Effect of particle size and transparent solar dryer cover on the proximate analysis of dried onion.

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Authors Contributions

This work was carried out in collaboration among all authors. All authors read and approved the manuscript.

Abstract

In this work, we investigate effect of particle size and transparent solar dryer cover on the proximate analysis of dried onion.

A solar drying unit was developed and constructed for drying the of red onion slices in order to determine the proximate composition of fresh and dried red onion using multi-crop direct solar dryer. Also, the evaluation and effect of particles size and multi-crop transparent solar dryer cover on the proximate analysis of red onion during drying. Consequently, the higher efficiency of the solar collector was obtained at the higher airflow rate. The moisture content of dried onion slices was strongly affected by the thickness of the onion slices and the density of the polyethylene. The final moisture content of dried onion slices ranged from 10.85% to 13.01%, 4.95% to 6.01% ash, 4.69% to 5.26% fibre, 11.17% to 13.09% fat, 6.70% to 5.60% protein and 68.64% to 68.03% carbohydrate for particle sizes of 3mm, 5mm and 7mm dry-basis depending on drying temperature cycle for low density polyethylene cover. While the final moisture content of dried onion slices ranged from 9.85% to 12.01%, 5.96% to 6.01% ash, 3.69% to 4.26% fibre, 13.17% to 12.09% fat, 5.70% to 6.60% protein and 61.64% to 58.03% carbohydrate for particle sizes of 3mm, 5mm and 7mm dry-basis depending on drying temperature cycle for high density polyethylene cover.

INTRODUCTION

Solar drying technology seems to be one of the most promising alternatives to reduce the post-harvest losses (Wiriya et al, 2009). Solar drying technology is one of the renewable energy resources particularly for low temperature heating and is a very attractive option for the small scale and resource poor enterprise (Chavda and Kumar, 2009). Due to the current trends towards higher cost of fossil fuels and uncertainty regarding future cost and availability, use of solar energy in food processing will probably increase and become more economically feasible in near future. Solar dryers can be constructed from locally available materials at a relatively low capital cost and there are no fuel costs. Thus, they can be useful in areas where fuel or electricity are expensive, land for sun drying is in short supply or expensive, sunshine is plentiful but the air humidity is high (Velayudham *et al*, 2015; Bindu *et al*, 2016).

Solar drying technology produces better quality products and is considered to be an alternative for drying agricultural products in developing countries (Gürlek, *et al*, 2009, Tunde and Akintunde, 2011).

A solar dryer has three main components and these are drying chamber, solar collector and some type of airflow system. A drying chamber is an enclosed, insulated structure inside which both solar collection and drying takes place. It is often insulated to increase efficiency (Chavda and Kumar, 2009). The solar collector (or absorber) is often a dark coloured box with a transparent cover and glass or polyethylene is recommended for the absorber cover. The solar collector can be of any size and should be tilted toward the sun to optimize collection. The size of solar collector required for a certain size of dryer depends on the ambient temperature, amount of sun, and humidity (Green and Shwartz, 2001; Chavda and kumar, 2009). Tilting the collectors is more effective than placing them horizontally, for two reasons. First, more solar energy can be collected when the collector surface is more nearly perpendicular to the sun's rays. Second, by tilting the collectors, the warmer, less dense air rises naturally into the drying chamber (Chua and Chou, 2003; Prakash and Kumar, 2013). Solar dryers use one of two types of airflow systems which are natural (passive) and forced (active) convection. The natural convection utilizes the principle that hot air rises, and forced convection dryers force air through the drying chamber with fans. The effects of natural convection may be enhanced by the addition of a chimney in which exiting air is heated even more (Eltawil *et al*, 2012).

The Solar Dryers may be classified into several categories, depending upon the mode of heating or the mode of their operations and airflow systems. Depending on how heat is provided for drying, solar dryers can be broadly divided into four categories namely; direct, indirect, mixed and hybrid types (Fudholi *et al.,* 2010; El-Sebaii and Shalaby, 2012).

Yaldiz and Erekin (2001) employed a solar cabinet dryer (consisting of a solar heater and a drying cabinet) for drying five different vegetable crops; pumpkin, green pepper stuffed pepper, green beans and onion. They concluded that the drying air temperature could increase up to 460C but the drying air velocity had an important effect on the drying process.

Onion (Allium cepa) is a vegetable crop which belongs to the family Allisceous. It is a biennial plant but usually grown as annual. Compared with other fresh vegetables, onions are relatively high in food value like carbohydrate content and rich in calcium and riboflavin (Singh and Heldman, 2009). Common onions are normally available in three colour varieties. Cream or brown onions (called red in some European countries) are full-flavoured and are the onions of choice for everyday use, with many cultivars bred specifically to demonstrate this sweetness (Oulton, Randal 2005*)*. Cream onions turn a rich, dark brown when caramelised and give French onion soup its sweet flavour. The red onion (called purple in some European countries) is a good choice for fresh use when its colour livens up the dish; it is also used in grilling. White onions are the traditional onions used in classic Mexican cuisine; they have a golden colour when cooked and a particularly sweet flavour when sautéed (Mower, Chris.2013). While the large, mature onion bulb is most often eaten, onions can be eaten at immature stages. Young plants may be harvested before bulbing occurs and used whole as spring onions or scallions. When an onion is harvested after bulbing has begun, but the onion is not yet mature, the plants are sometimes referred to as "summer" onions (Thompson, Sylvia 1995). Additionally, onions may be bred and grown to mature at smaller sizes. Depending on the mature size and the purpose for which the onion is used, these may be referred to as pearl, boiler, or pickler onions, but differ from true pearl onions which are a different species (Thompson, Sylvia 1995). Pearl and boiler onions may be cooked as a vegetable rather than as an ingredient and pickler onions are often preserved in vinegar as a long-lasting relish (Ministry of Agriculture; Fisheries and Food 1968). Onions are available in fresh, frozen, canned, caramelised, pickled, and chopped forms. The dehydrated product is available as kibbled, sliced, ring, minced, chopped, granulated, and powder forms. Onion powder is a seasoning widely used when the fresh ingredient is not available. It is made from finely ground, dehydrated onions, mainly the pungent varieties of bulb onions, and has a strong odour. Being dehydrated, it has a long shelf life and is available in several varieties: cream, red, and white (Smith, S. E. 2013).

There is a general increase in demand for processed onions in Nigeria which results to the importation of onion-processed food such as dehydrated onion in powder or pieces and onion oil obtained from the distillation of fresh onions due to the inability to provide the proper drying kinetics and dehydration of onion. Due to the high perishability of onion and other vegetables and inadequate or little knowledge of postharvest techniques of farmers have led to almost 69% of loss to the farmers annually (Samuel and Funmi 2010). Therefore, leads to the reduction of annual income of onion farmers.

These problems can be solved by developing the best drying technique that enable the dehydration of onion. This technique is mainly used for preservation and value addition of onion. Oniya et al., (2021) evaluate the effect of drying temperature on the drying characteristics and quality of red, white and cream varieties of Nigerian onions using a locally fabricated electrically powered dryer and was designed to achieve safe temperature and conditions at which onion would dry that will guarantee a minimal loss in the food value and flavour degradation. Lewicki and Witrowa (2005) used a forced convection dryer at 60 oC air drying temperature and 2 m/s air velocity for drying two different onion varieties. Yaldiz and Ertekin (2001) employed a solar cabinet dryer (consisting of a solar heater and a drying cabinet) for drying five different vegetable crops; pumpkin, green pepper, stuffed pepper, green beans and onion.

The aim of this research is to determine the effect of particle size and transparent solar dryer cover on the proximate analysis of dried onion using a fabricated multi-crop direct solar dryer..

MATERIALS AND METHOD

Materials

The raw material used in this study was onion bulbs (*Allium cape L.)* obtained from a produce merchant at Nigeria Stored Product Research Institute (NSPRI) in Ilorin, Kwara State, Nigeria. The variety used for the study was red onion. The following materials were used in this study;

i. Wood – It is the casing (housing) of the entire system. Wood was selected because it is a good insulator and relatively cheaper than metals.
ii. Stainless trays and knives.
iii. Weighing machine.
iv. Direct solar dryer.
v. Polyethylene for absorption of solar radiation.
vi. Wooden frames for constructing the trays.

Sample Preparation

The raw material used in this study was Onion bulbs (*Allium cape L.)* obtained from a produce merchant at Nigeria Stored Product Research Institute (NSPRI) in Ilorin, Kwara State, Nigeria. The varieties used for the study was red onion. The following equipments were used in the study.

- **Stainless trays and knives**

Stainless trays and knives were washed under running tap water and rubbed with a dried and clean towel to dry the water on the surface of the tray.

- **Onions**

Fresh red was purchased from a local market (mandate) in Ilorin, Kwara State, Nigeria. The onions were sorted, cleaned and peeled manually by removing the skin and the first layer. After peeling, the onion was washed under running tap water and left on a dried stainless trays for 1 hour to allow the residual wash water on the surface of the onions to evaporate, the onion was then sliced using a stainless knife in the direction perpendicular to the vertical axis. The onion slices were 3mm, 5mm and 7mm thick.

- **Weighing Machines**

A laboratory /weighing machine with readability of 0.1gm was used to take measurement for the weight of both the unsliced and the sliced onions.

- **Experimental multi-crop direct solar dryer**

The drying experiments were conducted in a laboratory using a multi-crop direct solar dryer which consists of the following: solar collector (high & low density polyethylene), drying chamber, chimney and a tray. The air passes into the central section of the duct where a tray of the material to be dried is suspended in the air stream. The entire dryer was designed to avoid heat losses and substantial temperature across the test sections. The slices (3mm, 5mm and 7mm thick) of the red onion was spread in a net-like tray placed in the solar dryer which were made from stainless steel wire net in both high density polyethylene and low density polyethylene dryer. The wooden net-like tray inside the solar dryer was divided into three sections to demarcate the onion varieties.

Methods

The direct solar dryer used for this study was fabricated locally. The direct mode of drying used consists of the drying chamber covered by a transparent material acting as the glazing, allows solar radiation into the chamber to heat up and increase the temperature of the air and the crop being dried. The main disadvantage of this type of dryer is its inability to control the crop temperature because of the direct absorption of radiation by the crop which might cause some crops sensitive to sunlight to lose some of its nutrients.

Design procedure

The multi-crop direct solar dryer was put in the sun idle for about 1 hour to achieve a steady state in respect to pre-set experimental drying conditions before conditions before each drying process. The initial weights of onion slices of the three varieties of onion were measured and taken. The onion slices after weighing were uniformly spread on each net-like tray inside the drying chamber with label red in both the low-density and high-density polyethylene dryers.

The weights of the onion sample (red) was measured at interval of 2 hours until it reaches constant weight i.e. the weight stops changing. The average experiment drying temperature is 50.23ºC at uniform air velocity.

Materials selection for the construction of the multi-crop direct solar dryer

In constructing the multi-crop direct solar dryer, the followings factors were considered;

- Availability of construction materials locally,
- Availability of the energy required for the drying, which was the sun.

The major components parts of the solar dryers are; solar collector which was polyethylene, drying chamber and drying tray. Figure 3.1 and Figure 3.2 shows the orthographic and isometric

BILL OF MATERIAL

SERIAL NO.	COMPONENT	MATERIAL	DIMENSION(mm)
1	**Solar Collector**	**Polyethylene**	**1750x1000**
2	**Absorber Plate**	**Aluminium**	**1750x1000**
3	**Heating Chamber**	**Wood**	**1750x1000x150**
4	**Drying Chamber**	**Wood**	**1000x1000x600**
5	**Insulation**	**Glass wool**	**50**
6	**Tray**	**Aluminium**	**500x850**

view of the solar dryer respectively. The materials used for the construction of the solar dryer were such that could make the dryer to be easily maintained, repaired and obtained at relatively lower cost than imported dryers.

The materials that were used to construct the solar dryer include;

1. **Polyethylene:** Polyethylene is a lightweight, durable thermoplastic with variable crystalline structure. It is transparent in nature, a property that allows the passage of sun rays. It was used as a cover for the solar collector. The two types of transparent cover used are briefly discussed as follows;

i. **Low-density polyethylene (LDPE) –** It is a thermoplastic made from the monomer ethylene. It was the first grade of polyethylene, produced in 1933 by Imperial Chemical Industries (ICI) using a high pressure process via free radical polymerization. (Dennis Malpass, 2010). Its manufacture employs the same method today. The EPA estimates 5.7% of LDPE (recycling number 4) is recycled in the United States. LDPE is defined by a density range 917-930 kg/m^3. It is not reactive at room temperatures, except by strong oxidizing agents, and some solvents cause swelling. It can withstand temperatures of 80^{0}C continuously and 90^{0}C (194^{0}F) for a short time. Made in translucent or opaque variations, it is quiet flexible and tough. LDPE has no branching (on about 2% of the Carbon atoms) than HDPE, so its intermolecular forces are weaker, its tensile strength is lower and its resilience is higher. Also because its molecules are less tightly packed and less crystalline due to the side branches, its density is lower. When exposed to ambient solar radiation (consistent sunlight) the plastic produces significant amounts of two greenhouse gases – methane and ethylene. Due to its low density properties (high branching) it breaks down more easily over time compared to other plastics, leading to higher surface areas.

ii. **High-density polyethylene (HDPE) –** It is a thermoplastic polymer produced from the monomer ethylene. It is sometimes called "alkathene" or "polythene" when used for HDPE pipes. With a high strength-to-density ratio, HDPE is used in the production of plastic bottles, corrosion-resistant piping, geomembrances and plastic lumber. HDPE is commonly recycled and has the number "2" as its resin identification code. HDPE is known for its high strength-to-density ratio. The density of HDPE can range from 930 to 970 kg/m^3. Although the density of HDPE is only marginally higher than that of low-density polyethylene, HDPE has little branching, giving it stronger intermolecular forces and tensile strength (38MPa versus 21MPa) than LDPE. The difference in strength exceeds the difference in density, giving HDPE a higher specific strength. It is also harder and more opaque and can withstand somewhat higher temperatures (1200C/2480F for short periods). High-density polyethylene, unlike polypropylene, cannot withstand normally required autoclaving conditions. The lack of branching is ensured by an appropriate choice of catalyst (e.g., Ziegler-Natta catalyst) and reaction conditions.

2. **Wood:** Wood is a porous and fibrous structural tissue found in the stems and roots of trees and other woody plants. Polyethylene is an organic material – a natural composite of cellulose fibers that are strong in tension and embedded in a matrix of lignin that resists compression. It was used for the construction of the cabinet and tray frames because it is strong in relation to its weight, it is insulating to heat and electricity and it has desirable acoustic properties.
3. **Mesh wire:** Mesh wire is a metal wire screen that is made up of low carbon steel wire or stainless steel wire. It is a versatile metal product that can be used effectively in countless applications globally. It was used for making tray (it holds the products). It was used because of it is readily available, cheap and strong in reliability.

Construction of multi-crop direct solar dryer

The materials used for the construction of the direct solar dryer are cheap and easily obtainable in the local market. The solar dryer consist of the solar collector (air heater), the drying cabinet and drying trays.

Operation of direct solar dryer

The dryer is a passive system in the sense that it has no moving parts. It is energized by the sun's rays entering through the collector glazing. The trapping of the rays is enhanced by the inside surfaces of the collector that were painted black and the trapped energy heats the air inside the collector. The greenhouse 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 'Ta' has relative humidity 'Ha' and the out-going air at a temperature 'Te', has a relative humidity 'He'. Because $Te > Ta$ and the dryer contains no item, $Ha > He$. Thus, there is tendency for the out-going hot air to pick more moisture within the dryer as a result of the difference between Ha and He. Therefore, insulation received is principally used in increasing the affinity of the air in the dryer to pick moisture.

Description and operation of the multi-cop direct solar dryer

The direct solar dryer involves directly exposing the material to the sun. The low cost direct solar dryer has the following component parts: The drying chamber, drying tray, a solar collector and a thermal storage system. The drying chamber was rectangle in shape and was made of wood with dimension of 10x10x6cm. Its wall was lagged with polyethylene to minimize heat loss. The tray held the drying product in the drying chamber. The solar collector collects heat energy and then transferred the heat energy into the drying chamber for drying process. The solar collector was made of wood and covered with polyethylene to allow the penetration of sun rays. The bottom and sides was insulated to minimize heat loss. The dryer is a passive system in the sense that it has no moving parts. The sun's rays entering through the transparent top energized the solar dryer. The trapping of the rays was enhanced by the inside surfaces and the trapped energy heated the air inside the dryer. The orthographic and isometric view of the dryer is shown in Figure 3.1 and 3.2 respectively.

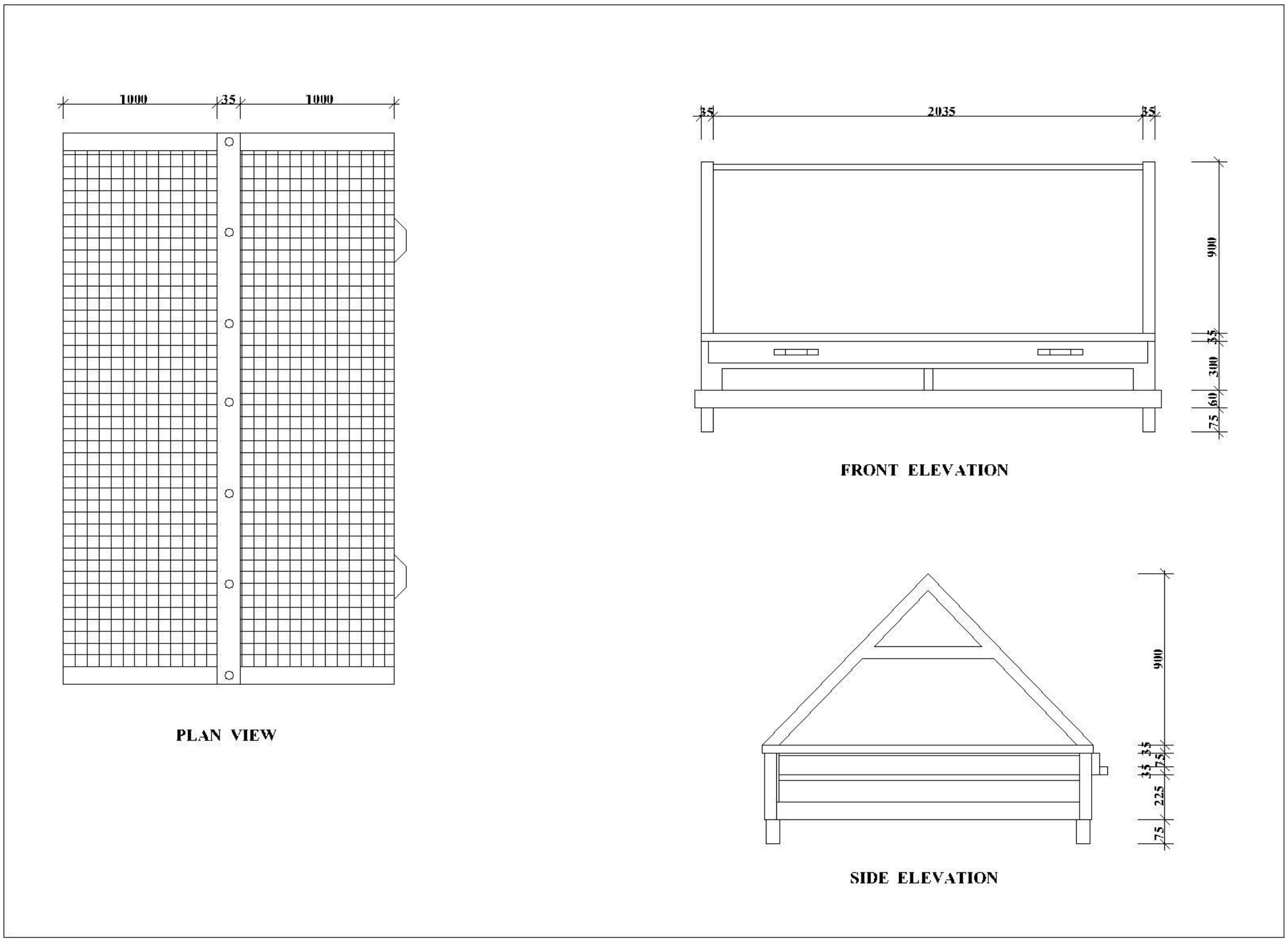

Figure 3.1: Orthographic view of a direct solar dryer.

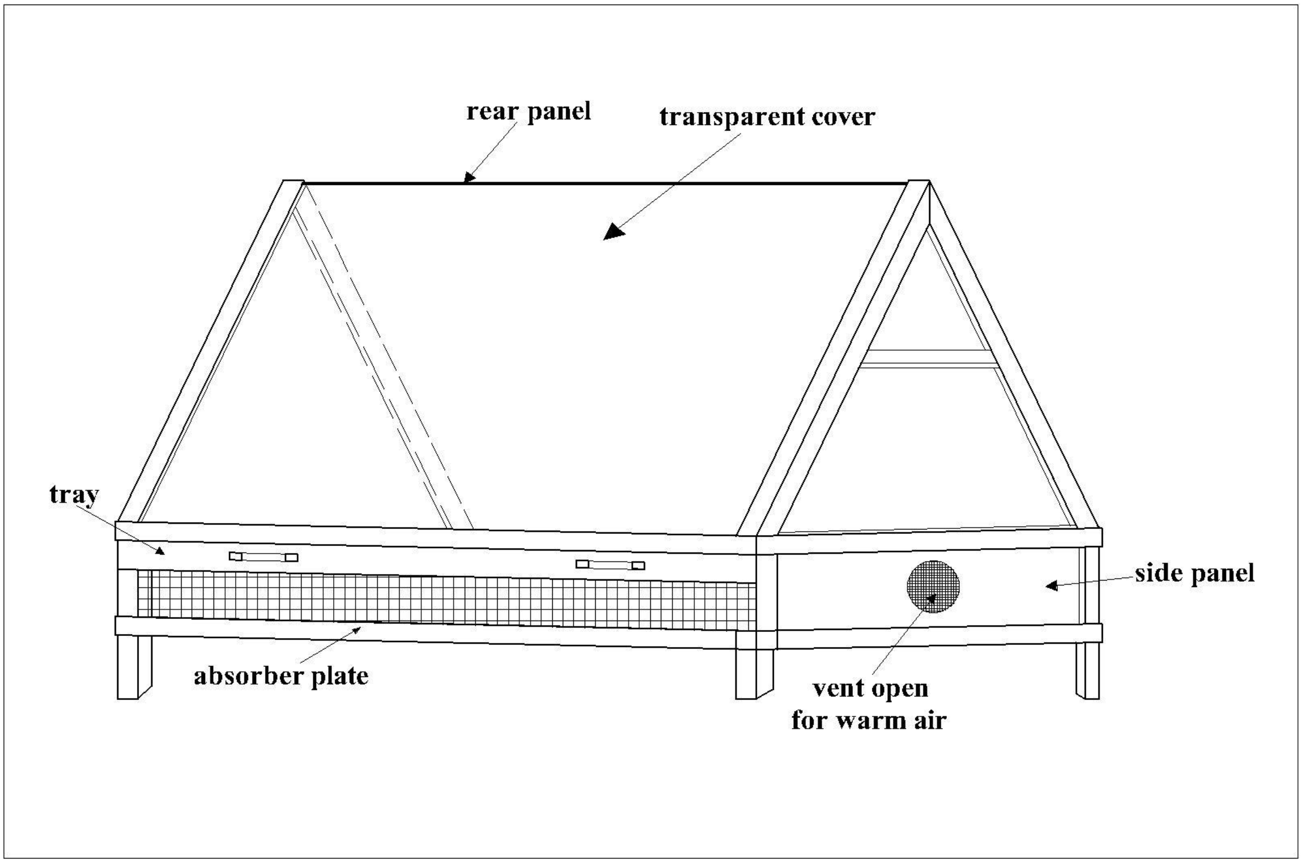

Figure 3.2: Isometric view of a direct solar dryer

Performance Evaluation Analysis of the multi-crop solar dryer

The solar dryer was tested to evaluate its performance. The dryer was loaded with slice onion. Under load test, the parameters that were calculated in the course of evaluating the dryer are; actual heat used to affect drying, rate of mass transfer and thermal efficiency of the dryer.

No load testing of the solar dryer

The solar dryer was tested at no load, the following were measured; the drying temperature compared with the external temperature, collector efficiency, the air flow into the solar collector, sunshine intensity and the internal temperature of the thermal storage system in the night.

Load testing of the solar dryer using onion slices

The load test of the solar dryer was done using onion slices. The thermal storage system kept the drying chamber temperature higher than the ambient during sunset thereby disallowing the reabsorbing of moisture by the drying onion samples. The parameters measured are; actual heat used to effect drying, rate of mass transfer and thermal efficiency of the dryer.

Actual heat used to effect drying in the solar dryer (H_D)

The quantity of heat used to effect drying of onion slices in kJ, H_D was determined as given in equation 3.1 as stated by Ehiem (2009):

$$H_D = CaTcM_RVc$$

Where;

C_a = specific heat capacity of air.
T_c = temperature difference in the dryer.
M_R = amount of moisture removed from the sample in kg.
V_c = volume of drying chamber

Rate of mass transfer in the solar dryer

The mass transfer rate Q_{mtr} in kgm³/s² was determined by using equation 3.2 as stated by Ehiem (2009):

$Q_{mtr} = M_cA_t (H_{r1} – H_{r2})q_2$

Where,
M_c = mass transfer coefficient of a free water surface;
A_t = total surface area of the three trays inside the dryer;
$H_{r1} – H_{r2}$ = the difference in initial and final humidity ratios
q_2 = air flow rate.

Thermal efficiency of the solar dryer

The thermal efficiency of the solar dryer Dc was calculated as stated by Ehiem (2009):

$$Dc = \frac{H_D \, x \, 100}{t \, x \, Qht}$$

Where;

H_D = the quantity of heat used in effecting drying, kJ;
Q_{ht} = heat transfer, kJ;
t = drying time

Onion Sample Preparation

In the preliminary research work, Nigeria red onion showed high retention of pungency and total soluble substance (TSS) after drying (NSPRI, 2005). Therefore, Nigeria red onion was used in this study. The onion was carefully transported to the processing centre to prevent any injuries to occur. They were manually graded and cleaned to sort out any damaged and diseased produce. Cleaned onion bulbs were sliced perpendicular to the axis into pieces 3mm, 5mm and 7mm thickness using knife. The slice thickness was chosen based on the thickness used by commercial dehydrators. Some quantities of the fresh sliced onion samples were used for chemical analysis.

Drying of Onion slices in the direct solar dryer

The fresh sliced onion sample weighing one kilogram was dried in a thin layer drying at 50.23^0C. The weights changes of the drying samples taking place was recorded every two hours until the product weight was constant. The drying was done in three replicates. After drying, samples were taking to the laboratory for chemical and sensory analysis while the remaining dried onion samples were put in the desiccators to cool and later stored. Plate 3.1 shows the cleaned onion while Plate 3.2 and 3.3 shows the sliced onion in the tray and in the dryer respectively. The dried onion stored at room temperature is presented in Plate 3.4.

Design and construction of a multi-crop direct solar dryer

The designed and constructed solar dryer consists of two major compartments or chambers being integrated together, the solar collector compartment (which can also be referred to as the air heater) and the drying chamber (which is designed to accommodate three layers of drying trays on which the produces are placed for drying).

In this solar dryer constructed, the greenhouse effect and thermo siphon principles are the Theoretical basis. A digital thermometer was used for the temperature measurement in the solar dryer, the initial moisture content was measured using variation in weight loss was measured using an electronic scale.

Initial Proximate Analysis

Initial proximate analysis was carried out to determine the nutritional composition of the samples of the three varieties using AOAC (2005). The parameters got from the analysis were for proteins, fat, crude fibre and ash contents and carbohydrate.

Initial and Final Moisture Content Determination

Fresh onion samples of 30g from each variety were placed in pre-weighed aluminum weighing dishes and dried in the solar dryer for some hours. The onion was retrieved then weighed. The weighing balance used for the scale had an accuracy of 0.01g. All measurement for each trial were replicated twice and moisture contents were calculated on dry basis using the following formula developed by ADOGA (2005) to obtain the initial moisture contents of red, white and cream onion samples used in this research work.

Plate 3.1: Cleaned onion

Plate 3.2: Sliced onion samples on a dryer tray ready for drying.

Plate 3.3: Sliced onion samples in a direct solar dryer.

Plate 3.4: Dried red onions at room temperature

$$MC = \frac{(Wi - Wf)}{Wf} \times 100$$

Where:
MC= moisture content
Wi = initial weight of the sample
Wf = final weight of the sample

.The final moisture content of the dried samples was determined manually and individually by weighing and comparing with the initial moisture content of the dried onion samples using infrared determination balance AD-4714A, (Centurion Scientific Ltd). The ambient temperature is 27^0C.

Initial and Final determination of Vitamin C content of onions

5g of the fresh onion sample was weighed into a 100ml volumetric flask and made up to 100ml with 3% metaphosphoric acid solution. The diluted samples were filtered using a Whatmann Filter paper No. 3; 10ml of the filtrate was pipetted into a small flask and titrated immediately with a standardized solution of 2, 6- dichlorophenol to a faint pink end point. The solution was used for vitamin C analysis by the method of the Official Method of Analysis of the Association of Official Analytical Chemists, AOAC (2005).

The Vitamin C content of the extracts was calculated from the relationship below;

$$\frac{V \times T \times 100}{W} = mg\ ascorbic\ acid\ per\ 100g\ sample$$

Where V = ml dye used for titration of aliquot of diluted sample
T = Vitamin C equivalent of dye solution expressed as mg per ml dye
W = gram of sample in aliquot titrated.

The final Vitamin C content was determined by weighing 5g of the dried onion sample from each variety into a 100ml volumetric flask and made up to 100ml with 3% metaphosphoric acid solution.

Drying

A sample of 1kg of sliced onion was used and dried at an ambient temperature of 43^0C for low-density polyethylene and 45^0C for high-density polyethylene in direct solar dryer. Before the samples were set to the drying chambers of the direct solar dryer, the dryer was set in the sun for some time to pre-determine the temperature. The drying took place from 10am to 8pm each day until the onion attains equilibrium weight.

Since the temperature of solar drying could not be controlled but the drying was carried out until constant and uniform weights of the sample were attained. The drying chamber were recorded from 10:00am to 8:00pm during each day trials and recorded the change in weight every two hours i.e. at 12pm, 2pm, 4pm etc.

Performance evaluation of a multi-crop direct solar dryer

The efficiency of the multi-crop direct solar dryer is defined as the ratio of amount of moisture removed using a fabricated dryer to total amount of moisture to be removed in percentage.

$$Efficiency = \frac{amount\ of\ moisture\ removed\ uding\ the\ fabricated\ dryer}{amount\ of\ moisture\ top\ be\ removed} \times 100\%$$

Proximate Analysis for Dried Onion Samples

Determination of protein contents

Protein content of the test samples were determined using Kjedhal method as described by AOAC (2005). One gram of test sample was weighed into digestion tube, 15ml of concentrated H_2SO_4 and one tablet of selenium catalyst was added. The mixture was digested on an electro-thermal heater until clear solution is obtained. The flask was allowed to cool after which the solution was diluted with distilled water to 50ml, 5ml of this was transferred into the distillation apparatus, 5ml of 2% boric acid was pipetted into 100ml conical flask (the receiving flask) and 4 drops of screened methyl red indicator was added. 50% NaOH was continually added to the digested sample until the solution turned cloudy and this indicates the alkalinity of the solution.

The distillation was carried out into the acid solution in the receiving flask with the delivery tube below the acid level. As the distillation is going on, the pink color solution of the receiving flask turned blue. Distillation was continued until the content of the round bottom flask is about 50ml. The resulting solution in the conical flask was titrated with 0.1 M HCl.

$$\%\ Nitrogen = \frac{Titre\ value \times 0.1HCl \times 0.014 \times 100 \times {}^{50}\!/_{5}}{Original\ weight\ of\ sample}$$

$$\%\ Protein = \%Nitrogen \times protein\ conversation\ factor$$

Determination of ash contents

The ash content was determined as described in Association of Official Analytical Chemists (AOAC) Official Standard and Methods (2005). A known weight of the onion was charred in a low flame. Thereafter, the sample was transferred to the furnace regulated at 600^0C for about 30 minutes. The sample was then cooled and re-weighed. The procedures were repeated until grey ash was resulted. The ash content was calculated as shown in equation developed by AOAC (2005).

$$C_{ash} = \frac{W_{ash}}{W_{sa}} \times 100$$

Where;

$$C_{ash} = the\ ash\ content\ in\ \%$$

$$W_{ash} = ash\ weight, kg$$

$$W_{sa} = sample\ weight, kg$$

Determination of crude fibre contents

The fiber content was determined by the method described in AOAC, (2005). Two grams of the samples were accurately weighed into fiber flask and 100ml of 0.255 N H_2SO_4 was added. The mixture was then heated under reflux for one hour with the heating mantle and the hot mixture was filtered through a fiber sieve cloth. The filtrate was thrown off while the residue was returned to the fiber flask to which 100ml of 0.313 N NAOH was added and heated under reflux for another one hour. The mixture was filtered through a fiber sieve cloth and 10ml of acetone was added to dissolve any organic constituent. The residue was washed with some hot water twice on the sieve cloth before it was finally transferred into crucible. The crucible containing the residue was cooled in the desiccators and later weighed to obtain weight W_2. The different W_1-W_2 gives the weight of fiber and the percent fiber was obtained as;

$$\%fibre = \frac{W_1 - W_2 \times 100}{Weight\ of\ sample}$$

Determination of fat contents

About 5g of each of the sample was weighed and wrapped in a filter paper and placed in an extraction thimble. The thimble was weighed before the addition of the sample (W_1), the thimble with sample (W_2) was then inserted in soxhlet apparatus. Extraction under reflux was carried out with petroleum ether (30-60^{0}C boiling range) for 5 hours. At the end of the extraction, thimble was dried in an oven for about 180s at 100^{0}C for the evaporation of the solvent and thimble was allowed to cool in a desiccators and later weighed (W_3) (AOAC, 2005).

$$\%Fat = (Weight\ of\ sample\{extracted\ fat\}) - (Original\ weight\ of\ sample) \times 100$$

$$\%Fat = (W_2 - W_3) - (W_2 - W_1) \times 100$$

Determination of carbohydrate contents

The carbohydrate contents were determined by the subtraction of the summation of crude protein, crude fiber, ash and fat contents in percentage from hundred percent.

$$\%Carbohydrate = 100 - (\%protein + \%fibre + \%ash + \%fat)$$

Drying Characteristics of Onions

Calculation of drying rate

Reduction in moisture was monitored during drying by measuring the weight of the samples at regular interval of 2 hours until the sample weight was constant. The drying rate was calculated using the following equation developed by Sugar (2001).

$$R = \frac{D_m}{dt} = \frac{m_i - m_f}{t}$$

Where;

R is the drying rate in g/h

Dm is the change in mass (g)

dt is the change in time (h)

t is the total time (h)

m_i and m_f are the initial and final mass of onion slice samples weights in g

Water losses during drying

The water loss (WL) is defined as the net weight loss of the fruit on initial weight basis and was estimated using the equation developed by Baroni and Hubinger (1998).

$$WL = \frac{w_i - w_f}{w_f}$$

Where;

w_i = initial mass of slices

w_f= final mass of slices after time

RESULTS AND DISCUSSION

Results

Construction of multi-crop direct solar dryer

The solar dryer was fabricated for the experimental purpose. The solar dryer consist of the following parts; the drying chamber and solar collector with 203.5 × 90cm, constructed with wood and has drying trays with dimension 200×85 cm. The multi-crop direct solar dryer is shown in Plate 4.1.

Evaluation of the Solar Dryer

The solar dryer was evaluated at no load to be able to evaluate its performance and later with load. The solar collector has a maximum temperature of 50.23^0C and an average temperature of 45^0C for the HDPE and 43^0C for LDPE, between 10am to 8pm, while the corresponding ambient temperature is 27^0C.

The multi-crop direct solar dryer was loaded with 1kg of red onion to evaluate its performance. The result for LDPE and HDPE was shown in Table 4.1 and 4.2 respectively.

Plate 4.1: Pictorial view of the multi-crop direct solar dryer

Table 4.1: Performance evaluation of the multi-crop direct solar dryer using LDPE cover

Sample Size	Initial Moisture Content (%)	Final Moisture Content (%)	Efficiency (%)
3mm	84.75	10.54	87.56
5mm	84.75	11.32	86.64
7mm	84.75	13.02	84.64

Table 4.2: Performance evaluation of the multi-crop direct solar dryer using HDPE cover

Sample Size	Initial Moisture Content (%)	Final Moisture Content (%)	Efficiency (%)
3mm	84.75	9.54	88.74
5mm	84.75	9.99	88.21
7mm	84.75	12.02	85.82

Drying rate of Onion

The drying rate for onion of both LDPE and HDPE were presented in Table 4.8, 4.9, 4.10, 4.11, 4.12 and 4.13 for 3mm, 5mm and 7mm respectively.

Table 4.8 represents the drying rate of 3mm sample of dried onion in low-density polyethylene. The onion sample of 1000g of each sample and variety is loaded in the dryer at 10am and is weighed every 2 hours until it reaches equilibrium weight. It is paused while the sun set at 8pm and starts again at 10am the following day. The 3mm sample dries for 12 hours.

Table 4.9 represents the drying rate of 5mm sample of dried onion in low-density polyethylene. The onion sample of 1000g of each sample and variety is loaded in the dryer at 10am and is weighed every 2 hours until it reaches equilibrium weight. It is paused while the sun set at 8pm and starts again at 10am the following day. The 3mm sample dries faster than the 5mm sample i.e. 12 hours and 14 hours respectively.

Table 4.10 represents the drying rate of the 3mm, 5mm and 7mm onion respectively in low density polyethylene. The onion sample of 1000g of each sample and variety is loaded in the dryer at 10am and is weighed every 2 hours until it reaches equilibrium weight. It is paused while the sun set at 8pm and starts again at 10am the following day. The 3mm sample dries for 12 hours, 5mm sample dries for 14 hours while 7mm dries for 20 hours.

Table 4.11 represents the drying rate of 3mm sample of dried onion in high density polyethylene. The onion sample of 1000g of each sample and variety is loaded in the dryer at 10am and is weighed every 2 hours until it reaches equilibrium weight. It is paused while the sun set at 8pm. The 3mm sample dries for 10 hours.

Table 4.12 represents the drying rate of 5mm sample of dried onion in high density polyethylene. The onion sample of 1000g of each sample and variety is loaded in the dryer at 10am and is weighed every 2 hours until it reaches equilibrium weight. It is paused while the sun set at 8pm and starts again at 10am the following day. The 3mm sample dries faster than the 5mm sample i.e. 10 hours and 12 hours respectively.

Table 4.13 shows the drying rate of the 7mm onion in high density polyethylene. The onion sample of 1000g of each sample and variety is loaded in the dryer at10am while the sunrise and is weighed every 2 hours until it reaches equilibrium weight. It is paused while the sun set at 8pm and starts again at 10am the following day. The 3mm sample dries for 10 hours, 5mm sample dries for 12 hours while 7mm dries for 18 hours.

Table 4.3: Proximate analysis of Fresh Red Onion

Component	Content (%)
Moisture	84.75 ± 0.52
Carbohydrate	14.29 ± 0.30
Protein	0.47 ± 0.01
Fiber	0.45 ± 0.03
Fat	0.30 ± 0.04
Ash	0.04 ± 0.01

Table 4.4: Proximate analysis of dried onion using LDPE cover

Sample Size	Mc (%)	Ash (%)	Fiber (%)	Fat (%)	Protein (%)	CHO(%)
3mm	10.851	4.952	4.686	11.171	6.702	68.638
	10.336	5.059	4.476	11.989	6.585	68.555
	10.429	5.932	4.455	11.922	6.515	68.747
5mm	11.842	7.052	4.366	12.092	7.558	71.087
	11.026	6.756	4.152	12.089	7.711	71.266
	11.089	7.035	4.130	12.952	7.620	71.174
7mm	13.023	7.025	5.414	13.100	5.632	67.806
	13.014	6.994	5.282	13.091	5.460	68.159
	13.008	6.011	5.255	13.094	5.600	68.032

Table 4.5: Physiochemical properties of LDPE

Sample Size	PH	TTA (%)	TSS (Brix)^0
3mm	3.46	1.690	1.7
	3.45	1.698	1.6
	3.46	1.690	1.7
5mm	7.35	0.834	2.02
	7.36	0.825	1.94
	7.37	0.852	1.96
7mm	6.87	0.787	2.15
	7.03	0.780	2.16
	7.03	0.797	2.17

Table 4.6: Proximate analysis of dried onion using HDPE cover

Sample Size	Mc (%)	Ash (%)	Fiber (%)	Fat (%)	Protein (%)	CHO(%)
3mm	9.851	5.952	3.686	13.171	5.702	61.638
	9.336	6.059	3.476	12.989	5.585	62.555
	9.429	6.059	3.455	12.922	5.515	62.747
5mm	9.842	6.052	3.366	14.092	5.558	61.087
	10.026	5.756	3.152	14.089	5.711	61.266
	10.089	6.035	3.130	13.952	5.620	61.174
7mm	12.023	6.025	4.414	12.100	6.632	57.806
	12.014	5.994	4.282	12.091	6.460	58.159
	12.008	6.011	4.255	12.094	6.600	58.032

Table 4.7: Physiochemical properties of HDPE

Sample Size	PH	TTA (%)	TSS (Brix)^0
3mm	3.33	1.490	1.4
	3.32	1.398	1.5
	3.31	1.400	1.5
5mm	7.01	0.734	2.0
	7.00	0.725	1.8
	7.00	0.752	1.9
7mm	6.99	0.787	2.3
	7.00	0.780	2.4
	7.00	0.797	2.3

Drying Rate of LDPE

Weight of sample = 1000g

Table 4.8: Drying rate of 3mm sample of onion at ambient temperature of 43^{0}C

Loss of Moisture (g)	Time Taken (h)
810	2
615	4
410	6
205	8
165	10
115	12
0	14

Table 4.9: Drying rate of 5mm sample of onion at ambient temperature of 43^0C

Loss of Moisture (g)	Time taken (h)
834	2
615	4
420	6
217	8
155	10
135	12
117	14
0	16

Table 4.10: Drying rate of 7mm sample of onion at ambient temperature of 43^0C

Loss of Moisture (g)	Time taken (h)
905	2
810	4
707	6
613	8
505	10
401	12
302	14
210	16
175	18
118	20
0	22

Drying Rate of HDPE

Weight of sample = 1000g

Table 4.11: Drying rate of 3mm onion sample at ambient temperature of 45^{0}C

Loss of Moisture (g)	Time taken (h)
800	2
600	4
400	6
200	8
105	10
0	12

Table 4.12: Drying rate of 5mm onion sample at ambient temperature of 45^{0}C

Loss of Moisture (g)	Time taken (h)
820	2
610	4
405	6
265	8
165	10
110	12
0	14

.

Table 4.13: Drying rate of 7mm onion sample at ambient temperature of 45^0C

Loss of Moisture (g)	Time taken (h)
900	2
800	4
700	6
600	8
500	10
400	12
300	14
200	16
110	18
0	20

DISCUSSION

Effect of size reduction on drying of onion

Table 4.4 and 4.6 shows the effect of the size reduction on the moisture content i.e. the onion in 3mm dries faster than that of 5mm and 5mm dries faster than that of 7mm either in low or high density polyethylene. The water in 3mm in LDPE and HDPE goes out and dries faster and the moisture content reduced drastically.

The size of the onion determines the rate of drying of the onion in the dryer. When a material is thin in a dryer, it dries more and faster than the thick material i.e. onion size 3mm reduced in moisture than onion in 5mm and 7mm in both type of dryer. Therefore, the material size is a great effect when considering drying rate of a material.

Effect and type of polyethylene

Table 4.4 and 4.6 shows the analysis on low density polyethylene and high density polyethylene respectively, this shows that the onion in the HDPE dries faster than that of LDPE i.e. the moisture content in HDPE reduces more than the LDPE.

This happens because the HDPE trapped heat faster and release slowly than that of the LDPE. The heat trapped from the sun is retained in the HDPE for longer time without being released and this cause a great change on the onion and this speed up the drying rate. Whereas the heat trapped in LDPE is released easily because of the thin polyethylene and the heat has little effect on the onion before the heat is released back to the surrounding.

Effect of heat on drying of onion

The average drying temperature of the LDPE dryer is 43^0C while that of HDPE is 45^0C to produce an effective drying rate of the onions and give a very suitable dried and moisture free onion flakes.

Effect of cover on the drying of onion

HD has the capability to allow sun-rays and disallow escape of sun-rays through the transparent cover. The sun-rays are trapped through the black surface while the LD allows the sun-ray into the dryer losses the sun-rays by refraction through the low by the cover.

The same trends go with 5mm and 7mm in HD and LD. Therefore the HD cover dries faster than the LD through to the density of the transparent cover even through the material are of the same particles and under the same ambient condition.

CONCLUSION AND RECOMMENDATIONS

Conclusion

1. The final moisture content of dried onion slices ranged from 10.85% to 13.01%, 4.95% to 6.01% ash, 4.69% to 5.26% fibre, 11.17% to 13.09% fat, 6.70% to 5.60% protein and

68.64% to 68.03% carbohydrate for particle sizes of 3mm, 5mm and 7mm dry-basis depending on drying temperature cycle for low density polyethylene cover. While the final moisture content of dried onion slices ranged from 9.85% to 12.01%, 5.96% to 6.01% ash, 3.69% to 4.26% fibre, 13.17% to 12.09% fat, 5.70% to 6.60% protein and 61.64% to 58.03% carbohydrate for particle sizes of 3mm, 5mm and 7mm dry-basis depending on drying temperature cycle for high density polyethylene cover.

2. The performance of existing solar fruit dryers can still be improved upon especially in the aspect of reducing the drying time and probably storage of heat energy within the system. Also, meteorological data should be readily available to users of solar products to ensure maximum efficiency and effectiveness of the system. Such information will probably guide a local farmer on when to dry his agricultural produce and when not to dry them.
3. Solar radiation can be effectively utilized for drying of agricultural produce in our environment if proper design is carried out. This was demonstrated and the solar dryer designed and constructed exhibited sufficient ability to dry agricultural produce most especially fruit items to an appreciably reduced moisture level.
4. This will go a long way in reducing fruit wastage and at the same time fruit shortages, since it can be used extensively for majority of the agricultural fruit crops. Apart from this, solar energy is required for its operation which is readily available in the tropics, and it is also a clean form of energy. It protects the environment and saves cost and time spent on open sun drying of agricultural produce since it dries fruit items faster. The fruit items are also well protected in the solar dryer than in the open sun, thus minimizing the case of pest and insect attack and also contamination.

Recommendations

1. From this study, Onion slice of 3mm is recommended because of its ability to dry faster.
2. High density polyethylene cover is recommended because of its ability to retain heat for more period and dry faster.
3. The direct solar dryer is recommended as a suitable means of drying vegetables because of its efficiency and suitability on the dried onion.

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