products. There is also the chance of blowing sparks into the product. These disadvantages are not obtainable in the indirect fired dryers. Here the hot combustion gases pass around with the drying air circulating and picking up heat before being distributed through the produce, the main advantages of heated air-drying are:

- Produce can be dried under any weather condition.
- The drying time is small, usually less than a day.

- The capacity of drying is high
- There is a minimum treatment loss of quality of grain at the end of drying which is approximated to the desired safe moisture contact level for milling.

The disadvantages however, are:

- Higher initial equipment cost.
- High cost of maintenance and fuel cost
- Increased fire hazard

It requires skilled labourers and there is a danger of contaminating the produce with smoke as in direct fired dryer.

2.8: Types of Dryers

The available type of dryers ranges from the use of forced air as a drying medium to heat assisted solar dryers. These can be broadly classified into three main types namely: convection, conduction and radiation dryers.

2.8.1: Convection Dryer

A convection dryer is sometimes referred to as direct dryers because the evaporating medium, which is usually air or hot gas, makes contact with the material being dried and moisture is carried away in the air stream (Dryden, 1976). Examples are:

Tunnel dryers, tray dryers and spray dryers.

(i) Tunnel dryers

Tunnel dryers make use of the batch drying process, where the material to be dried passes through the tunnel on wheeled trucks. When the material on one truck becomes dry, it is pulled out. The other trucks are then pushed forward and a fresh truck being pushed in at the opposite end. Hot drying gases usually flow from end to end in the tunnel or circulate. The hot air passes over the material, which is stacked or spread out on trays or the trucks. These dryer types are suitable for drying large quantities of materials such as bricks, ceramics, food products or heavy granular substances.

(ii) Tray dryers

Tray dryer can be used for a very wide range of drying duties such as food products, pigments, chemicals, and ceramic wares. The tray holds a batch of loose products (grain) at a depth of 0.6 m. the tr5ay base is of perforated metal that serves as ventilator for air passage at 14^0C above ambient temperature, moisture extraction rate will be up to one percent-hour or more. The materials are placed on the tray at even depth to allow even distribution of airflow.

(iii) Spray dryers

As the name implies, the product to be dried is sprayed onto a drying chamber through which hot air passes. The plant is actually used for drying liquid and semi-liquid substances. For example, milk, eggs, meat, vegetables extracts and a great variety of chemicals.

The drying air enters the dryer at a comparatively high temperature, because very quick rates of evaporation and heat absorption causes a very rapid fall in temperature, so that the substance being dried does not rise to a harmful temperature. To obtain satisfactory results from these type of dryer, it is essential that the substance be sprayed as globules of more or less uniform size, otherwise drying will not be uniform (Dryden, 1976).

2.8.2 Conduction dryers

Conduction dryers are also known as contact dryers and sometimes referred to as indirect dryers because evaporation proceeds from heat flow through a metal wall or plate on which the wet material rests. Examples include vacuum dryers, radial flow dryers and brook type dryers.

(i) Vacuum dryers

In this type of dryers, drying has to be carried out in vessels or chambers sufficiently strong to withstand external pressure, and a condenser with an air pump necessary to maintain the vacuum and draw off evaporated moisture. Majority of these dryers are batch dryers as a continuous-feed dryer necessitates the incorporation of a seal device to prevent loss of vacuum when the material enters and leaves the dryer.

When drying in a vacuum, a high rate of evaporation can be maintained at a low temperature as heating is by conduction through contact with hot steam heated metal surfaces of the dryer. Examples of products that can be dried in vacuum dryers are sugars, rubber, food staff (grains) and chemicals.

It is necessary to provide a stirrer or a re-circulator device that will equalize the air drying temperature over the drying material or the material is spread in a thin layer on steam heated trays.

(ii) Radial flow dryers

Radial flow dryers consist of two perforated metallic cylinder that are on the opposite sides of the drying bed, with this arrangement, hot air is driven up the central cylinder from the bottom and passes radically through the bed of grains the moisture extraction rate is similar to a tray dryer and it is necessary to provide stirring devices to aid in ensuring a reduction in the moisture gradient

(iii) The brooker batch dryer

This comprises of a firebox bed of four oil drums, a drying bed and a chimney for exhaust gases as reported by Brooker and Bakker (1974) and the drying bed is actually 1-2m above the firebox. A roof gives protection from rain. The ambient air rises from the heat exchanger from where it is warmed and gets in contact with the drying material. The dryer can be constructed economical with available local materials. For a very good result of end product to be achieved, a stirring device is provided to turn the crop regularly to allow equal exposure of air temperature through the products.

2.8.3: Radiation dryers

Radiation dryers are of broad categories in the sense that they are indeed a combination of types. In other words they are sometimes referred to as direct or indirect dryers. A typical example is the solar dryer, which is a combination of convection and radiation type of dryers.

2.9: Solar Dryers

Solar dryers are improved sun drying devices for dehydrating agricultural products. Although very expensive to produce, their end products are good looking, better testing, more nutritious and thus have enhanced marketability. They dry faster, safer and more efficiently than the traditional sun drying method (Obetta, 1989). A way of obtaining a low temperature rise is to heat the ambient air with solar energy through a solar collector. Generally, solar dryers are categorized into two broad classes as passive or active solar dryers.

2.9.1: Passive Solar Dryers

Passive solar dryers fall under two main groups; the direct and indirect passive solar dryers. Both use the principle of natural movement of heated air through radiation and convection means. In a direct passive dryer, the drying product is exposed to sun rays in a drying chamber covered with a transparent material made of glass or plastic. The drying chamber is a shallow insulated box with holes for cross ventilation. The sun’s rays produce short wave-length of solar radiation that penetrates the transparent cover and is then converted to low-grade heat when it strikes on opaque wall.

The energy produced then radiates on a long wave-length that cannot pass back through the cover. Thus it is utilized for drying the product in the chamber and producing a "green house effect". In the indirect passive dryers, the sun rays do not strike product to be dried. Drying is achieved by using a solar air collector, which channels hot air into the drying chamber. In this chamber the drying product is placed on mesh trays in layer. The solar collector should tilt towards the sun to optimize collection of more incident solar energy so that warmer and less dense air can rise naturally into the drying chamber.

b. Active solar dryers

Active solar dyers have similar operating principles such as that of passive solar dryer except that these dryers required mechanical or electrical means, such as fans for moving the solar energy in the form of heated air from the collector area to the dying chamber.

The drying product is spread on the tray screen in the chamber that ends with an exhaust stack, where moisture evaporated is discharged. The solar energy collected can be delivered as heat immediately to the drying chamber or it can be stored for later use if the storage facility is available (Obetta, 1989). However, solar energy storage facilities are bulky and very expensive, but are helpful in areas where the duration of sunlight is small.

2.10: Solar Drying of Fruits & Vegetables

In many parts of the world there is a growing awareness that renewable energy has an important role to play in extending technology to the farmer in developing countries to increase their productivity (Waewsak, *et al.*, 2006). Solar thermal technology is a technology that is rapidly gaining acceptance as an energy saving measure in agriculture application. It is preferred to other alternative sources of energy such as wind and shale, because it is abundant, inexhaustible, and non-polluting (Akinola, 1999; Akinola and Fapetu, 2006; Akinola *et al.*, 2006).

Solar air heaters are simple devices that heat air by utilizing solar energy and are employed in many applications requiring low to moderate temperature below 80^{o}C, such as crop drying and space heating (Kurtbas and Turgut, 2006). Drying processes play an important role in the preservation of agricultural products; they are defined as a process of moisture removal due to simultaneous heat and mass transfer (Ertekin and Yaldiz, 2004). According to Ikejiofor (1985) two types of water are present in food items; the chemically bound water and the physically held water.

In drying, it is only the physically held water that is removed. The most important reasons for the popularity of dried products are longer shelf-life, product diversity as well as substantial volume reduction. This could be expanded further with improvements in product quality and process applications.

The application of dryers in developing countries can reduce post harvest losses and significantly contribute to the availability of food in these countries. Estimations of these losses are generally cited to be of the order of 40% but they can, under very adverse conditions, be nearly as high as 80%. A significant percentage of these losses are related to improper and/or untimely drying of foodstuffs such as cereal grains, pulses, tubers, meat, fish, etc. (Togrul and Pehlivan, 2004).

Traditional drying, which is frequently done on the ground in the open air, is the most widespread method used in developing countries because it is the simplest and cheapest method of conserving foodstuffs. Some disadvantages of open air drying are: exposure of the foodstuff to rain and dust; uncontrolled drying; exposure to direct sunlight which is undesirable for some foodstuffs; infestation by insects; attack by animals; etc (Madhlopa, *et al.*, 2002).

In order to improve traditional drying, solar dryers which have the potential of substantially reducing the above-mentioned disadvantages of open air drying have received considerable attention over the past 20 years (Kalowole, 2011). Solar dryers of the forced convection type can be effectively used. They however need electricity, which unfortunately is non-existent in many rural areas, to operate the fans. Even when electricity exists, the potential users of the dryers are unable to pay for it due to their very low income.

Forced convection dryers are for this reason not going to be readily applicable on a wide scale in many developing countries. Natural convection dryers circulate the drying air without the aid of a fan. They are therefore, the most applicable to the rural areas in developing countries.

Solar drying may be classified into direct, indirect and mixed-modes. In direct solar dryers the air heater contains the grains and solar energy passes through a transparent cover and is absorbed by the grains. Essentially, the heat required for drying is provided by radiation to the upper layers and subsequent conduction into the grain bed.

In indirect dryers, solar energy is collected in a separate solar collector (air heater) and the heated air then passes through the grain bed, while in the mixed-mode type of dryer, the heated air from a separate solar collector is passed through a grain bed, and at the same time, the drying cabinet absorbs solar energy directly through the transparent walls or roof. Soponronnarit (1995) reviewed the research and development work in solar drying conducted in Thailand during the past 15 years (since 1980s). It was found that, in terms of techniques and economy, solar drying for some crops such as paddy, multiple crops and fruit is feasible. However, the method has not been widely accepted by farmers. Most of the solar air heaters developed in

Thailand has used modifications to the building roofs. Both bare and glass-covered solar air heaters were reported to be technically and economically feasible when compared to electricity but have not been able to compete with fuel oil.

Bahnasawy and Shenana (2004) developed a mathematical model of direct sun and solar drying of some fermented dairy products. The main components of the equations describing the drying system were solar radiation, heat convection, heat gained or lost from the dryer bin wall and the latent heat of moisture evaporation. The model was able to predict the drying temperatures at a wide range of relative humidity values. It also has the capability to predict the moisture loss from the product at wide ranges of relative humidity values, temperatures and air velocities.

Enein (2000) reported a parametric study of a solar air heater with and without thermal storage for solar drying applications. An optimization process for a flat-plate solar air heater with and without thermal storage was carried out. Three kinds of material for thermal storage were used, i.e. water, stones and sand. The average temperature of flowing air increases with the increase of the collector length and width up to typical values for these parameters. The outlet temperature of flowing air was found to decrease with an increase of the airflow channel spacing and mass flow rate. The thermal performance of the air heater with sensible storage materials is considerably higher than that without the storage. An optimal thickness of the storage material of about 0.12 m was found to be convenient for drying various agriculture products. In addition, the proposed mathematical model may be used for estimating of the thermal performance of flat platesolar air heater with and without thermal storage.

Pangavhen, *et al*. (2002) proposed a design, development and performance testing of a new convection solar dryer, the solar dryer is capable of producing average temperature between

50 and 55°C, which was optimal for dehydration of grapes as well as for most of the fruits and vegetables. This system was capable of generating an adequate natural flow of hot air to enhance the drying rate. The drying airflow rate increases with ambient temperature by the thermal buoyancy in the collector. The collector efficiencies ranged between 26% for mass flow rate of 0.0126 kg/s of air and 65% for mass flow rate of 0.0246 kg/s. This was sufficient for heating the drying air. The drying time of grapes was reduced by 43% compared to the open sun drying.

Bena and Fuller (2002) developed a direct-type natural convection solar dryer with simple biomass burner. It was expected to be suitable for small-scale processors of dried fruits and vegetables in non-electrified areas of developing countries. The capacity of the dryer was found to be 20–22 kg of fresh pineapple arranged in a single layer of 1-cm-thick slices. The key features of the biomass burner were found to be the addition of thermal mass on the upper surface, an internal baffle plate to lengthen the exhaust gas exit path and a variable air inlet valve. The author also suggested some modifications to further improve the performance of both the solar and biomass components of the dryer.

Ekechukwu and Norton (1999) presented a comprehensive review of the various designs, details of construction and operational principles for a variety of practical solar-energy drying systems. The appropriateness of each design type for applications used by rural farmers in developing countries was discussed.

Bennamoun and Azeddine (2003) studied a simple, efficient and inexpensive solar batch dryer for agricultural products through simulations. They used onion as the dried product, and the shrinking effect was taken into account. In addition, it was suggested that the study could be developed for other agricultural products and for the behavior of solar dryer in different seasons.

Sebaii, *et al*. (2002) reported a study of an indirect type natural convection solar which investigated experimentally and theoretically for drying grapes, figs, onions, apples, tomatoes and green peas. The drying constants for the selected crops were obtained from the experimental results and were then correlated with the drying product temperature. Linear correlation between drying constant and product temperature were proposed for the selected crops. The empirical constants of Henderson's equation were obtained for all the materials from investigation, which are not available in the literature. The proposed empirical correlation suggested that it could well describe the drying kinetics of the selected crops.

Gallali, *et al*. (2000) reported the result of an investigation of some dried fruit and vegetables (grapes, figs, tomatoes and onions) based on chemical analysis (vitamin C, total reducing sugars, acidity, moisture, and ash content) and sensory evaluation data (color, flavor, and texture). They compared products dried by solar dryers and natural sun drying. The study indicated that using solar dryers gives more advantages than natural sun drying, especially in terms of drying time.

Karathanos and Belessiotis (1997) reported the sun and solar air drying kinetics of some agricultural products, i.e. sultana grapes, currants, figs, plums and apricots. The drying rates were found for both solar and industrial drying operations. Air and product temperatures were measured for the entire industrial drying process. It was shown that most materials were dried in the falling rate period. Currants, plums, apricots and jigs exhibited two drying rate periods, a first slowly decreasing (almost constant) and a second fast decreasing (falling) drying rate period. In addition, they indicated that the industrial drying operation resulted in a product of superior quality compared to products dried by solar dehydration.

2.11: Benefits of Solar Drying of Fruits and Vegetables

Solar energy a form of sustainable energy has a great potential for wide variety of applications because it is abundant and accessible, especially for countries located in the tropical region. Solar drying of fruits and vegetables overcomes the drawbacks of traditional open sun drying such as, contamination from dust, insects, birds and animals, lack of control over drying conditions, possibility of chemical, enzymic, and microbial spoilage due to long drying times. Solar drying is advantageous over normal convective dryers like hot air dryer, which requires enormous fuel and energy cost.

Due to abundant availability of solar radiation attention has been gradually diverting to utilize this renewable energy for a number of applications. Among these dehydration of food & non-food items is an important sector. This solar drying enables Good Manufacturing Practices (GMP) & yields export worthy processed foods with long shelf life meeting the sanitary & phyto sanitary standards of the importing countries. This novel technology is a very viable & valuable one.

Solar drying of agricultural produce permits

(1) Early harvest;

(2) Planning of the harvest season;

(3) Long-term storage without deterioration;

(4) Taking advantage of a higher price a few months after harvest;

(5) Maintenance of the availability of seeds; and finally

(6) Selling a better quality product

Drying using the sun under the open sky for preserving food and agricultural crops has been practiced since ancient times. However, this process has many disadvantages, spoilt products due to rain, wind, moisture and dust; loss of produce due to birds and animals; deterioration in the harvested crops due to decomposition, insect attacks and fungi, etc. Further, the process is labor intensive, time consuming and requires a large area for spreading the produce out to dry. Artificial mechanical drying, a relatively recent development, is energy intensive and expensive, and ultimately increases the product cost. Solar-drying technology offers an alternative which can process the vegetables and fruits in clean, hygienic and sanitary conditions to national and international standards with zero energy costs. It saves energy, time, occupies less area, improves product quality, makes the process more efficient and protects the environment (Sharma et al., 2009). Some differences between the open sun drying and solar drying are shown in Table 1.

A typical solar food dryer improves upon the traditional open-air sun system in five important ways:

• It is faster. Foods can be dried in a shorter period of time. Solar food dryers enhance drying times in two ways. Firstly, the translucent, or transparent, glazing over the collection area traps heat inside the dryer, raising the temperature of the air. Secondly, the flexibility of enlarging the solar collection area allows for greater collection of the sun's energy.

• It is more efficient. Since foodstuffs can be dried more quickly, less will be lost to spoilage immediately after harvest. This is especially true of products that require immediate drying such as freshly harvested grain with high moisture content. It is hygienic. Since foodstuffs are dried in a controlled environment, they are less likely to be contaminated by pests, and can be stored with less likelihood of the growth of toxic fungi.

• It is healthier. Drying foods at optimum temperatures and in a shorter amount of time enables them to retain most of their nutritional value such as vitamin C.

• It is cheap. Uses freely available solar energy instead of conventional fuels to dry products.

Below are the tabular differences between open-sun drying and solar drying:

Table 1: Differences between open sun and solar drying

Open Sun drying	**Solar Drying**
Traditional method	More recent invention
Delayed drying	Fast drying
Problems of contaminating by birds, insect etc	No contamination
Less hygienic & less clean	Highly hygienic & very clean
Inferior quality products	Best quality products
May not meet GMP	Meets GMP requirements
Drying possible only on sunny days	Drying possible on all days including cloudy and rainy days with electrical backup
Poor sensory qualities to products-appearance/colour & texture	Highly acceptable sensory qualities to products-attractive appearance, colour & texture
Uneven drying	Even/uniform drying
More nutrient loss	Better nutrient retention
Low profit margins	Best profit margins due to quality products
Space requirement is higher	Low space is required

(Bena *et al*. 2002*).*

2.12: Importance of Solar Dried Food

For centuries, people of various nations have been preserving fruits, other crops, meat and fish by drying. Drying is also beneficial for hay, copra, tea and other income producing non-food crops. With solar energy being available everywhere, the availability of all these farmproduce can be greatly increased. It is worth noting that until around the end of the 18th century when canning was developed, drying was virtually the only method of food preservation.

Ikejiofor (1985) 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.

Also, food scientists have found that by reducing the moisture content of food to 10 to 20%, bacteria, yeast, mold and enzymes are all prevented from spoiling it (Gallali, *et al*., 2000). The flavour and most of the nutritional value of dried food is preserved and concentrated. Dried foods do not require any special storage equipment and are easy to transport (Waewsak, *et al.*, 2006). Dehydration of vegetables and other food crop by traditional methods of open-air sun drying is not satisfactory, because the products deteriorate rapidly, studies showed that food items dried in a solar dryer were superior to those which are sun dried when evaluated in terms of taste, colour and mould counts (Gallali, *et al*., 2000).

Solar dried food are quality products that can be stored for extended periods, easily transported at less cost while still providing excellent nutritive value (Alamu, *et al*., 2010). This project work therefore presents the design and construction of a solar dryer which was used in determining the physicochemical properties of tomato, pepper and okra.

The study is timely as it aimed at providing the Nigerians with a cheap, hygienic and efficient way of preserving her agricultural produce from the harvest for further in off harvest season. The introduction of an affordable and efficient solar dryer will help the Nigerians especially the low-income farmers to practice food preservation. The study helped discover the nutritional content of the dried products (tomatoes, pepper and okra).

CHAPTER THREE

3.0 MATERIALS AND METHODS

3.1: Materials Used for the Solar Dryer Construction

The following materials were used for construction of the passive solar dryer:

- Mild Steel Sheet (gauge14): was used as the casing (housing) of some parts of the chamber (side and back of the drying chamber). A 6mm thick mild steel sheet was also used for the absorber
- Glass – was used as the solar collector cover, the drying chamber and for the roofing. It permits the solar radiation into the system but reduces the flow of heat energy out of the systems.
- Galvanized iron frames for the drying trays.
- Nails and glue as fasteners and adhesives.
- Insect net at air inlet and outlet - to prevent insects from entering into the dryer.
- Hinges and handle for the dryer's door.
- Paint (black)

Also, a thermometer was used to measure the ambient and dryer temperature.

3.2: Sample Preparation

The vegetables used for this work was purchased at Nsukka main market barely two days after harvest. They were washed and cut into slices with sterilized stainless steel knife to reduce the microbial load and contaminants and blanched with steam for 3 minutes which according to Mate *et al.* (1999) and Ahmed *et al.* (2001) will help improve the drying process by reducing the drying time and yields better quality products. The samples were then divided into two parts; one part was subjected into open sun drying whereas the other one was loaded into the passive solar dryer constructed for the purpose from locally available materials. The solar dryer used for this work is of natural convection type.

In order for drying to be continual even when the sun is no more shining, a movable heat storage unit was incorporated into the dryer's chamber. To ascertain whether the dryer's temperature could be high enough to dry the vegetables, the empty (unloaded) dryer's temperature without heat storage was measured every 30 minutes for the period of testing and replicated five times consecutively. The dryer was tested with vegetable samples both when it was without and with the heat storage unit incorporated. These were conducted simultaneously with open sun drying as a control. At intervals of two hours each sample was weighed using a digital weighing balance and the moisture content was calculated from the weight loss. The figures were monitored and recorded until the samples were dried. Each sample was replicated four times to ensure precision and the average findings recorded.

3.3: Physicochemical Analysis

The physicochemical properties were determined in the National Centre for Energy Research and Development (NCERD) Laboratory, University of Nigeria, Nsukka. The properties include:

i. Moisture content ii. Protein content iii. Fat content iv. Fibre content v. Ash content vi. Carbohydrate content vii. Vitamin C content

Three samples analysed are the fresh vegetable, open sun dried and solar dried samples. The fresh, open and solar dried samples were analysed for proximate composition using the recommended method of Association of Official Analytical Chemists, AOAC (1990). Also, statistical analysis of the data was conducted by analysis of variance (ANOVA) using Completely Randomize Design (CRD) at probability of 5% (0.05) and means were separated by Duncan's New Multiple Range Test (DNMRT).

3.4: Physicochemical Analyses of Samples

The fresh, solar dried and open sun-dried vegetables were analysed for proximate composition as discussed below:

3.4.1: Nitrogen/Crude Protein Determination

The micro-Kjedahl method as described in Pearson (1976) was used. This method involves the estimation of the total nitrogen in the waste and the conversion of the nitrogen to protein with the assumption that all the protein in the waste was present as nitrogen. Using a conversion factor of 6.25, the actual percentage of protein in the waste was calculated

$$\% \text{ crude protein} = \% \text{ Nitrogen} \times 6.25 \qquad 3.1$$

Digestion

Apparatus used: Micro-Kjedahl digestion flask (500ml capacity) (Make: Barloworld U.K, model Fk 500/3l) Ohaus weighing balance (0.001g accuracy, model AR3130, Made in England).

Reagents used: Catalyst mixture (Mixture of 20g potassium sulphate, 1g copper sulphate and 0.1g selenium powder), concentrated tetraoxosulphate (VI) acid.

Procedure

1g of the ground waste sample was weighed into the Kjedahl digestion flask. 1g of the catalyst mixture was weighed and added into the flask. 15 ml of conc. H_2SO_4 was also added. Heating was carried out cautiously on a digestion rack in a fume cupboard until a green-wash clear solution appeared. The digest was allowed to clear for about 30 minutes. It was further heated for more 30 minutes and allowed to cool. 10 ml of distilled water was added to avoid caking. Then the digest was transferred with several washings into a 100 ml volumetric flask and made up to the mark with distilled water.

Distillation

Apparatus used: micro Kjedahl distillation unit (make: Barloworld, UK model 734205) 100 ml conical flask. (Receiver flask)

Reagents used: 40% NaOH, Boric acid indicator solution

Procedure

A 10ml aliquout was collected from the digest and put in the flask. A 100ml receiver flask containing 5ml boric acid indicator solution was placed under the condenser of the distillation apparatus so that the tip was 2cm inside the indicator. 10ml of 40% NaOH solution was added to the digested sample through a funnel stop cork. The distillation commenced by closing the steam jet arm of the distillation apparatus. The distillate was collected in the receiver flask (35ml).

Titration

Titration was carried out with 0.01M standard HCl to first pink colour.

$$\% \text{ Nitrogen} = \frac{Titrationvol. \times 0.014 \times M \times 100x}{wt.ofsample} \frac{100}{10} \quad 3.2$$

Where M= molarity of std HCl

% crude protein =% N x 6.25

Equation of the Reaction

$$\text{N in waste + conc. } H_2SO_4 \longrightarrow (NH_4)_2SO_4 \quad 3.3$$

$$(NH_4)_2SO4 + 2NaOH \xrightarrow{Catalyst} Na_2SO_4 + 2H_2O + 2NH_3 \quad 3.4$$

The ammonia generated was collected in excess boric acid.

$NH_3 + H_3BO_3 \longrightarrow NH_4BO_2 + H_20$ 3.5

After complete ammonia distillation, the ammonium borate solution was titrated with a standard HCl solution. Strong acid (HCl) displaces weak boric acid from its salt.

$NH_4BO_2 + HCl \longrightarrow NH_4Cl + HBO_2$ 3.6

1 mole of ammonia was equivalent to 1 mole of ammonium borate which was equivalent to 1 mole of HCl.

Knowing the amount of 0.01 M HCl used for the titration, the amount of ammonia bound to borate can be calculated. From thwas amount, the quantity of nitrogen in the sample can be calculated.

3.4.2: Crude Fibre Content Determination

This determination was done to have an idea of the materials that are indigestible in the waste. It was largely made up of cellulose and small lignin. Crude fibre was obtained as an organic residue left behind after the raw waste has been subjected to standard condition with organic solvents, dilute mineral acids and sodium hydroxide.

The A.O.A.C (1990) method was used. 1g of the sample was weighed (w_1) into a 600ml beaker and 150ml of preheated 0.128M H_2SO_4 was added to it. This was heated for 30 minutes and filtered under suction and washed with hot distilled water until the washings were no longer acidic. The residue was then transferred to a beaker and boiled for 30 minutes with 150ml of preheated KOH (0.223M). It was filtered and washed with hot water until the washings are no longer alkaline. The residue was washed three times with acetone and dried in an oven at 105^oC for 2 hours. It was then cooled in a desiccator, weighed (W_2) and ashed in a muffle furnace (make: Vecstar, model LF3, made in U.K) at 500^oC for 4 hours. The ash obtained was cooled in a desiccator and weighed (W_3). Using equation 19 below, the percentage crude fibre was calculated as:

$$\% \text{ Crude fibre} = \frac{W_2 - W_3}{W_1} \times \frac{100}{1} \qquad 3.7$$

Where:

W_1= weight of sample

W_2= Weight of dry residue

W_3=Weight of ash.

3.4.3: Determination of Moisture Content

The A.O.A.C method (1990) was used. Porcelain crucibles were washed and dried in an oven at 100^{o}C for 30 minutes and allowed to cool in a desiccator. One gramme of the raw waste was placed into weighed crucibles and then put inside the oven set at 105^{o}C for 4 hours. The samples were removed from the oven after this period and then cooled and weighed. The drying was continued and all the samples with the crucibles weighed until a constant weight was obtained and the percentage moisture content was determined using equation 20 below:

$$\% \text{ moisture} = \frac{A - B}{A} \times \frac{100}{1} \qquad 3.8$$

A = Original weight of sample

B = Weight of dried sample.

3.4.4: Ash Content Determination

The residue remaining after all the moisture have been removed and the fats, proteins, carbohydrates, vitamins and organic acids burnt away by ignition at about 600^{o}C was called ash. It was usually taken as a measure of the mineral content of the raw waste.

Using AOAC (1990) method, 1g of the finely ground samples were weighed into porcelain crucibles which have been washed, dried in an oven at 100^{o}C, cooled in a desiccator and weighed. They were then placed inside a muffle furnace and heated at 600^{o}C for 4 hours. After this, they were removed and cooled in a desiccator and then weighed. The ash content was determined using equation 21 below:

$$\% \text{ Ash} = \frac{A - B}{C} \times \frac{100}{1} \qquad 3.9$$

A = Weight of crucible + ash

B = Weight of crucible

C = Weight of original sample

3.4.5: Fat Content Determination

Pearson (1976) method was used. This involves the use of Soxhlet extraction apparatus. This method involves continuous extraction of waste with organic solvent such as petroleum ether for 4 hours or so depending on the volume of sample. To carry out the extraction, the flask was washed and dried in an oven. It was then cooled in a desiccator and weighed.

1g of the ground waste sample was accurately weighed and transferred into a rolled filter paper and then placed inside the extraction thimble. The thimble was placed inside the extractor. Some quantity of petroleum ether was poured inside the extraction flask (usually three-quarter of the volume of flask). The condenser and the flask were connected to the extractor. The whole unit was place on a heating mantle for 4 hours after which the petroleum ether was recovered. The oil collected in the flask was dried in an oven at 105^{o}C. It was then weighed and the percentage fat calculated as shown below

$$\% \text{ fat} = \frac{C - A}{B} \times \frac{100}{1} \qquad 3.10$$

C = weight of flask +oil

A = weight of empty flask

B = weight of original sample.

3.4.6: Determination of Carbohydrate Content

This was determined subtracting the sum of % ash, % protein, % fat, % moisture and % crude fibre from 100.

CHAPTER FOUR

4.0 DESIGN AND DESCRIPTION OF THE PASSIVE SOLAR DRYER

4.1: Design Considerations

The solar crop dryer was designed for drying agricultural products that requires low temperature rise above the ambient. A temperature rise o 40-60 ^{0}C was considered for the study. The produce used for the study is tomato, pepper and okra. The vegetables were chosen for the study because of their perishable nature and their availability locally. Therefore, proper preservation of the produce through drying will enhance the storability and transportability, and hence will further increase the economic gains from the crops. Solar drying is considered environmentally friendly, none contaminating and none polluting. Medium of heat transfer is essentially by air current and the drying system is passive. The intermittent nature of solar radiation was considered as important factor in the designs. The design therefore incorporates a heat storage system which stores and supplies heat to the drying chamber during the off-sunshine hours. Materials of construction are locally available and friendly to end-users with low maintenance cost.

4.2: Description of the Solar Dryer

The solar dryer is of the dimensions 176 x 152 x 54 cm as shown in figures 4 and 5. It consists of a solar collector (air heater), a drying chamber, heat storage unit and drying trays. The solar crop dryer is constructed of framed angle iron and transparent glass cover. Figures 4 and 5 below shows the various parts and the sectional view of the solar dryer

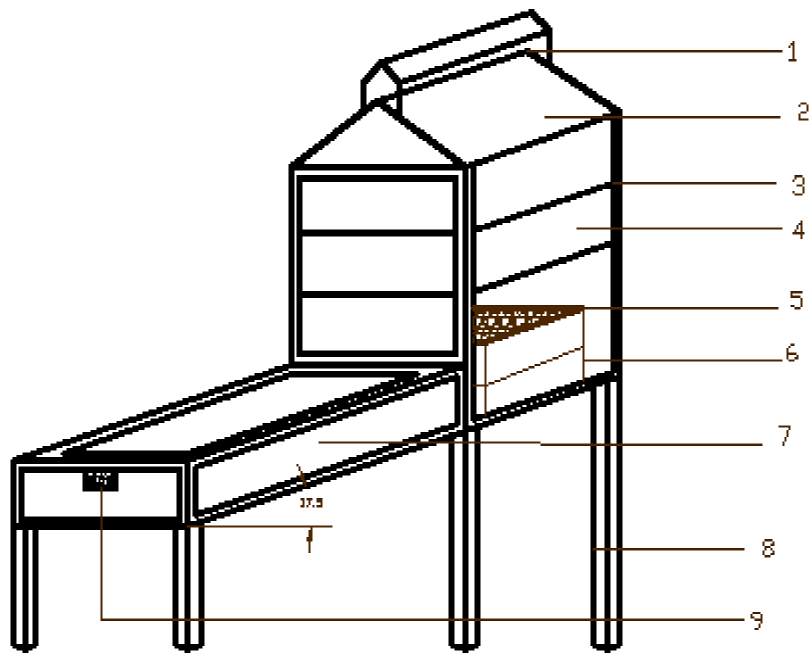

Fig 4: Isometric view of the Passive Solar dryer with various parts

1: Chimney 2: Glass roof 3: Drying tray 4: Drying chamber 5: Heat Storage unit 6: Heat storage support 7: Collector 8: Support 9. Air inlet

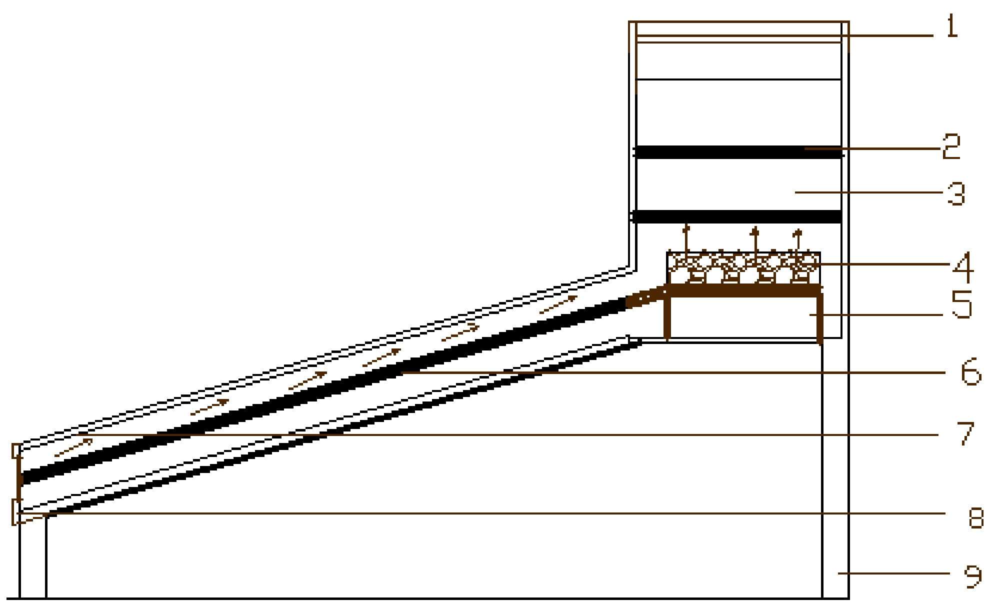

Fig 5: Sectional view of the solar dryer

1: Chimney 2: Drying Tray 3: Drying chamber 4: Heat Storage Unit 5: Heat Storage support 6: Absorber 7: Collector Glass 8: Air inlet 9: Dryer support

4.2.1: Drying chamber: The drying chamber is the section where crop drying processes takes place. It is constructed with 2cm angle iron frame and covered with 2cm thick transparent glass cover that allows direct solar radiation into the drying chamber. The chamber consists of two drying trays measuring 42 x 43 x 23cm. It has a hot air inlet, which is located at the bottom end of the chamber. This provision allows hot air from the integrated solar heat storage unit coming from the solar energy collector into the chamber while two exhaust air outlets were provided at the upper sides of the drying chamber. The roof of the dryer is covered with a transparent glass cover. This allows direct solar radiation into the chamber thereby enhancing crop drying operation.

4.2.2 Collector (Air Heater): The solar collector assembly consists of air flow channel enclosed by transparent cover (glazing). The heat absorber plate of the solar air heater of the collector was constructed using 3mm thick metal which was painted black and placed below the cover to absorb the incident solar radiation across the glass cover thereby heating the air between it and the cover. Mild steel was chosen because it’s absorptivity. One end of the solar collector has an air inlet vent of area 0.0888 m^2, which is covered by a galvanized wire mesh to prevent entrance of rodents, the other end opens to the plenum chamber. To determine the area of the collector with its dimensions:

The air gap height was taken as 5.6cm = 0.056m and the width of the collection assumed to be 45cm = 0.45m.

Thus, volumetric flow rate of air V'a = Va × 0.056 × 0.38 4.1

V'a = 0.15 × 0.056 × 0.38= 3.19 × 10-3m3/s

Thus mass flow rate of air: Ma = vaρa (Bolaji and Olalusi, 2008) 4.2

Density of air ρa is taken as 1.2252kg/m3 at S.T.P

Ma = 3.19 × 10-3 × 1.2252 = 3.91 × 10-3kg/s

Therefore, area of the collector AC

AC = (3.91 × 10-3 × 1000 × 30)/(0.5 × 982.11) = 0.239m2

The length of the solar collector (L) was taken as;

L = Ac/B 4.3

= 0.3537/0.45 = 0.53m Thus, the length of the solar collector was taken approximately as 0.6m.

Therefore, collector area was taken as (0.45 x 0.53) 2 = 0.239m^2

4.2.3: Cover plate: This is a transparent sheet that was used to cover the absorber, thereby preventing dust and rain from coming in contact with the absorber; it also retards the heat from escaping.

4.2.4: Polystyrene: This was used as insulator to minimize heat loss from the system.

4.2.5: Heat Storage Unit: the heat storage unit is an integral part of the drying chamber. It stores heat carried by hot air coming the solar collector. This discharges its stored energy during off sunshine hours. Mild steel rectangular box of dimension 40 x35 x13cm filled with black pebbles was incorporated at the base of the dryer's chamber.

The energy storage of the unit is estimated with;

$$Q = mc_p\Delta t \qquad 4.3$$

Where $m = c_p = \Delta t$

4.3: Design Equations

4.3.1: The energy balance equation for the drying process

The energy balance equation for the drying process was given by Ayensu (1997) as follows:

$$w_w L_w = wa\ C\ (T_i - T_f) \qquad 4.4$$

where w_w = weight of water evaporated from the crop and absorbed by the drying air; wa = weight of drying air; L_w = latent heat of vaporization for free water; C = Specific heat capacity of air; T_i = Initial temperature (inlet temperature); T_f = Final temperature (outlet temperature after moisture removal).

The drying equation of the form is given by Brooker et al. (1974) as follows:

$M(t) = Mo \exp(-kt)$ describes the process

$$\frac{dM}{dt} = \frac{h'A}{h_{fg}}(T_\infty - T_i) \quad 4.5$$

where dM/dt = rate of drying, h′ = heat transfer coefficient; T_i = Initial drying temperature inside the dryer; T_∞ = Final drying air temperature inside the dryer; h_{fg} = latent heat of vapourization; A = area of the dryer.

4.3.2: Change in temperature

The energy balance equation is as indicated in Equation (1):

$$w_w L_w = wa\, C\, (T_i - T_f) \quad 4.7$$

$$w_w L_w = wa\, C\, (\delta_t)$$

However, δt is also given in the Equation by Nelkon (1978) as Heat (Eu)

$$= m\, Ca\, (\delta_t) \quad 4.8$$

Where Eu = the useful energy inside the passive dryer, m = mass of drying air, Ca = specific heat capacity of air.

4.3.3: Weight of water removed

According to Basunia and Abe (2001), the total useful energy required evaporating moisture and the net radiation received by the tilted collector is given as:

$$Eu = A\, I\, Rb\, \acute{\eta} = I_{tt}\, x\, A\, x\, \acute{\eta} \quad 4.9$$

From the drying Equation (2),

$w_w L = Eu$

Therefore $W_w = I_{tt} x A x \acute{\eta}/L_w$ 4.10

Hence, the final moisture content would be

$$\frac{m_i w_T - 100 w_w}{w_T - w_w} \quad 4.11$$

4.3.4: The orientation of the Solar Collector

The flat-plate solar collector is always tilted and oriented in such a way that it receives maximum solar radiation during the desired season of used. The best stationary orientation is due south in the northern hemisphere and due north in southern hemisphere. Therefore, solar collector in this work was oriented facing south and tilted at 17.5^o to the horizontal. This is approximately 10^o more than the local geographical latitude (Nsukka a location in Nigeria, 6.87^oN), which according to Adegoke and Bolaji (2000), is the best recommended orientation for stationary absorber. This inclination is to allow easy and enhance air circulation. It is energized by the sun's rays entering through the glazing collector. The trapping of the rays is enhanced by the inside surface of the collector that was painted black and the trapped energy heats the air inside the collector. The green house effect achieved within the collector drives the air current through the drying chamber. If the vents are open, the hot air rises and escapes through the upper vent in the drying chamber while cooler air at ambient temperature enters through the lower vent in the collector. Therefore, an air current is maintained, as cooler air at a temperature T_a enters through the lower vents and hot air at a temperature T_e leaves through the upper vent.

When the dryer contains no items to be dried, the incoming air at a temperature 'T_a' has relative humidity 'H_a' and the out-going air at a temperature 'T_e', has a relative humidity 'H_e'.

Because $T_e > T_a$ and the dryer contains no item, $H_a > H_e$. Thus there is tendency for the out-going hot air to pick more moisture within the dryer as a result of the difference between H_a and H_e. Therefore, insulation received is principally used in increasing the affinity of the air in the dryer to pick moisture.

CHAPTER FIVE

5.0 RESULTS AND DISCUSSION

Drying was conducted in both rainy and dry seasons in order to evaluate the effect of seasonality on drying of the crops. For the rainy season the drying was conducted in June because by this period the rain has come fully and it also falls within the harvest period. The highest chamber and ambient day temperatures without the heat storage system incorporated recorded was 53.3 and 32.8°C respectively (Table 5 of the appendix) while the chamber and ambient temperatures with heat storage was 65.6 and 32.2°C (Table 6 of the appendix) respectively. Therefore, the incorporation of the heat storage unit into the dryer increased the chamber temperature and also results to prolonged emitted energy up to 2-3 of higher temperature within the drying chamber as shown in table 3 and figure 8. This consequently increased the drying process even after the sun has ceased shinning and during the cloudy periods of the day. During the dry season (December), there was a little rise in ambient temperature as compared with rainy season. The maximum ambient and chamber temperature obtained during the dry season was 34.6 and 68.2 °C. As a result of the relative rise in temperature during the dry season, the rate of moisture lose was faster than during the rainy season.

The open sun and solar drying were carried out simultaneously over the period. The open sun drying served as the control. The ambient and drying chamber temperatures throughout the duration of the drying process ranged between 22- 33°C and 30-65°C respectively. From the temperature graphs below, it could be deduced that the highest temperature is mostly recorded between 12 to 2pm noon (fig 6, 7, 8, 10 and 12) except for fig 9 and 11 that appears zigzag due to rainfall on the days.

Figures 13-27 (Tables 12-26 of the appendix) indicates that moisture loss in solar dried vegetables was faster and lower than the open sun dried samples and as such makes the solar dried products of lesser tendency to mould and bacterial growth. Also, the open sun dried samples had to be carried into the sheltered place each time it rained.

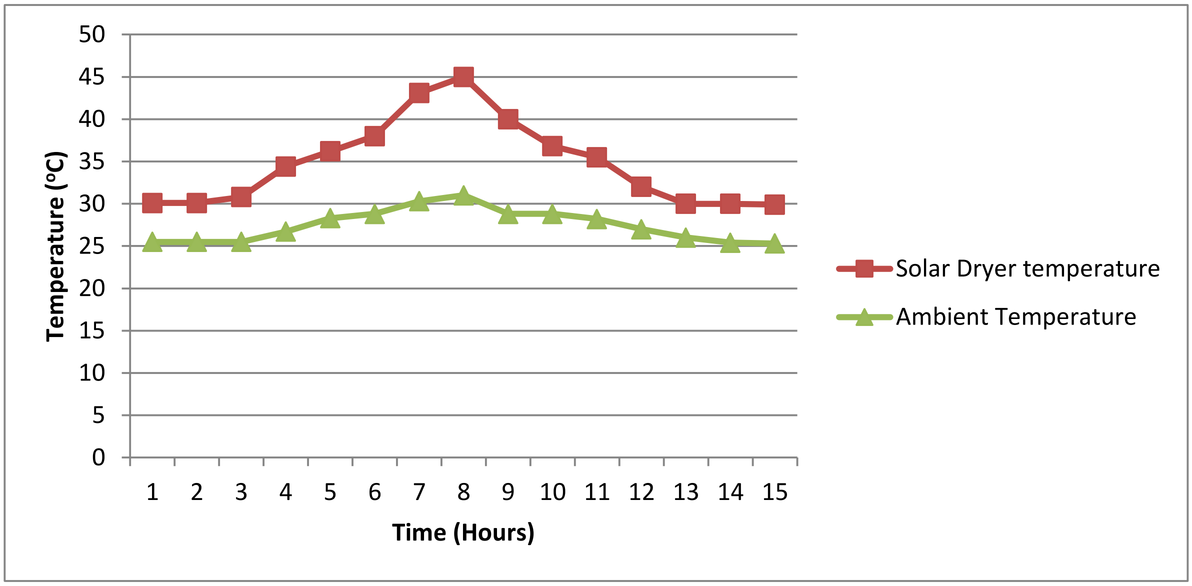

Figure 6: Graph of Average Unloaded Solar dryer and Ambient Temperatures (°C) without Heat Storage System (Rainy Season)

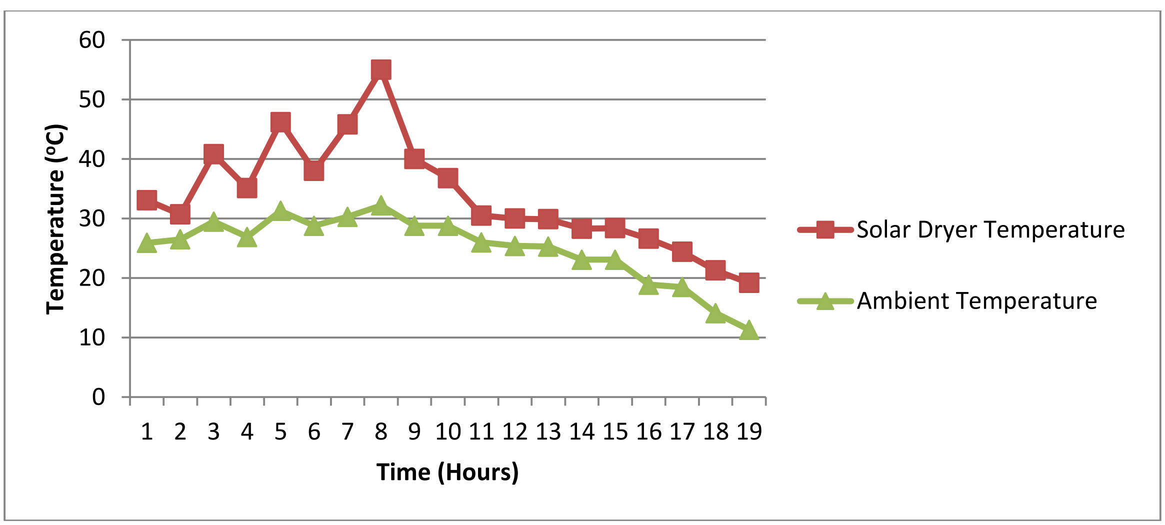

Figure 7: Graph of Average Unloaded Solar dryer and Ambient Temperatures (°C) with Heat Storage System during the Rainy Season

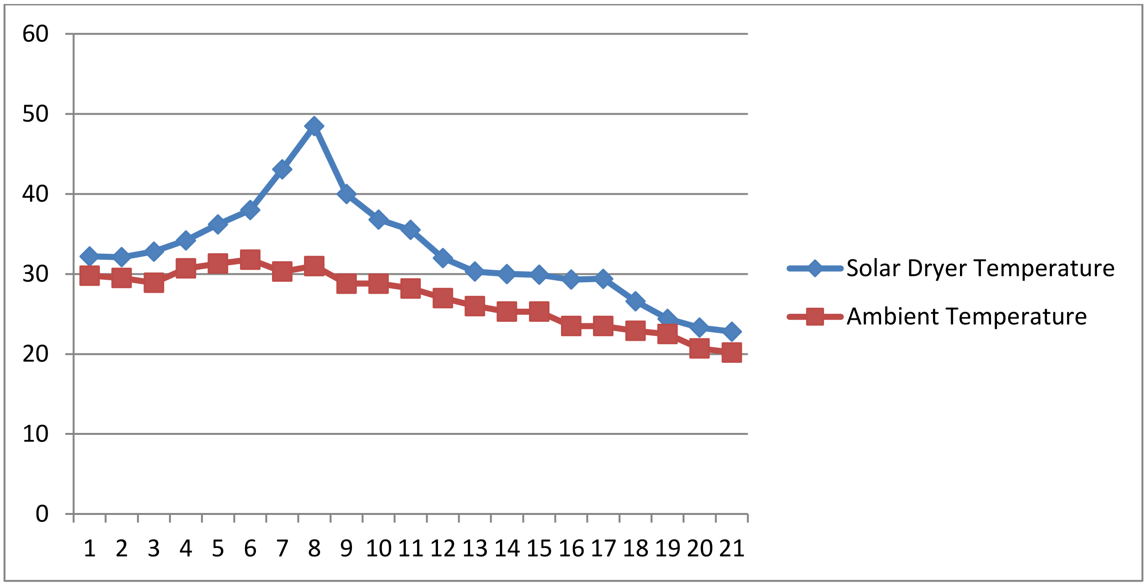

Figure 8: Graph of loaded Chamber and Ambient Temperature (^oC) with Heat Storage System during the Dry Season

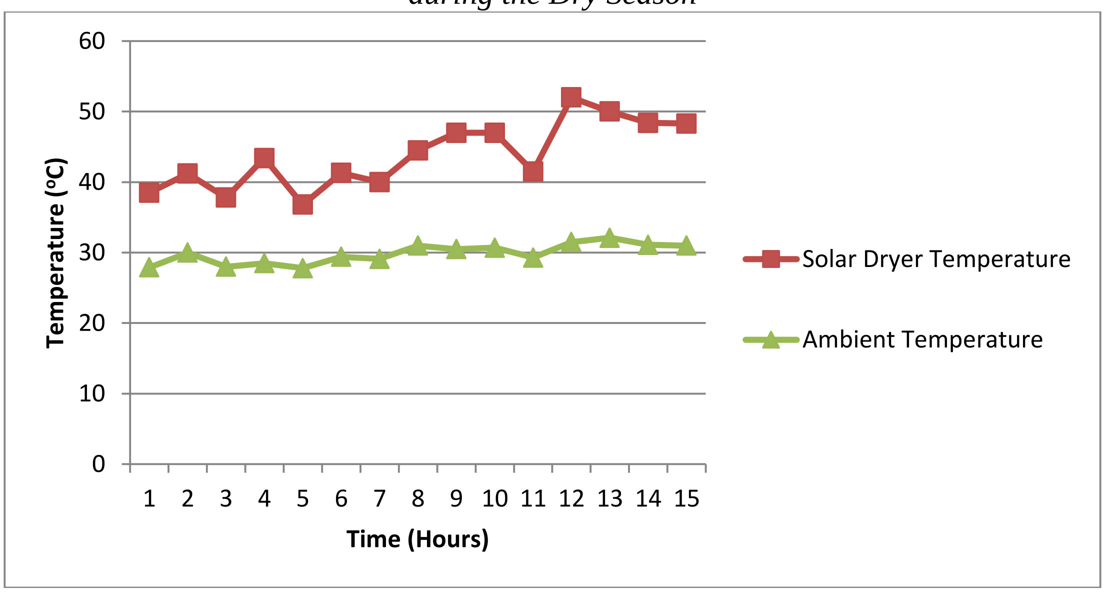

Figure 9: Graph of Average Loaded Dryer and Ambient Temperatures (^oC) with Vegetables (Week 1)

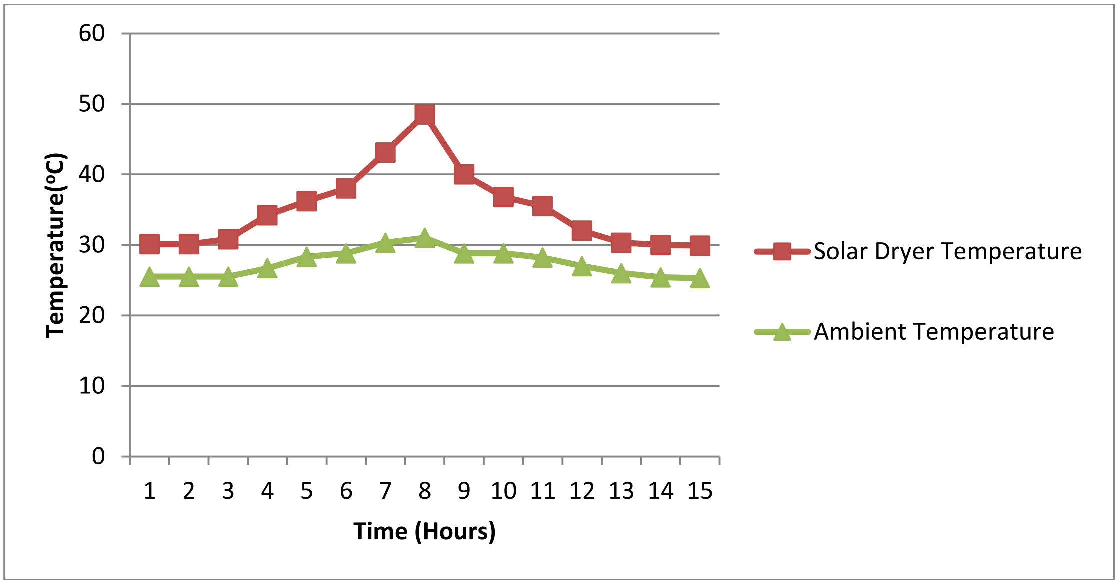

Figure 10: Graph of Average Loaded Dryer and Ambient Temperatures (ºC) with Vegetables (Week 2)

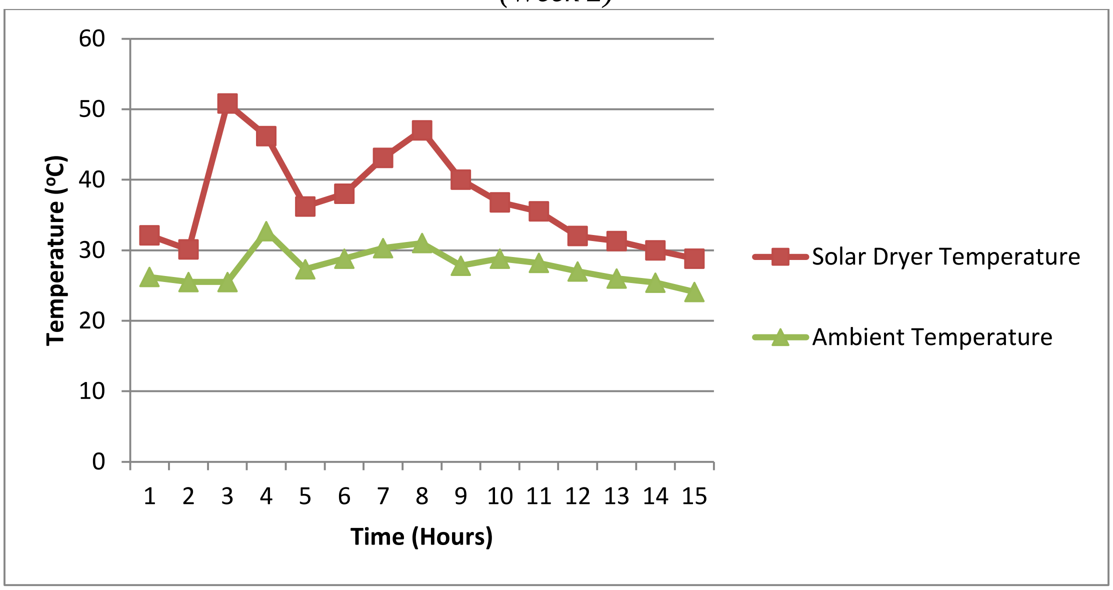

Figure 11: Graph of Average Loaded Dryer and Ambient Temperatures (ºC) with Vegetables (Week 3)

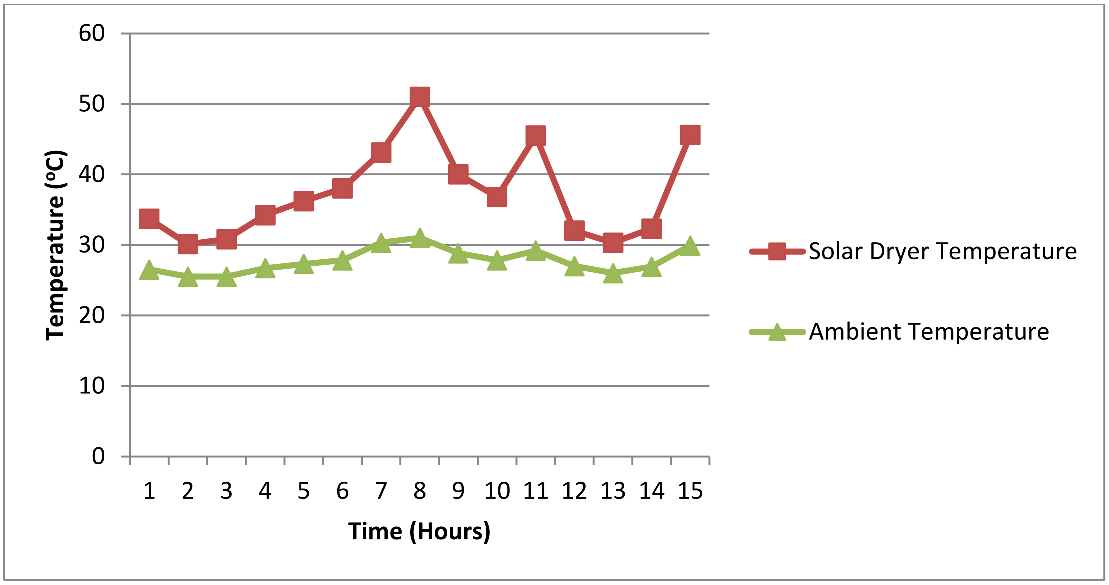

Figure 12: Graph of Average Loaded Chamber and Ambient Temperatures (^oC) with Vegetables (Week 4)

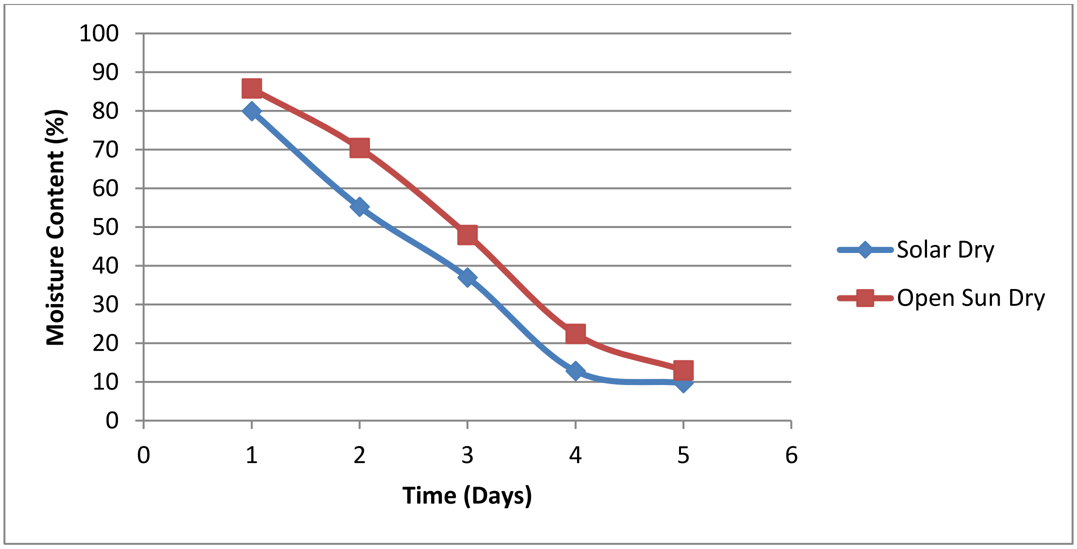

Figure 13: Graph of Reduction in Moisture Content of Solar and Open Sun Dried Tomato with time (Week 1)

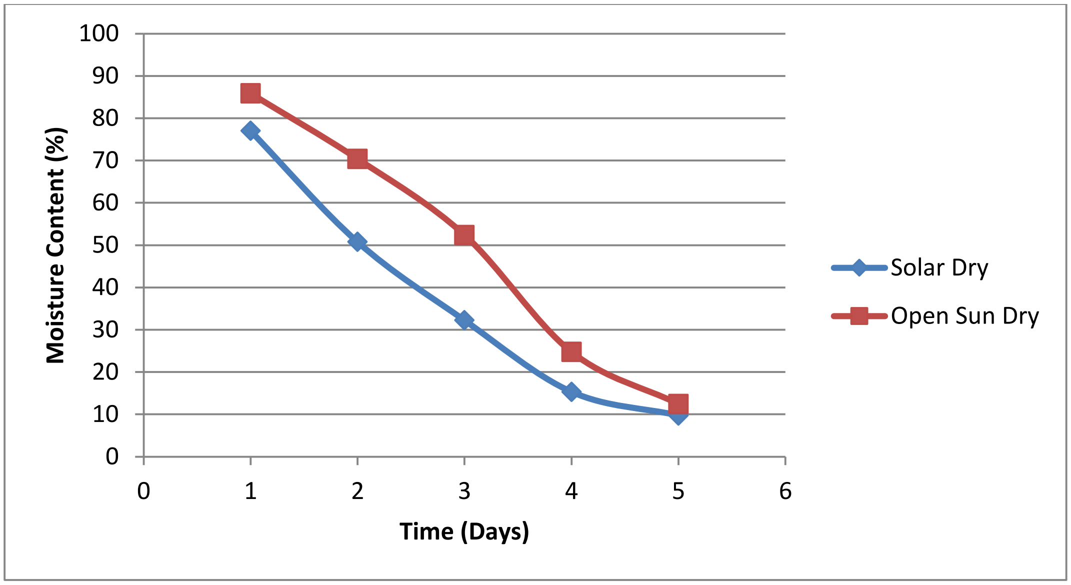

Figure 14: Graph of Reduction in Moisture Content of Solar and Open Sun Dried Tomato with time (Week 2)

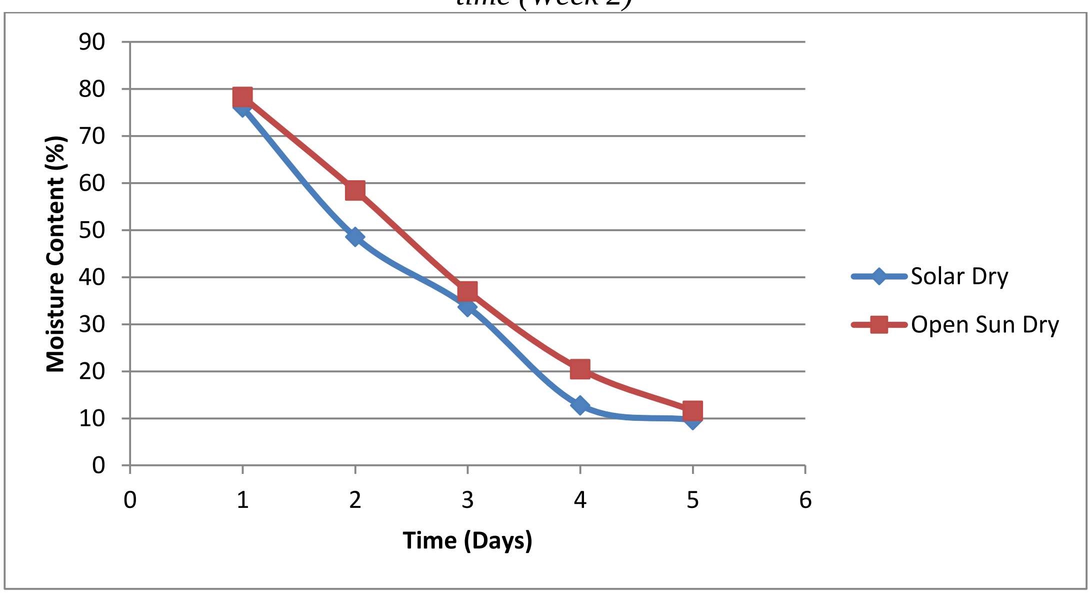

Figure 15: Graph of Reduction in Moisture Content of Solar and Open Sun Dried Tomato with time (Week 3)

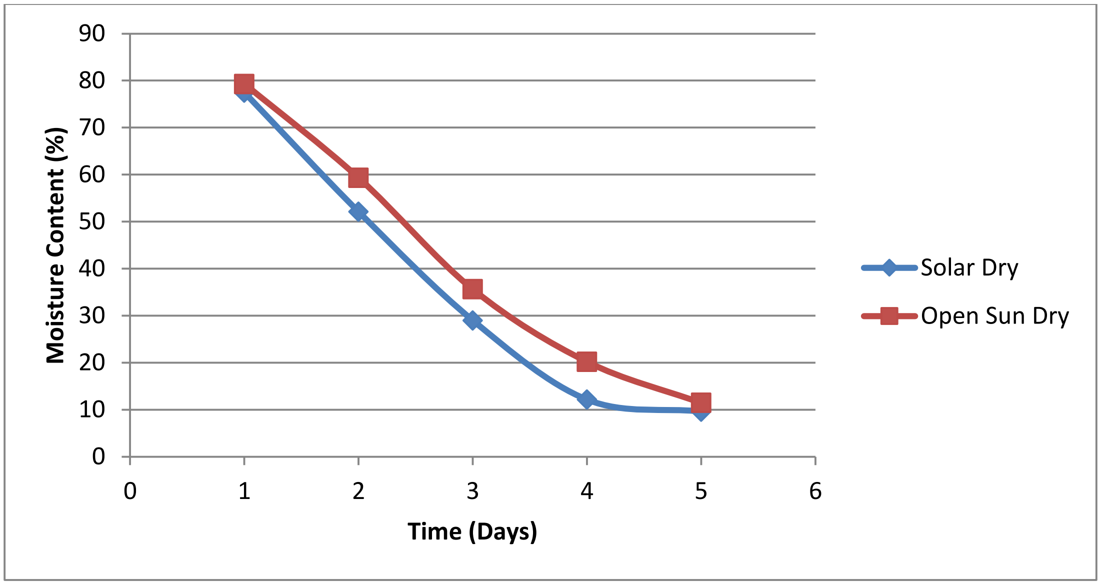

Figure 16: Graph of Reduction in Moisture Content of Solar and Open Sun Dried Tomato with time (Week 4)

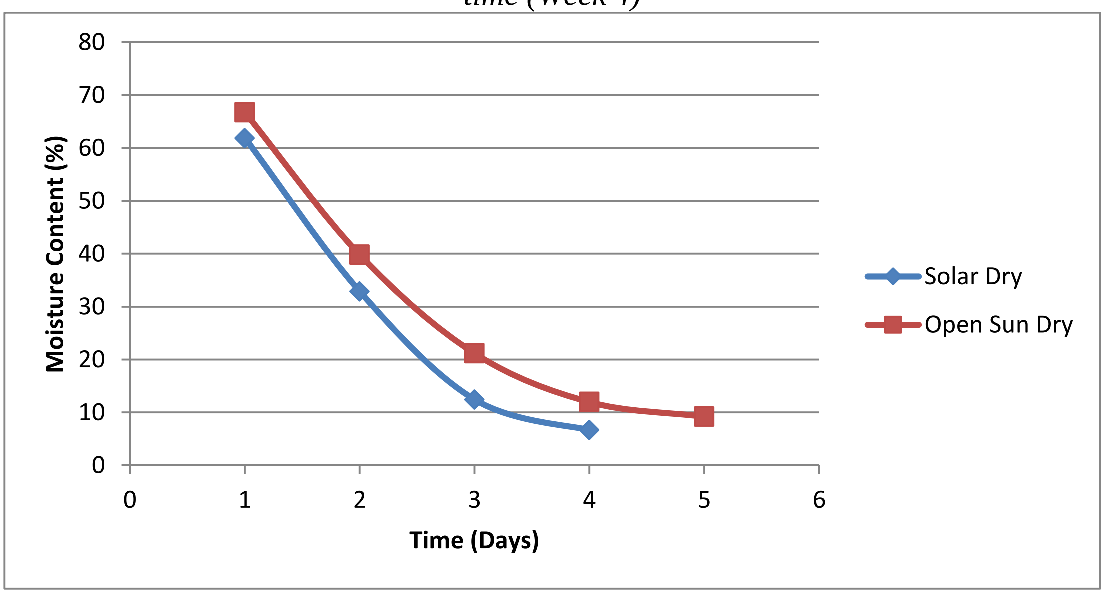

Figure 17: Graph of Reduction in Moisture Content of Solar and Open Sun Dried Pepper with time (Week 1)

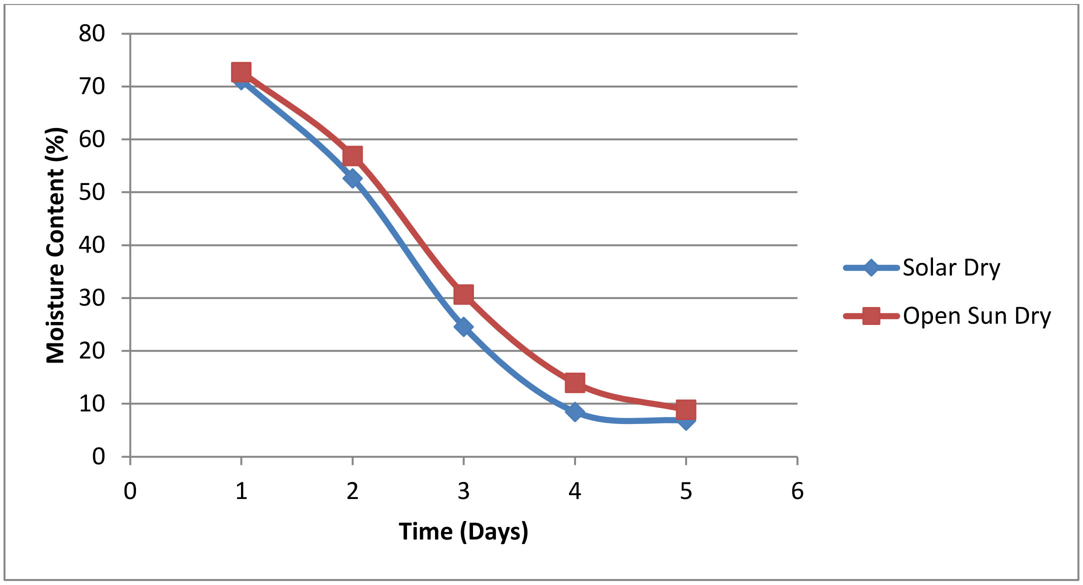

Figure 18: Graph of Reduction in Moisture Content of Solar and Open Sun Dried Pepper with time (Week 2)

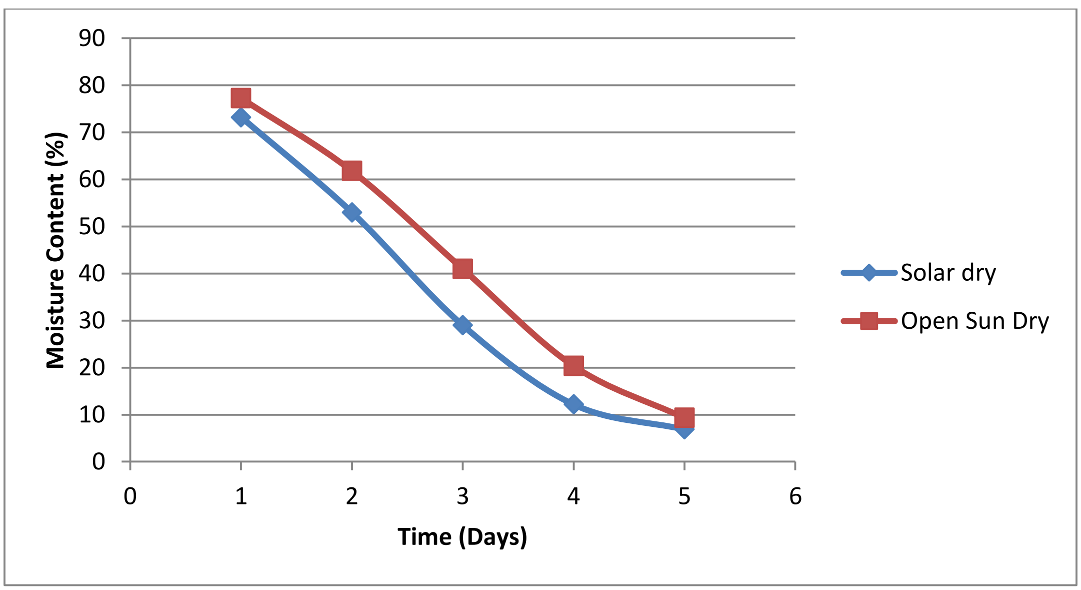

Figure 19: Graph of Reduction in Moisture Content of Solar and Open Sun Dried Pepper with time (Week 3)

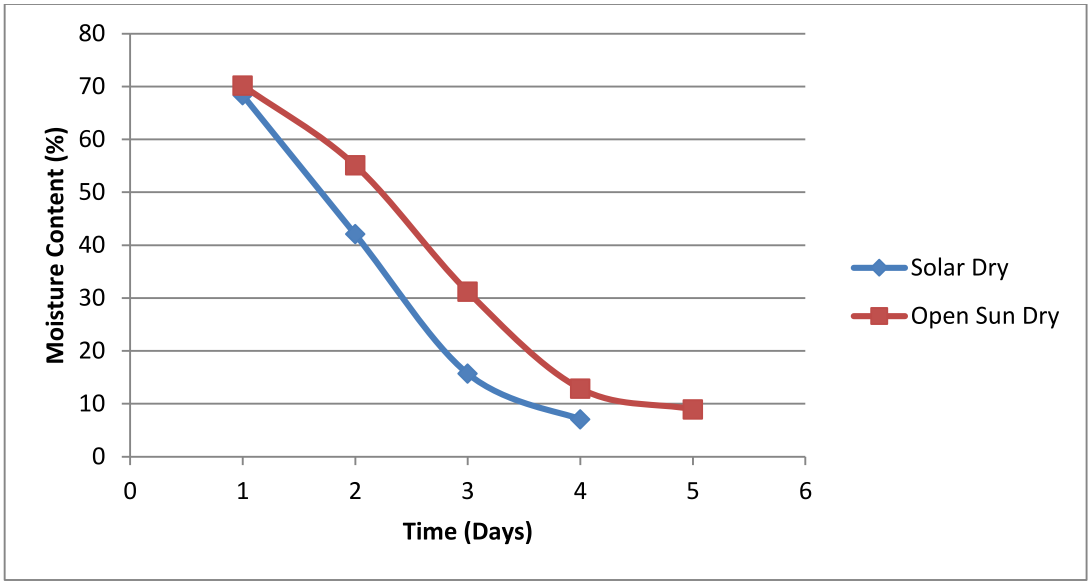

Figure 20: Graph of Reduction in Moisture Content of Solar and Open Sun Dried Pepper with time (Week 4)

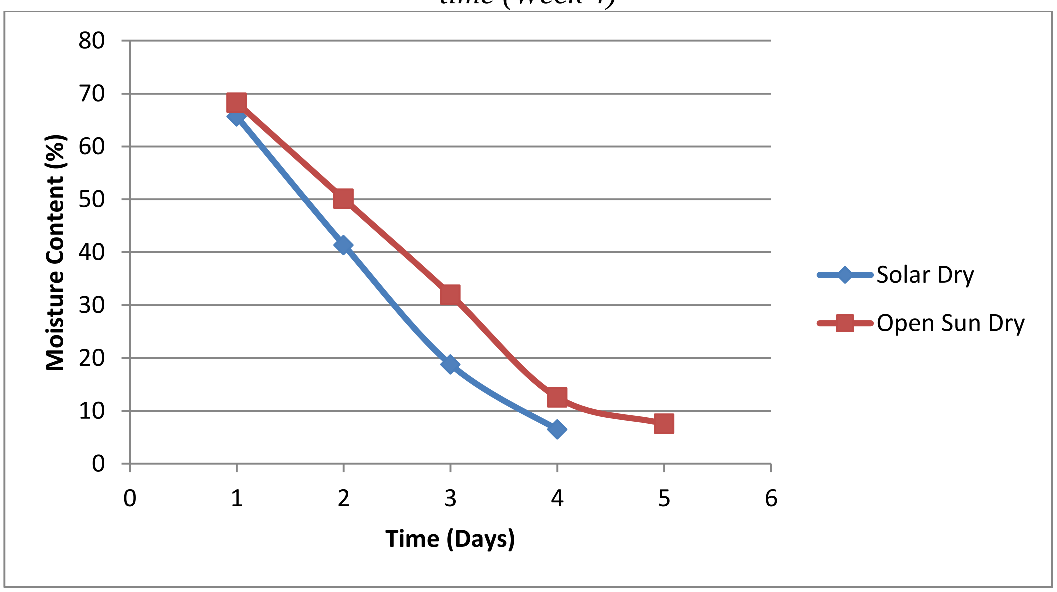

Figure 21: Graph of Reduction in Moisture Content of Solar and Open Sun Dried Okra with time (Week 1)

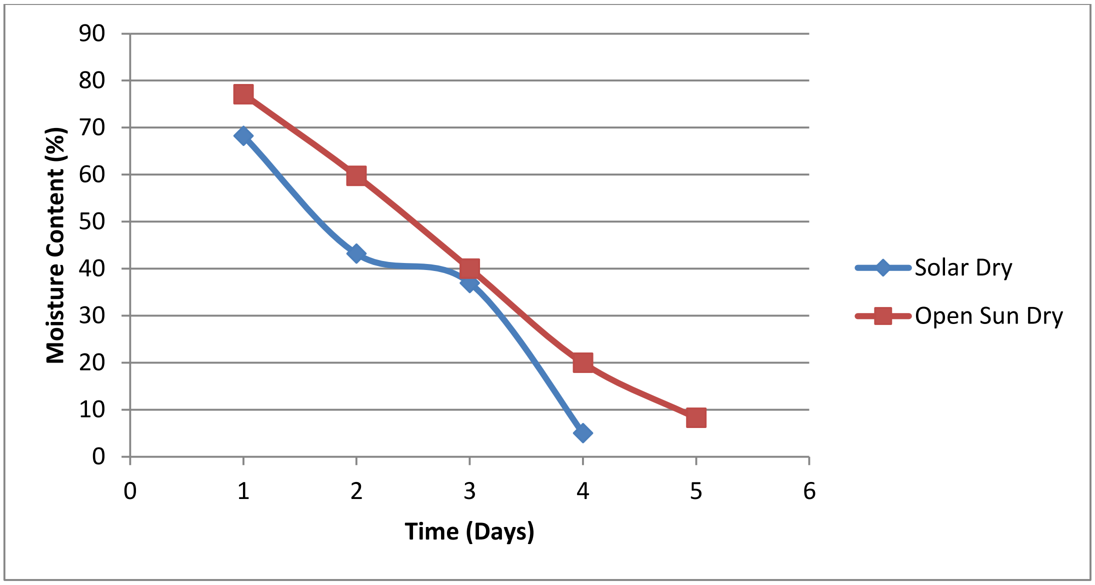

Figure 22: Graph of Reduction in Moisture Content of Solar and Open Sun Dried Okra with time (Week 2)

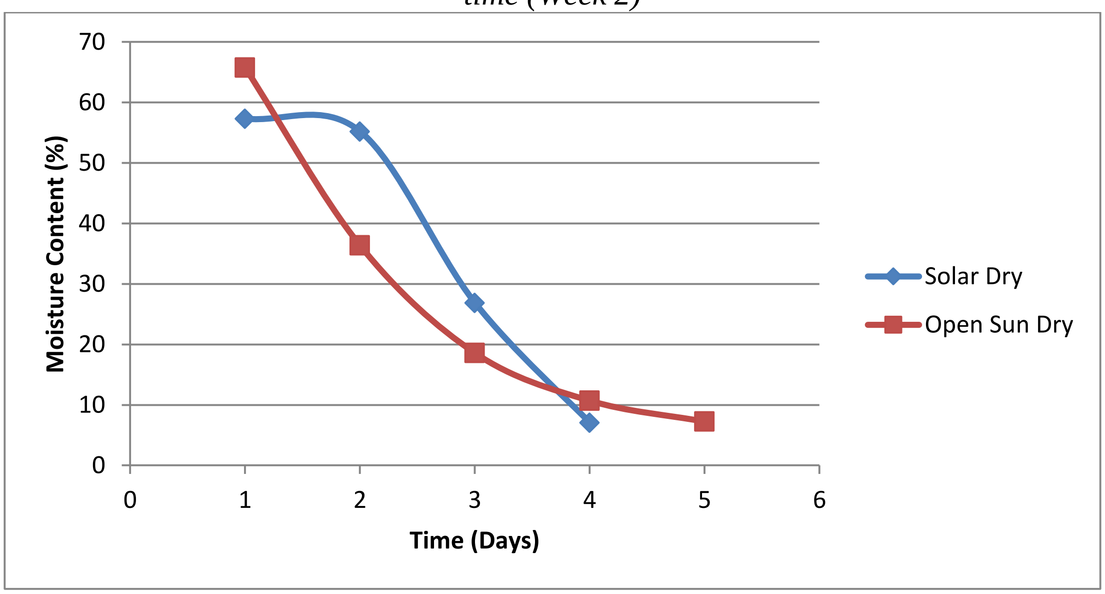

Figure 23: Graph of Reduction in Moisture Content of Solar and Open Sun Dried Okra with time (Week 3)

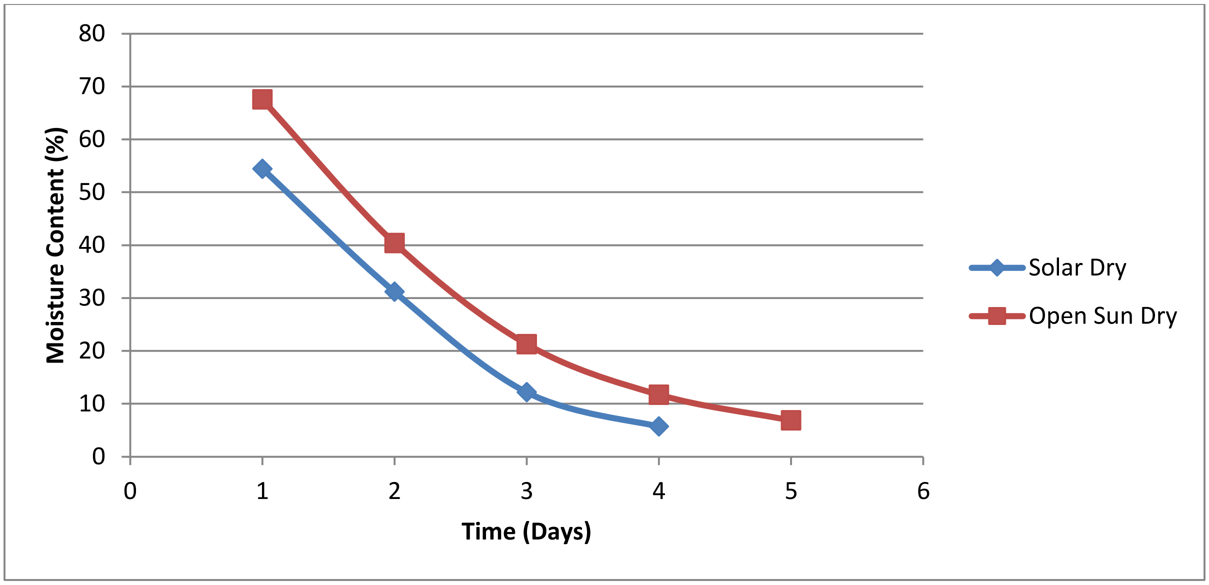

Figure 24: Graph of Reduction in Moisture Content of Solar and Open Sun Dried Okra with time (Week 4)

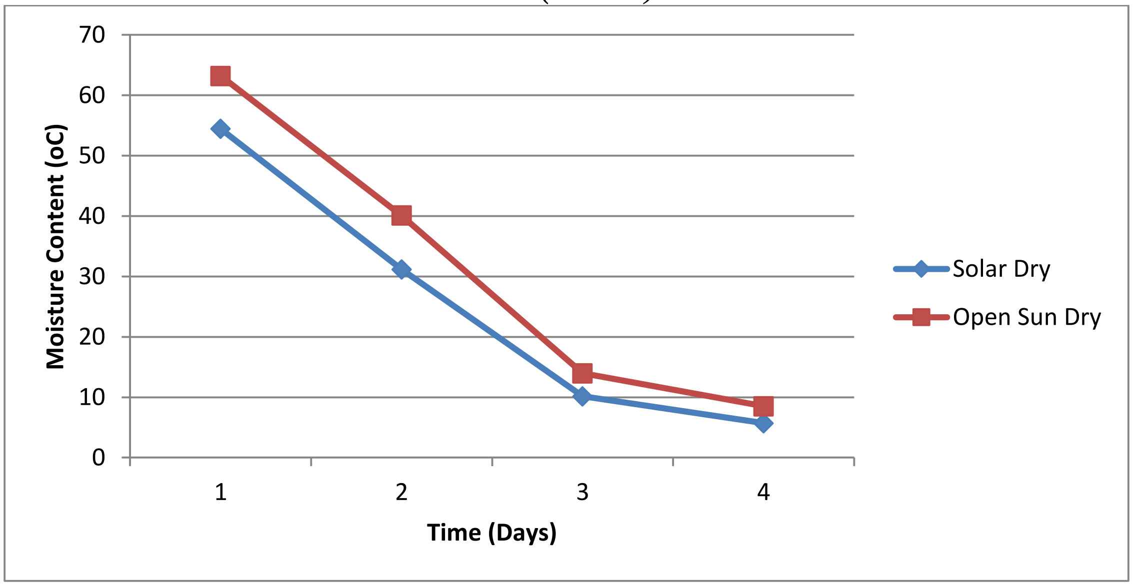

Figure 25: Graph of Reduction in Moisture Content of Solar and Open Sun Dried Tomato with time

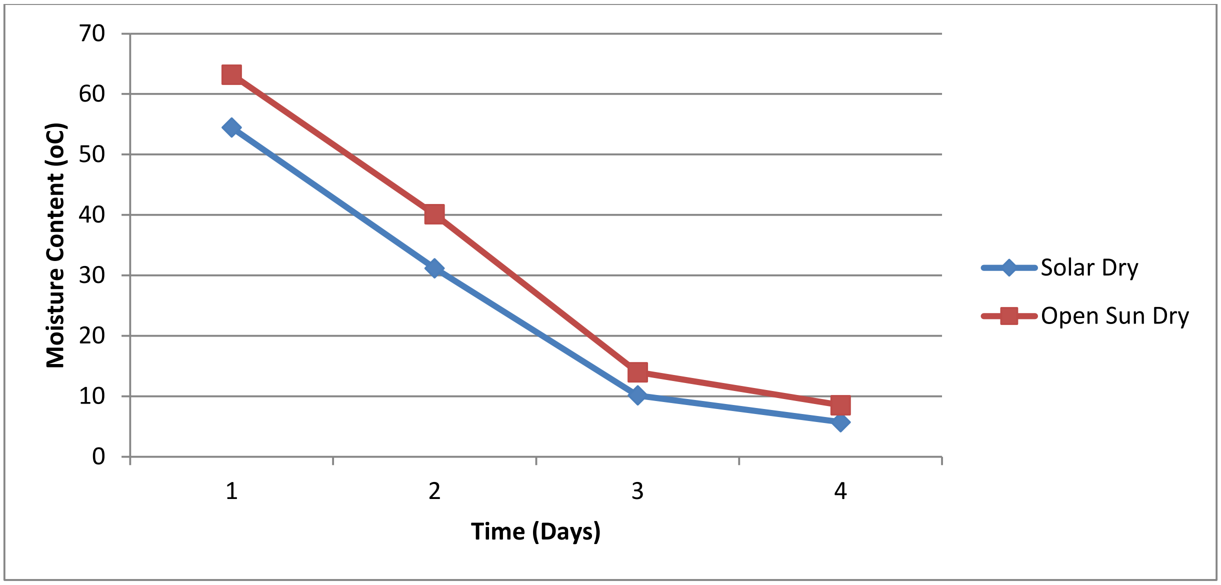

Figure 26: Graph of Reduction in Moisture Content of Solar and Open Sun Dried Pepper with time

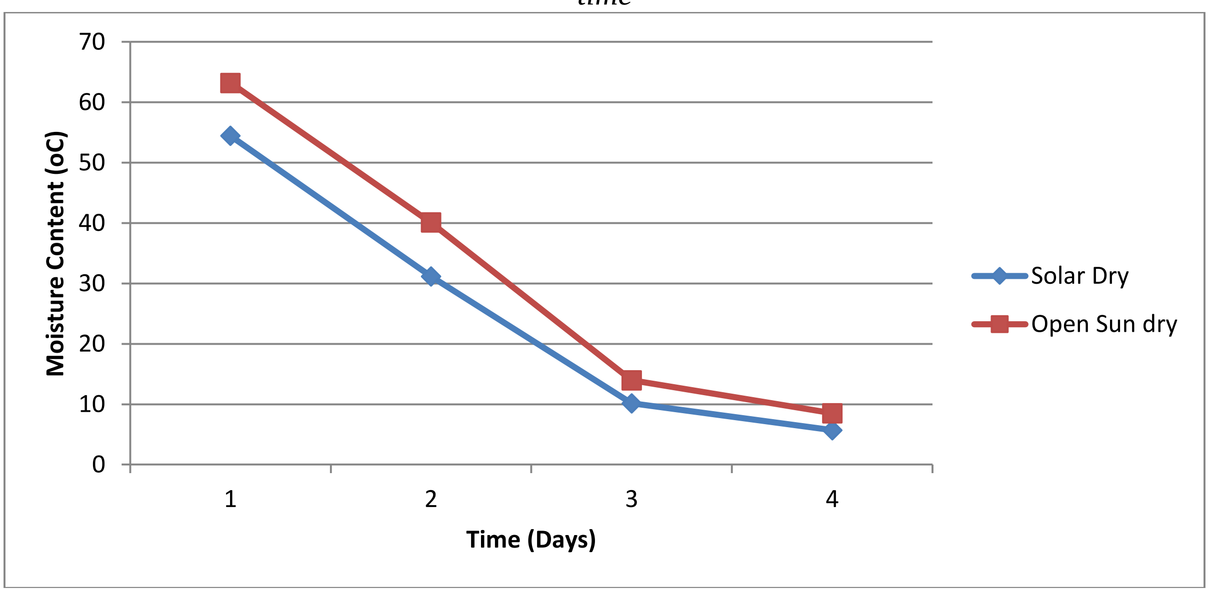

Figure 27: Graph of Reduction in Moisture Content of Solar and Open Sun Dried Okra with time

Tables 2 to 4 shows the proximate composition of fresh, solar and open sun dried vegetables.

Table 2: Physicochemical Evaluation of Fresh, Solar dried and Open sun dried tomato

Drying Method	Protein(%)	Ash(%)	Moisture(%)	Fat(%)	Fibre(%)	Carb(%)	VitC
Fresh	0.66^{a}±0.01	0.94^{a}±0.05	91.19^{a}±0.10	0.06^{a}±0.01	1.5^{a}±0.01	5.64^{a}±0.05	11.18^{a}±0.17
Open	1.89^{b}±0.01	5.26^{b}±0.01	11.21^{b}±0.2	3.17^{b}±0.01	2.05^{b}±0.01	76.42^{b}±0.02	0 .12^{b}±0.01
Solar	2.04^{c}±0.01	5.87^{c}±0.01	9.6^{c}±0.04	1.87^{c}±0.01	2.26^{c}±0.02	78.36^{c}±0.05	0.3^{c}2±0.01

Mean values along the same column for each sample with different superscript are significantly different at (P<0.05)

Table 3: Physicochemical Evaluation of Fresh, Solar dried and Open sun dried pepper

Drying Method	Protein(%)	Ash(%)	Moisture(%)	Fat(%)	Fibre(%)	Carb(%)	VitC
Fresh	1.28^{a}±0.01	1.24^{a}±0.01	87.18^{a}±0.09	0.52^{a}±0.01	2.21^{a}±0.01	7.59^{a}±0.09	19.61^{a}±0.17
Open	3.13^{b}±0.02	5.73^{b}±0.19	8.75^{b}±0.02	6.03^{b}±0.01	2.82^{b}±0.33	74.3^{b}±0.69	1.14^{b}±0.01
Solar	4.37^{c}±0.02	6.71^{c}±0.01	6.64^{c}±0.06	3.04^{c}±0.01	3.47^{c}±0.02	75.88^{c}±0.05	3.32^{c}±0.01

Mean values along the same column for each sample with different superscript are significantly different at (P<0.05)

Table 4: Physicochemical Evaluation of Fresh, Solar dried and Open sun dried okra

Drying Method	Protein(%)	Ash(%)	Moisture(%)	Fat(%)	Fibre(%)	Carb(%)	VitC
Fresh	0.71^{a}±0.01	1.06^{a}±0.01	82.75^{a}±0.01	0.75^{a}±0.01	2.45^{a}±0.01	12.39^{a}±0.01	14.08^{a}±0.09
Open	3.48^{b}±0.04	6.61^{b}±0.01	6.7^{b}±0.17	7.88^{b}±0.01	8.89^{b}±0.06	66.44^{b}±0.08	0.53^{b}±0.02
Solar	3.59^{c}±0.05	6.72^{c}±0.01	5.36^{c}±0.29	6.39^{c}±0.01	10.52^{c}±0.02	61.40^{c}±0.34	0.96^{c}±0.02

Mean values along the same column for each sample with different superscript are significantly different at (P<0.05)

The protein content of the solar dried vegetables was significantly higher (P > 0.05) compared to the open sun dried and fresh vegetables. This may be attributed to the controlled and relatively higher temperature of the solar dryer during the drying process. This was contrary to the result reported by Ukegbu *et al.* (2013), Hassan et al. (2007) and Elegbede (1998). The disparity may be due to the variety of vegetables used for the study.

Results of the ash content revealed that solar dried vegetable was significantly higher ($P < 0.05$) than the sun dried and fresh vegetables. The higher ash value of solar dried samples is similar to that reported by Onwuka *et al.* (2002). Ash content indicates the mineral content of food substances. The variation in the ash content might be attributed to the type of vegetable used, soil variation and maturity level of the vegetables.

Moisture content was significantly higher ($P < 0.05$) for fresh vegetables, followed by open sun and the solar dried vegetables respectively. The results showed that moisture content was higher in the fresh vegetables than in the open sun and solar dried vegetables. The high moisture content in the fresh vegetables is not surprising since it has been reported by Fakaye (2009) that fresh vegetables contain basically 85% water. The lower water content of open sun and solar dried vegetables is expected since Dupriez and Coener (1992) reported that drying involves lowering the amount of water to below 1 – 15% in vegetables.

Moisture content of food is very important on nutrient density and shelf-life of agricultural produce. On a general note, the removal of moisture, according to Morris et al. (2004) leads to an increase in concentration of nutrients. Therefore, for vegetables and fruits to be preserved for a long time before use, the moisture content has to be reduced. According to Kolawole *et al.* (2010), dried food substances, especially food crops with high moisture content will favour the growth of microorganism at a high growth rate and moisture content of >15% is said to promote enzymatic reactions and interactions of other constituents of the dried product leading to loss of vitamins (Fellows, 1997). The moisture content of the solar and open sun dried vegetables can be said to be within the acceptable moisture level for dried vegetables.

From tables 2-4 above it was observed that the open sun-dried vegetables had significantly higher fat values ($P < 0.05$) than the fresh and solar dried samples. This result was similar to that obtained by Ukegbu *et al.* (2013).

Crude fibre was significantly higher ($P < 0.05$) for solar dried okra .This indicates that solar dried vegetables contain more fibre than the sun dried and fresh vegetables. Dietary fibre in vegetables increases bulk and reduces food transit time in the alimentary canal and the incidence of constipation and other related diseases (Ifon *et al.* 2009). Fibre is useful for maintaining bulk, motility and increasing intestinal tract. It is also necessary for healthy condition, curing of nutritional disorders and food digestion (Ugwaegbute, 1989).

Carbohydrate content was significantly higher for solar dried vegetables compared to fresh and sun dried vegetables. Vegetables in their fresh state have been noted to be poor sources of carbohydrate (Uwaegbute, 1989). However, after drying, the carbohydrate content of vegetables increases (Kolawole *et al.,* 2011). Low carbohydrate content of fresh vegetables showed that they supply little or no energy when consumed except when supplanted with other foods (Rossello *et al.,* 2000).

In all the samples, vitamin C was most depleted in the sun dried vegetables. This could be attributed to oxidative destruction in the presence of heat, light, oxygen, moisture and metal ions (Russel and McDowell, 1989).

CHAPTER SIX

5.0 CONCLUSION AND RECOMMENDATIONS

5.1: CONCLUSION

It is concluded from this study that solar drying is nutritionally viable and that drying had effect on the nutrient content of the vegetables (protein, ash, fat, crude fiber and carbohydrate and vitamin C). Solar drying was observed to produce relatively better product in terms of nutrient composition compared to sun drying. Drying was also faster with the use of the solar drier. Solar drying produced vegetables with lower moisture content .Therefore, solar dryer can be used to preserve tomatoes pepper and okra and as well as other vegetables for off season purpose.

5.2: RECOMMNDATIONS

1. Other types of vegetables could be dried and evaluated using the solar dryer.

2. Pretreatments could be done using sodium chloride or potassium Meta bisulphate solution.

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APPENDIX A-CHAMBER AND AMBIENT TEMPERATURE CHANGE WITH TIME

Table 5: Unloaded Solar Dryer and Ambient Temperatures (ºC) without Heat Storage System (Rainy Season)

Time (min)	Day 1		Day2		Day3		Day4		Day5		Average	
	Dryer	Amb	Dryer	Amb	Dryer	Amb	Dryer	Amb	Dryer	Amb	Dryer	Amb
09:00	30.0	26.0	28.0	22.4	32.2	28.5	29.9	24.5	30.1	26.3	30.1	25.5
09:30	30.0	25.6	28.5	22.7	32.2	28.6	29.7	24.6	30.0	26.1	30.1	25.5
10:00	36.3	27.9	29.7	23.0	30.6	26.4	31.4	25.8	36.2	27.6	30.8	25.5
10:30	40.0	29.0	27.9	22.9	30.4	26.0	32.4	25.9	40.3	29.5	34.2	26.7
11:00	42.3	30.3	30.4	26.3	31.0	27.1	35.0	26.9	42.5	30.7	36.2	28.3
11:30	43.0	30.8	33.8	26.9	33.8	27.7	36.2	27.8	43.0	30.9	38.0	28.8
12:00	51.4	32.6	40.2	29.6	34.5	27.9	38.0	28.9	51.5	32.6	43.1	30.3
12:30	55.0	32.9	41.6	29.8	35.0	30.1	32.2	29.1	55.3	32.8	45.0	31.0
13:00	44.2	28.0	36.0	27.0	35.7	30.8	40.4	30.2	44.1	28.0	40.0	28.8
13:30	40.7	28.7	36.6	27.8	36.0	31.1	29.8	25.0	40.6	28.9	36.8	28.8
14:00	33.4	26.6	32.4	28.5	38.2	32.8	30.1	26.3	33.4	26.6	35.5	28.2
14:30	33.4	26.7	32.7	28.6	30.5	26.0	30.0	26.7	33.6	26.8	32.0	27.0
15:00	30.2	25.9	30.1	26.6	30.2	26.6	29.8	25.3	31.2	25.6	30.3	26.0
15:30	31.5	26.2	30.1	26.5	28.7	23.3	29.7	24.8	30.0	26.0	30.0	25.4
16:00	30.4	26.0	29.9	25.8	29.2	24.0	29.7	24.6	30.3	26.2	29.9	25.3

Table 6: Unloaded Solar dryer and Ambient Temperatures (^oC) with Heat Storage System (Rainy Season)

Time (min)	Day 1		Day2		Day3		Day4		Day5		Average	
	Dryer	Amb	Dryer	Amb	Dryer	Amb	Dryer	Amb	Dryer	Amb	Dryer	Amb
09:00	36.0	25.9	37.2	24.7	32.2	28.5	29.9	24.5	30.1	26.3	33.1	25.9
09:30	34.2	26.6	32.5	24.7	32.2	28.6	29.7	24.6	30.0	26.1	30.7	26.5
10:00	38.5	27.9	29.7	23.0	30.6	26.4	31.4	25.8	36.2	27.6	40.8	29.5
10:30	44.8	29.6	27.9	22.9	30.4	26.0	32.4	25.9	40.3	29.5	35.1	26.9
11:00	42.3	30.1	30.4	26.3	31.0	27.1	35.0	26.9	42.5	30.7	36.2	28.3
11:30	45.0	30.8	33.8	26.9	33.8	27.7	36.2	27.8	43.0	30.9	38.0	28.8
12:00	59.7	32.6	45.5	29.6	34.5	27.9	38.0	28.9	51.5	32.6	45.8	30.3
12:30	60.9	33.9	46.1	29.8	35.0	30.1	32.2	29.1	55.3	32.8	55.0	32.2
13:00	46.2	28.0	36.0	27.0	35.7	30.8	40.4	30.2	44.1	28.0	40.0	28.8
13:30	46.7	28.7	36.6	27.8	36.0	31.1	29.8	25.0	40.6	28.9	36.8	28.8
14:00	35.5	26.6	32.4	28.5	38.2	32.8	30.1	26.3	33.4	26.6	35.5	28.2
14:30	35.9	26.7	32.7	28.6	30.5	26.0	30.0	26.7	33.6	26.8	32.0	27.0
15:00	34.9	25.9	30.1	26.6	30.2	26.6	29.8	25.3	31.2	25.6	30.3	26.0
15:30	36.5	26.2	30.1	26.5	28.7	23.3	29.7	24.8	30.0	26.0	30.0	25.4
16:00	35.8	26.0	29.9	25.8	29.2	24.0	29.7	24.6	30.3	26.2	29.9	25.3
16:30	32.6	25.5	29.2	24.9	28.8	22.3	26.9	23.3	25.9	25.7	28.3	23.5
17:00	29.8	22.3	29.5	25.8	28.8	22.7	25.7	21.9	27.2	24.5	28.4	23.1
17:30	28.9	21.0	26.7	22.5	25.7	21.5	25.5	20.9	26.4	21.4	26.6	22.9
18:00	25.9	20.1	24.8	21.7	23.9	20.8	23.5	19.7	24.0	20.6	24.4	22.5
18:30	23.8	19.7	24.1	19.7	20.2	20.5	22.8	19.7	23.1	20.6	23.3	20.1
19:00	22.7	19.2	23.9	19.0	24.4	20.2	22.3	19.2	22.3	20.3	22.8	19.9

Table 7: Loaded Solar Dryer and Ambient Temperatures (^{o}C) with Heat Storage System during Dry Season

Time (min)	Day 1		Day2		Day3		Day4		Day5		Average	
	Dryer	Amb	Dryer	Amb	Dryer	Amb	Dryer	Amb	Dryer	Amb	Dryer	Amb
09:00	32.2	27.1	28.6	22.4	32.2	28.5	29.9	24.5	30.1	26.3	32.2	29.8
09:30	30.0	25.6	28.5	22.7	32.2	28.6	29.7	24.6	30.0	26.1	32.1	29.5
10:00	36.3	27.9	29.7	23.0	34.6	26.4	31.4	25.8	36.2	27.6	32.8	28.9
10:30	40.0	29.0	27.9	22.9	34.8	26.0	32.4	25.9	40.3	29.5	34.2	30.7
11:00	42.3	30.3	30.4	26.3	35.9	27.1	35.0	26.9	42.5	30.7	36.2	31.3
11:30	43.0	30.8	33.8	26.9	40.2	27.7	36.2	27.8	43.0	30.9	38.0	31.8
12:00	51.4	32.6	40.2	29.6	48.5	27.9	38.0	28.9	51.5	32.6	43.1	30.3
12:30	55.0	32.9	41.6	29.8	51.7	30.1	32.2	29.1	55.3	32.8	48.5	31.0
13:00	44.2	28.0	36.0	27.0	60.7	30.8	40.4	30.2	44.1	28.0	40.0	28.8
13:30	40.7	28.7	36.6	27.8	63.0	31.1	29.8	25.0	40.6	28.9	36.8	28.8
14:00	33.4	26.6	32.4	28.5	68.2	33.2	30.1	26.3	33.4	26.6	35.5	28.2
14:30	33.4	26.7	32.7	28.6	66.5	32.0	30.0	26.7	33.6	26.8	32.0	27.0
15:00	30.2	25.9	30.1	26.6	60.2	30.6	29.8	25.3	31.2	25.6	30.3	26.0
15:30	31.5	26.2	30.1	26.5	58.7	28.3	29.7	24.8	30.0	26.0	30.0	25.4
16:00	30.4	26.0	29.9	25.8	39.2	26.0	29.7	24.6	30.3	26.2	29.9	25.3
16:30	32.6	25.5	29.2	24.9	28.8	22.3	26.9	24.3	25.9	25.7	29.3	23.5
17:00	29.8	22.3	29.5	25.8	28.8	22.7	25.7	23.9	27.2	24.5	29.4	23.5
17:30	28.9	21.0	26.7	22.5	25.7	21.5	25.5	22.9	26.4	21.4	26.6	22.9
18:00	25.9	20.1	24.8	21.7	23.9	20.8	23.5	21.7	24.0	20.6	24.4	22.5
18:30	23.8	19.7	24.1	19.7	20.2	20.5	22.8	20.7	23.1	20.6	23.3	20.7
19:00	23.7	20.2	23.9	20.0	24.0	20.2	23.3	20.5	22.3	20.3	22.8	20.2

Table 8: Loaded Dryer and Ambient Temperatures (°C) with Vegetables (Week 1)

Time (min)	Day 1		Day2		Day3		Day4		Day5		Average	
	Dryer	Amb	Dryer	Amb	Dryer	Amb	Dryer	Amb	Dryer	Amb	Dryer	Amb
09:00	54.1	32.2	33.3	26.3	32.9	26.2	32.1	25.7	40.0	29.0	38.5	27.9
09:30	58.0	33.5	33.0	26.1	33.6	26.8	40.0	28.6	40.8	29.9	41.2	30.0
10:00	40.7	29.4	33.6	26.6	33.6	26.6	39.8	28.4	41.1	29.1	37.8	28.0
10:30	40.1	28.6	33.2	26.1	33.1	27.0	41.0	30.8	39.7	30.0	43.4	28.5
11:00	40.9	29.6	33.5	26.5	36.3	27.0	33.1	26.3	40.3	29.8	36.8	27.8
11:30	54.8	32.9	36.0	27.5	40.5	29.6	33.7	26.7	41.4	30.2	41.3	29.4
12:00	50.9	31.6	38.1	30.0	33.8	26.7	36.4	27.5	40.3	29.7	40.0	29.1
12:30	53.2	31.7	49.7	32.9	36.9	27.9	40.9	31.5	41.6	30.4	44.5	31.0
13:00	53.0	31.3	59.0	33.3	39.3	28.2	40.1	29.0	41.8	30.9	47.0	30.5
13:30	54.0	32.0	58.8	33.3	40.0	27.4	41.8	31.7	38.3	28.9	47.0	30.7
14:00	40.4	29.5	40.7	29.6	39.1	27.0	48.2	32.3	39.1	28.2	41.5	29.3
14:30	39.3	28.4	60.1	33.7	33.0	26.2	63.3	34.0	64.4	35.2	52.0	31.5
15:00	39.1	28.5	65.2	36.6	40.4	28.8	42.0	31.8	63.0	34.8	50.0	32.1
15:30	40.2	28.8	53.6	31.9	40.9	29.0	48.0	32.2	59.5	33.7	48.4	31.1
16:00	40.8	29.0	52.8	32.2	41.4	29.5	48.1	32.0	58.5	33.0	48.3	31.0

Table 9: Loaded Dryer and Ambient Temperatures (°C) with Vegetables (Week 2)

Time (min)	Day 1		Day2		Day3		Day4		Day5		Average	
	Dryer	Amb	Dryer	Amb	Dryer	Amb	Dryer	Amb	Dryer	Amb	Dryer	Amb
09:00	30.0	26.0	28.0	22.4	32.2	28.5	29.9	24.5	30.1	26.3	30.1	25.5
09:30	30.0	25.6	28.5	22.7	32.2	28.6	29.7	24.6	30.0	26.1	30.1	25.5
10:00	36.3	27.9	29.7	23.0	30.6	26.4	31.4	25.8	36.2	27.6	30.8	25.5
10:30	40.0	29.0	27.9	22.9	30.4	26.0	32.4	25.9	40.3	29.5	34.2	26.7
11:00	42.3	30.3	30.4	26.3	31.0	27.1	35.0	26.9	42.5	30.7	36.2	28.3
11:30	43.0	30.8	33.8	26.9	33.8	27.7	36.2	27.8	43.0	30.9	38.0	28.8
12:00	51.4	32.6	40.2	29.6	34.5	27.9	38.0	28.9	51.5	32.6	43.1	30.3
12:30	55.0	32.9	41.6	29.8	35.0	30.1	32.2	29.1	55.3	32.8	48.5	31.0
13:00	44.2	28.0	36.0	27.0	35.7	30.8	40.4	30.2	44.1	28.0	40.0	28.8
13:30	40.7	28.7	36.6	27.8	36.0	31.1	29.8	25.0	40.6	28.9	36.8	28.8
14:00	33.4	26.6	32.4	28.5	38.2	32.8	30.1	26.3	33.4	26.6	35.5	28.2
14:30	33.4	26.7	32.7	28.6	30.5	26.0	30.0	26.7	33.6	26.8	32.0	27.0
15:00	30.2	25.9	30.1	26.6	30.2	26.6	29.8	25.3	31.2	25.6	30.3	26.0
15:30	31.5	26.2	30.1	26.5	28.7	23.3	29.7	24.8	30.0	26.0	30.0	25.4
16:00	30.4	26.0	29.9	25.8	29.2	24.0	29.7	24.6	30.3	26.2	29.9	25.3

Table 10: Loaded Dryer and Ambient Temperatures (^oC) with Vegetables (Week 3)

Time (min)	Day 1		Day2		Day3		Day4		Day5		Average	
	Dryer	Amb	Dryer	Amb	Dryer	Amb	Dryer	Amb	Dryer	Amb	Dryer	Amb
09:00	31.0	26.7	28.0	22.4	32.2	28.5	29.9	24.5	30.1	26.3	32.1	26.2
09:30	30.0	25.6	28.5	22.7	32.2	28.6	29.7	24.6	30.0	26.1	30.1	25.5
10:00	36.3	27.9	29.7	23.0	30.6	26.4	31.4	25.8	36.2	27.6	50.8	25.5
10:30	40.0	29.0	27.9	22.9	30.4	26.0	32.4	25.9	40.3	29.5	46.2	32.7
11:00	42.3	30.3	30.4	26.3	31.0	27.1	35.0	26.9	42.5	30.7	36.2	27.3
11:30	43.0	30.8	33.8	26.9	33.8	27.7	36.2	27.8	43.0	30.9	38.0	28.8
12:00	51.4	32.6	40.2	29.6	34.5	27.9	38.0	28.9	51.5	32.6	43.1	30.3
12:30	55.0	32.9	41.6	29.8	35.0	30.1	32.2	29.1	55.3	32.8	47.0	31.0
13:00	44.2	28.0	36.0	27.0	35.7	30.8	40.4	30.2	44.1	28.0	40.0	27.8
13:30	40.7	28.7	36.6	27.8	36.0	31.1	29.8	25.0	40.6	28.9	36.8	28.8
14:00	33.4	26.6	32.4	28.5	38.2	32.8	30.1	26.3	33.4	26.6	35.5	28.2
14:30	33.4	26.7	32.7	28.6	30.5	26.0	30.0	26.7	33.6	26.8	32.0	27.0
15:00	30.2	25.9	30.1	26.6	30.2	26.6	29.8	25.3	31.2	25.6	31.3	26.0
15:30	31.5	26.2	30.1	26.5	28.7	23.3	29.7	24.8	30.0	26.0	30.0	25.4
16:00	31.0	25.8	28.9	25.8	29.2	24.0	29.7	24.6	30.3	26.2	28.8	24.1

Table 11: Loaded Dryer and Ambient Temperatures (^oC) with Vegetables (Week 4)

Time (min)	Day 1		Day2		Day3		Day4		Day5		Average	
	Dryer	Amb	Dryer	Amb	Dryer	Amb	Dryer	Amb	Dryer	Amb	Dryer	Amb
09:00	32.0	26.9	28.0	22.4	32.2	28.5	29.9	24.5	30.1	26.3	33.7	26.5
09:30	30.0	25.6	28.5	22.7	32.2	28.6	29.7	24.6	30.0	26.1	30.1	25.5
10:00	36.3	27.9	29.7	23.0	30.6	26.4	31.4	25.8	36.2	27.6	30.8	25.5
10:30	40.0	29.0	27.9	22.9	30.4	26.0	32.4	25.9	40.3	29.5	34.2	26.7
11:00	42.3	30.3	30.4	26.3	31.0	27.1	35.0	26.9	42.5	30.7	36.2	27.3
11:30	43.0	30.8	33.8	26.9	33.8	27.7	36.2	27.8	43.0	30.9	38.0	27.8
12:00	51.4	32.6	40.2	29.6	34.5	27.9	38.0	28.9	51.5	32.6	43.1	30.3
12:30	55.0	32.9	41.6	29.8	35.0	30.1	32.2	29.1	55.3	32.8	51.0	31.0
13:00	44.2	28.0	36.0	27.0	35.7	30.8	40.4	30.2	44.1	28.0	40.0	28.8
13:30	40.7	28.7	36.6	27.8	36.0	31.1	29.8	25.0	40.6	28.9	36.8	27.8
14:00	33.4	26.6	32.4	28.5	38.2	32.8	30.1	26.3	33.4	26.6	45.5	29.2
14:30	33.4	26.7	32.7	28.6	30.5	26.0	30.0	26.7	33.6	26.8	32.0	27.0
15:00	30.2	25.9	30.1	26.6	30.2	26.6	29.8	25.3	31.2	25.6	30.3	26.0
15:30	31.5	26.2	30.1	26.5	28.7	23.3	29.7	24.8	30.0	26.0	32.3	26.9
16:00	30.4	26.0	29.9	25.8	29.2	24.0	29.7	24.6	30.3	26.2	45.6	29.9

APPENDIX B- MOISTURE CONTENT LOSS WITH TIME (RAINY SEASON DRYING)

Table 12: Reduction in Moisture Content (WB) % of Solar and Open Sun Dried Tomato with time (Week 1)

Time (Hours)	Solar Dryer(%)	Average(%)	Open Sun Dry(%)	Average(%)	Time (Days)
0900-1100	85.14		88.60		
1100-1300	79.74	79.97	87.21	85.78	1
1300-1600	75.04		81.53		
0900-1100	60.85		77.62		
1100-1300	55.35	55.22	73.54	70.42	2
1300-1600	49.45		60.11		
0900-1100	43.35		57.84		
1100-1300	37.95	36.95	55.13	47.97	3
1300-1600	29.54		30.93		
0900-1100	18.26		26.60		
1100-1300	10.34	12.85	21.45	22.40	4
1300-1600	9.90		19.16		
0900-1100	9.75		15.22		
1100-1300	9.65	9.7	12.49	12.98	5
1300-1600			11.22		

Table 13: Reduction in Moisture Content (WB) % of Solar and Open Sun Dried Tomato with time (Week 2)

Time (Hours)	Solar Dryer	Average	Open Sun Dry	Average	Time (Days)
0900-1100	86.26		88.76		
1100-1300	74.88	77.03	86.40	85.89	1
1300-1600	69.95		82.52		
0900-1100	61.11		78.01		
1100-1300	49.87	50.77	72.22	70.42	2
1300-1600	41.33		62.03		
0900-1100	38.66		56.67		
1100-1300	32.45	32.24	54.45	52.42	3
1300-1600	25.62		46.13		
0900-1100	20.22		32.21		
1100-1300	15.54	15.32	25.40	24.76	4
1300-1600	10.21		16.06		
0900-1100	9.89		14.22		
1100-1300	9.70	9.74	11.91	12.45	5
1300-1600	9.63		11.23		

Table 14: Reduction in Moisture Content (WB) % of Solar and Open Sun Dried Tomato with time (Week 3)

Time (Hours)	Solar Dryer	Average	Open Sun Dry	Average	Time (Days)
0900-1100	86.20		87.77		
1100-1300	75.55	76.06	76.20	78.34	1
1300-1600	66.43		71.05		
0900-1100	59.77		67.43		
1100-1300	45.64	48.58	62.30	58.44	2
1300-1600	40.34		45.58		
0900-1100	36.23		40.33		
1100-1300	34.41	33.69	37.02	37.01	3
1300-1600	30.44		33.67		
0900-1100	17.20		29.02		
1100-1300	11.11	12.76	20.01	20.45	4
1300-1600	9.97		12.32		
0900-1100	9.66		11.97		
1100-1300	9.59	9.62	11.72	11.63	5
1300-1600			11.21		

Table 15: Reduction in Moisture Content (WB) % of Solar and Open Sun Dried Tomato with time (Week 4)

Time (Hours)	Solar Dryer	Average	Open Sun Dry	Average	Time (Days)
0900-1100	84.45		86.41		
1100-1300	77.60	77.46	79.30	79.31	1
1300-1600	70.32		72.21		
0900-1100	61.07		65.44		
1100-1300	54.32	52.09	60.61	59.34	2
1300-1600	40.88		51.97		
0900-1100	35.56		40.44		
1100-1300	30.29	28.99	36.61	35.63	3
1300-1600	21.12		29.85		
0900-1100	16.66		25.54		
1100-1300	9.99	12.14	20.11	20.22	4
1300-1600	9.78		15.01		
0900-1100	9.65		12.01		
1100-1300	9.55	9.60	11.22	11.47	5
1300-1600			11.18		

Table 16: Reduction in Moisture Content (WB) % of Solar and Open Sun Dried Pepper with time (Week 1)

Time (Hours)	Solar Dryer	Average	Open Sun Dry	Average	Time (Days)
0900-1100	70.22		73.33		
1100-1300	61.05	61.9	67.32	66.77	1
1300-1600	54.43		59.65		
0900-1100	40.88		49.27		
1100-1300	32.24	32.89	39.91	39.84	2
1300-1600	25.55		30.33		
0900-1100	18.82		26.66		
1100-1300	10.02	12.44	20.14	21.19	3
1300-1600	8.48		16.78		
0900-1100	6.95		14.58		
1100-1300	6.58	6.67	11.22	11.99	4
1300-1600			10.17		
0900-1100			9.98		
1100-1300			8.89	9.22	5
1300-1600			8.77		

Table 17: Reduction in Moisture Content (WB) % of Solar and Open Sun Dried Pepper with time (Week 2)

Time (Hours)	Solar Dryer	Average	Open Sun Dry	Average	Time (Days)
0900-1100	77.00		77.75		
1100-1300	71.23	71.22	72.34	72.71	1
1300-1600	65.42		68.05		
0900-1100	60.25		63.31		
1100-1300	54.64	52.63	58.05	56.86	2
1300-1600	43.01		59.22		
0900-1100	31.09		40.08		
1100-1300	27.72	24.56	31.60	30.64	3
1300-1600	14.88		20.23		
0900-1100	10.47		16.77		
1100-1300	9.21	8.47	13.84	13.96	4
1300-1600	7.73		11.26		
0900-1100	6.98		8.99		
1100-1300	6.59	6.79	8.82	8.85	5
1300-1600			8.75		

Table18: Reduction in Moisture Content (WB) % of Solar and Open Sun Dried Pepper with time (Week 3)

Time (Hours)	Solar Dryer	Average	Open Sun Dry	Average	Time (Days)
0900-1100	75.22		74.69		
1100-1300	69.08	68.38	70.32	70.18	1
1300-1600	60.84		65.52		
0900-1100	56.21		61.18		
1100-1300	40.33	42.06	56.30	55.07	2
1300-1600	29.65		47.74		
0900-1100	21.10		38.88		
1100-1300	15.66	15.71	32.41	31.17	3
1300-1600	29.54		22.22		
0900-1100	7.72		15.69		
1100-1300	6.82	7.08	12.87	12.86	4
1300-1600	6.71		10.03		
0900-1100			9.14		
1100-1300			8.89	8.93	5
1300-1600			8.75		

Table 19: Reduction in Moisture Content (WB) % of Solar and Open Sun Dried Pepper with time (Week 4)

Time (Hours)	Solar Dryer	Average	Open Sun Dry	Average	Time (Days)
0900-1100	80.08		82.20		
1100-1300	73.33	73.23	78.05	77.30	1
1300-1600	66.45		71.64		
0900-1100	61.81		67.01		
1100-1300	52.26	53.0	62.18	61.82	2
1300-1600	44.92		56.27		
0900-1100	37.80		50.01		
1100-1300	28.05	29.01	42.90	41.01	3
1300-1600	21.19		30.33		
0900-1100	16.32		26.27		
1100-1300	11.03	12.20	20.63	20.37	4
1300-1600	9.25		14.21		
0900-1100	7.23		10.34		
1100-1300	6.81	6.90	8.93	9.33	5
1300-1600	6.66		8.73		

Table 20: Reduction in Moisture Content (WB) % of Solar and Open Sun Dried Okra with time (Week 1)

Time (Hours)	Solar Dryer	Average	Open Sun Dry	Average	Time (Days)
0900-1100	72.85		74.48		
1100-1300	65.32	65.66	69.33	68.29	1
1300-1600	58.80		61.06		
0900-1100	50.77		57.55		
1100-1300	42.23	41.39	50.00	50.12	2
1300-1600	31.18		42.81		
0900-1100	27.01		38.65		
1100-1300	18.26	18.77	34.44	31.98	3
1300-1600	11.03		22.85		
0900-1100	7.72		15.26		
1100-1300	5.95	6.48	12.23	12.57	4
1300-1600	5.77		10.11		
0900-1100			8.83		
1100-1300			7.24	7.57	5
1300-1600			6.65		

Table 21: Reduction in Moisture Content (WB) % of Solar and Open Sun Dried Okra with time (Week 2)

Time (Hours)	Solar Dryer	Average	Open Sun Dry	Average	Time (Days)
0900-1100	75.12		83.65		
1100-1300	69.70	68.27	77.21	77.13	1
1300-1600	60.04		70..53		
0900-1100	50.85		67.62		
1100-1300	45.22	43.17	60.44	59.75	2
1300-1600	33.45		51.19		
0900-1100	27.33		47.88		
1100-1300	17.95	36.95	40.07	40.03	3
1300-1600	11.08		32.13		
0900-1100	7.21		26.60		
1100-1300	5..60	5.03	20.40	19.98	4
1300-1600	5.29		12.95		
0900-1100			7. 83		
1100-1300			7.05	8.27	5
1300-1600			6.92		

Table1 22: Reduction in Moisture Content (WB) % of Solar and Open Sun Dried Okra with time (Week 3)

Time (Hours)	Solar Dryer	Average	Open Sun Dry	Average	Time (Days)
0900-1100	65.19		78.60		
1100-1300	59.74	57.32	67.21	65.78	1
1300-1600	47.04		51.53		
0900-1100	34.85		47.62		
1100-1300	25.35	55.22	33.54	36.42	2
1300-1600	20.45		28.11		
0900-1100	16.35		21.84		
1100-1300	12.95	26.88	18.13	18.63	3
1300-1600	10.54		15.93		
0900-1100	9.26		12.60		
1100-1300	6.88	7.07	10.45	10.74	4
1300-1600	5.08		9.16		
0900-1100			8.00		
1100-1300			7.11	7.28	5
1300-1600			6.72		

Table 23: Reduction in Moisture Content (WB) % of Solar and Open Sun Dried Okra with time (Week 4)

Time (Hours)	Solar Dryer	Average	Open Sun Dry	Average	Time (Days)
0900-1100	65.25		77.60		
1100-1300	52.74	54.45	65.09	67.56	1
1300-1600	45.36		59.99		
0900-1100	38.85		47.62		
1100-1300	30.22	31.17	43.54	40.42	2
1300-1600	24.45		30.11		
0900-1100	18.31		27.84		
1100-1300	10.03	12.18	20.13	21.3	3
1300-1600	8.21		15.93		
0900-1100	6.11		13.60		
1100-1300	5.31	5.71	11.45	11.74	4
1300-1600			10.16		
0900-1100			7..22		
1100-1300			6.51	6.87	5
1300-1600					

APPENDIX C- MOISTURE CONTENT LOSS WITH TIME (DRY SEASON DRYING)

Table 24: Reduction in Moisture Content (WB) % of Solar and Open Sun Dried Tomato with time

Time (Hours)	Solar Dryer	Average	Open Sun Dry	Average	Time (Days)
0900-1100	85.50		88.40		
1100-1300	70.72	71.55	76.20	74.97	1
1300-1600	58.43		60.33		
0900-1100	44.85		57.43		
1100-1300	40.64	40.27	52.30	50.10	2
1300-1600	35.34		40.58		
0900-1100	30.23		35.33		
1100-1300	24.51	24.72	27.02	28.67	3
1300-1600	19.44		23.67		
0900-1100	15.20		19.02		
1100-1300	12.0	12.76	16.01	16.45	4
1300-1600	11.11		14.32		

Table 25: Reduction in Moisture Content (WB) % of Solar and Open Sun Dried Pepper with time

Time (Hours)	Solar Dryer	Average	Open Sun Dry	Average	Time (Days)
0900-1100	75.22		77.75		
1100-1300	71.00	68.88	72.34	72.38	1
1300-1600	60.42		67.05		
0900-1100	51.25		60.31		
1100-1300	40.64	42.63	58.05	55.86	2
1300-1600	36.01		49.22		
0900-1100	30.11		40.08		
1100-1300	25.72	25.23	31.60	30.63	3
1300-1600	19.88		20.23		
0900-1100	10.47		16.78		
1100-1300	9.21	9.47	13.84	13.96	4
1300-1600	8.73		11.26		

Table 26: Reduction in Moisture Content (WB) % of Solar and Open Sun Dried Okra

Time (Hours)	Solar Dryer	Average	Open Sun Dry	Average	Time (Days)
0900-1100	65.25		77.60		
1100-1300	52.74	54.45	61.09	63.22	1
1300-1600	45.36		50.99		
0900-1100	38.85		43.62		
1100-1300	30.22	31.17	46.54	40.09	2
1300-1600	24.45		30.11		
0900-1100	13.31		17.84		
1100-1300	10.03	10.14	13.13	13.96	3
1300-1600	7.08		10.93		
0900-1100	6.11		9.60		
1100-1300	5.31	5.71	7.45	8.52	4
1300-1600					

APPENDIX D - DETAILED RESULTS OF THE PHYSICOCHEMICAL PROPERTIES OF TOMATO (Control=Fresh produce)

Properties	Replication	Drying Method		
Protein (%)		**Control**	**Open**	**Solar**
	1	0.66	1.89	2.02
	2	0.64	1.87	2.03
	3	0.67	1.90	2.05
	4	0.65	1.88	2.04
	Total	2.62	7.54	8.14
	Mean	0.655	1.885	2.035
	StdDev	0.01290994	0.01291	0.01291

Properties	Replication	Drying Method		
Ash (%)		**Control**	**Open**	**Solar**
	1	0.99	5.26	5.88
	2	0.87	5.25	5.85
	3	0.95	5.27	5.87
	4	0.96	5.26	5.86
	Total	3.77	21.04	23.46
	Mean	0.9425	5.26	5.865
	StdDev	0.05123475	0.008165	0.01291

Properties	Replication	Drying Method		
Moisture Content (%)		**Control**	**Open**	**Solar**
	1	91.14	11.22	2.02
	2	91.33	11.23	2.03
	3	91.20	11.21	2.05
	4	91.09	11.18	2.04
	Total	364.76	44.84	38.42
	Mean	91.19	11.21	9.605
	StdDev	0.1036018	0.021602	0.044347

Properties	Replication	Drying Method		
Fat (%)		Control	Open	Solar
	1	0.07	3.15	1.88
	2	0.05	3.18	1.85
	3	0.06	3.17	1.87
	4	0.07	3.16	1.88
	Total	0.25	12.66	7.48
	Mean	0.0625	3.165	1.87
	StdDev	0.00957427	0.01291	0.014142

Properties	Replication	Drying Method		
Fibre (%)		Control	Open	Solar
	1	1.51	2.05	2.28
	2	1.50	2.03	2.26
	3	1.52	2.06	2.24
	4	1.51	2.04	2.25
	Total	6.04	8.18	9.03
	Mean	1.51	2.045	2.2575
	StdDev	0.00816497	0.01291	0.017078

Properties	Replication	Drying Method		
Carbohydrate (%)		Control	Open	Solar
	1	5.63	76.43	2.02
	2	5.61	76.42	2.03
	3	5.60	7639	2.05
	4	5.72	76.42	2.04
	Total	22.56	305.66	8.14
	Mean	5.64	76.415	2.035
	StdDev	0.05477226	0.017321	0.054772

Properties	Replication	Drying Method		
Vitamin C (%)		Control	Open	Solar
	1	11.20	0.11	0.30
	2	11.00	0.12	0.31
	3	11.10	0.10	0.32
	4	11.40	0.13	0.33
	Total	44.70	0.46	1.26
	Mean	11.175	0.115	0.315
	StdDev	0.17078251	0.01291	0.01291

APPENDIX D - DETAILED RESULTS OF THE PHYSICOCHEMICAL PROPERTIES OF PEPPER (Control=Fresh produce)

Properties	Replication	Drying Method		
Protein (%)		**Control**	**Open**	**Solar**
	1	1.28	3.14	4.37
	2	1.27	3.10	4.35
	3	1.28	3.13	4.37
	4	1.29	3.14	4.39
	Total	5.12	12.51	17.48
	Mean	1.28	3.1275	4.37
	StdDev	0.008165	0.01893	0.01633

Properties	Replication	Drying Method		
Ash (%)		**Control**	**Open**	**Solar**
	1	1.24	5.65	6.71
	2	1.24	5.66	6.72
	3	1.23	5.59	6.71
	4	1.25	6.01	6.70
	Total	4.96	22.91	26.84
	Mean	1.24	5.7275	6.71
	StdDev	0.008165	0.0190853	0.008165

Properties	Replication	Drying Method		
Moisture Content (%)		**Control**	**Open**	**Solar**
	1	87.10	8.77	6.58
	2	87.20	8.75	6.59
	3	87.30	8.75	6.71
	4	87.10	8.73	6.66
	Total	348.7	35.00	26.54
	Mean	87.175	8.75	9.605
	StdDev	0.095743	0.01633	6.635

Properties	Replication	Drying Method		
Fat (%)		Control	Open	Solar
	1	0.51	6.02	3.05
	2	0.51	6.05	3.03
	3	0.52	6.03	3.04
	4	0.53	6.02	3.05
	Total	2.07	24.12	12.17
	Mean	0.5175	6.03	3.0425
	StdDev	0.0095742	0.014142	0.009574

Properties	Replication	Drying Method		
Fibre (%)		Control	Open	Solar
	1	2.20	3.31	3.49
	2	2.21	3.11	3.44
	3	2.22	2.53	3.48
	4	2.20	2.52	3.45
	Total	8.83	11.26	13.86
	Mean	2.2075	2.815	3.465
	StdDev	0.009574	0.334913	0.023805

Properties	Replication	Drying Method		
Carbohydrate (%)		Control	Open	Solar
	1	7.67	74.32	75.86
	2	7.59	73.33	75.87
	3	7.45	74.97	75.94
	4	7.63	74.58	75.83
	Total	30.34	297.2	303.5
	Mean	7.585	74.30	75.875
	StdDev	0.095743	0.699667	0.016547

Properties	Replication	Drying Method		
Vitamin C (%)		**Control**	**Open**	**Solar**
	1	19.60	1.14	3.33
	2	19.62	1.15	3.32
	3	19.61	1.13	3.31
	4	19.60	1.12	3.30
	Total	78.43	4.54	13.26
	Mean	19.6075	1.135	3.315
	StdDev	0.009574	0.01291	0.01291

APPENDIX E - DETAILED RESULTS OF THE PHYSICOCHEMICAL PROPERTIES OF OKRA (Control=Fresh produce)

Properties	Replication	Drying Method		
Protein (%)		**Control**	**Open**	**Solar**
	1	0.71	3.49	3.65
	2	0.70	3.42	3.62
	3	0.72	3.48	3.54
	4	0.71	3.51	3.56
	Total	2.84	13.90	14.37
	Mean	0.71	3.475	3.5925
	StdDev	0.008165	0.03873	0.051235

Properties	Replication	Drying Method		
Ash (%)		**Control**	**Open**	**Solar**
	1	1.05	6.60	6.71
	2	1.05	6.62	6.71
	3	1.06	6.61	6.73
	4	1.07	6.62	6.72
	Total	4.23	26.45	26.88
	Mean	1.0575	6.6125	6.72
	StdDev	0.008165	0.009574	0.008165

Properties	Replication	Drying Method		
Moisture Content (%)		**Control**	**Open**	**Solar**
	1	82.76	6.65	5.77
	2	82.76	6.92	5.29
	3	82.74	6.72	5.08
	4	82.75	6.51	5.31
	Total	331.01	26.80	21.45
	Mean	82.7525	6.70	5.3625
	StdDev	0.009574	0.170685	0.290904

Properties	Replication	Drying Method		
Fat (%)		**Control**	**Open**	**Solar**
	1	0.74	7.88	6.39
	2	0.75	7.87	6.40
	3	0.74	7.89	6.41
	4	0.75	7.88	6.38
	Total	2.98	31.52	25.58
	Mean	0.745	7.88	6.395
	StdDev	0.005774	0.008165	0.0129

Properties	Replication	Drying Method		
Fibre (%)		Control	Open	Solar
	1	2.34	8.94	10.55
	2	2.35	8.81	10.50
	3	2.34	8.90	10.53
	4	2.35	8.93	10.51
	Total	9.38	35.58	42.09
	Mean	2.345	8.895	10.5225
	StdDev	0.005774	0.059161	0.022174

Properties	Replication	Drying Method		
Carbohydrate (%)		Control	Open	Solar
	1	12.40	66.44	66.92
	2	12.39	66.36	67.45
	3	12.40	66.40	67.71
	4	12.37	66.55	67.52
	Total	49.56	265.75	269.6
	Mean	12.39	66.4375	67.40
	StdDev	0.014142	0.081803	0.338329

Properties	Replication	Drying Method		
Vitamin C (%)		Control	Open	Solar
	1	14.00	0.53	0.99
	2	14.10	0.50	0.95
	3	14.20	0.52	0.94
	4	14.00	0.55	0.96
	Total	56.30	2.10	3.84
	Mean	14.075	0.525	0.96
	StdDev	0.095743	0.020817	0.021602

APPENDIX F - DETAILED STATISTICAL ANALYSIS OF THE PHYSICOCHEMICAL PROPERTIES OF TOMATO

GenStat Release 10.3DE (PC/Windows 7) 26 August 2013 08:19:42

Analysis of variance

Variate: Pro

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
MetDryn	2	4.5864000	2.2932000	13759.20	<.001
Residual	9	0.0015000	0.0001667		
Total	11	4.5879000			

Tables of means

Variate: Pro

Grand mean 1.5250

MetDryn	T1	T2	T3
	0.6550	1.8850	2.0350

All pairwise comparisons are tested.

Variance = 0.0002 with 9 degrees of freedom

Duncan's multiple range test

Experimentwise error rate = 0.0500
Comparisonwise error rates

2	0.9500	2.262
3	0.9025	2.361

Mean	vs Mean	t	significant
T1	T2	-134.7	Yes
T1	T3	-151.2	Yes
T2	T3	-16.4	

Identifier	Mean
T1	0.655
T2	1.885
T3	2.035

Analysis of variance

Variate: Ash

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
MetDryn	2	57.6504500	28.8252250	30253.88	<.001
Residual	9	0.0085750	0.0009528		
Total	11	57.6590250			

Tables of means

Variate: Ash

Grand mean 4.0225

MetDryn	T1	T2	T3
	0.9425	5.2600	5.8650

All pairwise comparisons are tested.

Variance = 0.0010 with 9 degrees of freedom

Duncan's multiple range test

Experimentwise error rate = 0.0500
Comparisonwise error rates

2	0.9500	2.262
3	0.9025	2.361

Mean	vs Mean	t	significant
T1	T2	-197.8	Yes
T1	T3	-225.5	Yes
T2	T3	-27.7	Yes

IdentifierMean	
T1	0.942
T2	5.260
T3	5.865

Analysis of variance

Variate: MC

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
MetDryn	2	1.741E+04	8.704E+03	1.983E+06	<.001
Residual	9	3.950E-02	4.389E-03		
Total	11	1.741E+04			

Tables of means

Variate: MC

Grand mean 37.335

MetDryn	T1	T2	T3
	91.190	11.210	9.605

All pairwise comparisons are tested.

Variance = 0.0044 with 9 degrees of freedom

Duncan's multiple range test

Experimentwise error rate = 0.0500
Comparisonwise error rates

2	0.9500	2.262
3	0.9025	2.361

Mean	vs Mean	t	significant
T3	T2	-34	Yes
T3	T1	-1742	Yes
T2	T1	-1707	Yes

Identifier	Mean
T3	9.61
T2	11.21
T1	91.19

Analysis of variance

Variate: Fat

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
MetDryn	2	19.4261167	9.7130583	63576.38	<.001
Residual	9	0.0013750	0.0001528		
Total	11	19.4274917			

Tables of means

Variate: Fat

Grand mean 1.6992

MetDryn	T1	T2	T3
	0.0625	3.1650	1.8700

All pairwise comparisons are tested.

Variance = 0.0002 with 9 degrees of freedom

Duncan's multiple range test

Experimentwise error rate = 0.0500
Comparisonwise error rates

2	0.9500	2.262
3	0.9025	2.361

Mean	vs Mean	t	significant
T1	T3	-206.8	Yes
T1	T2	-355.0	Yes
T3	T2	-148.2	Yes

Identifier	Mean
T1	0.063
T3	1.870
T2	3.165

Analysis of variance

Variate: Fibre

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
MetDryn	2	1.1868500	0.5934250	3391.00	<.001
Residual	9	0.0015750	0.0001750		
Total	11	1.1884250			

Tables of means

Variate: Fibre

Grand mean 1.9375

MetDryn	T1	T2	T3
	1.5100	2.0450	2.2575

All pairwise comparisons are tested.

Variance = 0.0002 with 9 degrees of freedom

Duncan's multiple range test

Experimentwise error rate = 0.0500
Comparisonwise error rates

2	0.9500	2.262
3	0.9025	2.361

Mean	vs Mean	t	significant
T1	T2	-57.19	Yes
T1	T3	-79.91	Yes
T2	T3	-22.72	Yes

Identifier	Mean
T1	1.510
T2	2.045
T3	2.258

Analysis of variance

Variate: Carb

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
MetDryn	2	1.373E+04	6.867E+03	3.270E+06	<.001
Residual	9	1.890E-02	2.100E-03		
Total	11	1.373E+04			

Tables of means

Variate: Carb

Grand mean 53.472

MetDryn	T1	T2	T3
	5.640	76.415	78.360

All pairwise comparisons are tested.

Variance = 0.0021 with 9 degrees of freedom

Duncan's multiple range test

Experimentwise error rate = 0.0500
Comparisonwise error rates

2	0.9500	2.262
3	0.9025	2.361

Mean	vs Mean	t	significant
T1	T2	-2184	Yes
T1	T3	-2244	Yes
T2	T3	-60	Yes

Identifier	Mean
T1	5.64
T2	76.42
T3	78.36

Analysis of variance

Variate: VitC

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
MetDryn	2	320.404267	160.202133	16291.74	<.001
Residual	9	0.088500	0.009833		
Total	11	320.492767			

Tables of means

Variate: VitC

Grand mean 3.868

MetDryn	T1	T2	T3
	11.175	0.115	0.315

All pairwise comparisons are tested.

Variance = 0.0098 with 9 degrees of freedom

Duncan's multiple range test

Experimentwise error rate = 0.0500
Comparisonwise error rates

2	0.9500	2.262
3	0.9025	2.361

Mean	vs Mean	t	significant
T2	T3	-2.9	Yes
T2	T1	-157.7	Yes
T3	T1	-154.9	Yes

Identifier	Mean
T2	0.115
T3	0.315
T1	11.175

APPENDIX G - DETAILED STATISTICAL ANALYSIS OF THE PHYSICOCHEMICAL PROPERTIES OF PEPPER

Analysis of variance

Variate: Ash

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
MetDryn	2	68.03182	34.01591	2791.37	<.001
Residual	9	0.10967	0.01219		
Total	11	68.14149			

Tables of means

Variate: Ash

Grand mean 4.559

MetDryn	P1	P2	P3
	1.240	5.728	6.710

All pairwise comparisons are tested.

Variance = 0.0122 with 9 degrees of freedom

Duncan's multiple range test

Experimentwise error rate = 0.0500
Comparisonwise error rates

2	0.9500	2.262
3	0.9025	2.361

Mean	vs Mean	t	significant
P1	P2	-57.49	Yes
P1	P3	-70.08	Yes
P2	P3	-12.59	Yes

Identifier	Mean
P1	1.240
P2	5.728
P3	6.710

Analysis of variance

Variate: Pro

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
MetDryn	2	19.3402167	9.6701083	41942.64	<.001
Residual	9	0.0020750	0.0002306		
Total	11	19.3422917			

Tables of means

Variate: Pro

Grand mean 2.9258

MetDryn	P1	P2	P3
	1.2800	3.1275	4.3700

All pairwise comparisons are tested.

Variance = 0.0002 with 9 degrees of freedom

Duncan's multiple range test

Experimentwise error rate = 0.0500
Comparisonwise error rates

2	0.9500	2.262
3	0.9025	2.361

Mean	vs Mean	t	significant
P1	P2	-172.1	Yes
P1	P3	-287.8	Yes
P2	P3	-115.7	Yes

Identifier	Mean
P1	1.280
P2	3.127
P3	4.370

Analysis of variance

Variate: MC

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
MetDryn	2	1.686E+04	8.428E+03	1.915E+06	<.001
Residual	9	3.960E-02	4.400E-03		
Total	11	1.686E+04			

Tables of means

Variate: MC

Grand mean 34.187

MetDryn	P1	P2	P3
	87.175	8.750	6.635

All pairwise comparisons are tested.

Variance = 0.0044 with 9 degrees of freedom

Duncan's multiple range test

Experimentwise error rate = 0.0500
Comparisonwise error rates

2	0.9500	2.262
3	0.9025	2.361

Mean	vs Mean	t	significant
P3	P2	-45	Yes
P3	P1	-1717	Yes
P2	P1	-1672	Yes

Identifier	Mean
P3	6.63
P2	8.75
P1	87.17

Analysis of variance

Variate: Fat

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
MetDryn	2	60.9179167	30.4589583	2.384E+05	<.001
Residual	9	0.0011500	0.0001278		
Total	11	60.9190667			

Tables of means

Variate: Fat

Grand mean 3.1967

MetDryn	P1	P2	P3
	0.5175	6.0300	3.0425

All pairwise comparisons are tested.

Variance = 0.0001 with 9 degrees of freedom

Duncan's multiple range test

Experimentwise error rate = 0.0500
Comparisonwise error rates

2	0.9500	2.262
3	0.9025	2.361

Mean	vs Mean	t	significant
P1	P3	-315.9	Yes
P1	P2	-689.7	Yes
P3	P2	-373.8	Yes

Identifier	Mean
P1	0.517
P3	3.042
P2	6.030

Analysis of variance

Variate: Fibre

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
MetDryn	2	3.16382	1.58191	42.06	<.001
Residual	9	0.33847	0.03761		
Total	11	3.50229			

Tables of means

Variate: Fibre

Grand mean 2.829

MetDryn	P1	P2	P3
	2.208	2.815	3.465

All pairwise comparisons are tested.

Variance = 0.0376 with 9 degrees of freedom

Duncan's multiple range test

Experimentwise error rate = 0.0500
Comparisonwise error rates

2	0.9500	2.262
3	0.9025	2.361

Mean	vs Mean	t	significant
P1	P2	-4.430	Yes
P1	P3	-9.170	Yes
P2	P3	-4.740	Yes

Identifier	Mean
P1	2.208
P2	2.815
P3	3.465

Analysis of variance

Variate: Carb

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
MetDryn	2	12155.8613	6077.9306	36404.48	<.001
Residual	9	1.5026	0.1670		
Total	11	12157.3639			

Tables of means

Variate: Carb

Grand mean 52.59

MetDryn	P1	P2	P3
	7.59	74.30	75.88

All pairwise comparisons are tested.

Variance = 0.1670 with 9 degrees of freedom

Duncan's multiple range test

Experimentwise error rate = 0.0500
Comparisonwise error rates

2	0.9500	2.262
3	0.9025	2.361

Mean	vs Mean	t	significant
P1	P2	-230.9	Yes
P1	P3	-236.4	Yes
P2	P3	-5.5	Yes

Identifier	Mean
P1	7.59
P2	74.30
P3	75.88

Analysis of variance

Variate: VitC

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
MetDryn	2	8.152E+02	4.076E+02	2.877E+06	<.001
Residual	9	1.275E-03	1.417E-04		
Total	11	8.152E+02			

Tables of means

Variate: VitC

Grand mean 8.0192

MetDryn	P1	P2	P3
	19.6075	1.1350	3.3150

All pairwise comparisons are tested.

Variance = 0.0001 with 9 degrees of freedom

Duncan's multiple range test

Experimentwise error rate = 0.0500

Comparisonwise error rates

2	0.9500	2.262
3	0.9025	2.361

Mean	vs Mean	t	significant
P2	P3	-259	Yes
P2	P1	-2195	Yes
P3	P1	-1936	Yes

Identifier	Mean
P2	1.135
P3	3.315
P1	19.608

APPENDIX H - DETAILED STATISTICAL ANALYSIS OF THE PHYSICOCHEMICAL PROPERTIES OF OKRA

Analysis of variance

Variate: Pro

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
MetDryn	2	21.290450	10.645225	7618.85	<.001
Residual	9	0.012575	0.001397		
Total	11	21.303025			

Tables of means

Variate: Pro

Grand mean 2.592

MetDryn	O1	O2	O3
	0.710	3.475	3.593

All pairwise comparisons are tested.

Variance = 0.0014 with 9 degrees of freedom

Duncan's multiple range test

Experimentwise error rate = 0.0500
Comparisonwise error rates

2	0.9500	2.262
3	0.9025	2.361

Mean	vs Mean	t	significant
O1	O2	-104.61	Yes
O1	O3	-109.06	Yes
O2	O3	-4.45	Yes

Identifier	Mean
O1	0.710
O2	3.475
O3	3.593

Analysis of variance

Variate: Ash

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
MetDryn	2	8.391E+01	4.196E+01	5.035E+05	<.001
Residual	9	7.500E-04	8.333E-05		
Total	11	8.391E+01			

Tables of means

Variate: Ash

Grand mean 4.7967

MetDryn	O1	O2	O3
	1.0575	6.6125	6.7200

All pairwise comparisons are tested.

Variance = 0.0001 with 9 degrees of freedom

Duncan's multiple range test

Experimentwise error rate = 0.0500
Comparisonwise error rates

2	0.9500	2.262
3	0.9025	2.361

Mean	vs Mean	t	significant
O1	O2	-860.6	Yes
O1	O3	-877.2	Yes
O2	O3	-16.7	Yes

Identifier	Mean
O1	1.058
O2	6.612
O3	6.720

Analysis of variance

Variate: MC

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
MetDryn	2	1.570E+04	7.850E+03	2.069E+05	<.001
Residual	9	3.415E-01	3.795E-02		
Total	11	1.570E+04			

Tables of means

Variate: MC

Grand mean 31.605

MetDryn	O1	O2	O3
	82.752	6.700	5.362

All pairwise comparisons are tested.

Variance = 0.0379 with 9 degrees of freedom

Duncan's multiple range test

Experimentwise error rate = 0.0500
Comparisonwise error rates

2	0.9500	2.262
3	0.9025	2.361

Mean	vs Mean	t	significant
O3	O2	-9.7	Yes
O3	O1	-561.8	Yes
O2	O1	-552.1	Yes

Identifier	Mean
O3	5.36
O2	6.70
O1	82.75

Analysis of variance

Variate: Fat

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
MetDryn	2	1.134E+02	5.669E+01	6.378E+05	<.001
Residual	9	8.000E-04	8.889E-05		
Total	11	1.134E+02			

Tables of means

Variate: Fat

Grand mean 5.0067

MetDryn	O1	O2	O3
	0.7450	7.8800	6.3950

All pairwise comparisons are tested.

Variance = 0.0001 with 9 degrees of freedom

Duncan's multiple range test

Experimentwise error rate = 0.0500
Comparisonwise error rates

2	0.9500	2.262
3	0.9025	2.361

Mean	vs Mean	t	significant
O1	O3	-847.5	Yes
O1	O2	-1070.2	Yes
O3	O2	-222.7	Yes

Identifier	Mean
O1	0.745
O3	6.395
O2	7.880

Analysis of variance

Variate: Fibre

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
MetDryn	2	149.897017	74.948508	55862.24	<.001
Residual	9	0.012075	0.001342		
Total	11	149.909092			

Tables of means

Variate: Fibre

Grand mean 7.254

MetDryn	O1	O2	O3
	2.345	8.895	10.523

All pairwise comparisons are tested.

Variance = 0.0013 with 9 degrees of freedom

Duncan's multiple range test

Experimentwise error rate = 0.0500

Comparisonwise error rates

2	0.9500	2.262
3	0.9025	2.361

Mean	vs Mean	t	significant
O1	O2	-252.9	Yes
O1	O3	-315.7	Yes
O2	O3	-62.8	Yes

Identifier	Mean
O1	2.345
O2	8.895
O3	10.523

Analysis of variance

Variate: Carb

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
MetDryn	2	7930.87835	3965.43917	98026.38	<.001
Residual	9	0.36407	0.04045		
Total	11	7931.24242			

Tables of means

Variate: Carb

Grand mean 48.742

MetDryn	O1	O2	O3
	12.390	66.438	67.400

All pairwise comparisons are tested.

Variance = 0.0405 with 9 degrees of freedom

Duncan's multiple range test

Experimentwise error rate = 0.0500

Comparisonwise error rates

2	0.9500	2.262
3	0.9025	2.361

Mean	vs Mean	t	significant
O1	O2	-380.0	Yes
O1	O3	-386.8	Yes
O2	O3	-6.8	Yes

Identifier	Mean
O1	12.39
O2	66.44
O3	67.40

Analysis of variance

Variate: VitC

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
MetDryn	2	474.393267	237.196633	70687.74	<.001
Residual	9	0.030200	0.003356		
Total	11	474.423467			

Tables of means

Variate: VitC

Grand mean 5.187

MetDryn	O1	O2	O3
	14.075	0.525	0.960

All pairwise comparisons are tested.

Variance = 0.0034 with 9 degrees of freedom

Duncan's multiple range test

Experimentwise error rate = 0.0500
Comparisonwise error rates

2	0.9500	2.262
3	0.9025	2.361

Mean	vs Mean	t	significant
O2	O3	-10.6	Yes
O2	O1	-330.8	Yes
O3	O1	-320.2	Yes

Identifier	Mean
O2	0.525
O3	0.960
O1	14.075

APPENDIX I: PICTURES OF THE CONSTRUCTED PASSIVE SOLAR DRYER

Fig 27: Front view of the constructed solar dryer (supervisor and supervisee)

Fig 28: Side view of the constructed solar dryer

Fig 29: Interior of the passive solar dryer without the heat storage incorporated

Fig 30: Interior of the passive solar dryer with the heat storage incorporated

Fig28: Temperature measurement of the collector

Fig 29: Temperature measurement of the drying chamber

Fig 30: Solar drying of the fresh produce

Fig 31: Solar dried produce

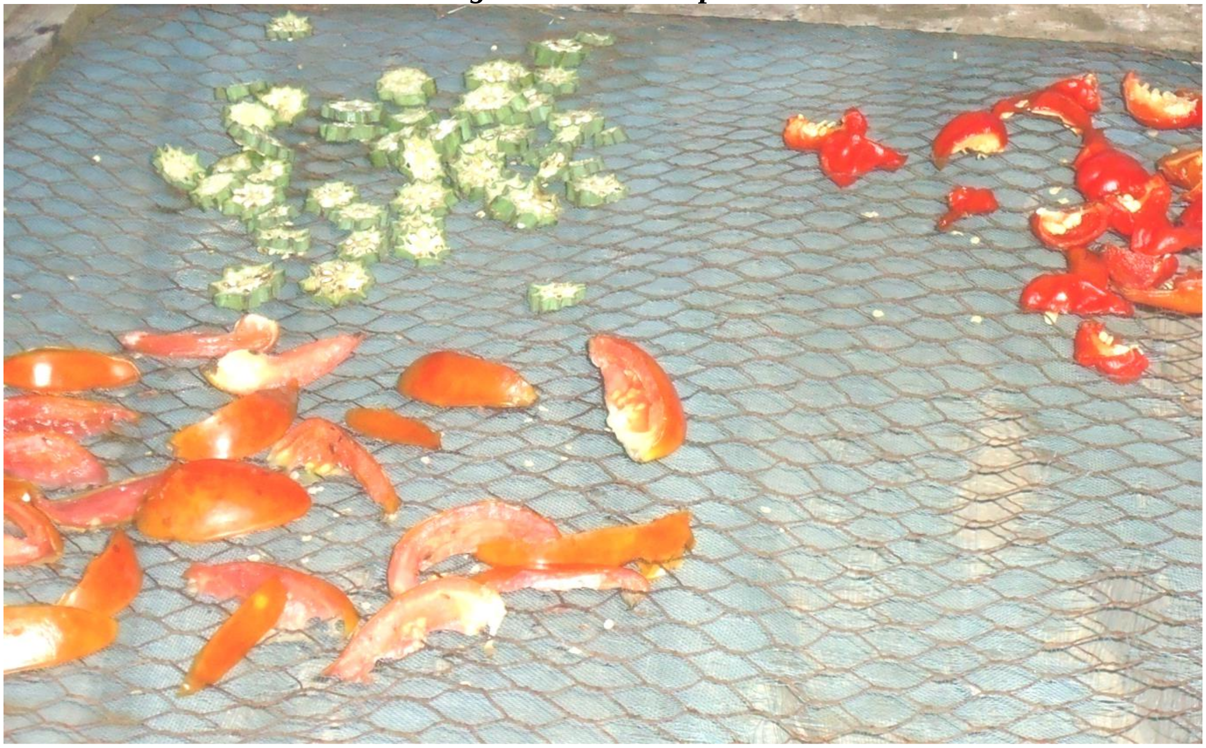

Fig 32: Open sun drying of the produce