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Design and Construction of a Tray Dryer for Groundnut Drying

Lawson, O.S.[1*], Agbetoye, L.A.S.[2], Olabinjo, O.O.[2], Olajide, O.G.[1]

[1]Agricultural and Bio-Environmental Engineering Technology Department, Rufus Giwa Polytechnic, Owo, Ondo State

[2]Agricultural and Environmental Engineering Department, Federal University of Technology, Akure, Ondo State

Corresponding author e-mail: olorunwalawson65@gmail.com

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Abstract

Drying is one of the oldest method of preserving food. Drying implies the removal of water from a product to an acceptance level for marketing, storage or for further processing. The numerous ways of usage of groundnut and its products has led to increase in its demand. However, the traditional method of drying involving exposing the groundnut seeds to sunlight and constantly spreading it to enhance uniform drying is associated with drudgery, unhygienic, time consuming, ineffective and results into high percentage seed losses. A tray dryer was constructed with the aim of improving on the traditional methods commonly used in Nigeria. The dryer can be used to measure drying rates of different varieties of groundnut at different initial moisture contents, drying air temperatures, drying air velocities of grain beds. The effects of different drying temperature, air velocity, can be investigated with the dryer. The dryer shows drying efficiency ranging from 77.54% to 79.32%. Also, the dryer is capable of reducing the moisture content of groundnut seeds of different varieties from 20% to average moisture content of 9% within average time of 7hrs.

Keywords: Drying, Groundnut, Moisture Content, Efficiency.

1.0 Introduction

Groundnut seeds processing is highly mechanized in developed countries. However, in the developing countries of the world including Nigeria and some West African countries, the traditional method of processing is the norm (Akintade and Bratte, 2015). Drying is one of the oldest method of preserving food. Drying implies the removal of water from a product to an acceptable level for marketing, storage or processing. In post-harvest technology, there are a number of methods of drying, these include, artificial, natural drying or mechanical drying.

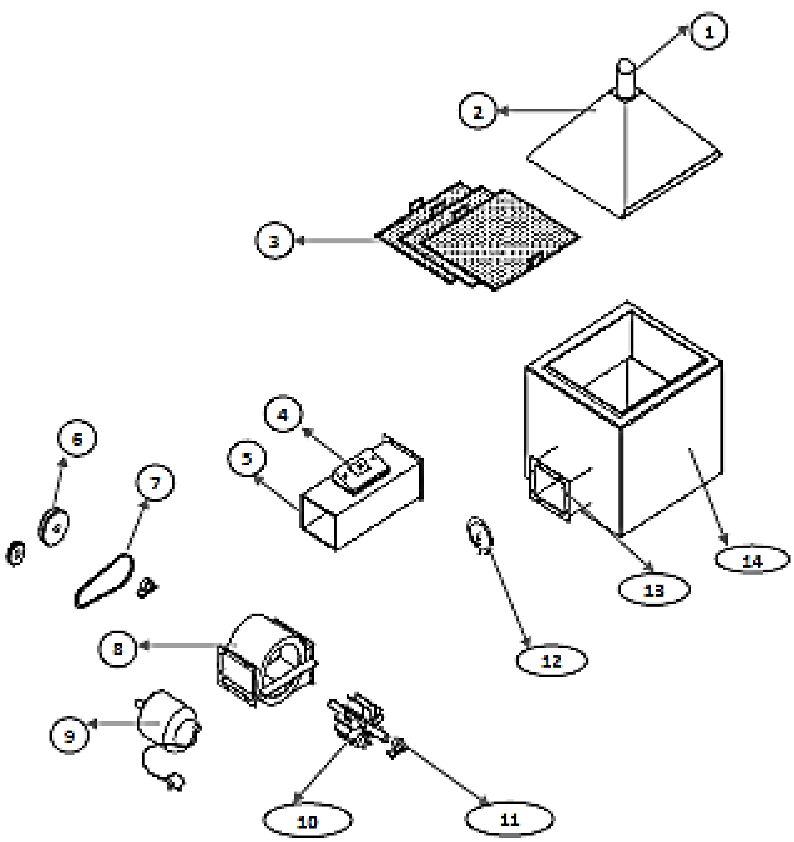
The traditional method of drying involve exposing the groundnut seeds to sunlight and constantly stirring it with hand to enhance uniform drying. This method of drying is labour intensive, unhygienic, associated with drudgery and resulting in great postharvest losses and has no provision for ergonomic factors. Not only these, the existing dryers produces from developing countries are very expensive.

According to Ajala *et al*. (2018), not only the problem of capital to import high technology faces the farmers and processors in developing countries but the problem of maintaining such dryers is a critical issue.

Consequently, construction of tray dryer with locally available materials will reduce the cost of such machines and promote affordability of such dryers. Therefore, the objective of this study is to develop an easy to operate low cost tray dryer for groundnut drying. (Figure 1 and Plate 1).

2.0 Material and Methods

Considering the environmental factors, economic factors and availability of this dryer to groundnut seeds processors, the materials used were sourced locally and they were selected based on some factors like ability to withstand heat, vibration, humid air fatigue and stress. The materials used for the construction of this convective hot-air dryer is easily maintained and repaired, and they can be source and obtained at cheaper cost.



PROJECT TITLE:DRYER/ COOLER FOR GROUNDNUT ROASTER			
Items	DESCRIPTION	QTY	DIM(mm)
1	CHIMNEY	1	ø100
2	HOOD	1	6000x1000x50
3	TRAY	3	500X500X200
4	HEATER/COOLING CONTROLLER	1	
5	HEATING DUCT/PLANUM	1	350x350x50
6	PULLEY	1	300x500x20
7	BELT	1	
8	FAN HOUSING	1	ø350
9	ELECTRIC MOTOR	1	1.5hp
10	FAN BLADE	12	200x20
11	BEARING	2	
12	HEAT COIL	1	
13	HOT AIR ENTRY	1	350x150x50
14	HEATING/COOLING CHAMBER	1	600X600X50

TITLE	EXPLODED VIEW OF DRYER/COOLER MACHINE			
SCALE	1:3	DATE	07-08-2019	
DIM	mm	DRAWN	LAWSON, O. S.	2 of 15

Figure 1: Exploded view of a tray dryer for drying groundnut

2.1 Design features of the tray dryer constructed.

The design features of this dryer is as shown in fig. 1.

(a) It is a convectional hot air dryer
(b) Expected number of tray : 3
(c) Expected production capacity : 6 kg/batch
(d) Initial moisture content of the groundnut seeds ranges from 18-20%.
(e) Desired finial moisture content : 8-10% wet basis
(f) Ambient temperature before entering dryer : 32.4^{0}c

2.2 Description of Major Components and Materials of Construction

The dryers is made of the following component parts:

Drying chamber; comprises of two layers, inner and outer, the outer cabinent dimension was 60cm height, 60cm width and 25cm breadth with inner dimension of 56cm height, 56cm width and 22cm breadth. The inside was constructed with galvanize frame which served as the skeletal frame of the dryer which was then covered with stainless sheet both inside and outside because of its corrosion resistance property, availability and medium cost. Groundnut loaded trays rest on vertical support made by galvanize angle iron of the drying chamber. The chamber was insulated to prevent heat loss using fibre glass of 2cm thickness between the inner and the outer walls.

Plate. 1: Fabricated groundnut drying machine

Blower (fan): The blower is the axial type (IB-9848A) 50HƵ, 220/230V, 0.7µF, 4P, 16W). The electric motor is the AC type, has a rating of 1.5KW. The blower is used to circulate heated air in the drying chamber. The blower was mounted on support bolted to a base at the back of the fan housing

The heated Element and Housing: A measured 2mm stainless steel was cut and folded to form a rectangular shape. This protrudes out of the middle section of the back of the chamber. The heating element is rated 3KW and mounted in front of the blower to supply heat to the dryer at position which ensures uniform hot-air circulation within the dryer.

Selection of heater was based on several factors like loading mass of the groundnut seeds, the optimum moisture content of the product and temperature difference in the chamber.

Tray: The trays were fabricated with stainless mesh of dimension 52cm x 52cm x 20cm and strategically placed at equal distance of 15cm apart to ensure uniform drying due to circulation of air in the cabinet. These are flat, square-shaped containers which contain the product to be dried. They are made of stainless steel, so that moisture from the product will not corrode the surface and thereby prevent contamination.

Hood: The drying chamber has a narrow opening of 20cm x 20cm made to aid movement of removed moisture from the product in the chamber to the surrounding. The hood has the shape of cone with square dimension 56cm at the four sides as the base and 13cm at the opening. The hood helps in diverging the moisture air from the chamber to the surrounding.

Control Box: The temperature sensor selected is a digital type connected to a temperature-controller in order to ensure a preset temperature range and thus prevent the device from being damaged. The live and neutral sources of current was connected to the contactor then to the temperature controller. The contactor helps in breaking the circuit (Kick off) when the temperature by the temperature controller attains the preset temperature.

2.3 Principles of Operation

The dryer works on the principle of convection heated air. The dryer was powered by electricity, the heated element generates heat and the suction fan provides the air, thereby creating heated hot air. Thus, during drying, vapour is generated throughout the material, transferred to the surface and removed by airflow at the surface. Heat is transferred to the material by conduction causing the moisture to change from liquid phase to vapour and evaporate at the surface. The chamber which is to contain the three set of trays on which the dehulled groundnut will be spread, it's made of stainless steel 2mm thick. The walled was lagged with fiberglass of 2 cm thickness (in order to absorb heat). The chamber comprises of two layers inner and outer, the outer cabinet dimension was 60 cm height, 60 cm width and 25 cm breadth with inner dimension of 56 cm height, 56 cm width and 22 cm breadth. It has an air inlet which is located by one side of the chamber at the bottom end; this provision allows air into the chamber. The trays rest on vertical supports made by angle-irons of the drying chamber. At the top of the chamber is a hood with chimney which helps in escape of excess heat and heated moist.

2.4 Design Analysis of the Tray Dryer

Design of Trays

Length of trays = 52cm = 0.52m

Breadth of trays = 52cm = 0.52m

Height of tray = 20 cm

Area of tray = L x B
= 52 x 22
= 2,704cm^2

Volume of tray = 0.2704m^3 x 0.2m^3

= 0.054m^3

Volume of the drying compartment

Volume = length x Breadth x height

V = L x B X H

V = 56 x 56 x 60

= 0.1882m^3

Amount of moisture to be removed

$$M_R = \frac{M\ (Q_1 - Q_2)}{(100 - Q_2)}$$

Where:

M, = Dryer capacity per batch 6 kg

Q_1 = Initial moisture content of the product to be dried = 20 %

Q_2 = Maximum desired final moisture content of the product = 10 %

Therefore

M_R = Amount of moisture to be removed per batch

$$M_R = \frac{6\ (20-10)}{100-10}$$

$$M_R = \frac{6\ (10)}{90}$$

= 6 (0.1111)
=0.667 kg

Mass of dried sample can be calculated using:

$Md = M_W - M_R$

Where: M_d = The mass of dried sample

M_w = Amount of water in the sample

M_R = Amount of moisture to be removed

Therefore:

$M_d = 10 - 0.667$

= 9.3 kg

2.5 Blower Design and Capacity

The blower was designed using

$P = Vph$
Where P = the power rating of the blower
V = air flow rate in $m^3/_5$
p = the density of air in kg/m^3 which is 1.115 kg/m^3 Ajisegiri *et al.* (2006)
h = pressure head in m, which is 1m

The minimum range of air velocity necessary for food products as recommended is 0.2- 0.5 $m^{3/}{}_5$, (Bulent *et al*. 2007; Ndukwu, 2009 and Ajala *et al*., 2018).

Substituting the above parameters into equation

$P = 0.2 \times 1.115 \times 1$
$= 0.223$
Approximately 0.2hp or 1.5Kw

2.6 Quantity of heat required to remove moisture content

The quantity of heat (Qt) required to remove moisture content was expressed in the equation is as stated by Adzimahand Seckley (2009)

$Qt = M_R C_P \Delta T$

Where: M_R = mass of water removed 0.667 kg
C_P = specific heat capacity of water (4.182 kg/kg ^0C)
ΔT = Temperature differences between dried samples and initial temperature of dryer
Initial temperature of dryer = 28 ^0C
And experimental temperature = 60^0c
Therefore change in temperature = 60- 28 = 32 ^0C
Substituting the above parameters

$Q_t = 0.667 \times 4.182 x32$

$Q_t = 89.26$ kj

$Q = 89.26 \times 10^3$ J

= 89.2606KJ

2.7 Quantity of heat required to effect drying

The quantity of heat required in drying (H_R) in KJ is giving by Adzimah and Seckley (2009)

$H_R = (M \times H_R) + (H_{xL} M_R)$

Where M = dryer capacity per batch 60kg

$H_k = C_T = (T_2 - T_1)$

C_T = specific heat of the product = 4.6KJ / kg ^0C

$T_2 - T_1$= Temperature difference 60-28 = 32 ^0C

H_l= latent heat of vaporization = 1248.1 KJ / Kg ^0C

M_R = Amount of moisture to be removed

Therefore substituting ; = 0.667 kg (Previously calculated)

$H_R = 60 \times 4.6(60-28) + 1248.1 \times 0.667$

$= 60 \times 147.2 + 44594.613$
$= 8832 + 832.4827$

= 9664.48 KJ

Therefore, the power of heating element can be calculated using:

$$\text{Power} = \frac{\text{Quantity of heat}}{\text{Time}}$$

Drying time for the product = 1hr

$$\text{Therefore: } p = \frac{9664.48}{1x\ 3600}$$

= 2.68

P = 2.68 KW

Therefore, from the above calculation a heating element of 3kw was selected

2.8 Actual heat used to effect drying (H_D)

$H_D = C_a T_C M_R$
Where;

C_a = specific heat capacity of air = 1.005 KJ/Kg ^0C

M_R = amount of moisture to be removed = 0.667 and T_C = temperature difference in the dryer cabinet = 60- 28 = 32 ^{0}C

The quantity of heat is therefore calculated to be;

H_D = 1.005 x 0.667
= 21.445 KJ

2.9 Design for Insulation

Using: $K = \frac{QL}{A\Delta T}$

Where: K = Thermal conductivity of stainless steel is 15W/mk 0.0549 W/m ^{0}c

Q = Quantity of heat transferred in J/S or

W is 89.2606 KJ = 24.795 J/S

L = Distance between the two isothermal planes?

A = Area of the surface in m^2 = 0.3136m ^{2}

(previously calculated)

ΔT = $T_1 - T_1$ is the change in temperature (^{0}C)

T_1 = Ambient temperature = 32.68 ^{0}C

T_2 = Temperature in the drying chamber = 51.43 ^{0}C

Therefore:

$$K = \frac{QL}{A\Delta T}$$

$$L = \frac{KA\Delta T}{Q}$$

$$= \frac{0.05491 \times 0.3136 \times 18.75}{24.795}$$

$$= \frac{0.3228708}{24.795}$$

= 0.013 m or 13mm

2.10 Performance Procedure and Experimental design

The groundnut seed were cleaned, sorted, and graded into different length and diameter. Average length is 10-12 mm and diameter 6-8 mm was used for this experiment and weighed on a digital weighing balance to have equal weight on each of the trays for the drying operation.The purpose of drying is to reduce the moisture content and makes the processing time for other machines to be reduce. The difference in weight between two consecutive time intervals gave the moisture evaporation. The experiment is a 3 x 3 x 3 factorial design with constant weight of groundnut seed 1.5kg the three factors are drying temperature (45 ^{O}C, 55 ^{O}C, 65 ^{O}C), drying time (5 hrs, 7 hrs, and 8 hrs) and air velocity (3.0, 4.0, 5.0 m^2/s), while the response is moisture loss, drying efficiency and drying rate. The experiments were stopped when the groundnuts attained safe storage moisture level of 8-10 %. This was observed through feeling on the hand from moist coming out of the chimney.

2.11 Performance evaluation of Groundnut Dryer

The machine was evaluated using equations according to Mujumdar (1997);

Moisture loss =I_m - F_m

Where *Fm*is final moisture content of groundnut seeds, *Im*is initial moisture content of groundnut seeds

Dryer efficiency = $\left(\frac{b}{d} \times 100\ \%\right)$

Where *b* is weight of dried groundnut seeds, *d* is weight of fresh groundnut seeds

Drying rate = $\frac{(Im - Fm)}{t} \times 100\ \%$

Where *t* is time of drying

3.0 Results and Discussion

3.1 Size and Weight of Different Varieties of the Groundnut Seeds

The size in length, breadth, thickness and volume of the groundnut seeds are shown in Table 1.0 below. The length varied from 12.15 mm to 16.74 mm, with highest recorded in Red Valencia variety, while the lowest was recorded in Runner type variety. Also, the breadth varied from 7.82 mm in Runner type to 8.75 mm in Red Valencia variety. The highest value of thickness of 9.24 mm was recorded in Red Valencia variety while the lowest value of 8.50 mm was recorded in Runner type. The mass of the varieties per seed on average varied from 0.483 g to 0.667 g, with highest value recorded in Red Valencia while the lowest value was recorded in Runner type. Similar to other parameters, the volumetric measurement showed that the Runner type produced the lowest value while the highest value was recorded in Red Valencia variety. In all the varieties (Red Valencia, Runner type, and Kampala) considered, there is significance difference in the means of length, breadth, thickness, mass and volume of the groundnut seeds.

Table 1.0: Groundnut sizes and weight as a function of the varietal differences

Variety	Length (mm)	Breadth (mm)	Thickness (mm)	Mass (g)	Volume (mm3)
Red Valencia	16.74a	8.75a	9.24a	0.667a	0.701a
Runner type	12.15c	7.82b	8.50b	0.483c	0.517b
Kampala	14.02b	8.65a	8.78b	0.598b	0.658a

Table 2.0: The moisture content, drying rate and drying efficiency of groundnut as influenced by varietal differences

Variety	Air flow rate (m^3/s)	Initial mass (Kg)	Initial moisture content (g/g)	Final moisture content (g/g)	Final mass (Kg)	Moisture loss (g/g)	Drying rate (Kg/h)	Drying efficiency (%)
Red Valencia	0.60a	1.5a	0.187a	0.080a	1.35a	0.107a	0.026a	90.0a
Runner type	0.33b	1.5a	0.187a	0.080a	1.35a	0.107a	0.019a	90.0a
Kampala	0.37b	1.5a	0.194a	0.086a	1.35a	0.107a	0.018a	90.0a

Table 3.0: Groundnut drying time, and temperature characteristics for drying

Variety	Time (hr)	Ambient temperature	Drying air temperature	Exit Chimney temperature	Wet bulb temperature	wet bulb depression
		(°c)	(°c)	(°c)	(°c)	(°c)
Red Valencia	5.71c	32.4ab	65a	59.0c	29.3a	35.6a
Runner type	7.22b	30.87b	55b	52.2b	29.0a	26.0b
Kampala	8.46a	34.77a	45c	43.1a	32.0a	13.0c

3.2 Drying of the Groundnut as Influenced by the Varieties and Drying Properties

The average amount of initial and final moisture content of the groundnut seeds, air flow rate, the quantity of groundnut loaded into the dryer are illustrated in Table 2.0. Also, the drying time during the drying tests for the three varieties of the groundnut revealed that the average amount of groundnut loaded in the dryer was 1.5 kg, and the average air flow rate ranged between 0.33 (Runner type) – 0.67 m^3s^{-1} (Kampala variety) (Table 2.0). The average drying time for the three batches of groundnut were 5.42, 7.22 and 8.46 hours for Red Valencia, Runner type and Kampala variety of groundnut, respectively. The average initial moisture content of groundnut during these tests were 0.187 (Red Valencia and for Runner-type) and 0.194 for Kampala variety, whereas the average final moisture content of the groundnut with different varieties 0.08, 0.08 0.086 for the Red Valencia, runner type and Kampala varieties.

On average, the moisture removal were 0.106, 0.108 and 0.105 for the Red Valencia, Runner type and Kampala variety of groundnut, respectively. On average, ambient air, drying air, and exit air temperatures during these tests were 32.8 °C, 30.87 °C and 34.77 °C for red Valencia, Runner type and Kampala variety of groundnut (Table 3.0). It was 65 °C, 55 °C and 45 °C for red Valencia, Runner type and Kampala variety of groundnut. Also the exit air temperature were 59.0 °C, 52.2 °C and 43.1 °C for Red Valencia, Runner type and Kampala variety of groundnut, respectively (Table 3.0). The average moisture loss for the different varietal tests during the groundnut drying trial revealed that higher value was recorded in Runner-type variety. The wet bulb depression is the difference between the dry-bulb temperature and wet bulb temperature of the drying air, whereas the temperature drop of the drying air is the difference between dry-bulb temperature of the drying air, and dry-bulb temperature of the exit air (Ahmad and Mirani, 2012). It was revealed that the drying efficiency has a strong correlation with the drying air temperature (Table 3.0). The higher the drying air temperature, the higher the drying efficiency of the dryer (Ahmad and Mirani, 2012). It can also be seen from this table that drying efficiency was 90 % during the different tests conducted on the different varieties of groundnut. The range of efficiency obtained in this study is similar to those reported by Ahmad and Mirani (2012). This variation in the drying efficiency of the dryer could be attributed to different drying air temperatures and humidity during these tests.

4.0 Conclusion

Tray dryer is the most widely used in agricultural drying for two good reasons. It is simple and economical in design and capable to dry products at high volume. Good airflow distribution will ensure the final moisture content of the dried products on the trays are uniform. The drying efficiency of the machine ranges between 77.54% to 79.32% this dryer provided more hygienic and dried products than the traditional method of drying.

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