DEVELOPMENT AND PERFORMANCE EVALUATION OF HYBRID-SOLAR DRYER FOR CASSAVA GRATE.

Abstract

A solar hybrid dryer for cassava grate was fabricated and evaluated for performance with major components such as chimney, drying chamber, solar collector, blower housing (heater and fan) unit, solar panel, aluminum frame and battery (which can be operated through solar heating system or a hybrid solar-electric heating system). Evaluation of the hybrid dryer was carried out to investigate the effect of drying temperature and variety of cassava (TMS96/1414, TMS92/0326 and TMS01/1368) on moisture loss, drying rate and drying efficiency. The dryer recorded maximum temperature of 55 °C and 45 °C in the drying chamber for hybrid and solar drying respectively which are higher than the 26 °C recorded for ambient. In all the experiments performed it took 7 hours for the moisture content of sample in the hybrid solar dryer to be reduced from average of 65 % to about 10.19 % without sacrificing quality of the dried cassava grate. For solar drying it took 13 hours to attain moisture content of 11% while open sun drying took 35 hours to reduce the moisture content to 13 %. The result showed that TMS96/0326 had the highest moisture loss (6.20 kg, 6.09 kg and 5.65kg) drying rate (0.899 kg/hr, 0.870 kg/hr and 0.807 kg/hr) for open sun, solar and hybrid drying method an indication that variety and temperature had effect on the drying process. The drying efficiency for hybrid drying was 78.71 %, 79.71 % and 73.42 % while solar drying had 47.76 %, 48.38 % and 44.53 % for TMS96/1414, TMS92/0326 and TMS01/1368 respectively; an indication that temperature, airflow rate and variety of cassava grate had significant effect on evaluated parameters hence the hybrid solar dryer is an efficient dryer for maintaining quality of dry cassava grate.

Keywords: hybrid-drying, temperature, variety, cassava-grate, evaluation.

Key contribution

- The hybrid dryer initiated a high temperature in the heating and drying chamber that was consistently maintained at 50.26 ^{o}C, in contrast to the conventional ambient temperature of 26.69 ^{o}C.
- In comparison to solar collector with an overall efficiency of 47.76%, 48.38%, and 44.53% in TMS92/1414, TMS96/0326 and TMS01/1368 respectively, the overall efficiency of the hybrid solar dryer for the varieties significantly increased to 78.71%, 79.21% and 73.42% respectively.
- An acceptable moisture level was quickly attained with the fabricated hybrid-dryer; hence could influence an increased storage stability of cassava grates.
- A varying drying performance was observed among varieties of cassava grates.

1.0 INTRODUCTION

Cassava (*Manihot esculenta*); a perennial woody shrub that produces very large tuberous roots maturity period typically greater than 9 months depending on the species (Okogbenin et al.,2006; Anyanwu and Komolafe, 2003; Ogwueche, 2000). It is the third largest source of carbohydrate in the world and Nigeria being the largest producer in the world (FAO, 2008) with about 45 million metric tonnes of cassava. High moisture of about 60% to 70% and lack of infrastructure such as motorable roads between farm and market result to rapid post-harvest physiological deterioration which normally commence within 48 to 72 hours after harvesting. The preservation of the roots has become more important to inhibit microbial activities, prolong the shelf life through methods such as drying. Drying involves the removal of moisture from food through heat transfer and surface moisture is evaporated by the heat with further movement of inner moisture to the surface which occur through addition of some sort of energy (Kilanko *et al.,* 2019).

Dryers of different specifications have been designed, fabricated and developed to dry agricultural products by many researchers and majority of these dryers were designed with complex features and some use expensive source of energy that is unrenewable energy which have not been adopted by the subsistent farmers due to the cost. Various forms of energy exist but the cheapest source of renewable energy is solar (sun). Open sun-drying is the most common method used to dry food products in most tropical and sub-tropical countries especially Nigeria (Rajkumar, 2007). It is labourous and time consuming since the food materials need to be covered at night and bad weather condition such as rain. It is expedient to develop a hybrid cassava grate dryer with low cost, simple in design and fabrication, durable, with minimal maintenance requirement (Duffie and Beckman, 2006) operating either on energy from sun-shine or electricity stored in a DC battery to power the fan and heater boosting reduction of relative humidity so as to enhance practice of on-farm processing of cassava into dry grate to increase storage life, reduce bulkiness, facilitate transportation by reducing water content to less than 15% and availability of farm land for farmers.

Comment [u1]: Revise

2.0 MATERIALS AND METHODS

2.1 Description of the hybrid solar dryer

The schematic diagram and component specifications of hybrid solar dryer used in this experiment with the parts are shown on Table 1 and Figure 1 below, which consist of drying chamber, solar collector unit, blower, heating chamber, DC battery and switch control unit. The drying chamber contains two drying trays made from stainless steel and perforated for easy in let of air. The drying trays are kept on the

Comment [u2]: Revise

aluminium frame fixed to the inner side walls of the drying chamber which can be easily removed to load or unload the drying product through the door. The trays are kept 0.1m apart from each other to ensure a uniform air circulation under and around the drying material. The outside frame of the drying chamber was made with aluminium fitted with glass because no reaction between the dryer and food material, it is strong, light, not decay able like wood and able to help conduct heat into the drying chamber. Chimney made from perforated glass covered with wire mesh to prevent contamination was made at the top of the drying chamber to blow out the humid drying air from inside the drying chamber. The heating chamber frames were fabricated from aluminum. At the front part of the heating chamber blower housing comprising of the axial fan, heater and control switch were mounted, holes were made in front of the heating chamber for proper ambient air flow convectively through the heating chamber. At the side of the dryer, a moveable stand was installed on which the solar collector was mounted. The solar panel was connected to the DC battery with solar charge control which in turn power the heater and the fan for effective drying. The blower sucked the ambient air which will be heated using heat obtained from either the heating chamber or the heater as an auxiliary heat source powered by the dc battery. A control switch was installed; which act as indicator to turn on or turn off the blower system. This enables the drying process to be controlled as desired. Thermometer was also installed to measure the temperature in the collector and drying chamber. Inside the solar collector chamber was painted black in order to ensure effective absorption of solar radiation.

Comment [u3]: Revise

Comment [u4]: Not define

Comment [u5]: Revise

Comment [u6]: Revise

Table 1: Description of the hybrid solar dryer components and specification.

s/n	Component	Specifications (mm)
1	Air inlet	750 x 360
2	Control panel (monocrystalline solar panel)	800 x 300
3	Fan housing	0 300
4	Blower Frame	660 x 340
5	Heater	12V

6	Heating chamber (Glass)	1110 x 380
7	Door	680 x 1000
8	Aluminum frame	1815 x 1560 x 480
9	Tray	765 x 727
10	Chimney coverer (wire mesh)	765 x 727
11	Solar panel	200watt
12	DC battery	12v
13	Blower	12v DC
14	On and off switch	
15	Solar wire	6mm

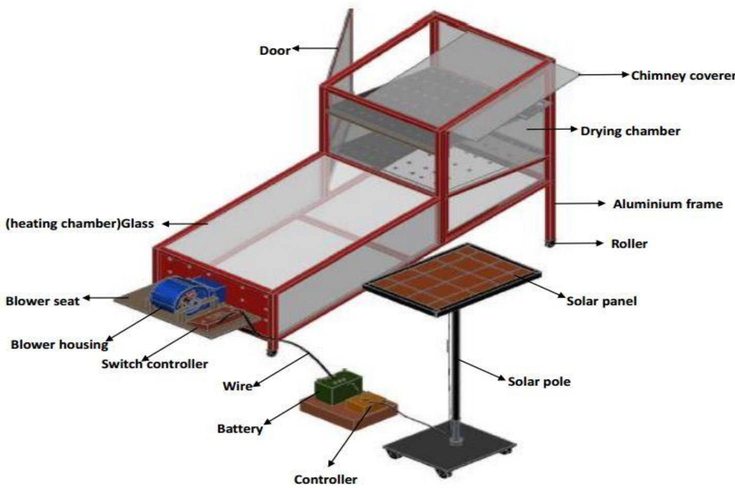

Figure 1: Schematic diagram of the hybrid solar dryer.

2.2 Heating Chamber unit

The heating chamber upper portion is covered with a transparent glass (4mm thick) which was sealed with flash band to reduce heat losses and fitted with aluminum frame. The bottom part is fitted with glass painted with black paint on it as heat storage material. Different materials are available for absorbers among which the dark materials are preferred due to their high absorbance. Black material with high absorbance and low long wave emittance are the most preferred absorber material. It is designed with an air inlet at the front point of the heating chamber. The sides were having a transparent glass cover to provide heating. Glass has a transmissivity of about 0.9 which is satisfactory.

Comment [u7]: Revise

2.3 Blower Housing unit

It consists of the axial fan and the heater powered by 12V DC battery and control switch attached to the fan. The axial fan housed in the blower housing is use to draw the atmospheric air in the chamber and to push out the heated air with a desired air velocity through a diffuser which assists in gradual release of heated air into the drying chamber. Heater was provided to heat air in the heating chamber so as to allow continuous drying process both in the day when weather is not favourable and at night to enhance maximum good quality dry cassava grate product.

Comment [u8]: Revise

2.4 Solar panel unit

It consists of the flat metal plate which intercepts and absorb solar energy connected to solar charge switch (controller) and it was in turn connected to the 12v battery with solar wire of 6mm thickness. The solar charge controller helps to prevent overcharge, improve charging quality and prevent discharge.

2.5 Drying cabinet or chamber

The drying cabinet with dimensions stated in Table 1 above consist of chimneys, trays and transparent glass (factors for consideration in selecting glass materials in this work include strength of material, durability, non-degradability when exposed to theUV ultra violet light and non-reactivity with food material). The drying cabinet frame was built from aluminum which could withstand the unfavourable weather condition. It contains chimney (an exhaust outlet) fabricated from glass with aluminum frame, positioned at the top of the chamber and it is joined with heating chamber at an incline angle to the bottom of the drying chamber which allows pre-heated air to pass through the cassava grate. Chimneys are used to generate buoyant forces on the air, thereby increasing the rate of air flow through the dryer. Perforated stainless steel was used to fabricate the trays due to high moisture and cyanide content of

Comment [u9]: Revise

Comment [u10]: Revise

cassava. The trays are kept 0.1m apart from each other to ensure a uniform air circulation under and around the drying material. The dimensions and detail design are given on Table 1, figure 1.

2.6 Design considerations

The following parameters were considered during the development of the hybrid solar dryer: 2.61 *Properties and the Quantity of the Material to be dried*: Solar drying system must be properly designed so as to meet particular drying requirement of specific products and to give optimal designed (Forson et al*.,* 2007) hence the initial and final moisture content of the cassava grate for the three different varieties were determined.

2.6.2 *Inclination of the Solar Collector*

The solar collector is always tilted and oriented in such a way that it receives maximum solar radiation during the period of experiment. Therefore, the angle of tilt for the solar collector in this research was 17.25°N. Inclination also allows easy runoff water and enhances air circulation (Bukola and Ayoola, 2008).

2.6.3 Angle of tilt of the solar collector

The angle of tilt (β) of a solar collector is given as

$$\beta = 10° + lat\Phi \qquad \text{……………………………………………………………………….. Eq. (i)}$$

where, Φ is the angle of the solar collector location (Misha *et al*., 2013).

Latitude of Akure, Ondo State (experiment location) was 7.25° N (Olajuyigbe, 2015) hence, the value of β used for the collector was

$$\beta = 10° + 7.25$$

$$\beta = 17.25°N$$

The quantity of air needed for moisture absorption in a given batch of cassava grate is estimated according to Ehiem et al. (2009); Nwajinka and Onuegbu (2014) as:

$$Q_a = \frac{M_R H_L}{C_a \rho_a (T_f - T_i)} \qquad \text{..............................Eq. (ii)}$$

Where;

Qa = quantity of air needed

MR = quantity of moisture to be removed (kg)

HL = latent heat of vaporization (2499.94 kJ/kg)

Ca = specific heat capacity of sample (3.68 kJ/kg^{o}C)

Comment [u11]: Revise

ρa = density of drying air (1.28 Kg/m^3)

Ti and Tf = 28.6 ^{o}C and 60 ^{o}C (initial and final temperatures of the drying air).

2.7 Working principle and testing

The developed hybrid solar dryer was placed in an open space in the farm where there was no tree and plant shadow to enhance maximum solar collection. During the day the solar collector absorb solar irradiance from the sun and transmit to the drying chamber with the aid of fan by forced convection while moist air from the grate is removed through the chimney. When the ambient temperature is low or when it rained, the thermostat switched is switched on to enhance generation of heat by the heater for continuous or complete drying process of the cassava grate. The solar irradiance collected by the solar panel mounted on a moveable pole is converted to electric current which is stored in the battery as back-up to power the heating coil, fan and control system. When the battery is not charged due to bad weather electricity can be used to power the dryer using an alternator. Drying chamber, collector, ambient temperature and relative humidity were measured concurrently.

Figure 2: Experimental set-up showing cassava grates drying process.

2.8 Experimental procedure

Drying experiments as shown in Figure 2 was conducted for three different cassava varieties (TMS96/1414, TMS92/0326 and TMS01/1368) in July 2022 during the rainy season at FUTA farm Obanla, Federal University of Technology Akure, Ondo State, Nigeria. Latitude of the experiment location was 7.25° N (Olajuyigbe, 2015) hence tilt of 17.25° was used for the collector. The air velocity of the fan was set by switching on the fan speed to the desired speed. The material used (TMS96/1414, TMS92/0326 and TMS01/1368) in this experiment was wet cassava grate obtained from FUTA farm. The initial moisture content determination was done according to the AOAC (2000). 50kg of freshly harvested 12 months' cassava root was using electronic weighing balance having accuracy of 0.01 kg (Platinum-A110C), peeled manually, washed and milled using the fabricated cassava grater powered by 5HP fuel engine, 5in pulley. Initial moisture content of the cassava varieties was 65.85 %, 66.59 % and 62.08% wet basis respectively. 10 kg of the grated cassava per batch was weighed using digital weighing balance and spread on the trays thinly with constant air flow rate of 0.15 m/s. Heated air temperature in the

Comment [u12]: Revise

heating chamber and drying cabinet were taken with the aid of thermometer (AISI 304/1.4301) with accuracy of ±2 °C. The entire procedure was carried out for the three varieties separately. 10 kg of cassava was also dried using open sun drying, this was done for the three varieties of cassava grate separately. The data generated was used to determine the performance of the hybrid solar dryer.

2.9 Performance Evaluation of hybrid solar dryer

The performance evaluation of the hybrid solar dryer was determine using the following; moisture content, amount of moisture removed, the drying rate and the drying efficiency.

2.9.1 Moisture content

The moisture content of the cassava grate on wet basis was determined according to Bennamoun (2012) for the three varieties (TMS96/1414, TMS92/0326 and TMS01/1368) as stated below:

$$M_c = \frac{m_i - m_f}{m_i} X\, 100 \quad \text{....................... Eq. (iii)}$$

2.9.2 Moisture removed from cassava grate

The amount of moisture removed from TMS96/1414, TMS92/0326 and TMS01/1368 cassava grate respectively was calculated according to Ehiem *et al. (*2009) as:

$$M_w = M_p \frac{(m_i - m_f)}{(1 - m_f)} \quad \text{................................ Eq. (iv)}$$

where;

Mc = initial water content in the cassava grate,

Mw = mass of water evaporated from cassava grate in kg,

M_p (kg) = initial mass of the cassava grate to be dried which for this design was 10 kg of cassava mash since it is a prototype dryer, and

m_i and m_f = initial moisture content and final moisture content respectively.

2.9.3 Average drying rate

The equation is given by the equation below according to Aliyu *et al.* (2013) and Debashree *et al*. (2022)

$$m_{dr} = \frac{m_w}{t_d} \quad \text{……………………………………Eq. (v)}$$

where, m_{dr} = drying rate,

m_w = mass of water present in the cassava grate, and

t_d = time taken for drying process.

2.9.4 Drying efficiency (η)

It is defined as the ratio of energy required to evaporate moisture from the food products by heated air.

The equation as reported by Gatea (2011) and Brenndorfer et al. (1987) is given as:

$$\eta SC = \frac{M_w x \Delta Hl}{AcxIc} \quad \text{………………………………Eq (vi (a))}$$

$$\eta h = \frac{M_w \ x \ \Delta Hl}{I \ x \ V} \quad \text{….. …………………………..Eq. (vi(b))}$$

Where;

ηSC = efficiency of solar collector

M_w = Moisture removed (Kg),

$\Delta HlorL$ = latent heat of vaporization of water (2499 KJ/Kg),

Ic = total radiation incident on the absorber surface isolation upon collector (903.22w/m^2),

Ac = area of collector (0.56m^2),

ηh = efficiency of heater

I = current, and

V = voltage.

3.0 Results

Table 2: Computation of moisture loss, drying rates and drying efficiency.

Variety	Moisture loss (kg)			Drying Rate (kg/h)			Drying efficiency (%)	
	Hybrid drying	Solar drying	Open sun drying	Hybrid drying	Solar drying	Open sun drying	Hybrid	Solar
TMS96/1414	6.20[c]	6.01[b]	5.58[a]	0.89[a]	0.86[b]	0.80a	78.71[b]	47.76[a]
TMS92/0326	6.28[c]	6.09[b]	5.65[a]	0.90[a]	0.87[b]	0.81[a]	79.71[b]	48.38[a]
TMS01/1368	5.78[c]	5.57[b]	5.08[a]	0.83[a]	0.80[b]	0.73[a]	73.42[b]	44.53[a]

Means in the same row with different superscript are significantly different ($P<0.05$). Key: TMS96/1414 = creamlike white cassava grate, TMS92/0326 = white cassava root grate, TMS01/1368 = yellow cassava grate.

Table 2 above show the result for performance evaluation of hybrid solar dryer. Moisture loss, drying rate and drying efficiency hybrid, solar and sun drying for three varieties of cassava (TMS92/0326, TMS96/1414 and TMS01/1368) root experimented as affected by cassava variety and drying method where shown. The moisture content obtained at different drying time for the cassava varieties (TMS96/1414, TMS92/0326 and TMS01/1368) when subjected to open sun drying, hybrid drying and solar drying respectively are reported on Figure 3a, 3b and 3c. The effect of time on relative humidity for ambient air, solar and hybrid are displayed on Figure 4a while Figure 4b recorded the temperature difference between open sun, solar and heater at different time during the experiment.

Comment [u13]: Revise

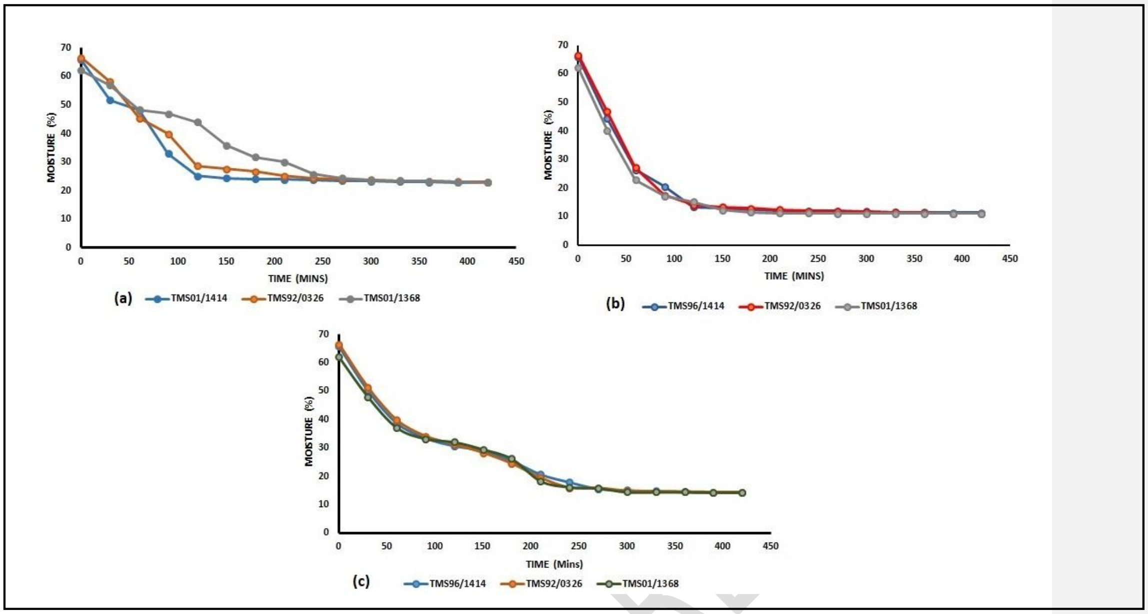

Figure 3: Moisture content of cassava varieties at varied time at different drying methods

(a) moisture content at varied time using open sun drying, (b) moisture content at varied time for hybrid drying, (c) moisture content at varied time for solar drying. Key: TMS96/1414 = creamlike white cassava grate, TMS92/0326 = white cassava root grate, TMS01/1368 = yellow cassava grate.

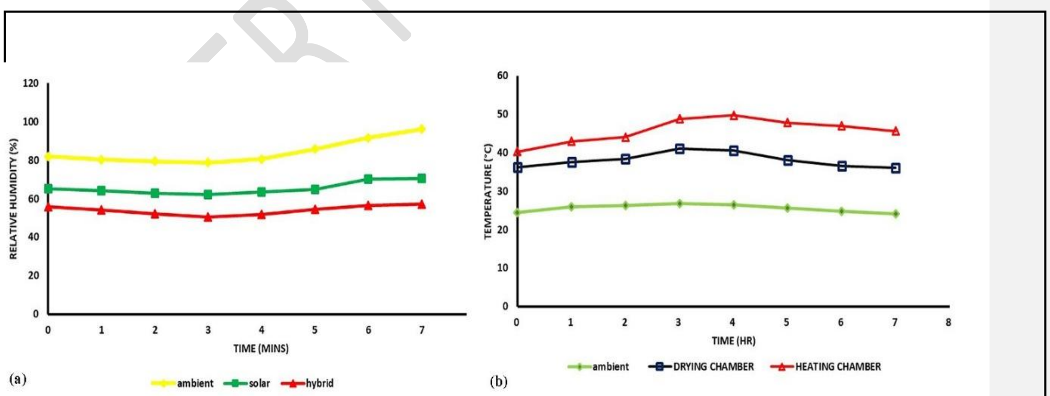

Figure 4: Effect of relative humidity and temperature on drying time

(a) Effect of relative humidity on drying time, (b) effect of drying temperature on time.

Key: Ambient = relative humidity of surrounding and temperature of drying in the open sun; solar – relative humidity using solar as source of drying; hybrid = relative humidity of drying using hybrid as source of drying; Drying chamber = temperature obtained in the drying section and heating chamber = temperature generated using heater.

4 Discussion

4.1 Effect of variety and drying time on moisture loss.

The moisture loss for TMS96/1414, TMS96/0326 and TMS01/1368 was 6.20 kg, 6.28kg and 5.78 kg for hybrid drying; 6.01 kg. 6.09kg and 5.57 kg for solar drying while open sun drying had 5.58 kg, 5.65 kg and 5.08 kg respectively. The result showed that the rate of moisture loss is affected by the drying method irrespective of the variety being used. Hybrid drying had the highest value for moisture removal for the three variety of cassava grate this may be due to the high temperature and low relative humidity as a result of the constant heat supply from the heater while the open sun drying had the lowest moisture loss. It was observed that variety have effect on the moisture removal from the sample; this might be due to the fact that cassava variety differs in moisture content and their inherent properties (their gene differs). As the drying time increases the rate of moisture content decreases as shown on Figure 3 (a, b, c), this may be due to the presence of bond water. This indicate that hybrid solar dryer aid the movement of moist air from the sample hence speeding up the rate of drying. It was observed that drying for the three variety is affected by the temperature in the solar collector with time as the rate of moisture loss almost double between 12noon and 1pm when the temperature was highest and relative humidity low compare to the loss that occurred between 10am-12noon and 1pm - 4pm; hence temperature obtained in the solar collector is majorly affected by solar radiation and weather conditions such as the relative humidity.

Comment [u14]: Revise

4.2 Effect of drying time on the drying rate.

The drying rate result for the three varieties of cassava and the three methods of drying applied for TMS96/1414, TMS92/0326 and TMS01/1368 are displayed on Table2above with initial starting weight of 10kg as 0.89kg/h, 0.90 kg/h and 0.83 kg/h using hybrid. The solar drying method drying rate were 0.86

kg/h, 0.87kg/h and 0.80 kg/h respectively while 0.80 kg/h, 0.81 Kg/h and 0. 73kg/h for open sun drying. The result showed that hybrid drying had the fastest rate of drying compare to solar drying and the open sun drying which had the lowest value for drying rate. The sharp variation between the open sun drying and the other two methods may be as a result of no means of storing the heat generated in the open drying. Aremu et al. (2020) also recorded highest drying rate using hybrid dryer for drying yam. The result indicates that the hybrid dryer exhibits sufficient ability to dry cassava grate at a reasonably rapid rate. It was also noted that variety had influence on the drying rate; TMS92/0326 had the fastest drying rate irrespective of the method of drying employed This characteristic behaviour is due to various forms in which water is present in food products. Hybrid drying rate was higher than result gotten from open sun drying. This is due to the fact that heat can be conserved using hybrid drying method when compare to the other process. Physical observation of the cassava grate from the TMS96/1414, TMS92/0326 and TMS01/1368 dried using the hybrid solar dryer showed that their colour was retained with slight change in TMS01/1368 while the samples from TMS96/1414, TMS92/0326 and TMS01/1368 dried using open sun drying process indicated colour change from white to brownish-white for TMS96/1414 and TMS92/0326 while the cassava grate from TMS01/1368 changed from yellow to brownish-yellow. The change in colour was attributed to non-uniform temperature distribution arising from surface interaction in the open environment, variation in solar intensity, dust particles and dirt that blows across the samples during the open sun drying. Also some signs of contamination and smell was also noticed, indicating that the cassava grate is gradually attaining deterioration and eventual decay. This is possibly due to infection from flies and other vectors that perch on the grate since it was exposed to the open environment also the longer hours it took to attain the final moisture content.

Comment [u15]: Revise

4.3 Efficiency of drying as affected by solar collector and heater.

Efficiency of TMS96/1414, TMS92/0326 and TMS01/1368 were 78.71%, 79.21% and 73.42% respectively for hybrid. 47.76%, 48.38% and 44.53% for solar collector. Efficiency for the hybrid and solar collector drying were affected by the variety of the cassava grate. This may be due to the fact that the moisture loss in the variety of cassava grate used varied. The efficiency of the solar collector was low compare to the hybrid this may be due to the fact that solar drying depends majorly on irradiation and time also season of the drying. The result gotten in this study for hybrid was the highest for the three varieties of cassava grate used for the experiment. The efficiency of drying was highest for TMS92/0326 both for solar and hybrid. Hybrid had the largest value this may be due to the fact that the temperature for drying was higher and consistent in hybrid compare to solar that depend on irradiance which is explained by Figure 4a. The result gotten in this study for hybrid was higher than the one gotten by Aremu et al. (2020) for yam chips. The result for solar drying efficiency was lower compare to that reported by Muhammadu and Abraham (2012) (52%) for cassava chips but higher than the value (29%) reported by Ahmad *et al* (2013) this may be due to the season the experiment was carried conducted.

Comment [u16]: Revise

4.4 Effect of relative humidity on drying method

The relative humidity affected by time for the three methods employed for drying is shown on Figure 4b. Open sun drying that is ambient temperature had the highest relative humidity which continue to increase as the drying time increases. The relative humidity for the hybrid drying was the lowest while ambient relative humidity was the highest throughout the drying period which enhanced the drying process resulting to quality product.

Comment [u17]: Revise

4.5 Effect of Drying Time on Moisture content

Effect of time on the moisture content of three varieties of cassava as affected by drying method is shown in Figure 3a, 3b and 3c. Decrease in moisture content for the three varieties of cassava with respect to the drying method was observed to decrease rapidly during the initial stage which can be attributed to the excess moisture on the surface of the cassava in both sun, solar and hybrid drying conditions. The moisture loss decreased as time progressed especially the hybrid drying which attained finally moisture content of 10.19% after 7 hours of drying while solar drying attained 14.37% and open sun drying obtained 22.37%.As the drying of the cassava grate continues, the moisture content substantially reduced hence, the more the quantity of moisture removed; the higher the quantity of energy required for further drying as the samples approaches equilibrium moisture content. That is, more energy is needed to remove moisture as the moisture content approaches the equilibrium moisture content as indicated in the figures (5 and 6). In all the experiments performed it took 7 hours for the moisture content in the hybrid solar dryer to be reduced from 65% to about 10.19 %. For solar drying it took 13 hours to attain moisture content of 11% while sun drying took 35 hours to reduce the moisture content from 65% to below 13%. This revealed that the hybrid solar dryer reduced drying time by over 50% irrespective of the cassava variety. This is further supported with the drying efficiency of over 75%. Higher rate of moisture removal was observed at initial stage of drying than in the later stages. Diffusion mechanisms majorly controls the drying process of cassava. Higher drying temperature resulted to faster moisture reduction, this is due to less humid in the drying air in the hybrid dryer, making it easier to remove more water from the cassava grate during the drying process.(Tunde-Akintunde and Afon, 2009; Akanbi et al., 2006; Mujumdar and Tsotsas, 2011).

Comment [u18]: Revise

Comment [u19]: Revise

Comment [u20]: Revise

4.7 Effect of drying time on the Temperature

The maximum temperature of 26.69^{o}C and minimum temperature of 24.69^{o}C was recorded for open sun drying. The highest temperature in the heating chamber for solar drying was 45.56^{o}C and the lowest was 40.24 ^{o}C and hybrid recorded 55^{o}C and 50.46 ^{o}C. the highest temperature in the drying chamber was 39.01 ^{o}C and lowest was 36.18 ^{o}C using solar drying. 50.26 ^{o}C was recorded as highest and 42.86 ^{o}C as the lowest for hybrid as shown on Figure 4b. The drying rate and moisture content decreased continuously with drying time. Higher rate of moisture removal was observed at initial stage of drying than in the later stages. This characteristic behaviour is due to various forms in which water is present in food products. It was observed that the temperature in the heating and drying chamber increases for the hybrid drying process compare to the ambient temperature. Temperature difference of 18.87 ^{o}C for solar drying and

Comment [u21]: Revise

28.31 °C for hybrid drying was observed which was higher than the ambient temperature throughout the drying experiments. During the drying process, the maximum (peak) temperature in the heating chamber and drying chamber was highest during the day between 12:00 pm and 1:30 pm for the solar drying. The peak for solar drying was around 1:30 pm and temperature continues to drop in the solar collector an indication that solar drying depends on solar radiation and weather conditions. The final weight of the sample in the dryer was lower than the weight of sample from the open sun drying. As the time increases the temperature of the drying chamber was not greatly affected compare to open sun drying; hence the higher the drying temperature in the solar and hybrid drying chamber, moisture reduction becomes faster due to the fact that the drying air is less humid. This makes it easier to take more water from the cassava grate from the three varieties during the drying process resulting to lesser drying time used compared to the open sun drying.

5. Conclusion

Cassava grate hybrid solar dryer fabricated performance was evaluated in this study. The following were concluded from the result:

- The hybrid dryer maintained consistent high temperature in the heating and drying chamber. The drying chamber temperature was about 50.26°C, whereas the ambient temperature was 26.69°C.
- The drying rate was highest in the hybrid solar dryer as compared to solar and open sun drying process for the three varieties of cassava experimented.
- The overall efficiency of the hybrid solar dryer during the experimental period was found to be 78.71%, 79.21% and 73.42% for TMS01/1414, TMS96/0326 and TMS01/1368 respectively for hybrid while 47.76%, 48.38% and 44.53% for solar collector. This indicate that fabricated hybrid dryer can dry cassava grate quickly to a safe moisture level and also ensures a better quality of the dried grate.

Comment [u22]:

- The result also depict that variety has effect on the drying performance of the dryer as displayed by the varied moisture content attained.

References

Comment [u23]: Change to fullstop

Akanbi, W. B., Oyediran., G. O., Olaniran, O. A., Adeyeye, S. A., Akande, M. O., Adediran, J. A. (2006): Effects of organic and inorganic fertilizers and their combination on Growth, Nutrient uptake and shoot yield of Celosia (Celosia argentea L.). Science Focus 11 (1) 84 – 90.

Ahmad, F., Mohd, H. R., Mohd, Y. O., Kamaruzzaman, S. (2013): Energy Consumption of Hybrid Solar Drying System (HSDS) with Rotating Rack for Salted Silver Jewfish. *Latest Trends in Renewable Energy and Environmental Informatics,* 294-298. ISBN: 978-1-61804-175-3.

Aliyu, B., Kabri, H. U., Pembi, P. D. (2013): Performance evaluation of a village-level solar dryer for tomato under Savanna Climate: Yola, Northeastern Nigeria, *Journal of Agricul. Eng. Int.: CIGR Journal,* 15(1),181 – 186.

Anyanwu, C. O., Komolafe, B. T. (2003):Agricultural Science for Schools and Colleges. Longman Publishers.

AOAC. (2000): Official Methods of Analysis of AOAC International. 17th ed. USA: AOAC International, Md.

Aremu, O. A., Odepidan, K.O., Adejuwon, S.O., Ajala, A.L. (2020): Design, Fabrication and Performance Evaluation of Hybrid Solar Dryer. *International Journal of Research and Innovation in Applied Sc.* 5(3),159-164. ISSN 2454-6194.

Bennamoun, L. (2012): An Overview on Application of Exergy and Energy for Determination of Solar Drying Efficiency, *Int. J. of Energy Eng.* 2(5), 184 – 194.

Brenndorfer, B., Kennedy, L., Oswin- Bateman, C.O., Trim D.S., Mrema, G.C., Wereko-Brobby, C. (1987):" Solar dryers; their role in post-harvest processing." Commonwealth Science Council, Commonwealth Secretariat, Marlborough House.

Bukola, O. B., Ayoola P. O. (2008): Performance Evaluation of a Mixed-mode Solar Dryer. Technical Report, *AU J.T.* 11(4),225-231.

Debashree, D. B., Mohanty1, R.C. Mohanty1, A.M., Shiv, S.D., Bijaya, B. N. (2022): Performance evaluation of the Absorbing Plate of a Hybrid Solar Dryer for Potato Drying. *IOP Conference Series: Earth Environmental Sci.* 1084(01),1-8. doi:10.1088/1755-1315/1084/1/012011.

Duffie, J.A., Beckman, W.A. (2006): "Solar Engineering of Thermal processes"3rd ed by Wiley Inter Science, New York, pp: 9-11. ISBN:9780471698678.

Ehiem, J.C., Irtwange, S.V., Obetta, S.E. (2009): Design and development of an industrial fruit and vegetable dryer. *Res. J. Appl. Sci. Eng. and Technol.* 1(2),44 –53.

FAO (2008). Corporate Document Repository. [Online]. The impact of HIV/AIDS on the agricultural sector.://www.fao.org/DOCREP/005/Y4636E/y4636e05.htm.

Forson F.K, Nazha M.A.A, Akuffo, F.O., Rajakaruna, H. (2007): Design of mixed mode natural convection solar crop dryers: Application of Principles and rule of thumb. *Renewable Energy,* 32, 1-14.

Gatea, A.A. (2011): Performance evaluation of a mixed-mode solar dryer for evaporating moisture in beans*. J. Agricul. Biotech. Sustainable Dev.* 3(4),65–71.

Misha, S., Mat, S., Ruslan, M.H., Sopian, K., and Salleh, E. (2013): Review on the Application of Tray Dryer

System for Agricultural Products. *World Appl. Sci. J.* 22 (3), 424-433
Muhammadu M. M. and Abraham, A. E. (2012): Design, fabrication and testing of solar dryer for drying cassava chip. *Res.* 4(11),59-69. ISSN: 1553-9865.
Mujumdar, A. S., Tsotsas, E. (2011): *Modern drying technology, volume 4: Energy savings* (Wiley-VCH, Weinheim).
Nwajinka, C.O., Onuegbu, C.U. (2014): Development of a solar cabinet dryer for root crops chips in Nigeria. *J. Agricul. Eng. Techno,* 22(2),47 – 58.
Ogwueche, N.I. (2000): Essential Agriculture for West African Schools and Colleges. Rejoint Communication Services Ltd.
Okogbenin, E., Egesi, C., Fregene, M. (2006): Marker Aided Introgression of CMD Resistance in Latin American Germplasm for the broadening of the Genetic base of cassava in Nigeria. NRCRI, Umudike Annual Report. 2-6.
Olajuyigbe, A.E., Adegboyega, S.A., Olalekan, O.A. (2015): Assessment of urban land use and environmental sensitive area degradation in Akure, Nigeria using remote sensing and GIS techniques, *European Sci. J.* 11(29),318- 339. ISSN: 1857-7431.
Rajkumar, P. (2007): *Comparative Performance of Solar Cabinet, Vacuum Assisted Solar and Open Sun Drying Methods.* (Unpublished) Thesis, Department of Bioresource Engineering, Mc Gill University, Montreal Canada.
Tunde-Akintunde and Afon (2009): Modelling of hot air drying of pretreated cassava chips. Agricultural Engineering International. Manuscript 1493 volume. Pp1-7.