Journal of Engineering Research Innovation and Scientific Development
2(2): 8-16 2024, https://doi.org/10.61448/jerisd22242
Print ISSN 2971-6594 Online ISSN 2971-6608
www.jerisddelsu.com

Experimental Investigation of the Drying Characteristics of Tapioca Under Solar Drying Condition

N.E. Emehute[1], E.M. Amagre[2], K. Owebor[3*], J.I. Oboh[4], S.O. Oweh[5]

[1]Department of Mechanical Engineering, University of Port Harcourt, Port Harcourt, Nigeria
[2,3,4,5]Department of Mechanical Engineering, Delta State University, Abraka, Nigeria

*Corresponding author: kowebor@delsu.edu.ng (K. Owebor)

Article History
Received: 25-01-24
Revised: 30-04-24
Accepted: 07-05-24
Published: 30-05-24

ABSTRACT
Agricultural products are subjected to one form of processing or the other, to either improve the shelf life of the products, or as a necessary condition before consumption. Solar drying is one method that helps to increase the shelf life of agricultural products. In this study, an experimental investigation of the drying characteristics of cassava chips popularly called tapioca was carried out for the purpose of improved shelf life and hygiene, under solar drying conditions in the month of December, 2023. An analysis of key parameters was conducted on the experimental data and post-processed in the Microsoft Excel environment. The results suggested that the moisture removal rate of tapioca was 0.2183 % to 6.3829% on dry mass basis, with cumulative drying time of 27hours in three days. The maximum and minimum energy values during the drying period were 15485.14kJ and 9.6243kJ, respectively. Thus, the average value obtained for solar collector efficiency varied from 6.99 % to 16.89 %. The study also established that the colour and texture of the tapioca under the drying conditions could be retained.

Keywords: Solar drying; drying characteristics; moisture removal rate; tapioca; drying time; agricultural product

1. Introduction

Agricultural produces require some form of processing so as to preserve them or before they are finally consumed. One of such processes is drying. Drying involves the removal of moisture from the produce so as to increase the shelf life, decrease microbial activities and improve the quality of the product. Sundrying is one of the popular and oldest method that has been applied for the drying of agricultural produce (Murugan & Saji Raveendran, 2021; Omonegho et al., 2023; Simo-Tagne et al., 2021). However, direct sundrying exposes the produce to insect contamination and dust. Other challenges associated with sun drying include fluctuation in weather condition, and longer drying time, among other factors. These challenges have led to technological advances in drying methods which includes the use of mechanically driven dryers, biomass gasifier and solar dryer. The latter demonstrates economical advantage and ease of controlling the drying temperature (Murugan & Saji Raveendran, 2021; Ndukwu et al., 2020; Njue & Wawire, 2021; Omonegho et al., 2023; Simo-Tagne et al., 2021; Suherman, Susanto, & Zardani, 2020).

Solar dryers have become very efficient in processing agro-based produces either for consumption or for industrial applications. Basically, there are four types of solar dryers, which include direct solar dryers, indirect solar dryers, mix-mode solar dryers and hybrid solar dryers (Naing & Soe, 2021; Obayopo & Alonge, 2018; Yahya Dasin et al., 2015). These solar dryers have found use in both industrial and agricultural applications. Numerous studies have been carried out on the drying of different agricultural produce such as vegetables, fruits, fish, meats, cereals, tobacco, pegaga leaf, cashew nut in shell, chilly, green peas, rosella flower, cocoa, cassava flour and chips and many aromatic plants (Huddar et al., 2022; I & I, 2022; Iwe et al., 2018; Komolafe et al., 2021; Murugan & Saji Raveendran, 2021; Naing & Soe, 2021; Ndukwu et al., 2020; Obayopo & Alonge, 2018; Tyona & Ojiya, 2020; Yahya Dasin et al., 2015). In Atalay (2019), the performance analysis of a solar dryer integrated with the packed bed thermal energy storage (TES) system was used to evaluate the storage potential of orange slices in Turkey. The experiment was conducted at sunshine and off-sunshine hours. It was proposed that the moisture content could be reduced from 93.5% to 10.28% during sunshine hours or 10.78% during off-sunshine hours. The total useful energy were 89.892 MJ and 88.11 MJ, respectively, while the exergy efficiency obtained ranged from 50.18 to 66.58% (Atalay, 2019). Similarly, the comparative analysis of the performance of cabinet solar dryer and open sun drying for 1kg of banana slices was carried out in Myanmar by Naing & Soe (2021). A duration of 14 hrs was used and the moisture content obtained were 14% and 40% for cabinet Solar dryer and open sun drying respectively. Huddar & Kamoji (2019)performed an experimental investigation on the performance of solar dryer on the drying of cashew kernel in Udupi India. The study reported efficiency of the solar dryer chamber was 51.7% with an average drying rate of 0.158 kg/h. The specific energy consumption of 12.42 kWh/kg and moisture content removal of 1.27 kg (5.26%) were reported. However, total reduction in moisture content was 41.2%. Huddar et al. (2022) did a comparative analysis and modelling using response surface methodology and artificial neutral network to determine the thermal performance of solar dryer for cashew kernel and found that the natural and forced convection solar dryer speeds were 1.0kg/h and 1.66kg/h, respectively, with thermal efficiency of 51.7% and 50.9%, for natural and forced convection, respectively.

Yahya Dasin et al. (2015) carried out an experimental comparison of the performance of solar dryer and open air sun drying on yam, tomato, pepper and fish in Yala, Nigeria. The performance evaluation results suggested that it took 3 hrs to dry 0.6kg of yam with moisture content of 58.3% on wet basis, in the solar dryer. For tomatoes and pepper with moisture content of 93.3% on wet basis and mass of 0.3kg, it took 2.5 hours to dry in the solar dryer, while, it took 10hrs to dry fish with mass of 0.25kg and moisture content of 68% on wet basis, in the solar dryer. In open air sun drying, it took 8 hrs to dry same mass of yam that was subjected to the same global solar radiation, 6hrs for tomato and pepper and 24hrs for fish under similar conditions. The thermal efficiency of the proposed solar collector was found to be 60% (Yahya Dasin et al., 2015). Kolawole et al. (2018) designed and constructed a solar dryer using local materials. Kolawole et al. (2018) evaluated the performance and economics of groundnut preservation using the solar dryer. The test results suggested that the optimum temperature of the solar dryer was 59oC, corresponding to an ambient temperature of 31oC, while the relative humidity of the dryer was 48.05%.

Thermodynamic analysis of a forced convective solar dryer integrated with black coated firebrick sensible thermal storage material (STSM) for drying cocoa in Nigeria was investigated by Komolafe et al. (2021). It was found that the maximum energy utilization of the drying chamber were 0.739 and 0.724 kJ/kg, respectively, during the first and second day. Furthermore, the energy utilization decreased with the increase in time of the day, from 12:00 to 18:00 hrs. The maximum energy efficiencies obtained for day 1 and day 2 at 10:00 hr were 28.0 and 58.2%, respectively. The exergetic efficiency during the first day varied between 1.52 and 65.81%, while it varied between 1.82 and 53.30% during the second day (Komolafe et al., 2021). In their work, Adeyemi et al., (2020),an evaluation of intermittent solar drying with the effect of seasonal variation on the quality of dried cocoa beans was carried out. Adeyemi et al. (2020) revealed that the moisture content could be reduced to 7% for a duration of 62hrs of intermittent solar drying, nonetheless, higher drying rate was recorded at dry season.

A passive indirect mode solar dryer using natural convection was designed, constructed and tested with meat and fish in Modibbo Adama University of Technology, Yola – Nigeria (Dasin et al., 2019). Fish and meat each weighing 0.5kg were dried using the solar dryer. It was proposed that the temperature of the dryer increases with increase in time, with maximum temperature recorded at 420oC at 2.00pm local time. The weight of the samples reduced were 0.029 kg and 0.019 kg at an average drying rate of 0.032 kg/hr and 0.040 kg/hr for meat and fish, respectively, at an average solar radiation of 521W/m2 and average relative humidity of 26.4%. The drying efficiency was obtained as 27%.Obayopo & Alonge (2018) investigate the drying characteristics of two species of fish, catfish and tilapia, in the tropics using a direct solar dryer. The drying process was carried out during the dry and wet season under natural and forced convective (1.5 m/s, 2.5 m/s, 3.5 m/s fan speed) drying conditions. The results obtained showed that the drying air attained by the dryer was satisfactory and the maximum temperature difference between the dryer and the ambient temperatures was 35oC. The moisture content of the dried samples were 13.97% and 13.35% for catfish and tilapia, respectively, during dry season, and 15.68% and 14.9%, respectively, for catfish and tilapia during the wet season. Maximum drying efficiency of 74.3% was recorded for the dryer during dry season and the dried samples at 3.5 m/s fan speed were observed to have better drying rates. Tyona & Ojiya (2020) designed a solar dryer to determine the drying characteristics of fish in Makurdi, Nigeria. The results revealed that average daily moisture loss from the fish was high, especially during dry season which was attributed to the high dryer temperatures and decrease in atmospheric humidity, with efficiency of the solar dryer estimated to be 76 % and the moisture content reduced from 87 % to 13 %.

A hybrid solar dryer was designed and fabricated by Omonegho et al., 2023 and used to evaluate the effect of drying temperature on three varieties of cassava (TMS96/1414, TMS92/0326 and TMS01/1368), moisture loss, drying rate and drying efficiency. The dryer recorded maximum temperature of 55oC and 45oC in the drying chamber for hybrid and stand-alone solar drying, respectively, which are higher than the 26ºC recorded for ambient temperature. The result showed that TMS96/0326 had the highest moisture loss (6.20 kg/kg, 6.09 kg/kg and 5.65kg/kg), drying rate (0.899 kg/hr, 0.870 kg/hr and 0.807 kg/hr) for open sun, solar and hybrid drying, respectively. This confirmed that cassava variety and temperature had effect on the drying performances. 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. Njue & Wawire (2021) perform an evaluation on a cassava solar dryer in Busia County and observed that traditional drying method is 7 days lower than solar dryer for every 4.6kg of wet cassava chips.

While the literature has suggested the different applications of solar drying of agricultural produce, including cassava, no single study has investigated the drying characteristics of tapioca, one of the food products of cassava processing. Tapioca is listed among the major foods that are consumed by the native peoples of Ijaw ethnic nationality in Nigeria. Tapioca is normally eaten with dried or smoked fish. While sun drying can be used in processing tapioca, the high moisture removal for the production of tapioca may contribute to frustration and a longer processing time. Additionally, hygiene improvement is another key factor. This study therefore attempts to use solar dryer for the processing of cassava into tapioca. In doing this, the drying performance, moisture removing rates, and other drying characteristics of tapioca at different drying time intervals as well as the effect of drying on nutritive quality of tapioca was carried out.

2. Materials and Methods

2.1 Experimental Set-up

An experimental study was carried out on the drying characteristics of tapioca by the use of indirect solar dryer. The solar dryer comprises of two parts namely, the drying chamber and the solar flat plate collector. The Solar collector unit was made of galvanized iron coated with black paint to absorb solar irradiation on the absorber plate and to heat up inlet air into the drying chamber (Senthil et al., 2021). A transparent glass sheet of thickness 0.5 cm was placed over the coated iron collector to accomplish heating and enhance glazing efforts by minimizing the thermal losses, dust particles, rain and other unwanted material which could impact negatively on the collector plate, thereby reducing the heated air temperature. The solar collector absorber plate unit (1.04 m by 0.95 m) and drying chamber which can hold up to 1kg of the sample, were thermally insulated with wool to reduce the thermal losses. Air via natural flow, was passed through the two ventilation openings, under the solar collector plate and heated up before reaching the drying chamber. The purpose for the solar collectors was to obtain higher drying rate and allow for adequate air flow into the drying chamber during the drying process. In order to avoid contamination of the products by insects during drying, healthy mosquito nets were installed at the air entrance.

A digital scale was installed on a transparent glass on the side of the solar dryer as shown in Figure 2, thus eliminating the challenge of opening and closing the door of the solar dryer which could contribute to energy loss during drying. During drying carried out from 9am-6pm, the door was made air tight to reduce thermal losses. To allow for proper air circulation in the drying bin, the bin was made of a rectangular wire mesh tray which holds the products of 1kg. The chimney was insulated to prevent heat loss and also elevated to improve airflow and increase buoyancy.

An electronic weighing balance (Model A120, capacity 6kg, least count of 0.1g) was used to measure 1.0 kg of the sample product which were evenly distributed on the rectangular wire mesh tray. The temperature of drying air was measured using a resistance thermocouple thermometer (Model: 4-Channel K-Type Digital °C/°F/K unit conversion) and recorded as T_1,T_2,T_3 and T_4. T_1 and T_2 are the temperature of drying air at solar collector and absorber plate, respectively, $T_3$is the temperature of the sample (Tapioca) inside the solar dryer and T_4is the ambient air temperature. A digital hygrometer thermo pro Tp60 remote sensor (model No. TPR-60, 433mHz wireless) was located just above the product surface to monitor indoor/outdoor humidity and temperature. A digital infrared thermometer (model: TIR 8828,-50.0 to 1000°C; emissivity e=0.95) was used to measure heat radiation intensity during drying time,with interval of 1hr. The two solar collector absorber plates were scanned during the time of drying and the thermal radiation was calculated by applying the Stefan Bottzmann Law. A digital laser distance meter MV power (model: class II Laser product, P=1mw,° =6.35nm, battery: 2 x 1.5V AAA, least measured from 0.05m - 40m) was used to measure the area of solar collector, height of solar dryer and other parts of the solar dryer. Figures 1 and 2 show the schematic and pictorial view of the indirect solar dryer.

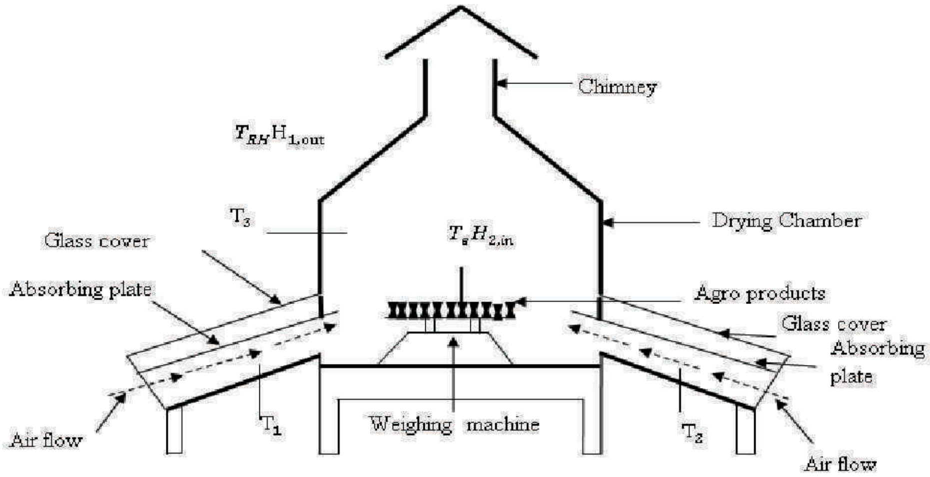

Figure 1: Schematic view of the solar dryer

Figure 2: Pictorial view of the indirect solar dryer

2.2 Experimental Procedure

Fresh cassava was procured from the local market and thoroughly washed to remove surface dust and contaminants. The cassava was then peeled to remove the outer skin, cooked until it reached a suitable consistency, and sliced into uniform pieces. The slices were sorted to ensure uniformity in size and quality before being soaked in water to facilitate further processing steps. Thereafter, 1kg of unprocessed tapioca was measured and recorded, then placed on the rectangular wire mesh tray. The experiment was conducted in December, 2023 under the environmental conditions of Choba, Port Harcourt. The experimental observations were recorded between 9:00am to 6:00pm for three days. The drying was carried out until there was no observable evaporation of water. The initial mass of the sample was measured and recorded. The weight of wire mesh was also measured and recorded before the experiment commenced. The rectangular wire mesh was placed on the top of the digital weighing balanced machine to obtain the mass of evaporation or the moisture removing rate at every one hour interval. Throughout the period of the drying process, the moisture losses, the solar intensity striking the surface of the solar panel; the air temperature entering inside drying section from the two solar collector plate and indoor/outdoor relative humidity were measured and recorded at one-hour interval. Figure 3 (a) and (b) show the fresh and dried samples, respectively, of the tapioca.

Figure 3: Samples of (a) fresh tapioca and (b) dried tapioca

2.3 Performance Characteristics Equation

The amount of the initial moisture removing rate M_i (%) on dry basis, is calculated using Equation 1 (Huddar & Kamoji, 2019; Ssemwanga et al., 2020)

$$M_i = \frac{W_w - W_d}{W_d} \times 100\% \quad (1)$$

where, W_w (kg)and W_d (kg) are the weight of wet and dry sample, respectively.

The final relative humidity or equilibrium relative humidity ERH(%), was calculated using sorption isotherms equation given by Huddar & Kamoji (2019).

$$a_w = 1 - \exp[-\exp(0.914+0.5630\,\text{In}(M))] \quad (2)$$

$$M = \frac{M_f}{(100 - M_f)} \quad (3)$$

$$ERH = 100\,a_w \quad (4)$$

where, a_w is the water activity; $M(kg_w)/(kg_s)$ on dry basis; m_f (%) is the final moisture content.

The mass of water removed from the product m_w (kg) was calculated by Equation 5:

$$m_w = \frac{m_p(m_i - m_f)}{100 - m_f} \quad (5)$$

where, m_p (kg) is the initial mass of the product to be dried

The amount of heat required to evaporate the water is given in Equation 6 (Huddar & Kamoji, 2019).

$$Q = m_w h_{fg} \quad (6)$$

where, Q (kJ) is the amount of energy required for the drying process and h_{fg} (kJ/kg_{wv}) is the latent heat of vaporization. The amount of heat needed is a function of temperature and moisture content of the crop(Obayopo & Alonge, 2018).

The latent heat of vaporization was calculated based on Equation 7 (Obayopo & Alonge, 2018):

$$h_{fg} = 431.158\,(597-0.56\,(T_{pr}) \quad (7)$$

where, T_{pr} (°C) is the product temperature.

The drying rate depends on the total mass of moisture to be evaporated from the sample products with time and is obtained in Equation8 (Obayopo & Alonge, 2018; Suherman et al., 2021):

$$d_r = \frac{M_w}{\Delta t}(hr) \quad (8)$$

where, d_r (kg/s) is the drying rate, M_w (kg) is the mass of moisture evaporated and Δt(hr) is the change in time required in hour. The mass flow rate of air m_a(kg/hr) depends on the mass flow rate at inlet and outlet solar collector area. The mass flow rate at inlet was determined by Equation9 (Obayopo & Alonge, 2018; Suherman et al., 2021):

$$m_a = Au\rho_a \quad (9)$$

For mass flow rate at inlet $m_{a,i} = A_{i,c}\,u\rho_a$ (10)

where, $A_{i,c}$ (m^2) is the inlet area of air entering the solar collector; u(m/hr) is the wind speed at location; and ° $_a$ (m^3/s) is the density of air inside solar dryer.

$$A_{i,c} = A_{i,c}\,u\rho_a \quad (11)$$

where, h_i(m) is the depth at inlet and w_i (m) is the width at inlet to solar collector. For mass flow rate at outlet, $m_{a,o}$ (kg/hr)was calculated by the following equation.

$$m_{a,o} = h_i\,w_i \quad (12)$$

where, $A_{o,c}$ (m^2) is the outlet area of air leaving the solar collector;

$$A_{a,o} = h_o\,w_o \quad (13)$$

where, h_o(m) is the depth at outlet and w_o(m) is the width at outlet of solar collector. The volumetric flow rate of air, V_a (m^3/s) according to Naing & Soe (2021) is obtain as

$$V_a = \frac{m_a}{\rho_a} \quad (14)$$

The heat gained by drying air or the total heat at the collector outlet is given by the Equation15 (Yahya Dasin et al., 2015).

$\dot{Q}_O = w_s A_{o,c}\ \rho_a\ (T_{S,c} - T_0\, C_V)$ (15)

where, Q_O (J/s) is heat at the output of solar collector plate; $T_{S,C}$ (°C)is the average temperature of T_1 and T_2; T_0 (°C) is the ambient air temperature at T_4 and c_V (J/(kg°C) is the specific heat capacity. The total heat received by solar collector is given by Equation 16 (Ssemwanga et al., 2020)

$(Q_I \triangleq IA_{0,C}$ (16)

Where (Q_1 (J/s) heat input at solar collector plate; I (w/m^2) is the solar irradiation and $A_{i,c}$ (m^2) the inlet area for solar collector plate. The efficiency of solar flat plate collector by dividing equation (15) by (16) (Fagunwa et al., 2009; Komolafe et al., 2021), that is;

$\eta_c = \frac{Q_o}{Q_i}$ (17)

where $^{o}{}_{c}$ (%) is the efficiency of solar flat plate collector. The radiation energy per unit time from a black body is proportional to the fourth power of the absolute temperature and can be expressed in the equation given by Stefan-Boltzmann law as follows:

$q = \sigma T^4 A_{o,c}$ (18)

where q (w)is the heat transfer per unit time; σ (watt/(m^2 K^2) is the Stefan-Bolzmann Constant; T (K)is the absolute temperature in kelvin; and $A_{o,c}$ (m^2) is the area of emitting body (i.e. solar outlet collector area). For hot object other than ideal radiators, the law is expressed in the form (Yahya Dasin et al., 2015);

$q = A_{o,c}\ \varepsilon\sigma T^4_{h_{avg}}$ (19)

where e is the emissivity coefficient of the object and $T^4_{h_{avg}}$ (K)is the average hot solar pate collector.For the black body the incident radiation (also called irradiation) is partly reflected, absorbed or transmitted. Therefore, since the hot plate solar collector is radiating energy to its surroundings environment temperature (i.e. the ambient temperature at T_4), the change in heat (i.e. loss in radiation heat) can be expressed as

$q = A_{o,c}\ \varepsilon\sigma\ \left(T^4_{h_{avg}} - T_{am}\right)$ (20)

where T_{am} (K)ambient temperature of radiator (e the ambient temperature at T_4) .

3. Results and Discussion

The experimental results have been presented and discussed. This includes the moisture removal rate, relative humidity, mass of removed water, heat required for the evaporation of water, drying rate of tapioca and solar collector's efficiency.

3.1 Moisture removal rate for tapioca chips

Figure 4 shows the rate of moisture removal from the sample, on hourly basis. Figure 4 suggests a decrease in the moisture removal rate from 10:00am to 6:00pm. Furthermore, a decrease in the moisture removal rate is also seen from day 1 to day 3. The maximum and minimum moisture removing rate per day during the period of drying is 6.3829 and 2.6144%, 5.3627 and 1.8404%, and 2.2916 and 0.2183% for the first day, second day, and third day, respectively. Weather fluctuation at about 1 – 3 pm on the first day, resulted in an almost steady moisture removal rate. However, on the third day at about 3:00 pm – 6:00 pm, the moisture removal rate remains steady at 0.218 %. This was relatively due to the removal of all the water content of the sample. The decrease in moisture content with drying period was low between the hours of 9.00 to 11.00am and 4.00 to 6.00pm owing to low solar strength at the early morning and evening hours of the drying days. This findings supported prior review of Omonegho et al. (2023); Suherman et al.(2020) that as drying continues, the moisture content reduces.

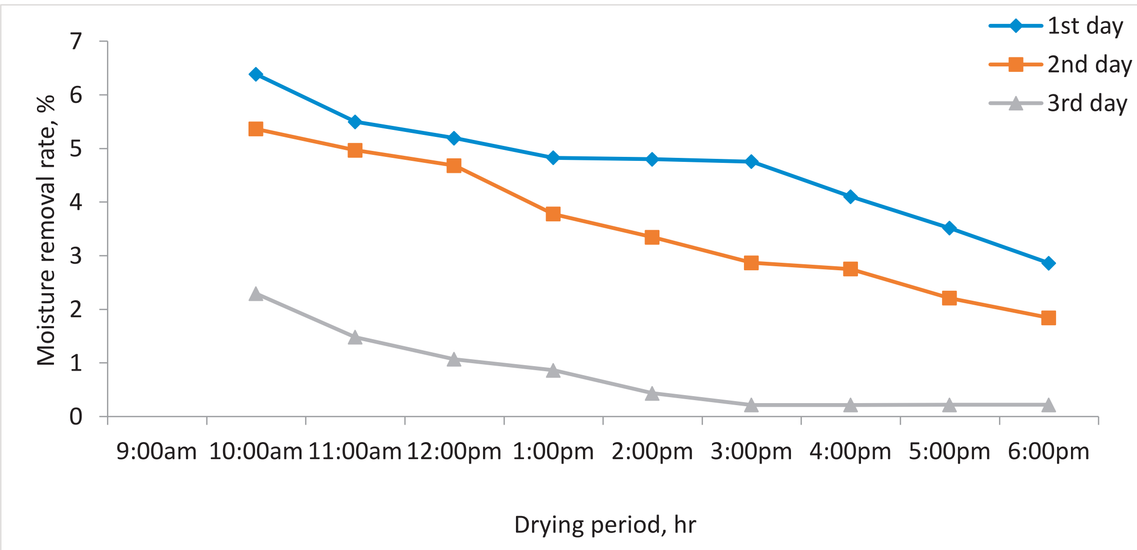

Figure 4: Effect of time of the day on the moisture removing rate on dry basis (%)

3.2 Relative humidity of tapioca chips

Figure 5 illustrates the changes in relative humidity over a specified time period.

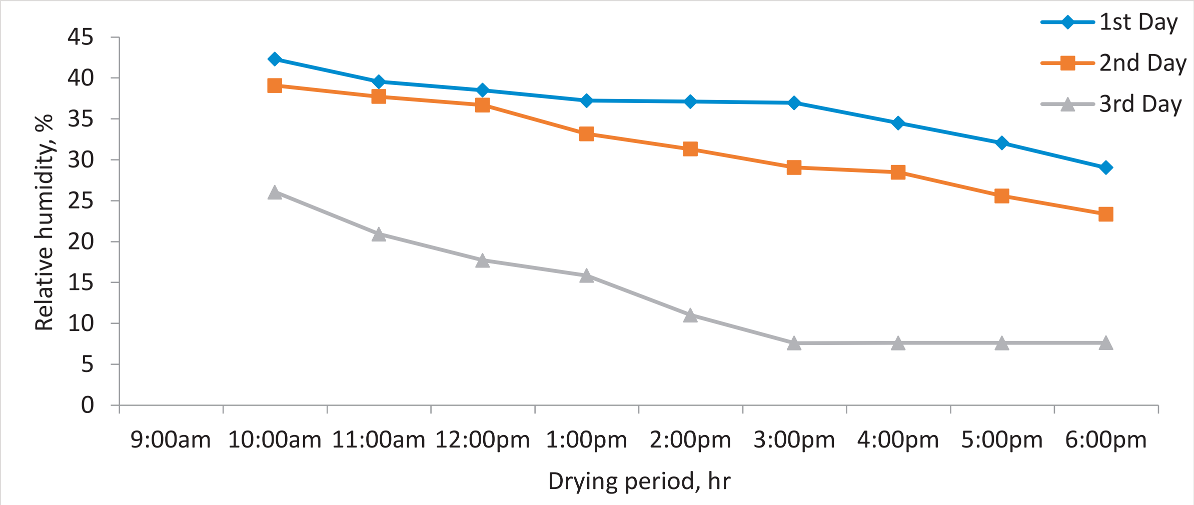

Figure 5: Variations of relative humidity with respect to time

From Figure 5, the first day had the highest relative humidity which decreases with time but not linear. This is followed by second day and then third day. The peak and lowest relative humidity(RH) value obtained during the study period of tapioca sample is 42.3004 and 7.6260 % respectively. The lowest value corresponds to around 3:00pm in third day while the highest is on the first day at about 11:00am. This research findings corroborated other researches (Naing & Soe, 2021; Suherman et al., 2020; Suherman et al., 2021) that the as temperature increase, more water is evaporated and this causes the reduction of the moisture content of tapioca, which in turn also reduce the value of relative humidity inside the dryer. The relative humidity is also higher in the morning than afternoon due to same reason.

3.3 Mass of water to be removed from tapioca chips

Figure 6 illustrates the changes in the mass of water removed over a specified time period.

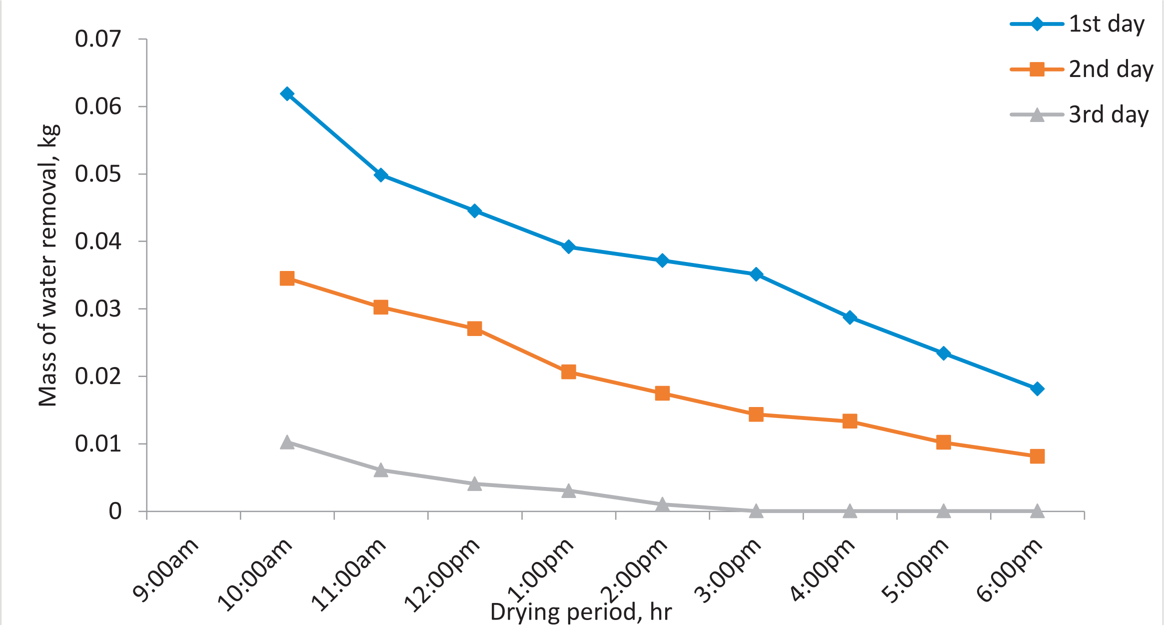

Figure 6: Variations of mass of water removed with respect to time

From Figure 6, it was noticed that mass of water to be removed from 1kg of tapioca chips sample during the early drying days are more and reduced significantly during the period of drying. Also, mass of water decreased from 0.0648 to 0.0277kg, 0.0419 to 0.0048kg, and 0.0176 to 0.0003kg (i.e. from 9:00am to 6:00pm on each day to the succeeding day during the period of drying) respectively. The results buttress the early empirical reviews of (Adeyemi et al., 2020; Dasin et al., 2019; Fagunwa et al., 2009) that drying rate decreases irrespective of the season or period with element of re-absorption as seen from figure 6.

3.4 Amount of heat required to evaporate the water of from tapioca chips
Figure 7 illustrates the effect of time on the heat required to evaporate the water.

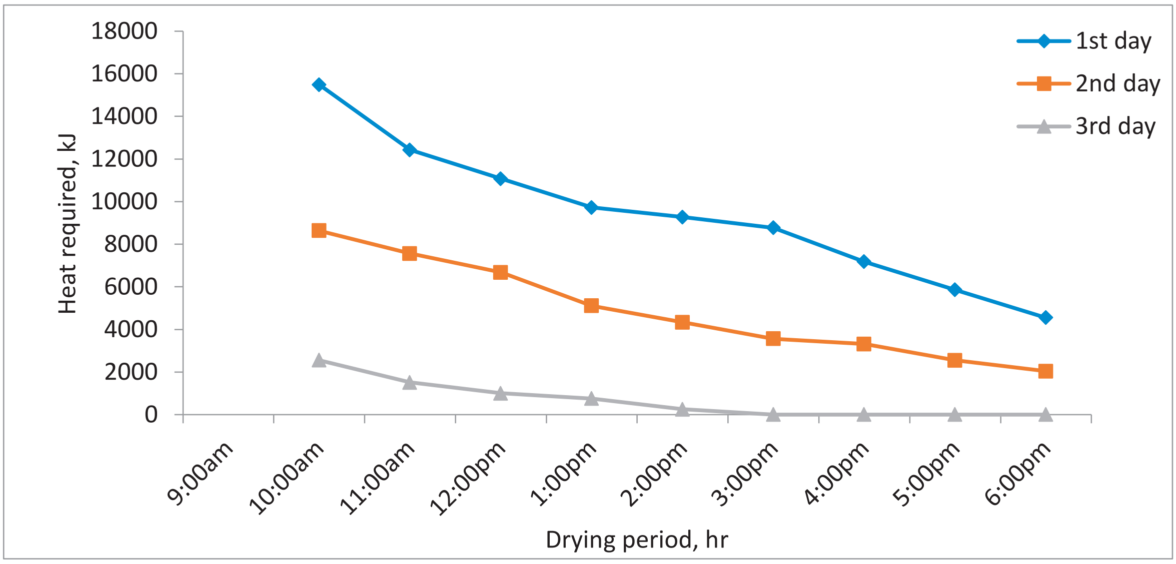

Figure 7: Effect of time on heat required to evaporate the water

From Figure 7, it can be observed from the experimental study for 1kg of tapioca chips, the amount of heat required to evaporate the water with respect to time under solar drying conditions decreases with time with first day having the highest and third day being the least. Also, the maximum and minimum energy value during drying day is 15485.14 and 9.6243kJ, respectively.

3.5 Drying rate of tapioca
Figure 8, shows the plot of drying rate with time under solar drying condition for tapioca chips.

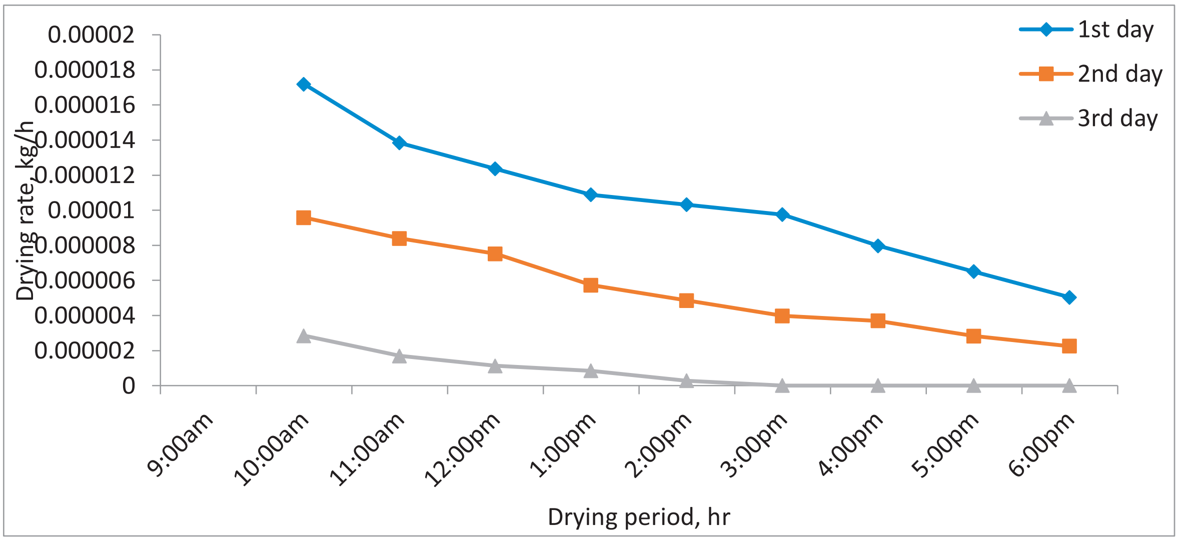

Figure 8: Effect of time on the drying rate

As shown in Figure 8, it was observed that the drying rate obtained decreases from 1.7183×10-5 to 5.0408×10^{-6}kg/hr, 9.5813×10^{-6} to 2.2602×10^{-6}kg/hr and 2.8451×10^{-6} to 1.0656×10^{-8}kg/hr; respectively during the days. This findings is different from those of (Suherman et al., 2021; Suherman, Susanto, Firdauzi, et al., 2020) that drying rate was initially high then decreases as drying continue, the difference may be as a result that this study was conducted in different location, season and on tapioca while Suherman et al., 2021 study was on ginger which invariably have different moisture content. Although Suherman, Susanto, Firdauzi, et al., 2020 work was centered on cassava chips, the solar dryer was a multi-tray type relying totally on solar energy and thermal conductivity of aluminium. This trays have high effectiveness factor during initial drying and decreases as drying progress. However, the findings supported (Obayopo & Alonge, 2018; Tyona & Ojiya, 2020) and natural law that drying rate is usually faster during the day and slower at night

3.6 The solar collector efficiency of tapioca

Figure 9 shows the variation of solar collector efficiency, ° $_c$ with respect to time under solar drying condition for tapioca chips. ° $_c$.

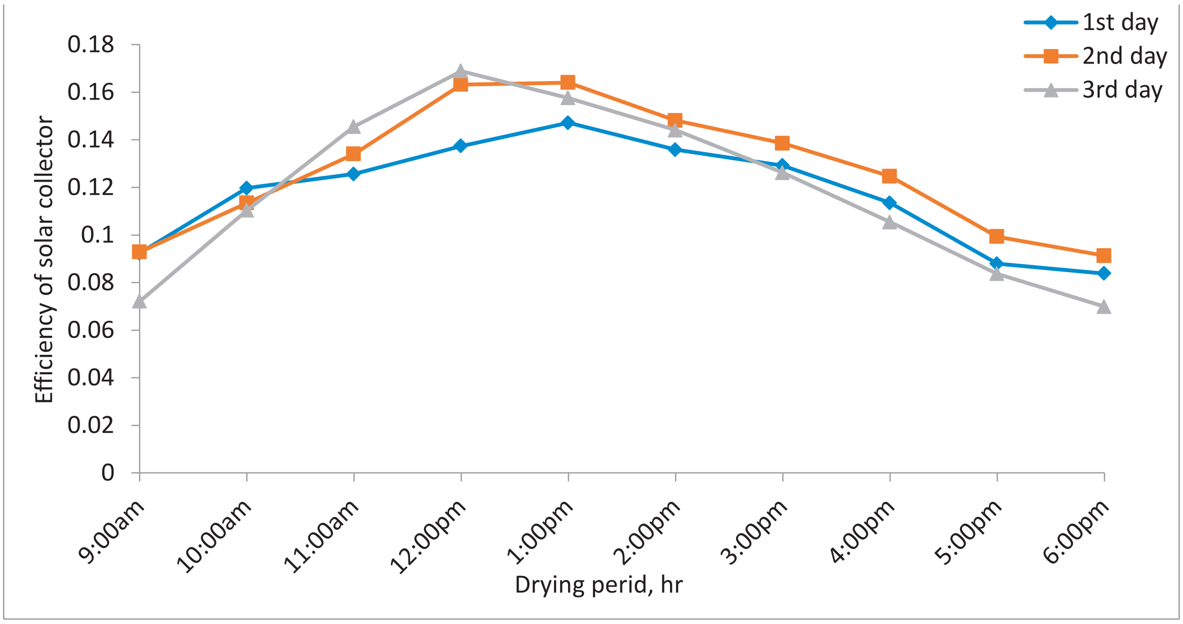

Figure 9: Variations of the collector efficiency with respect to time

As revealed in Figure 9, the solar collector work effectively when inlet air temperature is above the ambient air temperature as at when the solar collector temperature is increasing and the ambient air temperature decreasing. More so, it was observed that, in a situation whereby all η_c parameters are ideal, that means η_c increased from morning to noon and decrease from noon to evening (i.e. 9:00am to 12:00noon and 12:00noon to 6pm) due to increasing and decreasing solar radiation during the drying time. It was recorded that the ° _c for tapioca sample lies between 0.0699 to 0.1689 , during the drying days. The results is attest those of (Huddar et al., 2022; Kolawole et al., 2018; Suherman et al., 2021).

4. Conclusion

Agricultural products are subjected to one form of processing or the other, to either improve the shelf life of the products, or as a necessary condition before consumption. Solar drying is one method that helps to increase the shelf life of agro products. In this study, an experimental investigation of the drying characteristics of Tapioca (or cassava chips)was carried out, using solar dryer. The key parameters considered were the moisture removing rate, relative humidity, volume of water being removed, quantity of heat needed to evaporate the water from the sample products and drying rate The results show that the moisture removal rate of tapioca was 0.2183 % to 6.3829 % on dry mass basis. Also, all the output parameters decreased significantly with lower intensity of the sun and consequently continued until constant drying rate was achieved from 4:00pm to 6:00pm during the period of study. The efficiency of tapioca drying increased from 9:00am to 12:00noon and gradually decreased from noon to 6:00pm. It was deduced that the solar dryer has a better efficiency when used in drying tapioca and should be used in place of sun-drying due to the advantage of colour and texture retention and hygiene. Furthermore, the following recommendations are suggested:

i. a forced convention solar drying should be investigated for the agro products of this study to ascertain the effect on the effectiveness of the system.
ii. since the drying is location dependent, it is suggested that the drying characteristics of other agro products including tapioca should be carried out in other locations with emphasis on the quality of samples dried under solar drying condition in terms of the colour, texture, appearance and hygiene.
iii. also, an optimization of the process design and sampling should be examined in order to achieve improved drying rate.

References

Adeyemi, S. A., Obayopo, S. O., & Akharume, F. (2020). Evaluation of Intermittent Solar Drying with Seasonal Variation on the Quality of Dried Cocoa Beans. SDRP Journal of Food Science & Technology, 5(1), 27–39. https://doi.org/10.25177/jfst.5.1.ra.10612

Atalay, H. (2019). Performance analysis of a solar dryer integrated with the packed bed thermal energy storage (TES) system. Energy, 172, 1037–1052. https://doi.org/10.1016/j.energy.2019.02.023

Dasin, D. Y., Zakari, A. I., & Yahuza, I. (2019). Development of Solar Energy Dryer for Fish and Meat Tested in Modibbo Adama University of Technology Yola. International Journal of Trend in Scientific Research and Development, Vol.3(2), 773–777. https://doi.org/10.31142/ijtsrd21484

Fagunwa, a O., Koya, O. a, & Faborode, M. O. (2009). Development of an Intermittent Solar Dryer for Cocoa Beans. Agricultural Engineering International: CIGR Journal, 11, 1–14.

Huddar, V. B., & Kamoji, M. A. (2019). Experimental investigation on performance of small passive solar greenhouse dryer for cashew kernel drying. AIP Conference Proceedings, 2019. https://doi.org/10.1063/1.5092904

Huddar, V. B., Razak, A., Cuce, E., Gadwal, S., Alwetaishi, M., Afzal, A., Saleel, C. A., &Shaik, S. (2022). Thermal Performance Study of Solar Air Dryers for Cashew Kernel: A Comparative Analysis and Modelling Using Response Surface Methodology (RSM) and Artificial Neural Network (ANN). International Journal of Photoenergy, 2022. https://doi.org/10.1155/2022/4598921

Dare-Adeniran, O.I, Areola, R.I. (2022). Design and Construction of a Solar Dryer for Preservation of Agricultural Products in Ile-Oluji, Ondo State Nigeria. 09(04).

Iwe, M. O., Okoro, C., Eke, A. B., & Agiriga, A. N. (2018). Mathematical modelling of thin layer solar drying of Ighu. Agricultural Engineering International: CIGR Journal, 20(4), 149–156.

Kolawole, A., Ikubanni, P. P., Agboola, O. O., & Anifowose, O. B. (2018). Development and performance evaluation of an economic solar grain dryer. International Journal of Mechanical Engineering and Technology, 9(10), 589–604.

Komolafe, C. A., Waheed, M. A., Kuye, S. I., Adewumi, B. A., & Daniel Adejumo, A. O. (2021). Thermodynamic analysis of forced convective solar drying of cocoa with black coated sensible thermal storage material. Case Studies in Thermal Engineering, 26, 101140. https://doi.org/10.1016/j.csite.2021.101140

Murugan, P. C., & Saji Raveendran, P. (2021). Experimental Studies on the Application of Biomass Gasifier for Drying Tapioca in Remote Areas. IOP Conference Series: Materials Science and Engineering, 1084(1), 012107. https://doi.org/10.1088/1757-899x/1084/1/012107

Naing, T. T., & Soe, C. T. (2021). Comparative analysis of the performance of cabinet solar dryer and open sun drying for Banana slices. IOP Conference Series: Materials Science and Engineering, 1127(1), 012015. https://doi.org/10.1088/1757-899x/1127/1/012015

Ndukwu, M., AFAM, G., & NWAKUBA, N. (2020). Development and Optimization of a Manual Fed Cassava Root Chipper for Household Cassava Processors. Turkish Journal of Agricultural Engineering Research, 283–295. https://doi.org/10.46592/turkager.2020.v01i02.006

Njue, R., & Wawire, N. (2021). Performance evaluation of a cassava solar dryer in Busia County. 17(10), 1296–1301. https://doi.org/10.5897/AJAR2021.15719

Obayopo, S. O., & Alonge, O. I. (2018). Development and Quality Analysis of a Direct Solar Dryer for Fish. Food and Nutrition Sciences, 09(05), 474–488. https://doi.org/10.4236/fns.2018.95037

Omonegho, P., Alaba, J., Olumurewa, V., & Kolawole, M. (2023). Development and Performance Evaluation of Hybrid-Solar Dryer for Cassava Grate. 22(10), 37–47. https://doi.org/10.9734/AFSJ/2023/v22i10671

Senthil, R., Kishore, K. K., Rohan, R. K., & Juneja, A. (2021). Enhancement of absorptance of absorber surfaces of a flat plate solar collector using balck coating with graphene. Energy Sources , Part A: Recovery, Utilization, and Environmental Effects, 43(20), 2595–2608.

Simo-Tagne, M., Tagne, A. T., Ndukwu, M. C., Bennamoun, L., Akong, M. B. O., El Marouani, M., & Rogaume, Y. (2021). Numerical Study of the Drying of Cassava Roots Chips Using an Indirect Solar Dryer in Natural Convection. Agric Engineering, 3(1), 138–157. https://doi.org/10.3390/agriengineering3010009

Ssemwanga, M., Makule, E., & Kayondo, S. I. (2020). Performance analysis of an improved solar dryer integrated with multiple metallic solar concentrators for drying fruits. Solar Energy, 204, 419–428. https://doi.org/10.1016/j.solener.2020.04.065

Suherman, S., Susanto, E. E., Ayu, A. D., & Dea, S. (2021). Experimental investigation of ginger drying using hybrid solar dryer. Journal of Applied Science and Engineering (Taiwan), 24(4), 553–564. https://doi.org/10.6180/jase.202108_24(4).0011

Suherman, S., Susanto, E. E., Firdauzi, A., & Wuryaningtyas, N. (2020). Solar dryer applications for cassava slices drying. AIP Conference Proceedings, 2197. https://doi.org/10.1063/1.5140947

Suherman, S., Susanto, E. E., & Zardani, A. W. (2020). Performance study of hybrid solar dryer for cassava starch Performance Study of Hybrid Solar Dryer for Cassava Starch. 080003.

Tyona, M., & Ojiya, E. (2020). Design, Fabrication and Characterization of a Solar Fish Dryer. Nigerian Annals of Pure and Applied Sciences, 3(3b), 156–174. https://doi.org/10.46912/napas.183

Yahya Dasin, D., Dasin, D. Y., Godi, N. Y., & Kingsley, O. C. (2015). Experimental Investigations of the Performance of Passive Solar Food Dryer Tested in Yola-Nigeria. International Journal of Energy Engineering, 2015(1), 9–15. https://doi.org/10.5923/j.ijee.20150501.03