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Experimental Studies of Effects of Geometry on Drying Rate and Properties of Ginger (Zingiber officinale Rosc.) with Solar-hybrid Dryer

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Abstract
Poor drying and processing methods employed by Nigerian farmers have led to loss of quality of dried ginger produced. Therefore, there is need to improve the drying and processing methods so that the quality of the products will be improved. To achieve this, a natural convection solar dryer was designed and constructed to dry ginger slices in different geometries. A 3 kg capacity hybrid dryer which was solar and biomass fueled was designed. The ginger samples were grouped into peeled and unpeeled. The specimens (peeled and unpeeled) were cut into cylindrical (Ø 0.2 m, thickness 0.008 m) and rectangular (0.03 x 0.025 m, thickness 0.008 m) shapes and 2.7 kg each were dried using open air, solar assisted and hybrid dryer. The initial and final moisture contents considered were 82.3% and 10% (wet basis), respectively. The average ambient conditions were 30 ºC air temperature and 15% relative humidity with daily global solar radiation incident on horizontal surface of about 20MJ/m^2 /day. The weather conditions considered are of Ogbomoso, Nigeria. A prototype of the dryer is so designed and constructed that has a maximum collector area of 1.03m^2. The percentage essential oil retention of cylindrical was higher than that of rectangular.
Keywords: Solar biomass dryer, Ginger, geometry, drying, essential oil Radiation

1. Introduction

Food crops, in the unprocessed form, are perishable being susceptible to biologically and physically induced deterioration. Preservation is always essential for all food crops in order to retain desired nutritional level, for as long as possible. While Green (2001) and Aworh and Egounlety (2009) estimated food losses in developing countries as being 50% for fruits and vegetables and 25% for harvested food grain, Karim and Hawlader, (2005) estimated wastage of fruits every year to be between 30-40%. These estimates show that every year, substantial quantities of food crops are lost through spoilage. The reasons for persistence of the wastage include ignorance about appropriate method(s) of preservation of produce, non-availability of preservation facilities and inadequate transportation system during harvest season. The age long identified methods for food preservation are, freezing, vacuum packing, canning, preserving in syrup, food irradiation, addition of preservative chemicals, and dehydration/drying. According to Jangam and Mujumdar, (2010) drying is the most popular method of food preservation. Drying to a safe moisture content level hinders microbial growth within the stored material. Drying of agricultural products is an important unit operation under post harvest phase. The drying process has been improving from ancient time when it was a matter of necessity to this time that properties of food, quality of product, and mechanism of drying are being studied for efficient drying.

Traditionally, food crops are dried by open sun-drying. The method that is widely used by Nigerian farmers for preservation of agricultural crops is traditional open sun drying (Eze and Agbo, 2011). Sun's radiant heat is used in evaporating moisture from agricultural crops. This is because a large quantum of solar energy is released to the earth surface especially in tropical regions. Process of drying traditionally involves spreading crops on ground or any surface that is available in the sun. It is a thin layer drying, and crops will be stirred or turned at intervals for improved drying. Crop temperature when drying in the sun ranges from 5 to 15 ^{o}C above ambient temperature. Factors that affect drying duration and rate are initial moisture content, desired final moisture content, properties of crop, airflow, intensity of sun and season.

Solar energy can be used directly or indirectly depending on the properties of crops that are being dried. The sun being intermittent in supply, can be enhanced by other sources of energy such as biomass, conventional fuel etc. Part of the disadvantages of sun drying is over drying, susceptibility of crop to spoilage, losses due to inadequate drying, fungi attacks during drying, insects, birds, rodents' encroachment exposure to ultraviolet radiation and unpredictable weather effects (Panchal *et al.*, 2013).Some of the open-air sun drying problems are solved through the use of a solar dryer that comprises collector, drying chamber and sometimes chimney (Madhlopa *et al.*, 2002). For effective use of solar dryer, it is important to have information on seasonal and daily variation of sunshine, humidity, temperature, wind speed and direction during drying (Krokida *et al.*, 2006). Sun drying takes relatively long duration of drying. Nigeria has average insolation of between 3.8 – 7.15

kWh/m^2 day and sunshine hour (h/d) of 5 -7 (McDaniels, 1984).

Ginger (*Zingiber officinale* Rosc.) is one of the important agricultural crops that are produced in Nigeria. It is an herbaceous perennial plant as well as tropical herb extensively grown for its pungently aromatic underground stem. It is an important export crop valued for its powder, oil and oleoresin. Nigeria's ginger is highly valued for its aroma, pungency, high oil and oleoresin contents (Njoku *et al*., 1995). Likewise Eze and Agbo (2011) reported that the quality of fresh ginger (that is freshly harvested) produced in Nigeria is the best in the world. However, it has been observed that the quality of dried ginger is low due to low level of mechanization of ginger processing (Onu and Okafor, 2003). Also, dried ginger from Nigeria attracts low price in the world market because of its low quality due to mould growth, loss of some volatile oils by evaporation (Yiljep *et al.,* 2005).

Some work have been done by researchers on usage of biomass burner as a backup heater of a solar dryer and some of them are: Madhlopa and Ngwalo (2007), Thanaraj *et al*. (2004), Prasad and Vijay (2005), Tarigan and Tekasakul (2005), Bena and Fuller (2002), Kumar *et al*. (1999), Serafica and del Mundo (2005), Bhattacharya *et al* (2000), Fuller *et al.* (2004). Most of them work on different configurations and fuel type with advantages and disadvantages. Therefore, this work considered the ways by which quality of dried ginger produced in Nigeria can be improved through different geometries and processes when solar and biomass dryer and a solar biomass dryer were used.

2. Design Feature of the dryer

The hybrid solar and biomass (figure 1) consists of a solar drying section and a biomass stove section. The dryer has the shape of a cabinet with tilted transparent top, consisting primarily of a drying chamber, biomass stove, and solar collector. The solar dryer consists of transparent single glazing (2 mm thickness), four drying trays of perforated wire mesh base (area 0.192m^2), two adjustable vents (0.66x0.08 m^2) which serves as a chimney to prevent condensation. The single glass inclined at 18.13^o according to Ogbomoso Latitude (8.13^o) and it has a metallic frame in which all the sides are wood to prevent heat loss. The openings at the base of the dryer are to allow hot air in when using biomass and fresh air when using solar.

Charcoal stove is to provide indirect heating to dryer and its temperature could be controlled by maintaining the combustion in the stove with opening or closing of the primary air supply. The charcoal stove dimension is 0.61 x 0.66 x 0.58 m and surrounded by brick walls of 0.70 x 0.75 x 0.67 m. A perforated tray is provided inside the stove for charcoal burning. The charcoal is being fed through a door of 0.54 x 0.42 m. The exhaust gases exit via a 0.039 x 0.02 m and 70 cm long chimney located at one side of the stove. To lengthen the flow path of exhaust gases and maximize the transfer of heat to the stove top, three metal baffle plates are inserted at a distance of 0.09 m above the grate and below the chimney in the burning chamber. The brick chamber has 9 rectangular holes for fresh air entry having dimension of 0.005 m^2. To prevent excessive temperature in the drying cabinet a metal plates with fibre glass in between is placed between the solar dryer and biomass stove that is also act as a thermal device.

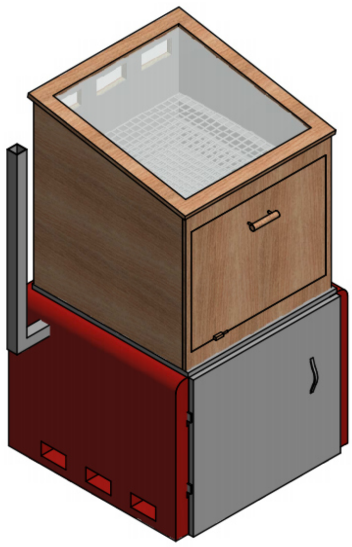

Figure 1: Solar-biomass Dryer

3. Experimental Procedure

19 kg 'Tafin-Giwa', (yellowish variety with plump rhizomes) variety of ginger was purchased from

Ogbomoso market and divided into four parts. One part was peeled and cut into 30 x 25 x 8 mm in length, breadth and thickness respectively and placed in the dryer. The second part was cut into the same dimension but without peeling. The third part was peeled and cut into cylindrical shape of 0.08 m diameter and 0.02 m long and placed in the dryer. The fourth part was unpeeled and cut into cylindrical shape with dimensions 0.08 x 0.02 m in diameter and length respectively and placed in the dryer. The performance test of the dryer was carried out in stages. The first being to measure temperature distribution across the trays with no load using solar and biomass and to ascertain that the heat supplied by biomass does not exceed the acceptable temperature for ginger drying. The second is to measure the moisture loss in ginger chips on the dryer with the solar heating during the day and then with only biomass heating during the night. The third is to determine the quality of the dried ginger. The temperature changes were monitored using mercury thermometers fixed in the trays while ambient temperature was monitored with thermo-hygrometer. Drying chamber and ambient temperatures, relative humidity, air flow and rate of weight reduction were measured using mercury thermometer, thermo-hygrometer and hot wire anemometer respectively. Five trials were conducted in the dryer both when loaded and on no load. Drying was stopped when the crop reached their constant weight.

After drying, samples (solar, hybrid and open sun) were ground into powder and sieved with a 20 mm mesh sieve. The colour of the ground sample was determined using colourimeter. The aroma test was done using human palate. The volatile oil content was determined for each sample using gas chromatography.

4. Solar Dryer Design Consideration

The following points were considered in the design of the natural convection solar dryer system:
a- the amount of moisture to be removed from a given quantity of wet ginger
b- harvesting period during which the drying is needed
c- the daily sunshine hours for the selection of the total drying time
d- the quantity of air needed for drying
e- daily solar radiation to determine energy received by the dryer per day
f- wind speed for the calculation of air vent dimensions
4.1 Design Procedure

(i) Design Calculations

In design calculations and size of the dryer, the design conditions applicable to Ogbomoso, Nigeria are required. The input and assumptions summarized in Table 1 are used for the design of the ginger dryer. From the conditions, assumptions and relationships, the values of the design parameters were calculated. The results of the calculations are summarized in Table 2.

In design calculations, there are some constants to be used and a few assumptions which have to be made; these were stated in the parameters that were used in the calculations (Alonge and Hammed, 2007, Akoy *et al*., 2003, Alamu *et al*., 2010, Folaranmi, 2008).

(1) Amount of moisture to be removed from a given quantity of ginger (W_w) is given by Alonge and Hammed, (2007) as:

$$W_w = \frac{W_g\left(M_i - M_f\right)}{100 - M_f} \tag{1}$$

Where,
W_g =Initial mass of wet ginger (kg)
M_i = Initial moisture content (%)
M_f = Final moisture content (%)

Final relative humidity or equilibrium relative humidity ERH (%) was determined as follows according to Ogheneruona and Yusuf, (2011):

$$ERH = 100a_w \tag{2}$$

$$a_w = 1 - \exp\left[-\exp\left(0.914 + 0.5639\ln M\right)\right]$$

$$M = \frac{M_f}{100 - M_f}$$

Where,
a_w = water activity and M = moisture content kg_w/kg_s (dry basis)

(2) Quantity of heat needed to evaporate water from ginger is given by Ogheneruona and Yusuf, (2011); Youcef-

Ali *et al*., (2001) as:

$$Q = W_w \times h_{fg} \tag{3}$$

Where,

Q = Amount of energy required for drying process (kJ)
W_w = Mass of water (kg)
h_{fg} = latent heat of evaporation
but,

$$h_{fg} = 4.186 \times 10^3 (597 - 0.56(T_{pr})) \tag{4}$$

Where,
T_{pr} = Product temperature (^{0}C)

The total heat energy, E (kJ) required to evaporate water was calculated as follows:

$$E = m(h_f - h_i)t_d$$

Where E = total heat energy, kJ
m = mass flow rate of air, kg/hr
h_f and h_i = final and initial enthalpy of drying and ambient air respectively, kJ/kg dry air
t_d = drying time, hrs
Enthalpy of moist air in drying air at temperature T is given as (Brooker *et al.,* 1992)

$$h = 1006.9T + w(2512131.0 + 1552.4T)$$

(3) Average drying rate is given by Alonge and Hammed, (2007) as:

$$W_{dr} = \frac{W_w}{t_d} \tag{5}$$

Where
t_d = drying time

(4) The quantity of air needed for drying is given by Alonge and Hammed, (2007) as:

$$W_a = \frac{W_w L}{C_a \rho_a (T_i - T_f)} \tag{6}$$

Where,
L = Specific Latent heat of vapourization from crop to be dried
C_a = Specific heat capacity of the air at constant temperature (kJ/kg^{0}C)
ρ_a = Density of drying air (Kg/m^3)

(5) The volume flow rate of air is given by Alonge and Hammed, (2007), Alamu *et al*., (2010), Folaranmi, (2008) as:

$$Q_a = \frac{W_a}{t_d} \tag{7}$$

(6) Air vent dimension is given by Alonge and Hammed, (2007) as:

$$A_v = \frac{Q_a}{V_w} \tag{8}$$

V_w = wind speed

(7) Width of air vent is given by Alonge and Hammed, (2007) as:

$$B_v = \frac{A_v}{L_v} \tag{9}$$

L_v = vent length (assumed to be length of the dryer)

(8) Air Pressure head is given by Alonge and Hammed, (2007) as follows

The pressure difference across the bed of dryer is as a result of density difference between ambient air and air inside the dryer.

$$P = 0.00308 g(T_i - T_{am})H \tag{10}$$

Where, H = pressure head
g = Acceleration due to gravity

T_{am} = Ambient temperature

(9) According to Alonge and Hammed, (2007) the solar drying collector area A_c can be calculated as:

$$A_c I\eta = E = m(h_f - h_i)t_d \quad (11)$$

$$A_c R_b I\eta = E = Q_a \rho_a C_a (T_i - T_f)t_d$$

Therefore: $$A_c = \frac{E}{I\eta} \quad \text{or} \quad A_c = \frac{E}{IR_b\eta} \quad (12)$$

I = Total global radiation on horizontal surface during drying (kJ/m^2)

η =collector efficiency

R_b = the ratio of solar radiation on a tilted surface to that on horizontal

E = Total useful energy received by the drying air (KJ)

Table 1: Inputs and Assumptions into the Design

S/N	Items	Conditions or Assumptions
1	Location	Ogbomoso (latitude 8.133)
2	Crop/Variety	Ginger, "Tafin Giwa"
3	Drying Period	November, 2011
4	Loading rate M_P (kg/days)	3
5	Initial Moisture Content M_i (%) w.b	82
6	Final Moisture Content M_f (%) w.b	10
7	Ambient Air Temperature, T_{am} (^{0}C)	35
8	Ambient Relative Humidity, RH_{am} (%)	18
9	Maximum Allowable Temperature, T_{max} (^{0}C)	60
10	Drying time (Sunshine hours) t_d (hours)	33
11	Mean Incident Solar radiation, I (MJ/m^2/day)	79
12	Collector efficiency, η (%)	15.56
13	Average Wind speed (km/hrs)	2.3
14	Thickness of the material (mm)	8
15	Vertical distance between two adjacent trays (cm)	15

Table 2: Values of Design Parameters

S/N	Parameter/ Unit	Value	Data or Equation used
1	Initial humidity ratio, w_i (kgH20/kg dry air)	0.0028	T_{amb}, RH_{amb}
2	Initial enthalpy, h_i (kJ/kg dry air)	41.50	T_{amb}, RH_{amb}
3	Equilibrium relative humidity, RH_f (%)	51.45	M_f and Equation 3.2b
4	Final enthalpy, h_f (kJ/kg dry air)	75.00	W_i and T_f
5	Final humidity ratio, w_f (kgH20/kg dry air)	0.013	RH_f and h_f
6	Mass of water to be evaporated, M_w (kg)	2.45	Equation 3.4a
7	Average drying rate, m_{dr} (kg/hr)	0.074	Equation 3.6
8	Quantity of air needed, w_a (m^3)	254.02	Equation 3.7
9	Volumetric air flow rate, (Qa) m^3/hr	7.697	Equation 3.8
10	Total useful energy, E (MJ)	9.802	Equation 3.13
11	Solar collector area, A_c (m^2)	0.695	Equation 3.12
12	Vent area, A_v (m^2)	3.338x10^{-3}	V_a, wind speed
13	Air pressure, P (Pa)	0.62	Equation 3.11
14	Vent length, L_v (m)	0.62	
15	Vent width, B_v (m)	0.054	Equation 3.10

NB: Values in numbers 1, 2, 4 and 5 were obtained using psychrometric chart

5. Results and Discussion

5.1 Temperature distribution during no load test

The first test was conducted over a period of 26 hours. Table 3 shows the temperature distribution in each tray when using solar during the day and biomass at night with no load. The corresponding humidity was also shown. Highest temperature 52^{o}C was recorded after six hours in first tray and the highest temperature of 50^{o}C was maintained in tray 4 at night: this has to be done because temperature higher than this will affect the properties of ginger that is to be dried. Also, figure 2 shows the comparison of ambient temperature and cabinet temperature. The results show that the dryer performed well in raising the cabinet temperature above the ambient temperature and can be used in drying of ginger without affecting its properties and there can be 24 hrs continuous drying.

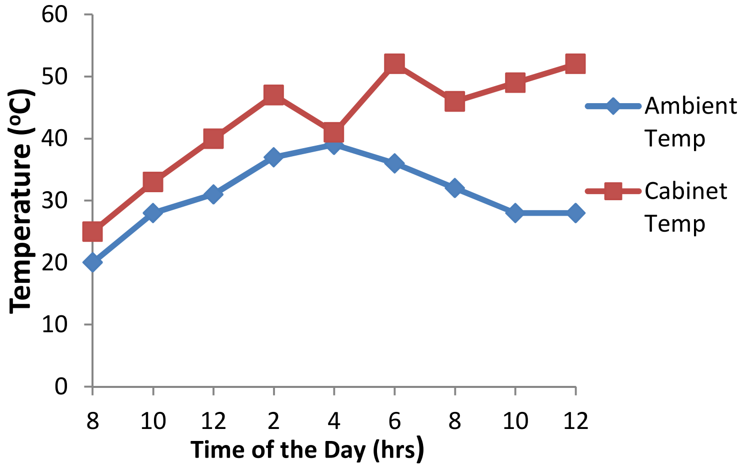

Figure 2: Hourly Variation of Air Temperature in the Solar Biomass Hybrid Dryer

Table 3: Temperature and Relative Humidity Variations During No-load Testing*.

Time of the Day(hrs)	**Tray 1 Temp (°C)**	**Tray 2 Temp (°C)**	**Tray 3 Temp (°C)**	**Tray 4 Temp (°C)**	**Cabinet Relative Humidity (%)**
8 – 10am	34	32	30	30	50
10 – 12noon	41	40	38	37	50
12 – 2pm	52	48	41	41	25
2 – 4pm	44	44	39	39	20
4 – 6pm	44	45	46	48	25
6 – 8pm**	38	40	41	43	37
8 – 10pm**	39	41	45	47	20
10 – 12mid-night**	41	43	47	50	20

*Readings were taken after 2 hours exposure
** Readings taken when biomass was used as source of heat- no solar energy available

5.2 Moisture Loss in ginger using hybrid dryer

Drying parameters at different tray level and open sun were recorded. It was found that there were significant variations in the drying parameters at different tray levels during the day and at night for peeled, unpeeled rectangular and cylindrical shaped ginger. Figure 3 to 6 show the percentage of moisture content in products for peeled and unpeeled ginger that was cut in cylindrical and rectangular shape during the drying period.

During the day, slices on top tray dried faster than those at the bottom tray for example in unpeeled rectangular shaped ginger, the moisture content in the first eight hours are 26.35, 51.26, 58.26 and 65.02 (wb) % in tray 1,2,3 and 4 respectively. These rates of moisture reduction continued throughout the day but changes as the moisture content of the product reduces, as it is difficult to remove moisture from partially dried product. The maximum temperature for trays 1, 2, 3 and 4 during the day ware 57, 48, 44, 41 °C respectively and for biomass are 51, 49, 43 and 40 °C for trays 4, 3, 2, and 1 respectively.

At night when biomass heating was in operation, the slices on the bottom tray dried faster than those at the three upper trays, this was as a result of high heat from the biomass reaching the bottom tray first than three others. After 32 h of drying the final moisture content for peeled and unpeeled rectangular shaped ginger were 3.1, 8.3, 8.5 and 8.96, 10.15, 11.34 respectively for trays 1, 2 and 3. While moisture contents for cylindrical peeled and unpeeled ginger were 11.2, 11.3, 11.7 and 8.3, 9.8, 16, respectively for trays 1, 2, and 3. The implication of this is that unpeeled ginger retains more moisture than peeled type and the rate of moisture loss is slower in unpeeled ginger than peeled one, this shows that skin has effect on the rate of moisture movement. Lower moisture content level was recorded in rectangular shaped ginger than cylindrical, this may lead to more essential oil loss in rectangular than cylindrical type.

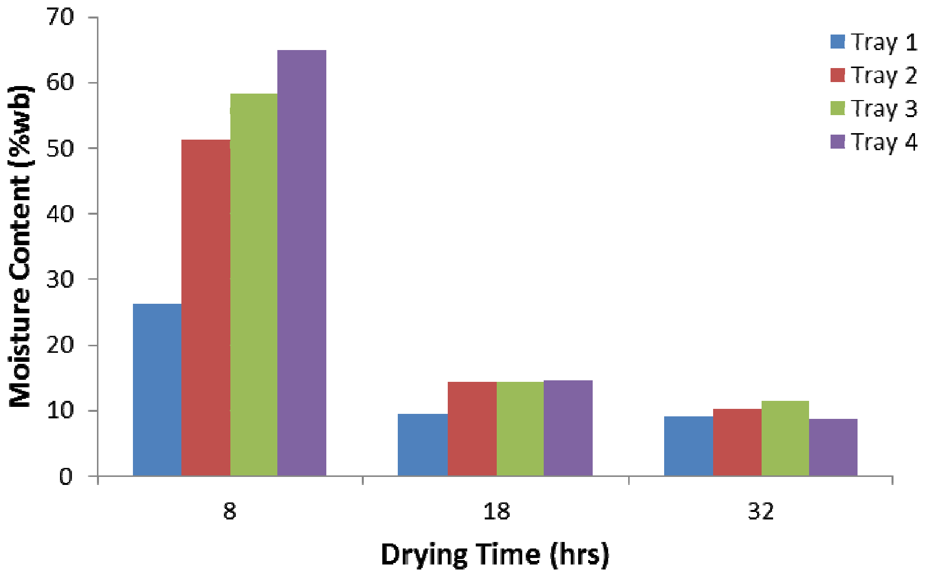

Figure 3: Variation of Moisture Content of Unpeeled Rectangular shaped Ginger with Time during Drying

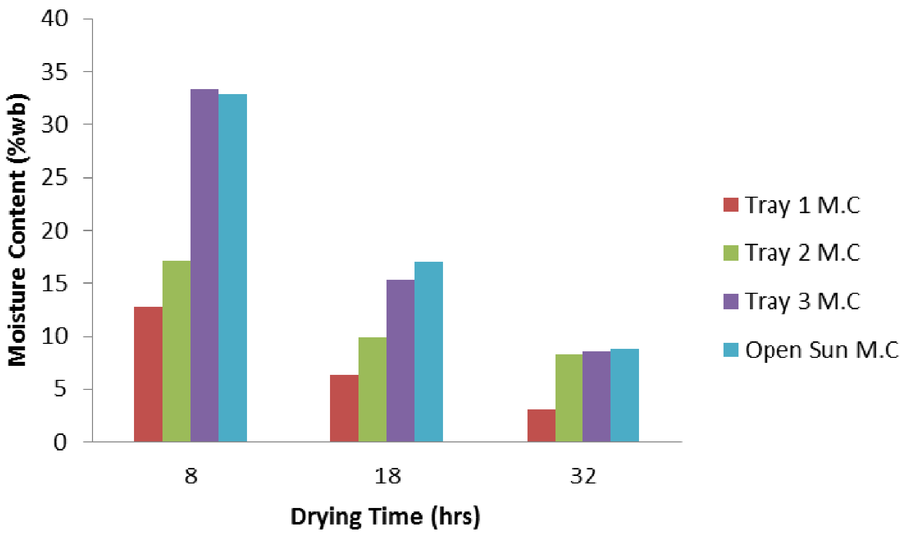

Figure 4: Variation of Moisture content peeled Rectangular Shaped Ginger with Time during Drying

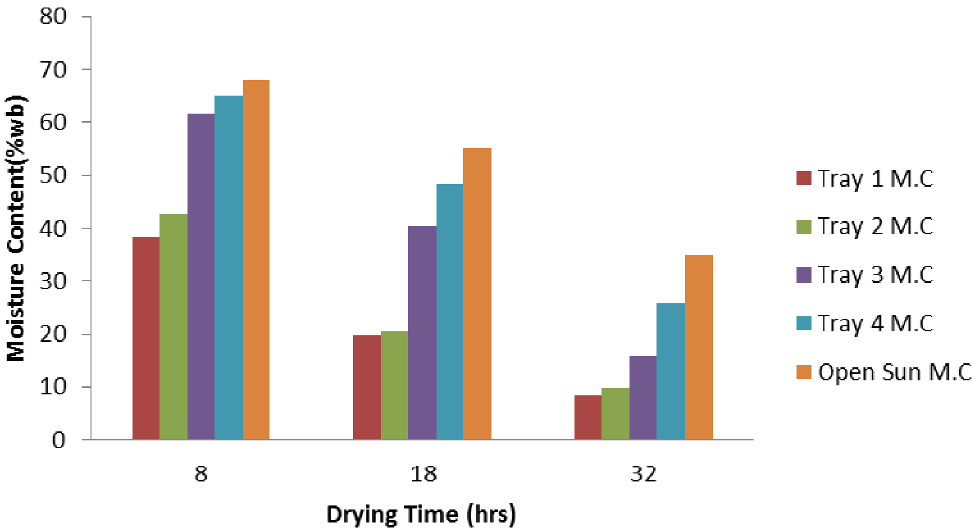

Figure 5: Variation of Moisture Content Unpeeled Cylindrical Shape with time during Drying

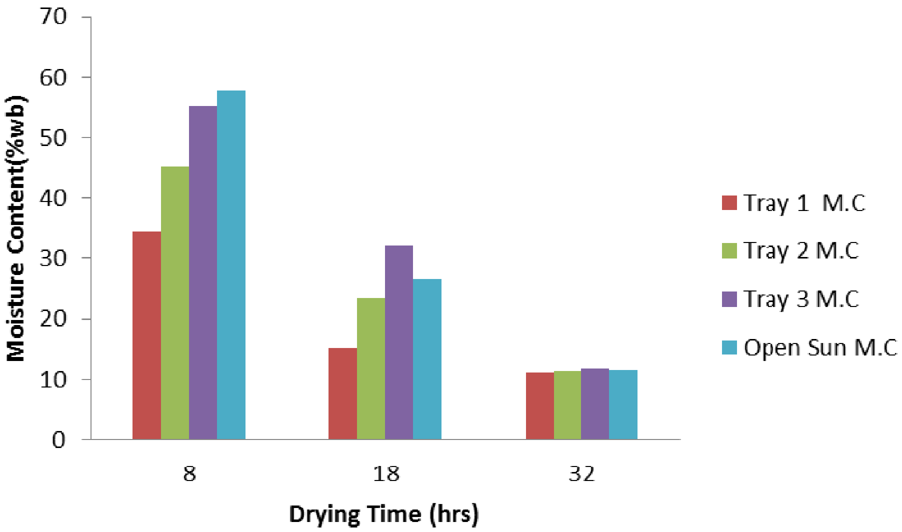

Figure 6: Variation of Moisture content Peeled Cylindrical Shaped Ginger with time during Drying

Table 4: Temperatures within the Different Trays inside the Dryer with Time During Ginger (*Zingiber officinale*) Drying.

Time of the Day (hrs)	**Temp of tray 1 (°C)**	**Temp of tray 2 (°C)**	**Temp of tray 3 (°C)**	**Temp of tray 4 (°C)**
8.00am	30	27	25	24
10.00am	32	26	24	23
12.00noon	40	31	30	29
2.00pm	41	38	34	31
4.00pm	39	36	32	31
6.00pm	31	29	28	26
8.00pm	34	35	38	39
10.00pm	37	39	40	44
12.00mid- night	36	38	40	44
2.00am	38	39	39	42
4.00am	40	43	49	51
6.00am	33	33	35	37
8.00am	27	28	29	30
10.00am	39	36	37	39
12.00noon	46	44	43	41
2.00pm	57	48	44	41
4.00pm	46	44	40	40

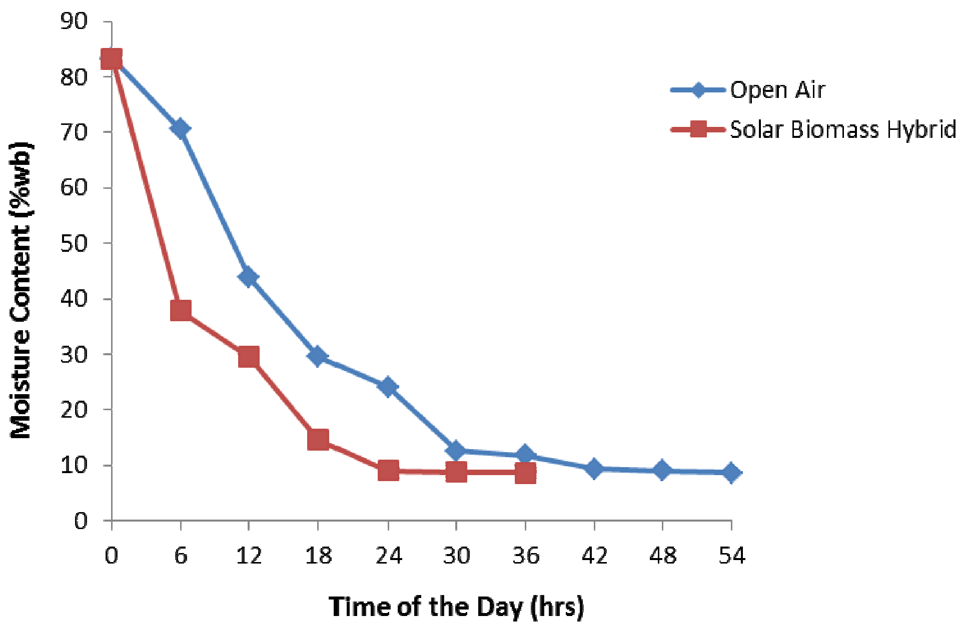

Figure 7:Variation of Moisture Content with Time for Ginger (*Zingiber officinale* Rosc.*)* during Open Air and Solar Biomass Drying.

5.3 Results of Open Sun Drying of Ginger

From table six, the maximum ambient temperature is 45°C and the minimum is 24°C. This temperature is not as high as the temperature attained when using dryer. Also average temperature is 29°C, the implication of this is that it will take more time to dry ginger to acceptable level and there may be deterioration as the drying period is being extended. There was sharp weight reduction in the first 6 h, this is as a result of high moisture content of ginger at the initial stage. From figures 5 and 6, the rate of moisture reduction of ginger drying in open sun was lower than the solar biomass. Also, from figure 7, comparison of solar-biomass and open sun moisture reduction shows that ginger dried in the dryer attain the desire moisture level before that open sun drying.

Table 6: Variation in Ambient Temperature and Relative Humidity with Time

Day	Time of the Day (hrs)	Ambient Temp. (^{0}C)	Ambient Humidity (%)
One	10am	29	20
	12noon	37	20
	2pm	37	20
	4pm	37	20
	6pm	33	20
Two	7am	32	64
	8am	22	62
	10am	33	20
	12noon	39	20
	2pm	45	20
	4pm	38	20
	6pm	35	20
Three	6am	24	63
	8am	24	55
	10am	30	21
	12noon	38	20
	2pm	42	20
	4pm	40	20
	6pm	37	20

Table 7: Weight of Ginger During Open Air Drying.

Day	Time of the Day (hrs)	Weight in grammes
One	10am	680.00
	12noon	550.47
	2pm	462.82
	4pm	370.89
	6pm	314.50
Two	7am	314.40
	8am	305.15
	10am	278.20
	12noon	201.99
	2pm	187.26
	4pm	165.69
	6pm	154.87
Three	6am	154.90
	8am	148.65
	10am	143.76
	12noon	141.80
	2pm	139.90
	4pm	135.85
	6pm	137.68
	6am	137.68

5.4 Quality Evaluation

The colour of dried ginger using hybrid, solar and open air are cream, deep yellow and light brown respectively. Volatile oil contents after drying in the hybrid dryer were 2.10%, 0.90%, 1.40% and 2.40% for peeled cylindrical, peeled rectangular, unpeeled rectangular and unpeeled cylindrical samples, respectively. It was found out that volatile oil from unpeeled was higher than the peeled; this may due to peeling process in which some of the oil might have been removed. The aroma of peeled and unpeeled solar dried ginger were very faint pungent smell and very sharp half spicy and peppery, slightly sweet smell respectively. From table 8, the aroma of peeled and unpeeled open sun dried ginger were very sharp irritating smell and sharp irritating smell respectively. Also, the aroma of peeled and unpeeled solar hybrid were very faint non- spicy, non-lemony smell dried ginger and Very sharp half spicy and peppery, half lemony and very sweet smell respectively. It was also observed that there is no much difference in quality of solar hybrid and in only solar dried products, but the quality of product was very low in open sun dried products.

The efficiency of the dryer was calculated from the ratio of energy used to evaporate the moisture in the product to the energy input to the dryer by solar and biomass or

$$\eta = \frac{WL}{IA + MC}$$

where W is the weight of the water evaporated from the product (kg), L the latent heat of evaporation of water (MJ/kg), I the insolation on the drier (MJ/m^2), A the area of front sloping glazed surface (m^2), M the mass of the biomass fuel used in the stove (kg) and C the calorific value of the biomass fuel (MJ/kg). Charcoal (1.2 kg) was burned for the drying of ginger the efficiency calculated is 13.7%.

Table 8: Aroma Variations in Samples

Sample's Nature	**Aroma**
Peeled solar dried ginger	Very faint pungent smell
Unpeeled solar dried ginger	Very sharp half spicy and peppery, slightly sweet smell
Peeled sun dried ginger during solar drying	Pungent but irritating smell
Unpeeled sun dried ginger during solar drying	Very faint spicy and lemony smell
Peeled solar-biomass dried ginger	Very faint non- spicy, non-lemony smell
Unpeeled solar-biomass dried ginger	Very sharp half spicy and peppery, half lemony and very sweet smell
Peeled sun dried ginger during solar-biomass drying	Very sharp irritating smell
Unpeeled sun dried ginger during solar-biomass drying	Sharp irritating smell

6 Conclusions

A natural convection solar biomass heating was developed for continuous drying. The performance of it was tested with ginger that was cut into cylindrical and rectangular shape. It was found that solar-biomass dryer reduced drying time by 30-40%. The percentage of oil retention for peeled and unpeeled cylindrical are 2.10% and 2.4% respectively while the percentage oil retention in peeled and unpeeled rectangular are 0.9 and 1.4 respectively. Cylindrical retains more volatile oil than rectangular shaped ginger. The quality evaluation shows that solar biomass developed maintained high quality than open sun.

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