DESIGN CONSTRUCTION AND TESTING OF INDIRECT TYPE PASSIVE SOLAR DRYER FOR GROUNDNUTS *(Arachis hypogaea Linnaeus)*

M.Sc. THESIS

LELISE TILAHUN DUFERA

MAY, 2013
JIMMA, ETHIOPIA

DESIGN CONSTRUCTION AND TESTING OF INDIRECT TYPE PASSIVE SOLAR DRYER FOR GROUNDNUTS *(Arachis hypogaea Linnaeus)*

LELISE TILAHUN DUFERA

A Thesis Submitted to the Department of Post harvest Management, College of Agriculture and Veterinary Medicine, Jimma University, in Partial fulfillment of the Requirements for The Masters of Science in Post Harvest Management

MAY, 2013
JIMMA, ETHIOPIA

Jimma University College of Agriculture and Veterinary Medicine
Department of Post –Harvest Management
ThesisSubmissionRequestForm (F-05)

Name of Student:Lelise Tilahun ID No. MSc.05599/03

Program of Study: Post Harvest Management (durable crops)

Title: Design Construction and Testing of Indirect Type passive Solar Dryer for Groundnuts *(Arachis hypogaea Linnaeus)*

I have completed my thesis research work as per the approved proposal and it has been evaluated and accepted by my advisers. Hence, I hereby kindly request the Department to allow me to present the findings of my work and submit the thesis.

____
Name & signature of student

We, the thesis advisers have evaluated the contents of this thesis and found to be satisfactory, executed according to the approved proposal, written according to the standards and format of the University and is ready to be submitted. Hence, we recommend the thesis to be submitted.

Major Advisor: ____________________ __________________ __________________
Name Signature Date

Co-Adviser: ____________________ __________________ __________________
Name Signature Date

Internal Examiner (If Depends on the Verdict)

Name ____________________ Signature ______________ Date________________

Decision/suggestion of department graduate council (DCG)

____
____

____________________ __________________ ______________
Chairperson, DCG signature Date

____________________ __________________ ______________
Chairperson, CGS Signature Date

DEDICATION

This thesis work is dedicated to my beloved father Ato Tilahun Dufera.

STATEMENT OF THE AUTHOR

I declare that this thesis is the result of my own work and that all sources or materials used for this thesis have been duly acknowledged. This thesis has been submitted in partial fulfillment of the requirements for the degree of Master of Science at Jimma University, College of Agriculture and Veterinary Medicine and is reserved at the University Library to be made available to users. I confidently declare that this thesis has not been submitted to any other institutions anywhere for the award of any academic degree, diploma, or certificate.

With accurate acknowledgment of the source, users are free to use this thesis without special permission. Permission for extended quotation or duplication of the manuscript in whole or in part may be granted by the Post Harvest Management Department Head, or Dean of School of Graduate Studies of Jimma University. In all other instances, however, permission should be obtained from the author.

Name: Lelise Tilahun Dufera

Place: Jimma, Ethiopia

Signature: _________________

Date of Submission: _____________

BIOGRAPHICAL SKETCH

Lelise Tilahun Dufera was born in April, 1980 at Begi Woreda, West wollega Zone of Oromiya Region. She attended her elementary and junior secondary school at Begi elementary and junior secondary school and High School at Akaki Adventist School and Assoa Senior secondary School. Following the completion of her secondary education, she joined Debub University, and graduated with B.Sc. Degree in Agricultural Engineering and Mechanization on July 7, 2005.

After graduation she was employed By Benishangul Gumuz Regional State, Agriculture and Rural Development Office , Assoa Rural Technology Promotion Center where she has worked as a team leader in the production of small scale agricultural implements and wood and metal workshop team and small scale rural industry and energy sources team for three years and four months. Then she has joined Technoserve Ethiopia where she has worked as assistant business advisor for ten months. Then after, she joined the graduate studies program of Jimma University College of Agriculture and Veterinary Medicine to pursue her study leading to a Master of Science degree in post harvest management.

ACKNOWLEDGEMENTS

Above all, I am very grateful to the almighty God who is always with me in all my life and help me in all my ups and downs.

Next to God, I am profoundly indebted to my major advisor Dr. Ali Mohammed and co-adviser Ato Kibret Alemayehu for their unreserved advice, guidance and valuable suggestions in each and every step of my research work and thesis write up. Without the encouragement, insight and professional expertise of my advisors, the completion of this work would have not been possible.

My immense thank is to my husband Ato Zerihun Misgana for his encouragement and support during my study. I am glad to convey my sincere thanks to the laboratory technician of Animal Nutrition of JUCAVM (Jimma University College of Agriculture and Veterinary Medicine), Ato Abiyot Hunde for his assistance in laboratory activities

I gratefully acknowledge the immense contribution made by CIDA for its financial support and Jimma University College of Agriculture and Veterinary Medicine for its facilitation during class and research work.

.

ABBREVIATIONS

A	Area of the collector
Ad	Area of the drying bed
ANOVA	Analysis of variance
Ao	Cross-sectional area of the air out let
AOAC	Association of Official Analytical Chemists,
ASAE	American Society of Agricultural Engineers
Av	Cross-sectional area of the air-heater duct
Ca	Specific heat capacity of air at constant pressure
Cc	Specific heat of peanuts
CRD	Completely randomized design
CV	Coefficient of variation
D	Density of peanut in wet bases
de	Wetted perimeter
Do	Diameter of air out let(chimney
Dr	Drying rate
dT	Change in temperature of the product
E	Total heat energy required for the drying process
g	Gravitational acceleration
h	Drying depth of peanuts
H	Height of the hot air column
h1	Height below bed of the dryer
h2	Height above bed of the dryer
I	Extraterrestrial hourly radiation on a horizontal surface
Ic	Total radiation received on an inclined surface
Id	Diffuse radiation on horizontal surface
ID	Surface direct radiation on horizontal
Idt	Diffuse radiation on an inclined surface

ABBREVIATIONS (continued)

IDt	Direct radiation received on an inclined surface
IG	Total radiation received on horizontal surface
Ion	Extraterrestrial radiation measured on plane normal to the radiation
Irt	Reflected radiation on an inclined surface
Isc	Solar constant
Kc	Pressure loss factor of drying the collector
L	Collector length
LSD	Least significant difference
Lt	Latent heat of vaporization of water
Lv =Wc	Length of the air-heater duct
M	Moisture content of peanut pods in Kg water/Kg of dry mater
Ma	Mass of air required to dry a given sample
$M_{f.wb}$	The final moisture fraction on wet basis
$M_{i.wb}$	The initial moisture fraction on wet basis
M_w	Quantity of moisture to be removed
n	N^{th} day of the year starting from January 1(in this design October 15
NASA	National Aeronautics and Space Administration
NMIE	National Metrology Institute of Ethiopia
P	Atmospheric pressure
p1	Air density at drying temperature (air density below bed)
P_c	Critical pressure of water
Pc	Pressure drop in a collector
Pd	Pressure drop in the dryer
PT	Total Pressure drop
R	Specific gas constant
R_g	Gas constant for water vapor

ABBREVIATIONS (continued)

Ta	Average ambient temperature
T_b	Boiling point of water
T_c	Critical temperature of water
Td	Total time required to dry a given sample
Tf	Temperature of drying air leaving the dryer
To	Temperature of drying air leaving air heater
T_{pt}	Temperature of the product
USDA	United States department of agriculture
V	Average air velocity
Va	Volume flow rate of air
Vc	Average air velocity at the exit of the air-heater
Vo	Air viscosity at To
Wc	Width of the collector
Wv	The width of the air inlet vent
W_w	Initial total crop mass
X	Total amount of moisture percentage to be removed

SYMBOLS

β	Optimum collector slope (tilt angle)
δ	Angle of declination
η	Overall drying efficiency
θ	Incident angle
θ z	Solar zenith
θh	Hour angle
ρ	Air density outside the dryer
ρ 2	Air density above bed
ρ1	Average air density at To
φ	Latitude of the location
Ψ	Surface solar azimuth
ω	Solar altitude
б	Reflectance value of surfaces

TABLE OF CONTENTS

TABLE OF CONTENTS(continued)

LIST OF TABLES

LIST OF FIGURES

LIST OF TABLES IN THE APPENDICIES

DESIGN CONSTRUCTION AND TESTING OF INDIRECT TYPE PASSIVE SOLAR DRYER FOR GROUNDNUTS *(Arachis hypogaea Linnaeus)*

ABSTRACT

The objective of this research was to design an indirect type passive solar groundnut dryer constructing its prototype and evaluating the performance of the dryer compare to sun and shade drying. The dryer designed consists of three units: air-heating solar energy collector, drying chamber, and Chimney. The performance evaluation was conducted using Completely Randomized Design (CRD) with a total number of 27 observations (3 depths x 3 drying methods x 3replications) .Greater drying rates were obtained with the solar dryer at similar drying depths for all drying methods used. Drying of groundnut in solar dryer from around 25% (wet basis) to the final moisture content about 10% has taken 24hrs, 29hrs, and 38hrs at 5, 10, and 15 cm depth of drying respectively; and this reduced the drying time by 9hrs and 54hrs at 5cm depth, by 13hrs and 53hrs at 10cm depth, and by 16hrs and 52hrs at 15cm depth for sun and shade drying respectively. Average dryer efficiency was estimated to be about 25 %, 20.68%, and 15.78% at 5, 10, and 15cm depth of drying respectively. Physical and proximate content analysis of the dried groundnut showed drying method and drying depth affects the proximate content and germination capacity of groundnuts. shade dried groundnuts samples has resulted in the highest crude fat content (45.93%), crude protein content (26.58%) and germination capacity (89.33%) at 10cm depth; solar dried groundnuts has resulted in the next highest crude fat content (42.91%) and statistically similar crude protein content with the sun dried samples at all 5, 10 and 15 cm depths of drying. The highest crude fiber content was obtained in the groundnuts samples dried in solar dryer (7.27%) and shade drying with the next highest value (6.84, 4.82%). The best drying depth for high crude fiber content was 15cm. The groundnuts samples dried with solar dryer at 15 cm depth have the highest ash content (3.5%) and sun dried samples have the lowest ash content with statistically similar value at all depths. High Carbohydrate content was obtained in groundnuts samples dried in open sun drying (33.76%) and solar dried samples with the next highest value (27.8%).

1. INTRODUCTION

Reduction of post harvest losses in developing countries can significantly contribute to the availability of food. 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 100%. 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 (Bala and Woods, 1994; cited in Ebuy,2007).

According to Bolaji (2005) moisture contributes greatly to the deterioration of agricultural products particularly in the tropics. When crops are harvested, the amount of moisture they contain is of little consequence if the crops are to be consumed immediately, but if the crops are to be stored for a reasonable length of time, it is essential that its moisture level be reduced to a certain well-defined limit. These will prevent the production of undesirable chemical compositional changes in the food items by bacteria, mould and enzymes which will spoil the food items (Habou *et al.,* 2003; Bolaji, 2008).

Peanut (*Arachis hypogaea* L.) which belongs to the genus *Arachis* in sub tribe *Stylosanthinae* of tribe *Aeschynomeneae* of family *Leguminous .It* is the sixth most important oilseed crop in the world and contains 48-50% oil and 26-28% protein, and is a rich source of dietary fiber, minerals, and vitamins (Nigam *et al.,* 2004) .Drying is one of the most important aspects of groundnut quality. If the seeds are not dried to safe moisture content (6-10%), quality deteriorates quickly and the probability of microbial invasion is increased (Sanders *et al.,* 1982; cited in Baker, 2002).

Peanuts contain about 50% fat, of which about 80% is unsaturated. Oleic and linoleic acids account for the majority of the total unsaturated fatty acids in typical peanut. Although linoleic acid is essential for humans, it is susceptible to lipid oxidation (Nawar, 1996; cited in Baker, 2002). Lipid oxidation also influences the chemical, sensory, and nutritional properties of edible oils and fatty foods and thus plays an important role in determining their use and shelf-life

(Dobarganes and Ruiz, 2003; Anwar *et al.*, 2003; cited in Anwar, 2007). In the presence of oxygen, light, moisture, and high temperatures, oxidation of fatty acids can occur (Nawar, 1996; cited in Baker, 2002) and has been found to be a major source of off-flavors and decreased quality in peanuts (Ory *et al.,* 1985; cited in Baker, 2002). Therefore it is essential to dry groundnut relatively soon after harvesting to prevent mold and aflatoxin formation, and the formation of off-flavors caused from fungal lipase action and oxidative rancidity by decreasing water content of the seed.

Drying of agricultural products such as corn, rice, millet, beans, sorghum, pepper, and groundnut requires a considerable amount of energy, which must be available when the crop is harvested. The application of solar energy in drying of agricultural products has tremendous potential, since it can easily provide the low temperature heating required for drying. Drying processes using solar energy range from traditional open sun drying to solar dryers (Bolaji, 2005).

Drying using the sun under the open sky for preserving agricultural crops may be the most inexpensive and extensively used option since early times *(*Chavda and Kumar, 2009) and this practice has some obvious disadvantages (Twidell and Weir, 1986).This method is unhygienic since the crops are easily contaminated by animal droppings and consequent infestation by fungi and bacteria. Human health is thus endangered as a result of food poisoning. This method also prolongs drying and may result in the deterioration of the quality of the crops. Moreover, more labor is involved as the crops are being moved frequently in and out during the day and night and from rain. They are also watched in order to prevent physical attacks birds and other animals. Therefore drying groundnuts using this method may result in loss of quality and adverse economic effects on domestics and international markets.

So, in order to minimize the moisture content of groundnuts to safe moisture content while it is still protected from external quality degrading agents, developing artificial dryers is important. But it is a well known fact that in rural areas, conventional sources of energy like petrol and electricity are either totally absent or are not readily available to develop active dryers, which have higher rate of performance. An indirect type conventional solar dryer has therefore been designed; its prototype was constructed and evaluated for performance for drying groundnuts.

Objectives

General Objective

To design, construct and evaluate a prototype of indirect type passive solar dryer, for drying of peanuts

Specific objectives

- To design an indirect type passive solar dryer for drying of peanuts
- To construct a prototype of the dryer for drying of peanuts
- To evaluate the effect of solar drying on proximate content and germination capacity of peanut seeds relative to sun drying and shade drying

2. LITERATURE REVIEW

2.1. Peanut production

According to USDA report in 2010/11 production year Peanut is grown on 21.33 Million hectares worldwide with a total production of 35.40 million metric tons and an average productivity of 1.66 metric tons per hectare (USDA data).Developing countries constitute 97% of the global area and 94% of the global production of this crop. The production of groundnut is concentrated in Asia and Africa (56% and 40% of the global area and 68% and 25% of the global production, respectively) (Nigam *et al.,* 2004). In Ethiopia peanut grows widely in Harar, Wolega, Metekel and Gojam among others (Legesse,2010) and in Jimma zone Groundnuts is one of the traditional high value products produced (Ethiopian Research Team Draft Report, 2010).

Poor agricultural practices and post harvest treatments of peanuts can lead to an infection by fungus such as *Aspergillus flavus and Aspergillus parasiticus* releasing the toxic substance aflatoxins (Legesse, 2010).At the time of harvest, groundnut pods generally contain 35-60% moisture. Until the moisture is reduced to <10%, the pods are prone to mould attacks (Nigam *et al.,* 2004) and drying is one of the most critical operations in maintaining peanut seed quality (Krzyzanowski *et al.,* 2006).

In Sub-Saharan Africa peanut is primarily a smallholder crop that provides resource-poor farmers with a cheap source of protein and a cheap source of soil fertility when grown in rotation with other crops. Compared with other crops its impact on the natural environment is relatively benign. However, it can be harmful to human and animal health when contaminated with aflatoxins produced by the *Aspergillus flavus* fungus that thrives in harvested peanuts due to poor drying and storage in warm and moist environments (Stockbridge, 2006).

2.2. Drying

Drying is defined as a process of moisture removal due to simultaneous heat and mass transfer. It is a classical method of food preservation, which provides longer shelf-lighter weight for transportation and small space for storage (Erteken and Yaldiz, 2004).It is one of the most important means for the preservation of many kinds of agricultural products (Tarigan and Tekasaku, 2005).It is a simple process of excess water (moisture) removal from a natural or industrial product in order to reach the standard specification moisture content. It is an energy intensive operation. Especially essential is to reduce the foodstuff moisture content, as these have in general a water content much higher (around 25–80%, but generally for agricultural products around 70%) than the one suitable for long term preservation. Reducing moisture content of foodstuff down to a certain level slows down the action of enzymes, bacteria, yeasts and moulds. Thus food can be stored and preserved for long time without spoilage. Another case of drying (or dewatering) is the total removal of moisture until food has no moisture at all. Dehydrated food, when ready to use, is re-watered and almost regains its initial conditions (Belessiotis and Delyannis, 2011).

2.3. Principle of Drying

There are two stages in a typical drying process: the first stage is the removal of surface moisture; the second stage is the removal of 'internal moisture' from within the solid material. The drying process is therefore divided into a "constant rate" period and a "falling rate" period. During the constant rate drying period, the surface of the material is still wet and the rate of drying is governed by evaporation of free moisture from the product's surface or near surface areas. The rate of drying is dependent on the vapour pressure difference between the surface and the air. As drying progresses, the product's surface is no longer wetted, but dry portions of the solid jut out into the drying air film. The drying rate falls and moisture must move from the product's interior to the surface before it can evaporate. This is called the falling rate period of drying and it is in this period that the crop usually achieves its final desired moisture content that is safe for storage (Sankat, K.C(n.a)).

2.4. Effect of Drying on Grain Quality

Drying may impact product quality, yield and the entire process economics (Algood *et al.,* 1993; cited in Palacios *et al.,* 2004) so the operation must not be considered as merely the removal of moisture since there are many quality factors that can be adversely affected by incorrect selection of drying conditions and equipment. The desirable properties of high-quality grains include: low and uniform moisture content, minimal proportion of broken and damaged grains, low susceptibility to subsequent breakage, high viability; low mould counts, high nutritive value; consumer acceptability of appearance and organoleptic properties (FAO, 1994).

2.5. Drying grains using solar energy

Drying of agricultural products such as corn, rice, millet, beans, sorghum, pepper, and groundnut requires a considerable amount of energy, which must be available when the crop is harvested. The application of solar energy in drying of agricultural products has tremendous potential, since it can easily provide the low temperature heating required for drying. Drying processes using solar energy range from natural drying (open sun and shade drying) to solar dryers. The climatic conditions during harvest season in some areas may be such that unheated or natural air can be used to reduce the moisture content in the crop to safe storage moisture (FAO, 1994; Bolaji, 2005).

2.6. Open sun drying

Open sun drying, where the product is exposed directly to the sun allowing the solar radiation to be absorbed by the material, is one of the oldest techniques employed in agriculture (Tarigan and Tekasaku, 2005).the major disadvantage of this method is contamination of the products by dust, birds, animals and insects, spoiled products due to rain, wind and moisture, and the method totally depends on good weather conditions. Furthermore, the process is labor intensive, unhygienic, unreliable, time consuming, non-uniform drying, and requires a large area for spreading the produce out to dry *(*Chavda and Kumar, 2009).

2.7. Shade drying

The shade drying method consists essentially of exposing the threshed products to the air under shade. To obtain the desired moisture content; the grain is spread in thin layers on a drying-floor, where it is exposed to the air for a maximum of 10-15 days (FAO, 1994). Shade drying requires full air circulation and it takes a little longer than sun drying, but it prevents the loss of a food's natural color and better preserves its vitamins and minerals (FAO,2002).

2.8. Solar dryer

The term solar dryer is applied to a structure made for the deliberate use of solar energy to heat air and/or the products to achieve dehydration, or drying, of the products, and the process is called solar drying(Tarigan and Tekasaku, 2005).One of the most significant potential applications of solar energy is drying. It is the oldest of stabilization operations of agricultural products practiced by people. Drying of various products is intensively carried out in industry and agriculture. Its mechanism, typically non-stationary and based on complex mass and heat transfer laws, is well known. Its particularity resides in the fact that the departure of water molecules from the products is done due to the difference in water vapor partial pressure between the product surface and surrounding air. This difference in partial pressure is obtained by heating of air circulating in natural convection in a collector (Gbaha *et al*., 2006).

Solar dryers produce better looking, better tasting, and more nutritious foods, enhancing both their food value and their marketability. They also are faster, safer, and more efficient than traditional sun drying techniques (Roger and Gregcire, 2009).

Solar dryers fall into two broad categories: active and passive. Passive dryers can be further divided into direct and indirect models. A direct dryer is one in which the food is directly exposed to the sun's rays. This type of dryer typically consists of a drying chamber that is covered by transparent cover made of glass or plastic. The drying chamber is a shallow insulated box with holes in it to allow air to enter and leave the box. The food is placed on a perforated tray that allows the air to flow through it and the food. In an indirect dryer, the sun's rays do not strike the food to be dried. In this system, drying is achieved indirectly by using an air collector that channels hot air into a separate drying chamber. Within the chamber, the food is placed on mesh trays that are stacked vertically so that the air flows through each one (Roger and Gregcire, 2009).

3. MATERIALS AND METHODS

3.1 Description of the Study Area

The experiment was conducted in JimmaUniversity College of Agriculture and veterinary Medicine Ethiopia. Jimma is located at 335 km South West Ethiopia at elevation of 1710 m above sea level with an average rainfall of 1000 mm. The area experiences 8 to 10 months of rainfall. The main rainy season extends from May to September and the small rainy season takes in February, March and April. The temperature of Jimma vary from maximum of about 28 ^{0}C in the hottest month to as low as 8 ^{0}C in the coolest month. The annual average temperature is 20 ^{0}C (Haile and Tolemariam, 2008).

Figure.1 shows Isometric drawing of the designed natural convection indirect type solar peanut dryer. Three main components of the dryer are: 1) air-heating solar energy collector (which consists of cover plate, absorber plate and insulator) through which the drying air is heated as it flows over an absorber plate:

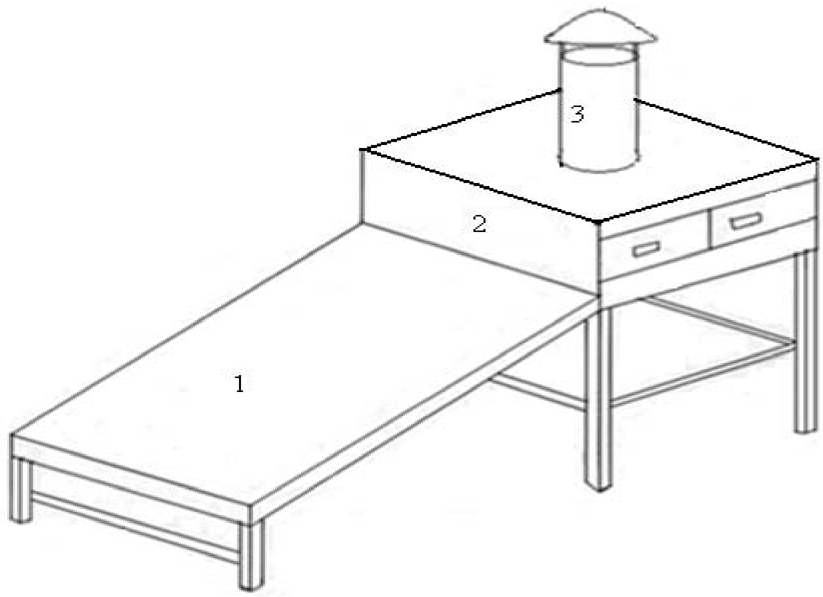

Figure 1. Isometric drawing of the designed natural convection indirect type solar groundnut dryer

a) Cover Plate (glass cover):

This is transparent sheet used to cover the absorber, thereby preventing dust and rain from coming in contact with the absorber. It also retards the heat from escaping (i.e. forming a confinement for heated air). It is placed above the absorber. The material that is used for cover plate is glass.

b) Absorber Plate:

This is a metal plate painted black and placed below the cover to absorb the incident solar radiation transmitted by the cover thereby heating the air between it and the cover.

c) Insulator*:*

This is used to minimize heat loss from the system. It is placed under the absorber plate. The insulator is made of wood (*cordial Africana*).

2) Drying Chamber:

The drying chamber is made of wooden box held in place by wooden support. The material is chosen since wood is a poor conductor of heat and it has smooth surface finish; heat loss by radiation is also minimized.

3) Chimney:

The Chimney is made of aluminum sheet and mounted on the top center part of the dryer above the drying chamber for removing the humid air from the dryer.

3.2. Working principle of the dryer

The solar ray passes through the cover plate and absorbed by the black painted absorber plate. The ambient air from outside is blown naturally through the inlet vent of the dyer and heated in the solar energy collector; the outside air coming from the ambient moves the heated air up wads due to pressure difference between the air (Sankat, K.C(n.a*))* and the warm air flows through a layer of groundnut on trays and becomes moist; finally this moist air is vented out through a chimney

.

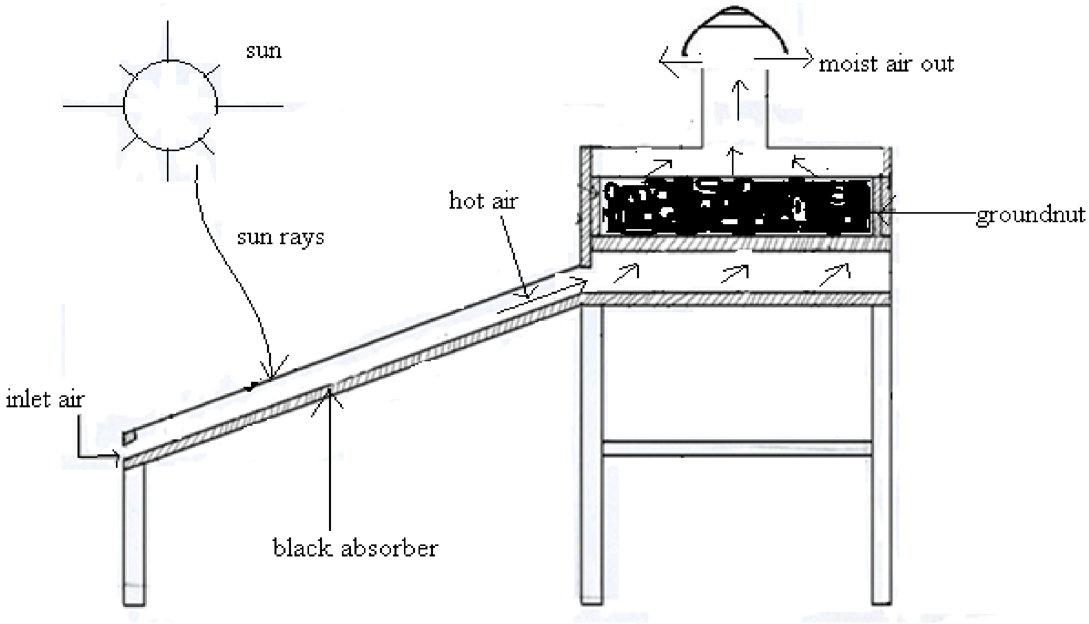

Figure 2. Working principle of indirect type passive solar dryer

3.3. Design and Construction of Solar Peanut Dryer

3.3.1. Design Procedure

The size of the dryer was determined as a function of the drying area needed per kilogram of ground nuts and the drying temperature was established as a function of the maximum limit of temperature the groundnuts might support. The designed dryer has a capacity of drying 100 kg of groundnut and was designed for Jimma condition

3.3.2. Design Calculations

To carry out design calculations the following conditions and assumptions were used.

Table 1. Design conditions and assumptions used

`No	Items	Conditions or assumption	Source
1	Location	Jimma	-
2	Crop	Peanuts	-
3	Variety	Local	-
4	Drying period(harvest period)	October	-
5	Drying per batch	100Kg	-
6	Initial moisture content	25%	-

7	Final moisture content (moisture content for storage)	10%	-
8	Ambient air temperature, (20 years Average for harvest period)	18.97^{0}C	NMIE
9	Ambient relative humidity, (20 years Average for harvest period)	70.09%	NMIE
10	Maximum allowable temperature	35^{o}C	FAO,1989
11	Incident solar radiation (average for past 30 years)	5.39KWh/m^2/day	NASA
12	Angle of declination	-8.46(degrees)	NMIE
13	Latitude of Jimma	7.667 degree North	NMIE
14	Drying rate	0.3%/hr	
15	Minimum and maximum drying temperature rise above ambient	8 ^{o}C and 25^{o}C	FAO,1989
16	diffuse radiation on horizontal surface	2KWh/m^2/day	NMIE
17	Daily sunshine hour	11.9hr	NMIE
18	Direct radiation	4.99KWh/m^2/day	NMIE
19	Height above bed of the dryer (h2)	0.2m	-
20	Height below bed of the dryer (h2)	0.15m	-
21	Drying depth of peanuts	0.15m	-

1. Optimum collector slope (tilt angle) (β)

The optimum collector slope, β, can be calculated as (Brenndorfer et al., 1985).

$\beta= \varphi-\delta$---(1)

Where:

δ= angle of declination for Jimma, Ethiopia

φ= the latitude of the location.

Putting $\varphi=7.667^0$ N (NMIE)

and $\delta=-8.46^0$ (NMIE)

gives

β=16 degrees.

2. The total radiation received on an inclined surface(Ic)

The total radiation received on an inclined surface can be calculated as (Colliver, 1991)

$Ic=IDt+Idt+Irt$ --(2)

Where:

IDt = direct radiation received on an inclined surface

Idt= diffuse radiation on an inclined surface

Irt =reflected radiation on an inclined surface.

The value of the direct radiation received on an inclined surface diffuse radiation on an inclined surface and reflected radiation on an inclined surface in Eq. (2) can be estimated using the following expressions (Colliver, 1991)

$IDt=(IG-Id)\cos\theta/\sin\omega$ --(3)

$Idt=Id\,[\{(IG-Id)/I\}\,(\cos\theta/\cos\theta_z) + \{(1+\cos\beta)/2\}\{1-(IG-Id)/I\}]$ ---------------------------(4)

$Irt=ID\,б\,[(1-\cos\beta)/2] + Idб\,[(1-\cos\beta)/2]*[1+\sin^2(\theta_z/2)]/\cos/\Psi/]$ ---------------------------(5)

Where:

IG= total radiation received on horizontal surface

Id= diffuse radiation on horizontal surface

θ = incident angle

ω= solar altitude

I= extraterrestrial hourly radiation on a horizontal surface

θ_z = solar zenith

Ψ = surface solar azimuth

θ_h = hour angle

ID= surface direct radiation on horizontal

б= reflectance value of surfaces

The value of incident angle and solar altitude in Eq. (3) can be estimated using the following expressions (kreider and Kreith,1982)

$\omega=\sin^{-1}[(\cos\delta\cos\varphi\cos\theta_h)+\sin\delta\sin\varphi]$ ---(6)

$\theta=\cos^{-1}[(\cos\delta\cos(\varphi-\beta)\cos\theta_h)+\sin\delta\sin(\varphi-\beta)$ ---(7)

Where:

Θh=the number of hours between solar noon and the time of interest multlied by 15 degree (kreider and Kreith, 1982). (Time of interest in this design=solar noon)

Using Eq. (6 and 5) to find the value of ω and θ and putting IG=1630588J/m2/hr,and Id=605042 J/m2/hr in Eq. (3)the total direct radiation received on an inclined surface(IDt) is found to be =1067553J/m2/hr.

The value of extraterrestrial hourly radiation on a horizontal surface and solar zenith in Eq. (4) can be estimated using the following expressions (Colliver, 1991)

$$\theta_z=\cos^{-1}(\sin\varphi\sin\delta+\cos\varphi\cos\delta\cos\theta_h) \quad (8)$$

$$I=I_{on}\cos\theta_z \quad (9)$$

$$I_{on}=I_{sc}(1+0.034\cos(360n/365.25)) \quad (10)$$

Where:

Ion= extraterrestrial radiation measured on plane normal to the radiation (W/m2)

Isc=solar conistant

n= the nth day of the year starting from January 1(in this design October 15 (n=285)is used

Using Eq. (8, 9 and 10) to find the value of θ z ,I and Ion putting Isc=1353w/m2,n=285, gives θ z =16.127degree and I=4709218.827J/m2/hr and using Eq. (4)the value of diffuse radiation on an inclined surface (Idt)is found to be =137160.3896J/m2/hr.

The value of surface solar azimuth in Eq. (5) can be estimated using the following expression (kreider and Kreith,1982)

$$\Psi=\sin^{-1}[\cos\delta\sin\theta_h/\cos\varphi] \quad (11)$$

And this gives Ψ=0 degree and putting б=15% for bare ground in Eq. (5) gives reflected radiation on an inclined surface (Irt)=617834.9924J/m2/hr.and total radiation received on an inclined surface(Ic) is 1822548.835J/m2/hr.

3. Air flow requirement

The total quantity of moisture to be removed from peanut to bring it to the desired moisture from the initial moisture content is used to determine the total mass flow of air required for drying. The quantity of moisture to be removed (Mw) depends on the crop and can be found from the following relationship (Forson, 2007).

$$M_w=\frac{W_w[M_{i\cdot wb}-M_{f\cdot wb}]}{(1-M_{f\cdot wb})} \quad (12)$$

Where:

Ww= the initial total crop mass

Mi, wb=the initial moisture fraction on wet basis

Mf, wb= the final moisture fraction on wet basis

Putting Ww =100 kg, Mi,wb = 0.25, and Mf,wb =0.1 gives MW as 16.677 kg.

From the basic energy balance equation for the drying process the mass of air required to dry a given sample of moist peanut to safe storage is calculated as follows (Alonge and Hammed, 2007).

Ma=WwLt/(Cap1(To-Tf)--(13)

Where:

Ma= mass of air required to dry a given sample of moist peanut to safe storage

Lt= latent heat of vaporization of water in J/kg (at drying temperature)

Ca= the Specific heat capacity of air at constant pressure kJ/kg.oC

To= temperature of drying air leaving air heater

Tf =the temperature of drying air leaving the dryer and

ρ1= air density at drying temperature

And air density at drying temperature in Eq. (13) can be estimated using the following expression

ρ1=P/RTo--(14)

Where:

P= the atmospheric pressure

R = the specific gas constant

Putting P=101.3Kpa,R=287 J/(kg·K)To=26.97^{o}C gives ρ1=1.177m^{3}/kg.

The value of latent heat of vaporization of water, in Eq. (13) can be estimated using the following expression (Forson et al., 2007).

$$Lt=R_g\, T_c\, T_b \ln(P_c/105)\, \frac{(T_c-T_{pt})^{0.38}}{(Tc-Tb)^{1.38}} \qquad \text{-----(15)}$$

Where:

Lt= latent heat of vaporization of water in J/kg

Rg = the gas constant for water vapour

Tc = the critical temperature of water

Tb,= the boiling point of water

Pc= the critical pressure of water

Putting Rg= 461 J/kg.k,Tc=374^{o}CTb=, 100^{o}C,Pc=,22058452.5 N/m^2 and Tpt=24.97 in Eq. (15) and Since bound water is to be evaporated from the product to be dried, estimating the value of Lt increasing by a factor of 15% according to (Forson,2007)gives Lt=2.7623MJ/kg.

Putting Ww=16.667kg;Lt=2.7623MJ/kg;Ca= 1040J/kg.^{o}C; P1=1.177kg/m^3;To=26.97; and since dew point temperature of the drying temperature is 21^{0}Cat 70% relative humidity;Tf should be above 21^{o}C so taking Tf= 22.97^{o}C in Eq. (13) gives Ma=9402.825kg

The volume flow rate is calculated from the relation

Va=Ma/Td ρ1---(16)

Where:

Va =the volume flow rate of air

Td= the total time required to dry a given sample of moist peanut to safe storage level and ρ1 air density at drying temperature

The value of the total time required to dry a given sample of moist peanut to safe storage Level in Eq. (16) can be estimated using the following expression:

Dr= X/Td ---(17)

Where:

X =the total amount of moisture percentage to be removed and

Dr =the drying rate

Putting X=15% and Dr=0.3%/hr gives Td as 50 hr.

Using Eq. (16) to find the value of Va putting Ma=9402.825kg,Td=50hr, ρ1=1.177m^3/kg gives Va=159.77m^3/hr.

4. Total amount of energy required for the drying process (E)

The total heat required (*E)* to evaporate the moisture and also keep the groundnuts at the dryer temperature will be computed from the following equation based on basic principles of heat transfer (Karlekar and Desmond, 1982).

E=WwCcdT+MwLt ---(18)

Where:

E= the total heat energy required for the drying process (J)

Ww =mass of peanuts in kg

Cc= specific heat of peanuts in J kg^{-1} K^{-1}

Mw= mass of moisture removed in kg

dT= change in temperature of the product in oC(Tpt-Ta).

The value of specific heat of peanuts in Eq. (18) can be estimated using the following expression (Yang et al., Na).

Cc=0.18+1.779M.881---(19)

Where:

M= moisture content of peanut pods in Kg water/Kg of dry mater and

Cc= in MJ/Kg.K,

putting the value of M=0.33, gives Cc=855.822J/Kg.K

The value of the temperature of the product in Eq. (18) can be estimated using the following expression (Forson, 2007).

Tpt=0.25{3To+Ta}---(20)

Where:

Tpt = the temperature of the product

Ta= average ambient temperature oC

Putting Ta=18.97oC gives Tpt =24.97oC and dT= (Tpt-Ta) =6oC

Putting *Ww=100kg*, Cc=855.822J/Kg.K, dT=6oC, MW=16.677 kg and Lt=2.7623MJ/kg in Eq. (18) gives E=46552747.3J

5. Area of the collector

From the total useful heat energy required to evaporate moisture and the net radiation received by the tilted collector, the solar drying system collector area, A_c [m^2], can be calculated from the following equation taking the overall drying efficiency for natural convection solar crop dryers (η) which ranges from 10 to 15 % according to (Forson,2007)

A = E/IcTdη---(21)

Where:

A= the Area of the collector, m^2

E= total energy required for drying process,J

Ic= radiation received by the tilted collector,$J/m^2/hr$

Td= drying time (hr)

η= the overall drying efficiency.

Putting E=46552747.3J, Ic=1822548.835$J/m^2/hr$, Td =50 hr and η=12%, in Eq. (21) gives $A=4.25m^2$

6. Collector length (L)

Taking the ratio of the length of the air-heater (solar collector) to the width as 1.5, in the recommended range for optimum performance of the air heater (Forson, 2007), gives L=2.5m and Wc=1.7m.

Where L,is the length of the collector and Wc, is the width of the collector.

7. The width of the air inlet vent (Wv)

Following from the continuity equation, for one-dimensional steady flow the weighted average velocity at the exit of the air-heater is related to the channel overall cross-section by the relation

Vc=Va/(WcWv) --(22)

Where:

Vc= average air velocity at the exit of the air-heater

puttingVa=159.77m^3/hr.,Wc=1.7m and Vc=0.2m/s (720m/hr)(since for airflow by natural convection, the average velocity of the drying air, Vc, at the exit(or outlet) of the collector is expected to be between 0.20 and 0.40 m/s(Forson,2007)) gives Wv=13cm

The recommended height of the air-heater inlet vent above the ground level, y,is 0.40m to allow air to flow naturally through it(Forson,2007).

8. Area of the air outlet

From the suggestion by (Bruce, 1978; cited in Forson, 2007) regarding inlet and outlet vents areas for natural ventilation; the cross-sectional area of the air out let (Ao) is related to the cross-sectional area of the air-heater duct (Av=Lv*Wv) by the relation.

Av=2Ao= Lv*Wv=2(Ao)=Av/2=3.14Do2/4

Where Do,is the diameter of air out let(chimney).Putting the value of Av=Lv*Wv=0.221; gives Do=37.5cm

8. Total pressure drop

Pressure drop in a collector is calculated as (Corvalan and Zambrano, 1991) using the following formulas:

Pc=KcLpV2/2gde--(23)

Kc=0.316/Re0.25,2000<=Re<=100000 --(24)

Re=deV/Vo ---(25)

Where:

Pc= Pressure drop in a collector in mmH2O

Kc= pressure loss factor of drying the collector

L= collector length in m; p,is average air density(at To) in kg/m3

V= average air velocity in m/s

g=gravitational acceleration

de= wetted perimeter(de=2LWc/(L+Wc))

Vo= air viscosity at To in m2/s.

putting de=2.023,V=0.2m/s,Vo=1.5688*10-5m^{2}/s in Eq. (25) gives Kc= 3.977*10^{-6} and puttingL=2.5m,p=1.208Kg/m3,g=9.8m/s2 in Eq. (23) gives Pc=0.1118 *10^{-6}mmH2O= 0.00000109638347pa

Pressure drop in the dryer (Pd) is calculated as using the following formula (*Folaranmi, 2008*):

Pd={h1(p-p1)+h2(p-p2)}g---(26)

Where:

h1=height below bed of the dryer

h2= height above bed of the dryer

p= air density outside the dryer

p1= air density below bed;p2,is air density above bed

Putting p=1.208Kg/m^{3}, p1=1.177Kg/m^{3}, p2=1.192Kg/m^{3}, h1=0.15m,h2=0.2m gives Pd=0.07693pa. When all pressure drops are accounted for the gross pressure drop is about six-fold the value of PT(Forson,2007) therefore the total pressure drop will be PT=0.46158pa

10. Height of the hot air column

The height of the hot air column is the minimum height of the exit vent above the collector inlet for moist air escape to the ambient under air circulation by natural convection can be calculated as (Alonge and Hammed, 2007).

H = PT/(0.00308 (To-Ta) g)---(27)

Where:

H= Height of the hot air column in m

Putting PT=0.46158pa, To=26.97^{0}C Ta=18.97^{o}C and g=9.8m/s^2 in Eq. (27) gives H=1.91m

11. Area of the drying bed

The effective drying bed area Ad is obtained by relating the solid density of the wet material to its mass and the corresponding volume as ,Ad=Ww/D Δh

Where:

D= the density of peanut in wet bases

Ww= mass of peanut to be dried; and h is the drying depth of peanuts.

Putting Ww =100kg, Δh =0.15m and D=250kg/m^3 the area of the drying bed is Ad=2.67m^2.and the length of the dryer (Ld) is 1.57m.

Four trays (0.785m x0 .85m) are used for drying peanuts in the dryer for ease of operation.

The detail drawing of designed dryer is then shown in figure 3 to 10 below.

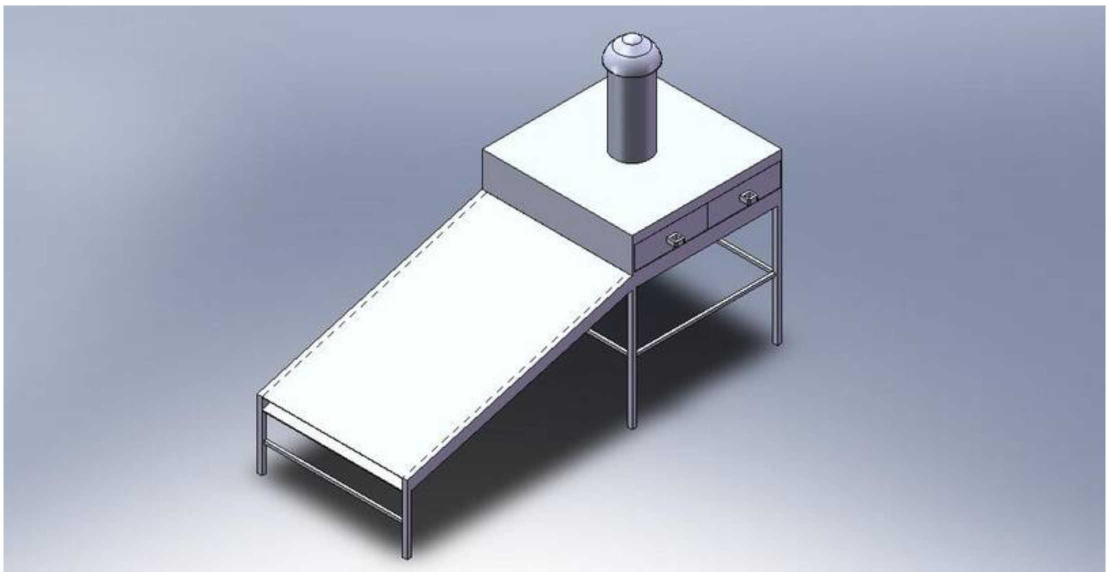

Figure 3.3-dimentional view of the dryer

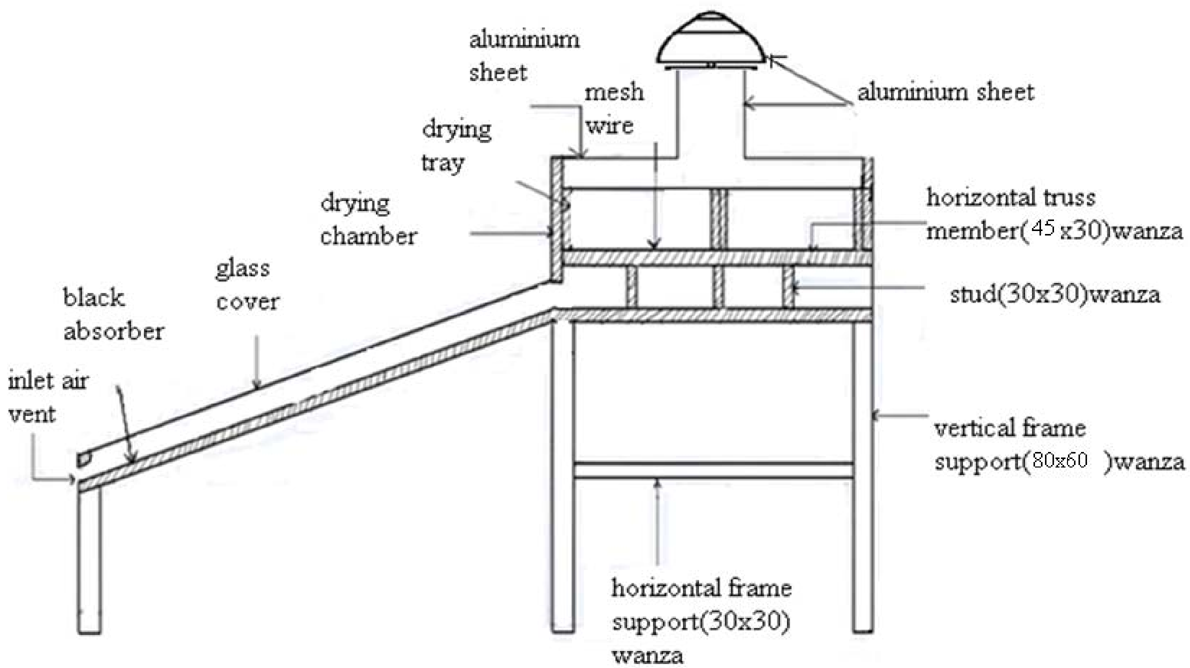

Figure 4. Sectional view of the indirect type passive solar

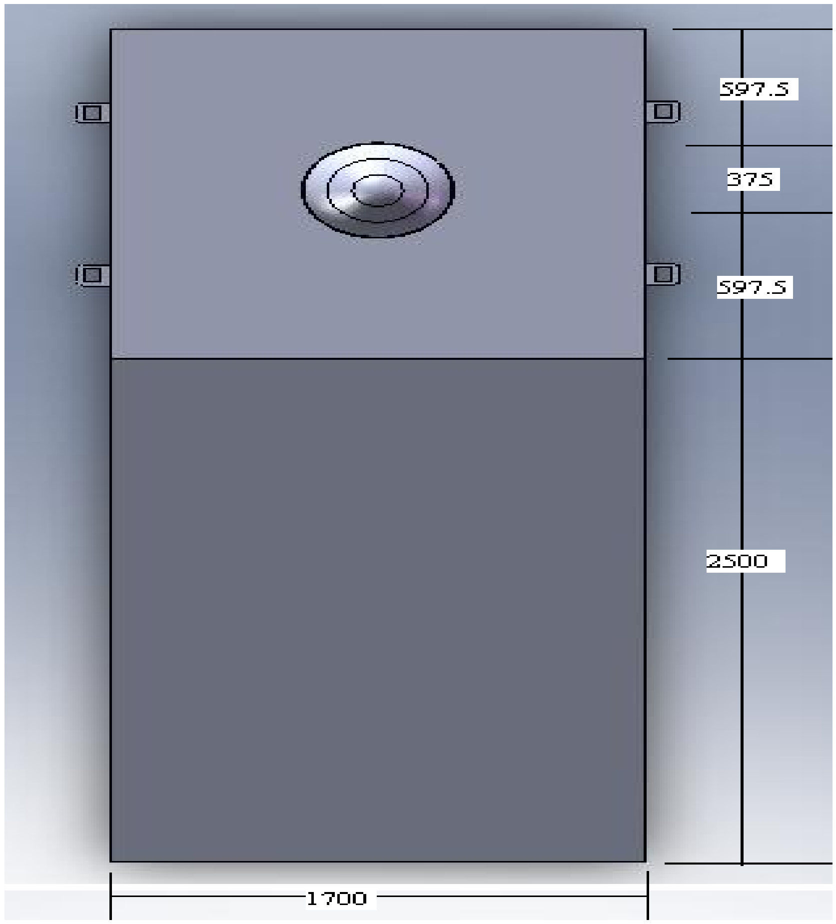

Figure 5. Top view of the indirect type passive solar groundnut dryer

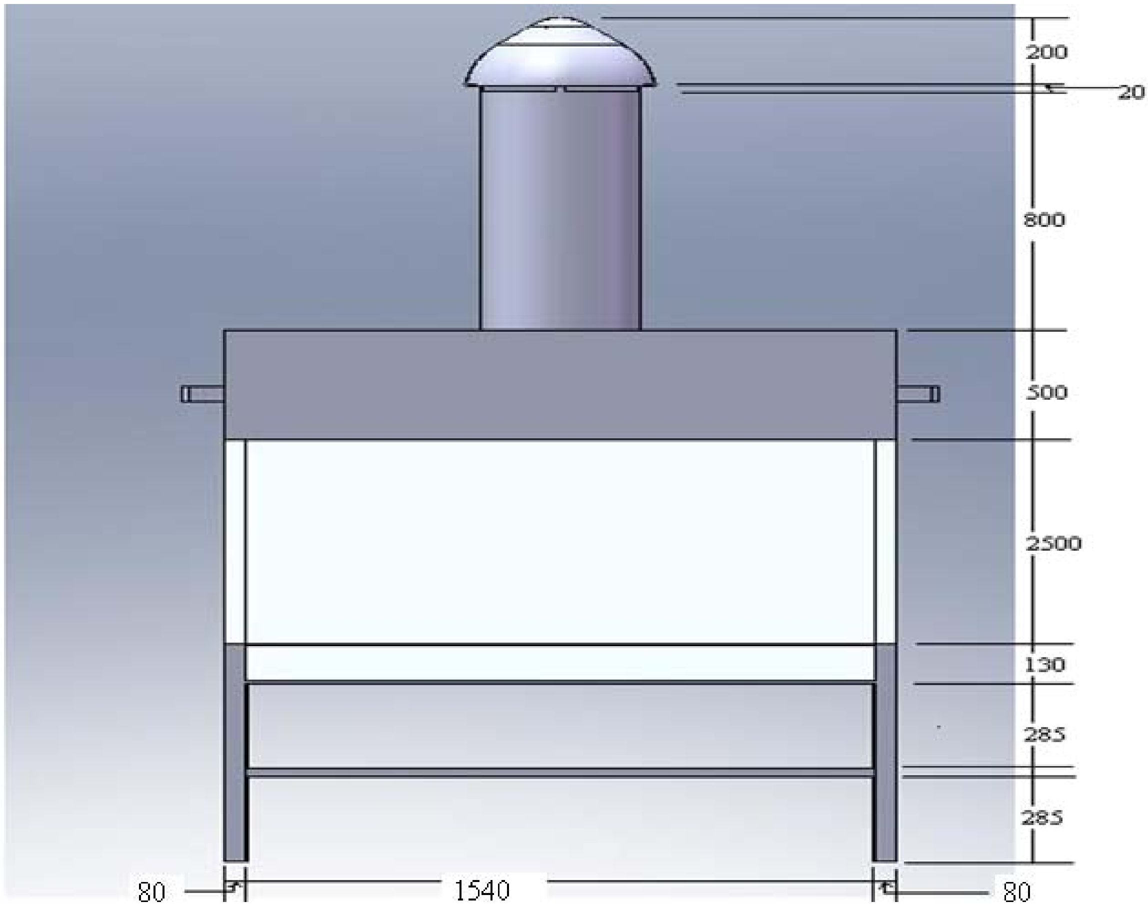

Figure 6.Front view of the indirect type passive solar peanut dryer

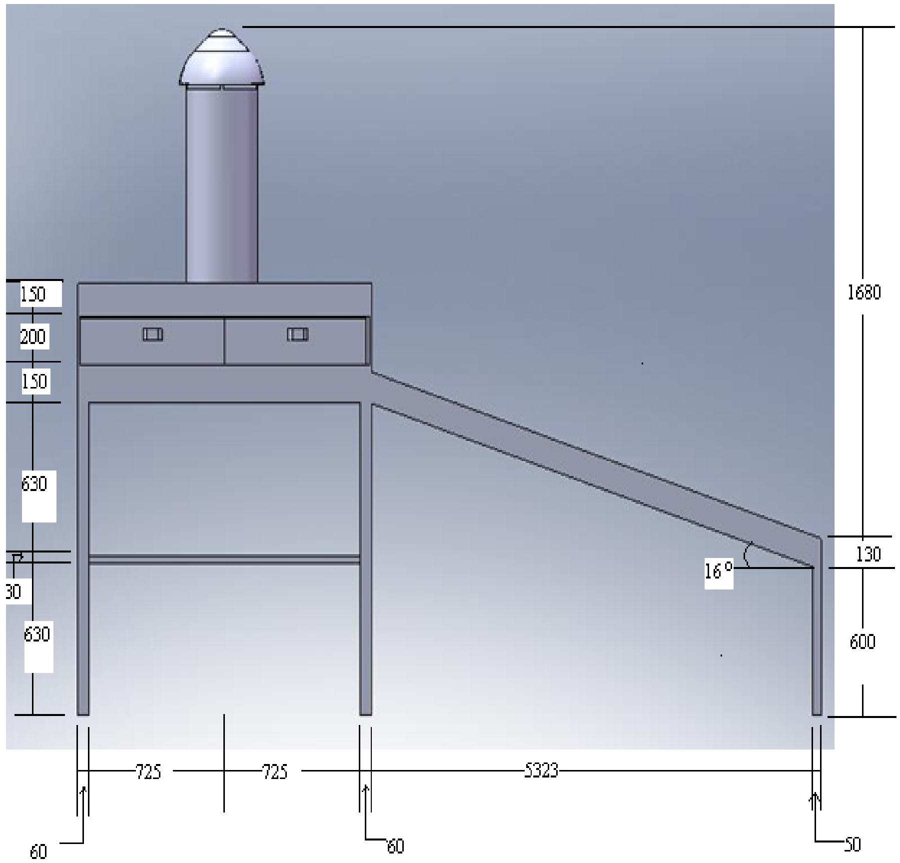

Figure 7.Side view of the indirect type passive solar groundnut dryer

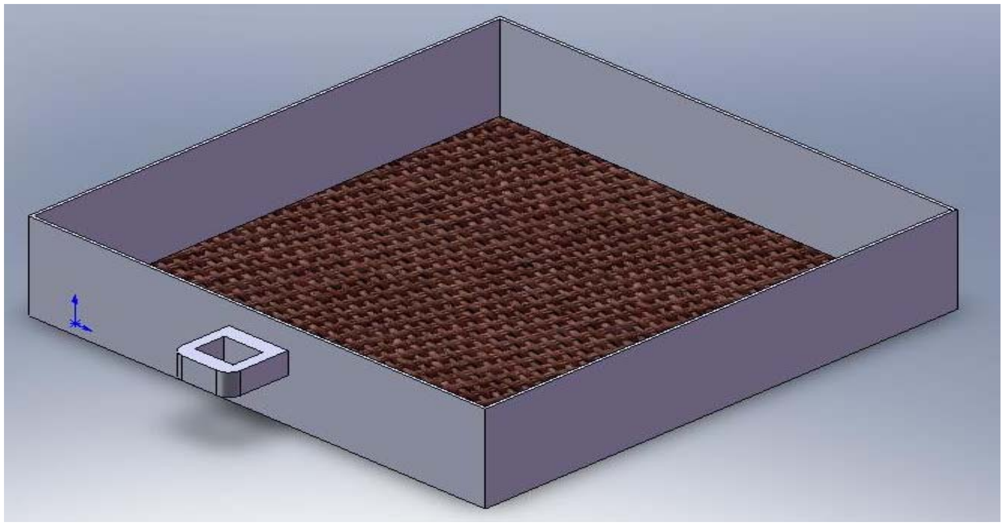

Figure 8.3-dimentional view of tray

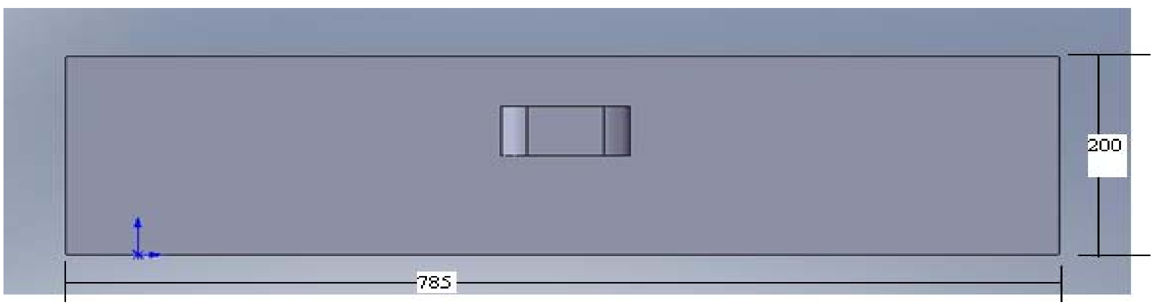

Figure 9.front view of tray

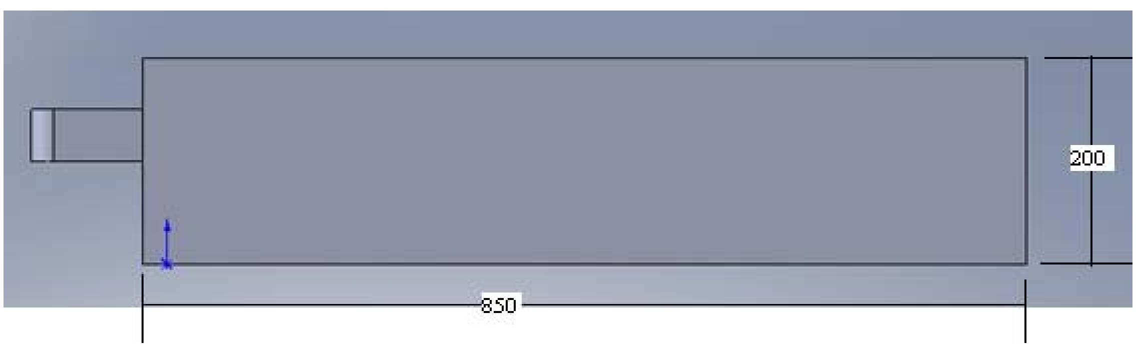

Figure 10.side view of tray

All dimensions in mm

3.4. Experimental materials

3.4.1. Groundnut samples for testing

Freshly harvested groundnuts was obtained from farmers around Jimma Zone and the initial moisture content of the samples was determined by drying the ground nuts at 130°C in a ventilated oven until constant weight is achieved following *ASAE (*2002)method and the samples was measured using digital display electronic balance.

3.4.2. Prototype of the designed dryer

A natural convection indirect type solar dryer was designed and the prototype was constructed. The constructed prototype was sized to have a capacity of drying 10kg of peanut which was used in experimental drying tests and consisted of air-heating solar energy collector (which consists of cover plate, absorber plate and insulator) through which the drying air is heated as it flows over an absorber plate, Drying Chamber and Chimney as shown in Fig.11.

Figure 11.Picture of the prototype of solar dryer of groundnut

1) Chimney, 2) Drying chamber and 3) Dir-heating solar energy collector

3.5. Experimental Design

Factorial arrangement using completely randomized design (CRD) was used for the comparative evaluation of the effect of the dryer and open sun and shade drying on Quality of peanuts. The factors were drying methods (with three levels, solar dryer (So), open sun drying (Su) and shade drying (Sh)) and depth of drying (with three levels depth 1(5cm), depth 2 (10cm) depth 3 (15cm)) and a total of nine independent experiments with three replications were conducted.

3.6. Performance Test of the Dryer

3.6.1. Drying rate of the dryer

The moisture content of the groundnuts was measured every six hours during the drying process following *ASAE* S410.1 and the drying rates were computed by dividing % moisture loss to time taken. The open sun drying and shade drying of samples were also employed simultaneously, to provide for comparisons.

3.6.2. Temperature and relative humidity

Temperature and relative humidity was measured using mercury-in-glass thermometer and digital hygrometer respectively.

3.6.3. Overall drying efficiency

The overall thermal performance of the drying system, including collector and chamber, is indicated by drying system efficiency. It measures the effectiveness of using input solar radiation for drying product in the dryer system. When solar energy is the only heat the drying, system efficiency can be calculated as according to Forson (2002).

$\eta=(E/IcTdA)X100$

Where:

η = Overall Drying efficiency %

E = Total energy required for the drying process (J)

Ic= Total solar isolation on inclined surface for the total drying time (J/m2)

Td=Total drying time (hr)

A= area of solar collector (m^2)

3.7. Proximate Analysis and germination test of dried peanuts

The proximate composition analyses of the samples were done using standard analytical procedure AOAC methods (1990).Total ash (method 14:006), crude fibre (method 14.020), total fat (method7.056) and protein (method 2.057) were assayed and carbohydrate was obtained by difference.

3.7.1. Crude protein

Crude protein of groundnut was determined using Kjeldahl method as described in AOAC (1990). About 0.3 g of ground groundnut flour was weighed in to Kjeldahl digestion flask and catalyst mixture (K_2SO_4 mixed with $CuSO_4.5H_2O$ in the ratio of 1:10) was added in to each flask. Then, 10 ml of concentrated H_2SO_4 (98%) was added and the sample was digested at a temperature of 420°C for about 3 hours until the solution was clear white. With the completion of digestion (when the digested sample becomes colorless or light blue) the samples were allowed to cool. After the samples were cooled, 30 ml of distilled water was added in to each digestion flask followed by 25 ml of 40% NaOH. Immediately the contents were distilled by inserting the digestion tube line in to the receiver flask that contains 25 ml of 4% boric acid solution. The collected ammonia distillate was then titrated against a standardized 0.1N HCl until the end of the titration was attained (where the titration color changes from green to purple). Then the volume of HCl consumed was read from the burette and the nitrogen content % was calculated as follows:

$$N\ (\%) = \left[\frac{V_{HCl} \times N_{HCl}\ (\text{ca } 0.1) \times 14}{\text{Sample weight in g on dry matter basis (db)}}\right] \times 100$$

Where:

V_{HCl} = volume of HCl in liter consumed

N_{HCl}= the normality of HCl used and 14 is the molecular weight of nitrogen

The obtained nitrogen percentage was expressed on dry matter basis and the resulting value multiplied by a factor of 6.25 to obtain percentage crude protein of each sample.

3.7.2. Crude fat

Crude fat was determined according to AOAC (1990). Ground groundnut (2 g) sample was dried in air draught oven at 130°C for 1 hr. The sample was extracted with anhydrous ether in a soxhlet extractor for about 4 hours and the ether was allowed to drain out of the thimbles for 30 min. The solvent was evaporated by drying the beakers at 105°C for 30 min in air draught oven and the mass left was determined as percentage of crude fat.

The crude fibre content of the samples was determined by digestion according to AOAC (1990) method.

3.7.3. Ash

Ash content was determined according to AOAC (1990). Ground groundnut (2 g) sample was dried in air forced oven at 120°C for 1 hr, carbonized over a blue Bunsen burner and was ignited in a muffle furnace at 600°C until free from carbon and residue appears grayish-white and percentage of ash was calculated on dry matter basis (db) as:

$$Ash(\%) = \frac{(m_3 - m_1) * 100}{m_2 - m_1}$$

Where:

m_1 =mass of crucible in g

m_2 = mass of crucible and sample in g before ashing and

m_3 =mass of the sample after making ash in g

3.7.4. Carbohydrate

Total carbohydrate was determined by difference according to AOAC (1990).

3.7. 5. Percentage germination test

Seed germination test was conducted using standard procedures of ISTA (1996). Three hundred groundnut seeds per sample were used. The seeds were kept in Petri-dishes lined with filter paper moistened with about 4 ml distilled water in three replicates 20 seeds per Petri-dish) and incubated at room temperature (25°C) for 5 to 8 days. The germinated seeds were counted visually up on appearance of radicle and/or plumule and percentage germination was calculated as follows:-

$$\text{Germination (\%)} = \left[\frac{\text{Number of germinated seed}}{\text{Number of seed planted}}\right] \times 100$$

3.8. Method of Data Analysis

3.8.1. Method of Data Analysis for dryer performance

The measured values of temperature in the dryer, drying rate of the dryer and dryer efficiency were compared with the design value.

3.8.2. Method of Data Analysis for proximate content and germination capacity

Statistical analyses were performed on Germination capacity and proximate content, over all the treatments. All the data collected were first tested for homogeneity before being subjected to analysis of variance (ANOVA) and the result were analyzed with CRD using SAS 9.2 program. Means were compared for the significant factors by least significant difference (LSD) test, and significance was accepted at 5% level.

4. RESULTS AND DISCUSSIONS

Table 2. Analysis of variance (ANOVA) table for proximate content, drying rate and germination capacity of groundnut (Pr > F) values

parameters	fat	protein	crude fiber	ash	carbohydrate	Germination capacity
DM	<.0001	<.0001	<.0001	<.0001	<.0001	<.0001
DD	0.2827	0.0109	0.0006	<.0001	0.4885	<.0001
DM*DD	0.5877	0.0064	0.0509	<.0001	0.1730	<.0001
R-Square	0.83	0.92	0.99	0.99	0.92	0.99
C.V	2.31	4.88	2.40	1.17	6.31	2.73

4 .1.Dryer Performance indicators

The procedure outlined above has been used to construct the prototype of an indirect type conventional solar dryer for groundnut to specification and tested. In all, three tests were carried out to evaluate the performance of the dryer. In the tests 10,7 and 3.4 kg of groundnut were dried at 15,10,and 5 centimeters depth with three replications respectively. The test results of the dryer under the three depths(15cm,10cm,and5cm) are provided in Tables 3 4, and 5 respectively.

4.1.1. Drying rate

The highest drying rate is obtained for groundnuts dried with the artificial dryer at 5 ,10 and,15cm depth (Figure 12,13,and 14) .Drying of groundnut in solar dryer from around 25% (wet basis) to the final moisture content about 10% has taken 24hrs, 29hrs, and 38hrs at 5, 10, and 15 cm depth of drying respectively, and 33,42 and 54 hrs by sun and 78 ,82 and 90hrs by shade drying at 5,10 and 15 cm depth respectively. As drying depth increases the drying rate decreases for all drying methods and in general greater drying rates are obtained with the solar dryer at similar drying depths for all drying methods used. Similar result was obtained by Ezekoye and Enebe (2006) that in the development and performance evaluation of modified integrated passive Solar grain dryer the drying rate of the dryer for groundnut was 0.198g /day while that of open air was 0.100g/day and this shows that solar dryers reduces the drying time required for drying groundnuts.

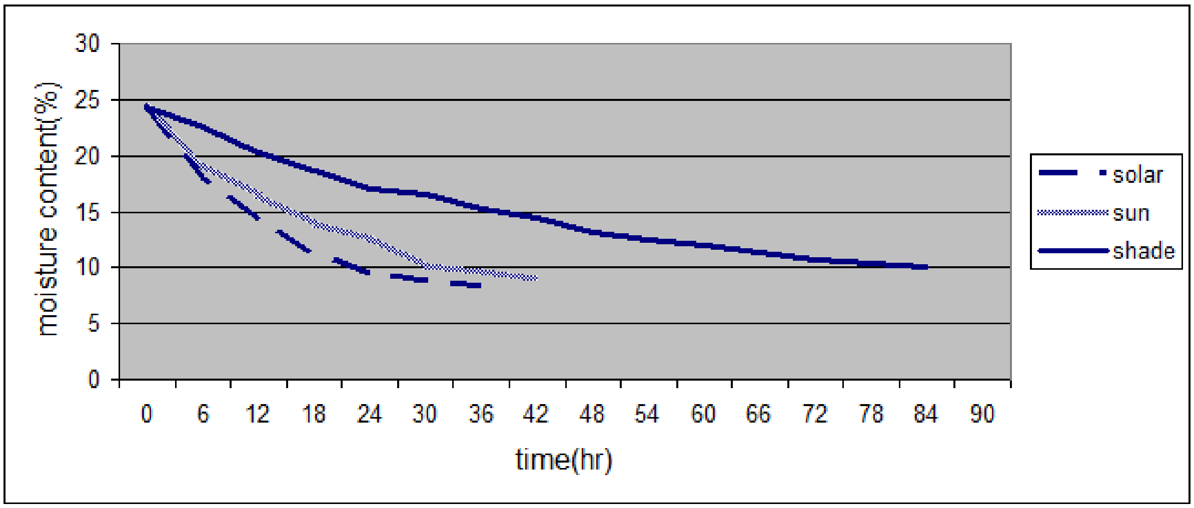

Figure 12.Moisture content verse drying time at 5 cm depth of drying with solar,sun and shade drying

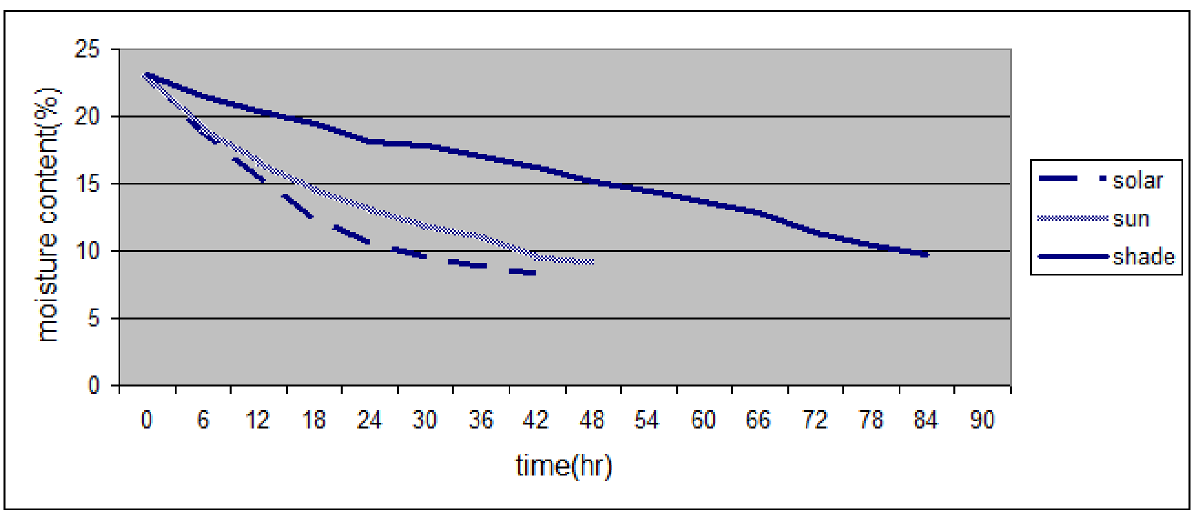

Figure 13.Moisture content verse drying time at 10cm depth of drying with solar,sun and shade drying

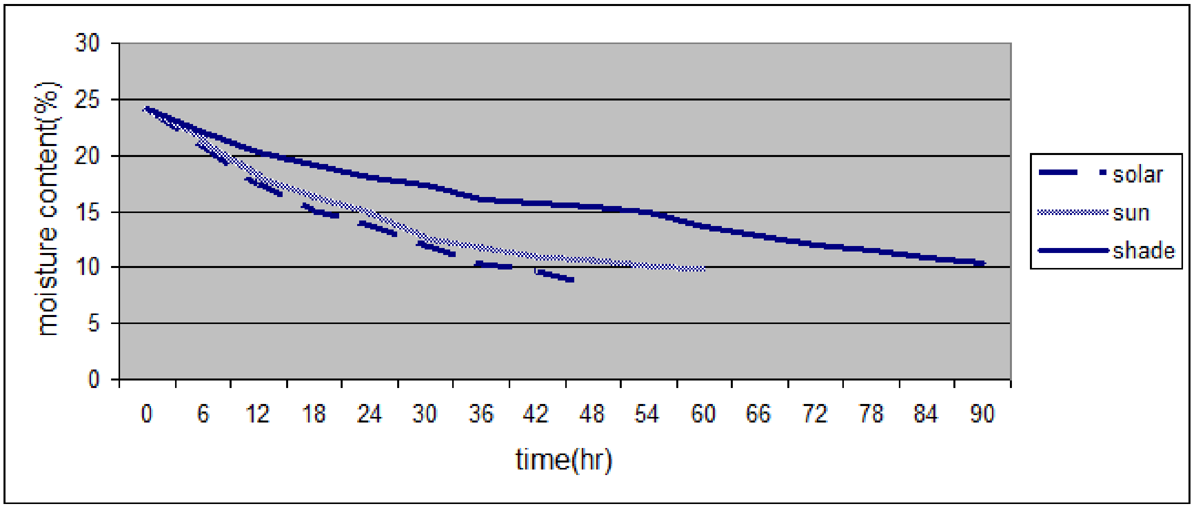

Figure 14.Moisture content verse drying time at 5 cm depth of drying with solar,sun and shade drying

Table 3 .Test results of the dryer at 5cm, 10cm and 15 cm drying depths

No	Parameter	Designed/ estimated value	Measured value		
			15cm depth	10cm depth	5cm depth
1	Average ambient temperature(^{o}c)	18.97	25.66	26.66	24.66
2	Average ambient relative humidity (%)	70.09	51.33	50.33	57.33
3	Drying efficiency (%)	12	15.78	20.68	25
4	Maximum drying temperature rise above the ambient (^{o}C)	8	11	11	11
5	Average drying rate(%moisture/hr)	0.3	0.29	0.31	0.45
6	Temperature in the dryer (^{o}C)	24.97	30.66	32.33	29
7	Temperature of air at collector out let (^{o}C)	26.97	32.33	35	31
8	Temperature of the air leaving the chimney (^{o}C)	22.97	28	30.33	26.33
9	Relative humidity of air at collector out let (%)	45	32.33	31	37.33
10	Relative humidity of air leaving the chimney (%)	55	45	39.66	51.33

4.1.2. Temperature and relative humidity of the ambient air, air at collector out let, in the dryer and leaving the chimney

Temperature at collector out let, inside drier, and leaving the chimney was higher than ambient temperature and corresponding relative humidity at collector out let, inside drier, and leaving the chimney was lower than ambient relative humidity (Table 3). As a result, drying rate of groundnut in a natural convection solar drier was found to be higher than that of open sun and shade drying at all drying depths (figure12,13and 14).

4.1.3. Overall drying efficiency

As it is seen from the table (Table 3) the drying efficiency of the dryer at all drying depths (5, 10, and 15 centimeters) is higher than the design value. This indicates that higher drying efficiency was obtained because of the higher rise in temperature of drying air leaving air heater(high temperature rise in the collector) Since drying efficiency is directly related to the change in temperature of the product which in turn directly related to the temperature of drying air leaving air heater .

4.2. Proximate content and germination capacity of dried groundnuts

4.2.1. Crude protein

Statistically significant ($p < 0.05$) effect were obtained for the interaction of drying method and drying depth on protein content of groundnuts (Table 2**)**. Crude protein content of shade dried groundnuts at 10cm depth has resulted in the highest value (26.58%). The next highest crude protein content was obtained in groundnut dried at 5cm depth under shade (23.92%) and the third highest crude protein content was obtained in groundnuts dried in shade at 15cm depth (21.9%). The groundnuts dried with artificial dryer and open sun at all depths resulted in statistically similar crude protein content with the lowest values relative to shade drying at all depths(Table 4). According to the report of Ayoola and Adeyeye (2010) on the effects of heating on the chemical composition and physico – chemical properties of *Arachis hypogea* (Groundnut) seed flour and oil; crude protein content of the raw samples were higher than those of the groundnut subjected to heat treatment (sun dried and roasted) and this may indicate that the lower protein contents observed in the solar dried and sun-dried samples and higher protein contents in the shade dried samples may be due to heat which would have affected the quantity of protein during drying. Similar result was also obtained by Bankole *et al*, (2005) in drying melon seeds using sun, oven, smoke and solar dryer that no significant difference was obtained on the protein content of sun and solar dried samples.

Table 4.Interaction effect of drying method and drying depth on crude protein, ash and germination capacity of groundnuts

Parameter	Drying depth	Solar dried	Sun dried	Shade dried
Protein	5	19.17d	18.27d	23.92b
	10	19.07d	18.45d	26.58a
	15	18.90d	18.39d	21.97c
Ash	5	2.66d	2.43e	2.99c
	10	2.68d	2.47e	3.13b
	15	3.50a	2.48e	3.14b
Germination capacity	5	30.33g	55.33e	40f
	10	60d	31.33g	89.33a
	15	81.33b	40.33f	75c

*Means with the same letter are not significantly different ($p < 0.05$) according to LSD (least significance difference) test.

4.2.2. Ash

The result of drying groundnuts using different drying methods at different drying depths showed significantly different ($p < 0.05$) values for the interaction effect of drying method and drying depth on ash content of groundnuts (Table 2). Groundnuts dried with the artificial dryer at 15cm depth has resulted in the highest ash content (3.5%) and the next highest ash content is of groundnuts dried under shade at 15and 10cm depths (3.14, 3.13%) respectively. groundnuts dried under shade at 5cm depth has also resulted in the third highest ash content (2.99%) . However, no significantly ($p>0.05$) different values was obtained among groundnuts dried with solar drying at 5 and 10 cm depths, and also no significantly ($p>0.05$) different values was obtained among groundnuts dried under open sun at all drying depths (5, 10 and15cm) (Table 4).

Similar result was obtained by Ayoola and Adeyeye (2010) during their assessment of the effect of heating on the chemical composition and physico – chemical properties of Arachis hypogea (Groundnut) seed flour and oil that from row, sun dried and roasted groundnut samples the ash content of both the raw and roasted groundnuts were higher than the sun-dried. This may indicate that sun drying decreases the crude ash content of groundnuts.

4.2.3. Germination Capacity

significantly different ($p < 0.05$) values were obtained for the interaction effect of drying method and drying depth on germination capacity of groundnuts (Table **).**The groundnut dried under shade at 10 cm depth has resulted in the highest germination capacity(89.33%) and the second highest germination capacity was obtained in groundnuts dried with artificial dryer at 15 cm depth(81.33%).The third highest germination capacity was obtained in groundnuts dried under shade at 15 cm depth(75%).In general best germination capacity was obtained in shade and solar dried groundnuts at deep drying depths. But the groundnuts dried in open sun drying were resulted in the lowest germination capacity relative to shade and solar drying method (Table 4).

Of the three drying methods, Shade drying and solar drying has resulted in greater germination capacity of groundnuts. The least germination capacity was recorded in sun dried groundnut and similar result was obtained by Aubrey and Paul (1969) during their experiment in Curing groundnuts under full and restricted sun and they obtain that the full-sun exposure treatment reduced germination of groundnut seeds compared with restricted sun exposure. Suresh et al, (2000) also obtained similar results for the groundnuts dried under the sun shade and mechanically dryer that the highest germination rate were recorded with shade drying.

4.2.4. Crude fiber

Crude fiber contents of groundnuts dried under shade, sun and artificial dryer are presented in table 4, and the effect of drying method has resulted in significantly different ($p < 0.05$) values (Table 2). Among the drying methods the groundnuts dried with the artificial dryer has resulted in the highest crude fiber content (7.27%). The second crude fiber content was obtained in the samples dried under shade (4.82%). The groundnut dried under open sun drying has resulted in the least crude fiber content (Table 5).

Table 5. Effect of drying method on crude fibre, crude fat and carbohydrate content of groundnuts

Parameter	Solar dried	Sun dried	Shade dried
Crude fibre	7.27a	3.77c	4.82b
Crude fat	42.91b	41.62c	45.93a
Carbohydrate	27.80b	33.76a	21.98c

*Means with the same letter are not significantly different ($p < 0.05$) according to LSD (least significance difference) test.

Groundnuts dried at (5, 10, and15cm) has resulted in significantly different ($p < 0.05$) values for Crude fiber contents (Table 2). The groundnuts dried at 15cm depth has resulted in the highest crude fiber content (5.45%).The crude fiber content of groundnuts dried at(10 and 5cm) depths has resulted in statistically similar values(Table 6).

Thermal processing or household cooking may alter the composition of fibers and thus alter their physiological effects' to human body (Weber and Chaudhary, 1987 cited in Azizah and Zainon, 1997). similarly during the assessment of Effect of processing on dietary fiber contents of selected legumes and cereals Azizah and Zainon, (1997) found different results of crude fiber content with different treatments of legumes and cereals when analyzed .In their assessment for groundnut they found significant decrease in crude fiber content of raw groundnut by roasting but no significant decrease by socking and boiling.

Table 6 .Effect of drying depth on crude fibre content of groundnuts

Parameter	5cm	10cm	15cm
Crude fibre	5.19b	5.21b	5.45a

*Means with the same letter are not significantly different ($p < 0.05$) according to LSD (least significance difference) test

4.2.5. Crude fat

In the drying of groundnut using different drying methods at different drying depths the effect of drying method has resulted in significantly different ($p < 0.05$) values on crude fat content of groundnut samples (Table 2). Groundnuts dried under shade resulted in the highest crude fat content (45.93%). Groundnut dried with the solar dryer has also resulted in the next percentage value (42.91%) of crude fat content. However, the groundnut dried with open sun has resulted in the least percentage of crude fat content (41.62%)(Table 5)..

Of the three drying methods shade drying generally resulted in high crude fat content. Ayoola and Adeyeye (2010) reported the effects of heating on the chemical composition and physico – chemical properties of *Arachis hypogea* (Groundnut) seed flour and oil. They found that crude fat content of the raw samples were higher than those of the groundnut subjected to heat treatment (sun dried and roasted) this indicate that heat treatment affects the crude fat content of groundnut. Similarly in this research result the lower fat contents observed in the solar dried and sun-dried samples may be due to heat which would have affected the quantity of fat during drying.

4.2.6. Carbohydrate content

Drying method has resulted in statistically significant effect ($p < 0.05$) on Carbohydrate content of groundnuts (Table 2). Groundnut dried under open sun has resulted in the highest Carbohydrate content (33.76%) and groundnut dried with the artificial dryer and under shade has resulted in the second and third percentage values (27.8%, 21.98) respectively(Table 5).

Similar result was obtained by Ayoola and Adeyeye (2010) during their assessment of the effect of heating on the chemical composition and physico – chemical properties of Arachis hypogea (Groundnut) seed flour and oil that from row, sun dried and roasted groundnut samples that sun dried and roasted groundnut samples has resulted in the highest Carbohydrate content than the freshly harvested groundnut samples. This may indicate that open sun dying contributes to the increment of Carbohydrate content of fresh groundnuts during drying.

4.3. Correlation analysis of groundnut proximate content dried with open sun at different drying depths

Correlation analysis between the proximate compositions of the open sun dried groundnuts showed that crude fat is strongly positively and significantly correlated with crude protein (r =70*) significantly and strongly negatively correlated with carbohydrate (r=81*),and positively and non significantly correlated with ash(r=48^{ns}).Crude protein is positively and significantly correlated with ash (r=71*) and strongly negatively and highly significantly correlated with carbohydrate (r=96**) but positively and non significantly correlated with crude fiber (r=26^{ns}).Crude fiber is positively and non significantly correlated with ash (r=20^{ns}),and negatively and non significantly correlated with carbohydrate(r=35^{ns}).Ash is strongly negatively and significantly correlated with carbohydrate (r=70*).

Table 7.Pearson Correlation coefficient of crude fat, crude protein, crude fiber, ash, and carbohydrate content of groundnut dried with open sun at different drying depths

	Crude fat	Crude protein	Crude fiber	Ash	carbohydrate
Crude fat	1	0.7026*	0.0186^{ns}	0.4822^{ns}	-0.8195*
Crude protein		1	0.2621^{ns}	0.7157*	-0.9673**
Crude fiber			1	0.2025^{ns}	-0.3566^{ns}
Ash				1	-0.7010*
Carbohydrate					1

** indicate highly significant at 5% probability level
* indicate significant at 5% probability level
ns= indicate non significant at 5% probability level

4.4. Correlation analysis of groundnut proximate content dried with solar dryer at different drying depths

Correlation analysis between the proximate compositions of the solar dried groundnuts showed that crude fat is positively and non significantly correlated with crude protein ($r=45^{ns}$), strongly positively and non significantly correlated with crude fiber($r=65^{ns}$), positively and non significantly correlated with ash($r=36^{ns}$) strongly negatively and highly significantly correlated with carbohydrate(r=95**), Crude protein is positively and non significantly correlated with crude fiber($r=25^{ns}$), negatively and non significantly correlated with ash($r=13^{ns}$), strongly negatively and non significantly correlated with carbohydrate($r=65^{ns}$) , Crude fiber is strongly positively and non significantly correlated with ash($r=66^{ns}$), strongly negatively and significantly correlated with carbohydrate(r=70*) and ash is negatively and non significantly correlated with carbohydrate($r=41^{ns}$).

Table 8. Pearson Correlation coefficient of crude fat, crude protein, crude fiber, ash, and carbohydrate content of groundnut dried with solar dryer at different drying depths

	Crude fat	Crude protein	Crude fiber	Ash	carbohydrate
Crude fat	1	0.4581^{ns}	0.6566^{ns}	0.36588^{ns}	-0.9513**
Crude protein		1	0.25905^{ns}	-0.13873^{ns}	-0.65709^{ns}
Crude fiber			1	0.66088^{ns}	-0.70575*
Ash				1	-0.41888^{ns}
Carbohydrate					1

** indicate highly significant at 5% probability level
* indicate significant at 5% probability level
ns= indicate non significant at 5% probability level

4.5. Correlation analysis of groundnut proximate content dried under shade at different drying depths

Correlation analysis between the proximate compositions of the shade dried groundnuts showed that crude fat is negatively and non significantly correlated with crude protein ($r=47^{ns}$), strongly positively and significantly correlated with crude fiber($r=82^{ns}$), positively and non significantly correlated with ash($r=41^{ns}$)positively and non significantly correlated with carbohydrate($r=3.9^{ns}$), Crude protein is negatively and non significantly correlated with crude fiber($r=45^{ns}$), negatively and non significantly correlated with ash($r=1.3^{ns}$), strongly negatively and significantly correlated with carbohydrate($r=89^{ns}$) , Crude fiber is strongly positively and significantly correlated with ash($r=74^{ns}$), positively and non significantly correlated with carbohydrate($r=5.9^{ns}$) and ash is negatively and non significantly correlated with carbohydrate($r=26^{ns}$).

Table 9.Pearson Correlation coefficient of crude fat, crude protein, crude fiber, ash, and carbohydrate content of groundnut dried under shade at different drying depths

	Crude fat	Crude protein	Crude fiber	Ash	carbohydrate
Crude fat	1	-0.4741^{ns}	0.8203*	0.4117^{ns}	0.0391^{ns}
Crude protein		1	-0.4595^{ns}	-0.0131^{ns}	-0.8944*
Crude fiber			1	0.7489*	0.0599^{ns}
Ash				1	-0.2677^{ns}
carbohydrate					1

** indicate highly significant at 5% probability level
* indicate significant at 5% probability level
ns= indicate non significant at 5% probability level

Different drying methods resulted in different correlation between proximate compositions in groundnuts and similar results were obtained by Kayode et al,(2011) In the assessment of Chemical Properties and Microbial Quality of groundnuts (*Arachis hypogaea*) Snacks in Lagos Metropolis; that correlation between proximate compositions of raw peanuts, peanut cake, roasted peanut, peanut candy, cooked groundnuts differs and this may indicate that different processing methods results in different correlation between proximate compositions in groundnuts.

5. SUMMARY AND CONCLUSIONS

In this research work from the performance evaluation of the designed solar groundnut dryer maximum temperature rise of 11°C than the ambient air temperature, an average relative humidity decrement of 19.4% in the collector out let during the drying period with system drying efficiency of about 15.45 % and higher drying rate than open sun and shade drying was obtained by solar dryer. As a result the drying time required to dry groundnut from 25% moisture content to 10% moisture content at 5, 10, and 15 cm depth of drying with traditional open sun drying was reduced by 9, 13 and 16hrs and with shade drying by 54, 53, and 52hrs respectively in natural convection solar dryer under the existing environmental conditions.

From the results of the performance evaluation of effect of the dryer on the proximate content and germination capacity of groundnut relative to sun and shade drying at different drying depths:

The effect of drying method has resulted in statistically significant ($p< 0.05$) values on crude fat, crude fiber and Carbohydrate content of groundnut samples. From the three drying methods used Shade drying has resulted in the highest crude fat content (45.93%) and the next highest crude fat content was obtained by solar drying (42.91%). The highest crude fiber content was obtained in the groundnuts samples dried in solar dryer (7.27%) and shade drying with the next highest value (4.82%).High Carbohydrate content was obtained in groundnuts samples dried in open sun drying (33.76%) and solar dried samples with the next highest value (27.8%).

The effect of drying depth has resulted in significantly different ($p< 0.05$) values on crude fiber content of groundnut samples from the three drying depths (5,10 and15cm) and high crude fiber content was obtained at 15cm drying depth of drying(5.45%).

The interaction effect of drying method and drying depth has resulted in significantly different ($p< 0.05$) values on crude protein, ash and Germination Capacity of groundnuts. Shade dried groundnuts samples has resulted in the highest crude protein content(26.58%) at 10 cm depth and statistically similar crude protein content was obtained in solar and sun drying at all (5,10 and 15 cm) depths of drying. The groundnuts samples dried with solar dryer at 15 cm depth have the highest ash content(3.5%) and the next highest ash content is of groundnuts dried under shade at 15 and 10cm depths(3.14, 3.13%) respectively and sun dried samples have the lowest ash content with statistically similar value at all depths. Shade dried groundnuts samples has resulted in the highest germination capacity (89.33%) at 10cm depth and the second highest germination capacity was obtained in groundnuts dried with artificial dryer(81.33%) at 15 centimeters depth.

In general the study showed that solar drying reduces the drying time required to dry groundnuts to the required moisture content relative to shade and sun drying, shade and solar drying were the best method of drying groundnut with high crude fat and crude fiber content and sun drying with high carbohydrate content, Shade drying at 10 cm depth was the best method of drying groundnut with high crude protein content, solar drying at 15cm depth was the best method of drying groundnut with high ash content , Shade drying at 10 cm depth and solar dryer at 15cm depth was the best method of drying groundnut with high germination capacity. But solar drying has an advantage of faster rate of drying than shade drying and this prevents the problem of fungal attack due to the existence of moisture. So from the three drying methods it can be concluded that the designed solar dryer is the best method of drying groundnut with best quality than open sun drying and shade drying at 15cm drying depth. But before practically using the designed solar dryer for drying purpose; the effect of the solar dryer on the microbial quality, mineral composition, shelling quality, and oil quality should be studied

REFERENCES

Agoreyo,B.O.,Akpiroroh,O.,Orukpe,O.A., Osaweren,O.R., and Owabor,C.N. 2011. The Effects of Various Drying Methods on the Nutritional Composition of Musa paradisiaca, Dioscorea rotundata and Colocasia esculenta. *Asian Journal of Biochemistry*, **6**: 458-464.Available online at http://scialert.net/abstract/?doi=ajb.2011.458.464 , retrieved on 07/02/2013

Akbulut, A. and Durmus, A.2010.Energy and energy analyses of thin layer drying of mulberry in a forced solar dryer. *Energy*, **35**:1754-1763

Alonge,A.F.and Hammed,R.O. 2007. A direct passive solar dryer for Tropical crops.African crope science preceeding **8**:1643-1646.

ANSI/AFPA NDS-1992 NDS National Design Specifications for Wood Construction, American Forest & Paper Association, Washington,DC.

Anwar, F., Chatha, S.A.S.and Hussain, A.I. 2007.Assessment of oxidative deterioration of soybean oil at ambient and sunlight.*storage Grasasy aceites*, **58 (4)**:390-395.

AOAC.1990. Official Methods of Analysis, 15th edition, *Association of Official Analytical Chemists*, Washington, DC. USA.

ASAE Standards. 2002. S410.1: Moisture measurement: Peanuts.St. Joseph, Mich. ASAE.

Azizah ,A.H. and Zainon, H.1997. Effect of processing on dietary fiber contents of selected legumes and cereals. *Malaysian Journal of Nutrition*, **3**: 131-136.

Baker IV, G. L. 2002. Flavor Formation and Sensory Perception of Selected Peanut Genotypes (*Arachis Hypogea* L.) as Affected by Storage Water Activity, Roasting, and Planting Date. PhD Dissertation, University of Florida.

Bankole, S.A., Osho1,A., Joda, A.O., Enikuomehin, O.A.2005. Effect of drying method on the quality and storability of'egusi' melon seeds (*Colocynthis citrullus* L.). *African Journal of Biotechnology*, **4(8)**:799-803.Available online at http://www.academicjournals.org/AJB, retrieved on 10/02/2013

Belessiotis, V.and Delyannis, E. 2011. Solar drying. *Solar Energy*, **85**:1665–1691.

Bolaji, B.O.2005.Performance evaluation of a box-type absorber solar air collector for crop drying.*Journal of Food Technology*, **3**:595-600.

Bolaji, B.O. 2008.Analysis of moisture transport in the solar drying of food items.*Pacific Journal of Science and Technology*, **9**:640-646.

Bolaji, B.O. and Olalusi, A.P.2008.Performance evaluation of a mixed-mode solar dryer.*AU Journal of Technology*, **11**:225-231.

Brenndorfer, B.,Kennedy, L.,Oswin Bateman, C. O.,Trim, D. S.and Mrema, G. C. 1985 Solar dryers: Their Role in Post-harvest Processing,Common wealth Secretariat .London.

Bruce H. R.1980. Understanding Wood: A Craftsman's Guide to Wood Technology.taunton press.USA.

Colliver,D.G.1991.Techniques of Estimating Incident Solar Radiation.In'Parker, B.F(ed).Solar Energy in Agriculture.Elsevier science publishing company.new York, USA.

Corvalan, R.and Zambrano, W. 1991.Free Convention Dryers. In'Parker, B.F(ed).solar energy in agriculture.Elsevier science publishing company.new York, USA.

Chavda, T. V.and Kumar,N. 2009. Solar Dryers for High Value Agro Products at Spreri.International Solar Food Processing Conference 2009.

Das,M.,Das,S.K.and Suthar, S. H. 2002. Composition of seed and characteristics of oil from karingda [*Citrullus lanatus* (Thumb) Mansf].*International Journal of Food Science and Technology,* **37(8)**:893-896.

Ebuy, H.T. 2007. Simulation of Solar Cereal Dryer using TRNSYS.An MSc Thesis. Presented to the School of Graduate Studies of Addis Ababa University, Addis Ababa, Ethiopia.

Erteken, C., Yaldiz,O.2004. Drying of eggplant and selection of a suitable thin layer drying model. *Journal of Food Engineering*, **63**:349–59.

Ethiopian Research Team Draft Report on 'Strengthening Women's Livelihoods through Collective Action: Market Opportunities in Smallholder Agriculture. June 2010, Addis Ababa, Ethiopia.

Ezekoye,B.Aand Enebe,O.M.2006. Development and Performance Evaluation of Modified Integrated Passive Solar Grain Dryer. *The Pacific Journal of Science and Technology*, **7:2**

FAO.1989. Mycotoxin prevention and control in food grains. Available online at http://www.fao.org/docrep/X5036E/x5036E0w.htm, retrieved on 01/07/2012

FAO.1994.Grain storage techniques - Evolution and trends in developing countries. Available at,http://www.fao.org/docrep/T1838E/T1838E0V.HTM#Natural%20and%20solar%20drying,retrived on 9/5/2013

FAO.2002.Improving nutrition through home gardening. Available online at http://www.fao.org/docrep/003/x3996e/x3996e42.htm,retrived on 9/5/2013

Folaranmi, J.2008.Design Construction and Testing of Simple Solar Maize Dryer. *Leonardo Electronic Journal of Practices and Technologies*, **13**: 122-130.

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

Gatea, A.A. 2011. Performance evaluation of a mixed-mode solar dryer for evaporating moisture in beans. *Journal of Agricultural Biotechnology and Sustainable Development*, **3(4)**:65-

71.Available online at http://www.academicjournals.org/JABSD retrieved on 01/07/2012

Gbaha, P., Andoh, H.Y., Saraka, J.K., Koua, B.K.and Toure, S. 2007. Experimental investigation of a solar dryer with natural convective heat flow. *Renewable Energy*, **32**: 1817–1829.

Gomez, K. A. and Gomez, A. A. 1984**.** Statistical Procedures for Agricultural Research. 2nd Edition. An International Rice Research Institute Book. A Wiley-Nescience Publication.

Habou, D., Asere, A. and Alhassan, A.M.2003.Comparative study of the drying rate of tomato and pepper using forced and natural convection solar dryers. *Nigeria Journal of Solar Energy*, **14**:36-40.

Haile, A. and Tolemariam, T., 2008. The feed values of indigenous multipurpose trees for sheep in Ethiopia: The case of *Vernonia amygdalina*, *Buddleja polystachya* and *Maesa lanceolata*. Livestock Research for Rural Development. Volume 20, Article No. 45. Available online at http://www.lrrd.org/lrrd20/3/hail20045.htm, retrieved on 01/02/ 2013

Hibbeler, R.C.2003.2003.Mechanics of materials.5th ed.pearson education,inc,Upper saddle river,New Jersey.

Immaculate, J., Sinduja, P. and Jamila, P.2012.Biochemical and microbial qualities of Sardinella fimbriata sun dried in different methods.*International Food Research Journal*, **19(4)**: 1699-1703.Available online at http://www.ifrj.upm.edu.my, retrieved on 07/02/2013

ISTA (International Seed Testing Association).1996. International Rules for Seed Testing.Vol. 24, Zurich,Switzerland.

Kayode ,F.O.,Oguntona ,C.R.B, Elemo, G.N., Bankole, A.O., Erukainure ,O.L.2011.Chemical Properties and Microbial Quality of Peanut (*Arachis hypogaea*) Snacks in Lagos Metropolis. *Fermentation Technology and Bioengineering* **1** :77-87.

kreider ,J.F.and Kreith,F.1982.Solar heating and cooling : active and passive design. Hemisphere Pub. Corp. New York .479 p.

Krzyzanowski, F.C., West, S.H.and Neto, G.D.B.F. 2006. Drying Peanut Seed Using Air Ambient Temperature at Low Relative Humidity.*Revista Brasileira de Sementes,* ***28 (3)****:01-05.*

Legesse,E. 2010. Aflatoxin Content of Peanut (*Arachis hypogaea*) in Relation to Shelling and Storage Practices of Ethiopian Farmers.An M.Sc Thesis Presented to the School of Graduate Studies of Addis Ababa University, Addis Ababa, Ethiopia.

Madlopa, A and Mponda, T.J. 2003.Dehydrating edible mushrooms using a locally made solar dryer.*Malawi Journal of Agricultural Sciences*, **2(1)**: 49-55.

McGill, A.S., R. Hard and J.R. Burt and F.D. Gunstone, 1974. Hept-cis-4-enal and its contribution to the off flavor in cold stored cod. *Journal of Science Food and Agriculture*, **25**: 1477-1489.

Mukhtar, F.B., 2009. Effect of storage temperature on post harvest deterioration of banana and plantain (*Musa* sp.). *International Journal of Physics and Applied Science*, **3**: 28-38.

Murthy, M.V. R. 2009. A review of new technologies, models and experimental investigations of solar driers. *Renewable and Sustainable Energy Reviews,* **13**: 835–844.

NASA Surface meteorology and Solar Energy: RETScreen Data. Available online at https://eosweb.larc.nasa.gov/cgibin/sse/retscreen.cgi?email=rets%40nrcan.gc.ca&step=1&lat=7.667&lon=36.833&submit=Submit, retrieved on 01/07/2012

Nigam, S.N, Giri, D.Y and Reddy, A.G.S. 2004. Groundnut seed production manual. Patancheru 502 324, Andhra Pradesh, India: International Crops Research Institute for the Semi-Arid Tropics, 32 pp.

Palacios, T.R. Potes ,L. B. Montenegro, R. A. and Giner, S. A. 2004. Peanut Drying Kinetics: Determination of the Effective diffusivity for In-Shell and Shelled Peanuts by Applying a short-Time Analytical Model to Measured Data. Drying 2004 – Proceedings of the 14th International Drying Symposium (IDS 2004).São Paulo, Brazil, 22-25 August 2004, vol. B, pp. 1448-1455

Roger, B.and Gregoire, P.E. 2009. Understanding Solar Food Dryers. Volunteers in Technical Assistance (VITA). Arlington, Virginia 22209 USA.

Stockbridge, M. 2006. Competitive Commercial Agriculture in Africa:Environmental Impacts. Background paper for the Competitive Commercial Agriculture in Sub–Saharan Africa(CCAA)Study.Availableonlineathttp://siteresources.worldbank.org/INTAFRICA/Resources/2579941215457178567/Ch13_Environmental.pdf, retrieved on 01/07/2012

Tarigan, E.andTekasakul, P. 2005. A Mixed-Mode Natural Convection Solar Dryer with Biomass Burner and Heat Storage Back-Up Heater. Australian and New Zealand Solar Energy Society Conference, 2005.

Waewsak, J., Chindaruksa, S. and Punlek, C. 2006.A mathematical modeling study of hot air drying for some agricultural products. *Thammasat International Journal of Science and*

Technology, **11**:14-20.

USDA, Foreign Agricultural Service**,** World Agricultural Production .Available online at http://www.fas.usda.gov/wap/current/,retrieved on 03/22/2012

Yang, C. Y., Fon, D. S. and Lin ,T. T.(na) Simulation and Validation of Thin Layer Models for Peanut Drying. Availableathttp://www.aseanfood.info/Articles/11022131.pdf, retrieved on 1/6/2012

APPENDICES

ANNEX 1. Analysis of variance (ANOVA) table for crude fat content

	DF	SS	MS	F value	Pr > F
DM	2	88.00991852	44.00495926	43.31	<.0001
DD	2	2.75631852	1.37815926	1.36	0.2827
DM*DD	4	2.93701481	0.73425370	0.72	0.5877
Error	18	18.2896667	1.0160926		
Total	26	111.9929185			
R-Square	C.V	Root MSE	Fat Mean		
0.836689	2.317669	1.008014	43.49259		

DF=degree of freedom; SS=sum of squares; MS=mean squares; R-Square=root square; C.V=coefficient of variation and Root MSE=root mean square of error

ANNEX 2 .Analysis of variance (ANOVA) table for crude protein content

Source of variation	DF	SS	MS	F value	Pr > F
DM	2	180.2686889	90.1343444	89.52	<.0001
DD	2	11.8133556	5.9066778	5.87	0.0109
DM*DD	4	20.4870222	5.1217556	5.09	0.0064
Error	18	18.1233333	1.0068519		
Total	26	230.6924000			
R-Square	C.V	Root MSE	Protein Mean		
0.921439	4.887580	1.003420	20.53000		

DF=degree of freedom; SS=sum of squares; MS=mean squares; R-Square=root square; C.V=coefficient of variation and Root MSE=root mean square of error

ANNEX 3. Analysis of variance (ANOVA) table for crude fiber content

Source of variation	DF	SS	MS	F value	Pr > F
DM	2	58.10708889	29.05354444	1800.84	<.0001
DD	2	0.37246667	0.18623333	11.54	0.0006
DM*DD	4	0.18784444	0.04696111	2.91	0.0509
Error	18	0.2904	0.01613333		
Total	26	58.9578			
R-Square	C.V	Root MSE	crude fiber Mean		
0.99507	2.401079	0.127017	5.290000		

DF=degree of freedom; SS=sum of squares; MS=mean squares; R-Square=root square; C.V=coefficient of variation and Root MSE=root mean square of error

ANNEX 4. Analysis of variance (ANOVA) table for ash content

Source of variation	DF	SS	MS	F value	Pr > F
DM	2	1.94746667	0.97373333	870.56	<.0001
DD	2	0.61042222	0.30521111	272.87	<.0001
DM*DD	4	0.81724444	0.20431111	182.66	<.0001
Error	18	0.02013333	0.00111852		
Total	26	3.39526667			
R-Square	C.V	Root MSE	ash Mean		
0.994070	1.179923	0.033444	2.834444		

DF=degree of freedom; SS=sum of squares; MS=mean squares; R-Square=root square; C.V=coefficient of variation and Root MSE=root mean square of error

ANNEX 5. Analysis of variance (ANOVA) table for drying rate

Source of variation	DF	SS	MS	F value	Pr > F
DM	2	0.20472751	0.10236375	4935395	<.0001
DD	2	0.04544211	0.02272106	1095479	<.0001
DM*DD	4	0.01904537	0.00476134	229565	<.0001
Error	18	0.00000037	0.00000002		
Total	26	0.26921537			
R-Square	C.V	Root MSE	drying rate Mean		
0.999999	0.050915	0.000144	0.282859		

DF=degree of freedom; SS=sum of squares; MS=mean squares; R-Square=root square; C.V=coefficient of variation and Root MSE=root mean square of error

ANNEX 6. Analysis of variance (ANOVA) table for carbohydrate content

Source of variation	DF	SS	MS	F value	Pr > F
DM	2	624.2497852	312.1248926	100.77	<.0001
DD	2	4.6198296	2.3099148	0.75	0.4885
DM*DD	4	22.2921481	5.5730370	1.80	0.1730
Error	18	55.7540000			
Total	26	706.9157630			
R-Square	C.V	Root MSE	carbohydrate Mean		
0.921131	6.318738	1.759956	27.85296		

DF=degree of freedom; SS=sum of squares; MS=mean squares; R-Square=root square; C.V=coefficient of variation and Root MSE=root mean square of error

ANNEX 7. Analysis of variance (ANOVA) table for germination capacity

Source of variation	DF	SS	MS	F value	Pr > F
DM	2	2560.888889	1280.444444	460.96	<.0001
DD	2	1634.000000	817.000000	294.12	<.0001
DM*DD	4	5881.777778	1470.444444	529.36	<.0001
Error	18	50.00000	2.77778		
Total	26	10126.66667			
R-Square	C.V	Root MSE	germination capacity Mean		
0.995063	2.737226	1.666667	60.88889		

DF=degree of freedom; SS=sum of squares; MS=mean squares; R-Square=root square; C.V=coefficient of variation and Root MSE=root mean square of error