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ORIGINAL RESEARCH ARTICLE

MODIFICATION AND PERFORMANCE EVALUATION OF ACTIVE SOLAR DRYER FOR HIGH MOISTURE TOMATO CROP

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ABSTRACT
In this study, two active solar cabinet dryers with capacity each to dry 10 kg of fresh vegetable were fabricated. The drying cabinet of the first dryer was fabricated using plywood and is refer to as unmodified dryer (UM) while the second dryer with white transparent glass and is refer to as modified dryer (MD). The performances of the two dryers in terms of total drying time, final moisture content obtained and preservation of nutritive values of the dried vegetable were investigated using tomato as sample. Ten kilogram of the sample were sliced to about 1cm and neatly arranged in the drying chamber for the drying process in a period of two days (8am-6pm). The results revealed that there was a reduction in total drying time of 2.5 hours, from 18 hours in UM to 15.5hours in MD which corresponds to reduction in moisture content (wet basis) from initial value of 92% to final moisture content of 12-13.3%. The results further revealed that maximum drying rate of 6.9 kg/h was observed for UM dryer and 9.4 kg/h for MD both obtained within 8 hours of drying time. The average temperature recorded in the MD was found more than the UM by about 13°C at 3.00pm. The efficiency of the MD in terms of reduction in total drying time was 13.89% higher than the UM. Proximate analysis result shows the composition of the dried tomato in the UM to be protein, 0.76%; lipids, 1.00%; vitamin E, 0.0083%; moisture content, 13.3%; ash, 0.60% and crude fiber, 1.80%. However, the composition of dried tomato in MD were protein, 0.69%; lipids, 0.90%; vitamin E, 0.0080%; moisture content, 12%; ash, 0.58% and crude fiber, 1.78%.

1.0 Introduction

Vegetable crops are grown in many parts of the world contributing significantly to income security and the nutritive diet (30-50% iron and vitamin A) of many households. Global production of fruits and vegetables tripled from 396 million MT in 1961 to 1.34 billion MT in 2003 (USDA, 2007). In spite these promising figures, hardly two percent of the produce is processed and 40-50 % is being wasted due to lack of processing and preservation infrastructure.

The situation is worse for farmers in the rural areas and requires urgent attention. Most of the harvested vegetables and fruits are susceptible to deterioration due to poor preservation.

The moisture content in the agricultural produce contributes greatly to the deterioration of vegetables and fruits. Therefore if the agricultural produce is to be stored for longer length of time, it is necessary to reduce its moisture level to certain well-defined limit. This will prevent the production of undesirable chemical compositional changes in the produce by bacteria, mould and enzyme which will spoil the vegetables and fruits (Bolaji et al., 2011).

Tomato (Lycopersicon esculentum Mill.) fruit is one of the most popular, as well as important, commodities in the world. Over 20 million metric tons of tomato is produced each year on a world basis. The United States, Italy, Spain, and the United Arab Emirate are the leading producers of this crop. In the United States alone, it ranks second only to potatoes in production among vegetable crops and contributes approximately 400million dollars to the economy. Nigeria is ranked 16th on the global tomato production scale, accounting to 10.79% of Africa's and 1.2% of total world production (Weingberger and Lumpkin, 2007).

Solar drying is a process of using solar energy to heat air so as to achieve drying of agricultural products (Ajay et al., 2009). Solar air heaters are simple devices usually employed to heat air by utilizing solar energy and in many applications requiring low grade to moderate temperatures below 80oC such as in crop drying and space heating (Bukola and Ayoola, 2008). The application of passive solar dryers for drying agricultural products in the tropics has often been hampered because crops mature during the peak of the rainy season when frequent downpours and overcast skies are the norm. This often slows down drying, causes rewetting during periods of downpours even in some cases where forced convection is used for the drying. The final dried product takes longer time to dry and does not have an attractive appearance because of moisture pick up during drying resulting in mould growth (Berinyuy et al., 2012).

Many researchers have studied drying pattern of vegetables using unmodified (UM) type of active solar dryer and reported various drying times, rate of drying and final moisture contents obtained; Bello et al (2013); Joel et al (2013); Ibrahim, (2005) and Wankhade et al (2013); investigated drying characteristics of okra using hot air dryers. Mu'azu et al (2012) studied drying pattern of tomato, Kabiru et al (2016) investigated drying characteristics of moringa leaves while Akintunde and Afolabi (2009); Hussan and Tabassum (2015), studied that of red pepper and onion respectively. However, drying characteristics of high moisture vegetables using this type of modified dryer system appears not to be available in the literature. Therefore, the main purpose of this study is to evaluate the performance of the MD in terms of total drying time, final moisture content and preservation of some active nutrients present in the dried sample and compare with the UM. In evaluating this dryer, tomato was used as experimental sample primarily because of its high moisture content of about 92% (wet basis).

2.0 Materials and Methods

2.1 Materials

2.1.1 Description of the Unmodified Dryer

The schematic diagram of the dryer with dimensions in centimeter is shown in Figure 1. The unmodified cabinet solar dryer (UM) consists mainly of solar collector, drying cabinet, and moisture extracting fan. The cabinet was constructed using plywood and covered with Aluminum sheet to protect it from rain. Inside the cabinet at mid position 5 perforated trays were placed. An opening was provided at the top of the cabinet to suck the moist air inside the dryer with the help of 0.5 hp suction fan. The power rating of the air suction fan was calculated from Equation (1) as given by Youcef–Ali et al (2001).

$$P_m = \frac{V_a \Delta P_T}{\eta_L \eta_m} \quad (1)$$

where: V_a is the volumetric flow rate of air (m^3/hr) and is defined as the ratio of mass flow rate of air/density of air, ΔP_T is the total pressure drop in the system (P_a), η_L is the fan efficiency factor (%) and η_m is the motor efficiency factor (%). Based on the power rating the photovoltaic (PV) solar cell was selected.

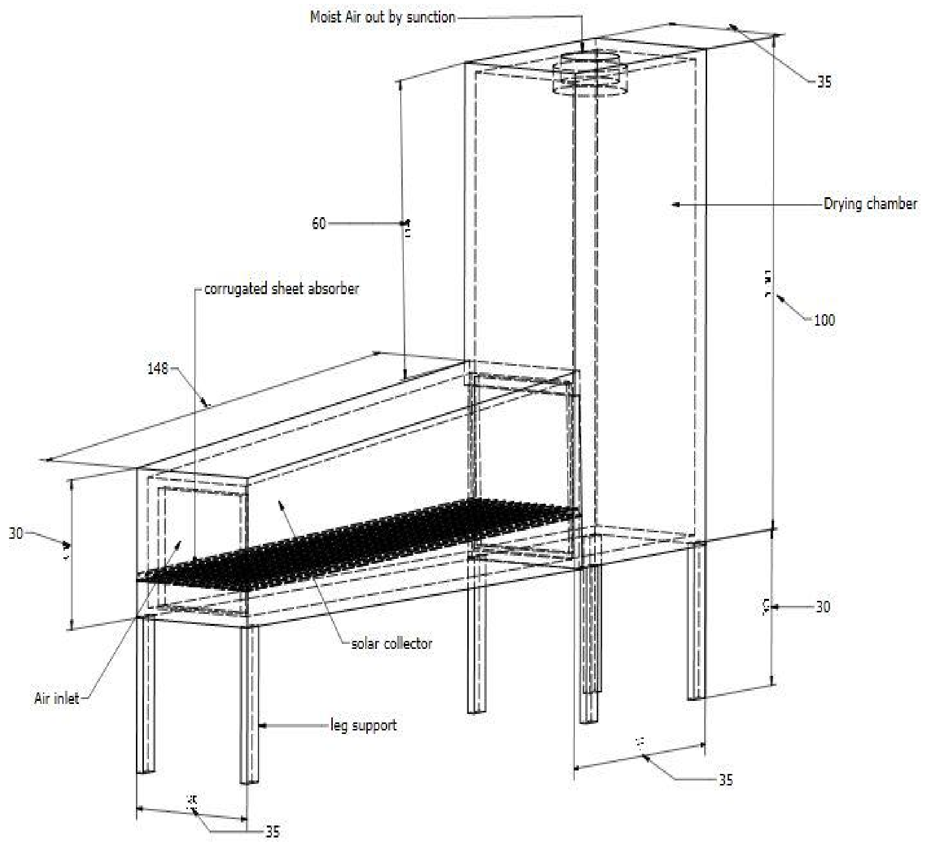

Figure 1: Schematic diagram of fabricated solar vegetable dryer

2.1.2 Description of the Modified Dryer

The existing dryer (UM) described above in Figure 1 was modified (MD) by replacing all the side walls of the drying chamber constructed using plywood with white transparent glass. The dimensions of the dryer remained unchanged as well as the number of trays and position of the moist air extracting fan. The choice of white transparent glass as replacement to plywood was based on the fact that glass has higher thermal conductivity (1.05 W/m K) than wood (0.13 W/m K). This means that glass material will allow more heat to pass to the vegetable to be dried than plywood.

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2.1.3 Solar Collector (Air Heater)

The solar collector was constructed from wooden box having gross dimensions of 148cm long, 50cm wide and 30 cm deep. The area of the solar collector was determined using equation (2) Sodha et al. (1987).

$$A_c \Phi \eta = E_T \qquad (2)$$

where: ET= Total useful heat received by the drying air (J), Φ = Total global solar radiation on horizontal surface during dry season (W/m^2) and η = 30 to 50% (collector efficiency). In this work, η = 44%. The optimum angle of tilt of the solar collector was equal to the latitude of the location and the minimum angle should be 15°. The total useful heat needed Q in Joules to transfer to the drying air was also estimated using Equation (3) as given by Youcef–Ali et al. (2001) and where Mw is the mass of water evaporated in kg; and hfg is the latent heat of vaporization of H_20 in J/kg, Q can be calculated using Equation 3.

$$Q = M_w \times h_{fg} \qquad (3)$$

The side walls and bottom were constructed using two layers of plywood (3 mm thick). Low density foam of 0.04m thick was inserted in the space between the two layers of the plywood. The absorber plate was formed from a corrugated iron sheets which is a good conductor of heat. It was painted with matt black paint in order to absorb the maximum amount of solar radiation. The solar collector was covered with one layer of a clear glass, 3 mm thick to reduce the reflection of radiation and heat losses by convection (Mu'azu et al., 2012). The solar collector was attached to the drying chamber by an air duct. The solar collector was oriented to face south direction and tilted to an optimum tilt angle of 15° at noon (Figure 1).

2.1.4 Drying Chamber

The side walls and bottom of the drying chamber were constructed from plywood (3 mm thick) and covered with aluminum sheet to protect it from rain. The shelves were made from Aluminum mesh and arranged horizontally as shown in Figure 1. The chamber door was located at the back side and constructed using the same material as the walls with dimensions of 60cm long, 35cm width and 35cm breadth. Drying air enters the chamber after leaving the solar collector through the bottom of the dryer connected with an air duct and passes through the trays from the bottom (Ajay et al., 2009).

2.1.5 Drying Air Conditions

The conditions of the drying air used in this work were determined by the method described by Mohammed et al (2010) and presented in Table 1.

Table 1: Drying air conditions used in this study

Parameter	Value
Location	Zaria, Nigeria (lat. 11°11'N)
Relative humidity, %	19
Mass flow rate of air, kg/s	0.039
Incidence solar radiation, MJ/m^2/day	20

2.1.6 Material Source and Preparation

Fresh tomato (*Lycopersicon esculentum*), were obtained from Galma farm, Zaria, along Jos Road, Nigeria. The tomato was sliced to approximate sizes of 1cm to increase the surface area exposed to drying air.

2.2 Methods

2.2.1 Drying Procedure

The experiment was performed in the month of April when the fabrications of the dryers were completed. Each experiment started at 8:00 am and continued till 6:00 pm for two days. At the initial stage, digital thermometer was inserted in each of the dryers to monitor variation of temperature with time inside the drying cabinet. To determine moisture loss on the drying samples during experiments, 10 kg of the sliced tomato were weighed and neatly arranged in the drying cabinet with maximum of 2 kg per tray. Samples were taken out of the solar dryer and weighed at various time intervals, ranging from 30 minutes at the beginning of the drying process to 1hr during the last stage. The drying process was stopped when no further changes in the masses of drying tomato were observed. The mass of the tomato samples were determined with the help of a digital electronic weighing balance having an accuracy of 1% and the moisture content (wet basis) in each case was calculated using Equation (4).

$$\mathrm{M_w = [(M_i - M_{dt})/M_i] \ x \ 100} \qquad (4)$$

where: $\mathrm{M_w}$ is the moisture content in percentage; $\mathrm{M_i}$ is the initial weight of the tomato in kg and $\mathrm{M_{dt}}$ is the weight of the tomato at any time during the drying process in kg.

The partially dried tomato in the first day was collected in a polyethylene bag and air tight to avoid moisture absorption at night. These partially dried tomatoes were again spread in the dryer in the following day and the drying process continued until no further changes in their masses were observed. Mu'azu et al (2012) reported that the rate of drying at any given time in the dryer can be estimated using Equation (5). Similarly, both atmospheric and dryer temperatures were monitored and recorded at 30 minutes interval (Wankhade et al., 2012).

$$\mathrm{R_d = (M_p - M_d)/t_d} \qquad (5)$$

where: Rd is the drying rate in kg/h; Mp is the weight of the tomato in kg; Md weight of the tomato at any given time in kg; td is the drying time (h) at which Md is obtained during the drying process. The total drying time is the difference between initial drying time and final drying time to achieve the equilibrium moisture content.

2.2.2 Proximate Analysis

The proximate analysis which include ash content, lipids content, total protein, water content, and crude fiber content of both fresh and dried tomato in the MD and UM were evaluated according to the standard established methods described by Joel et al. (2013). Lipids were determined by Soxhlet extraction of a sample of 10g, with hexane as solvent. The initial water content of the tomato was estimated after drying of 10 g of sample at 103°C in an oven to a

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constant weight. The estimation of vitamin E content was performed according to Jedlicka et al. (2005).

3.0 Results and Discussion

3.1 Variation of Temperature in the Dryer

Figure 2 and 3 depicts variation of temperature in both modified and unmodified dryer for the first and second day of drying process respectively. As seen in Figure 2, the unmodified dryer attained a maximum temperature of 49°C at about 3:00 pm while the modified dryer attained its maximum temperature of 58°C at 2.00pm. This means that the modification provides temperature rise of about 9°C (58°C-49°C) which resulted in increase in moisture removal from the tomato and consequently reduction in the drying time.

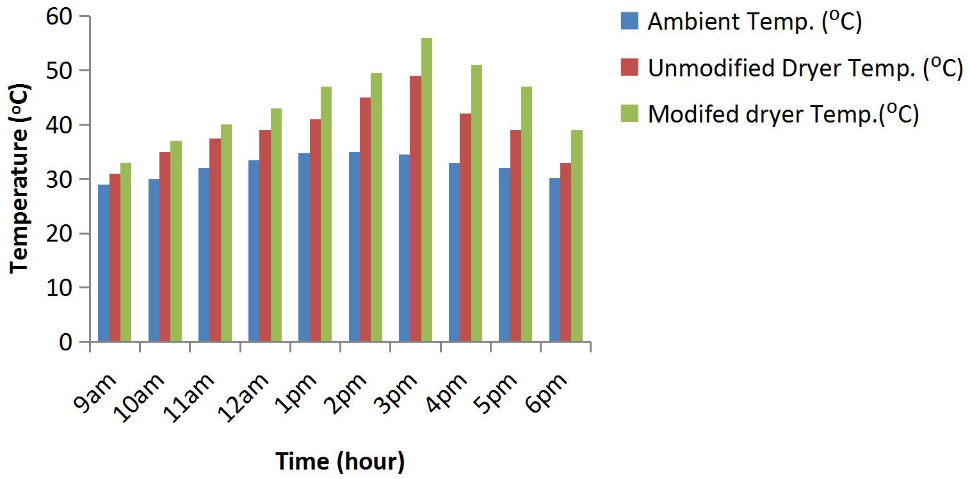

Figure 2: Variation of temperature inside and outside the dryer as a function of time in the first day

However, maximum ambient temperature of 35°C was recorded also at 2.00pm and minimum of 29°C at 9:00 a.m. This difference between air temperatures of the surrounding and cabinet solar dryer (modified and unmodified) is responsible for buoyancy effect which causes air flow as reported by Bolaji et al (2011); James and Peter (2012); El-Sebali and Shalaby (2011) and Adelaja and Babatope (2013).

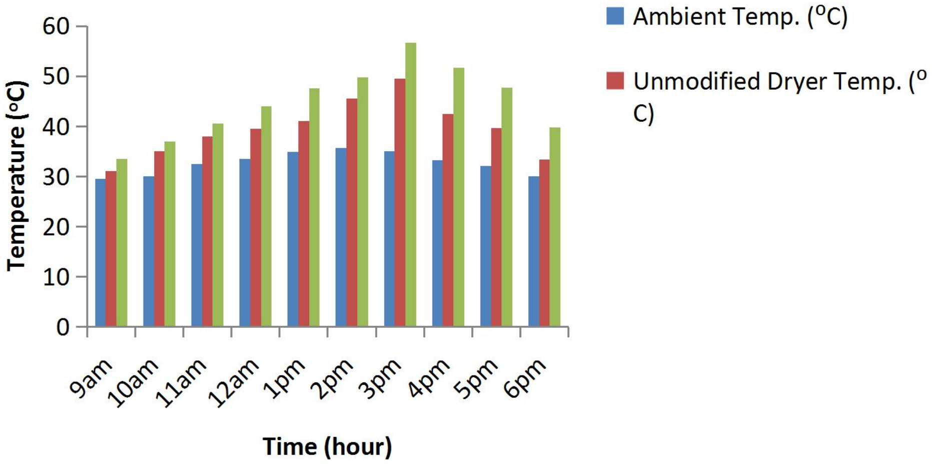

Figure 3: Variation of temperature inside and outside the dryer as a function of time in the second day

In the modified dryer, maximum of 56°C was recorded at 2.00pm and then declined while for unmodified dyer maximum temperature of 49°C was attained at 3.00pm. It can also be seen (Figure 2) that as surrounding temperature increases the temperature inside the cabinet solar dryer also increased and vice versa. These changes in temperature were due to the continuous rotation of the earth along its axis with maximum solar incidence of about 20MJ/m^2 per day obtained during peak time between 1-3pm as reported by Mu'azu et al. (2012). However, similar pattern of temperature variation was also observed in the second day of the drying process (Figure 3) with maximum temperatures of 56.7°C and 49.5°C recorded at 3pm for both modified and unmodified dryer respectively.

3.2 Variation of Moisture Content with Drying Time

The curves in Figure 4 depict the changes in moisture content of the drying tomato with time in both UM and MD. At the initial stage, the tomato had moisture content of 92% (wet basis) and decreased over time until a final moisture content of 13.3 % was achieved within total drying time of 18 hours for UM and 12% (wb) for MD in 15.5 hours for MD. Therefore, modification of the drying cabinet significantly reduced the drying time by 2.5 hours (18-15.5 hours) due to a quicker moisture removal from the tomato.

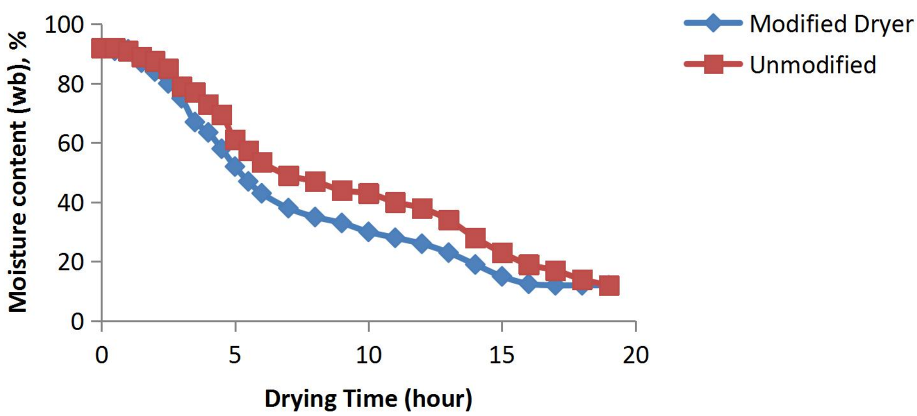

Figure 4: Variation of moisture content with time in the dryer

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The final moisture content of 12 and 13.3% (wb) achieved in this study were relatively higher than 5.7% (wb) obtained by Mu'azu et al. (2012) but in agreement with the result obtained by Adewale et al (2018). This could be attributed to the high relative humidity (19%) of the drying air used in this study. Significant reduction in moisture content was observed between 0-10 hours in UM and 0-8 hours in MD before declining to insignificant values. The rapid removal of moisture at the initial stage (0-10 hours) was due to evaporation of free moisture (unbound) from the outer surface layer and gradually progressed to internal moisture (bound). This internal moisture migrates from the inner layers to the surface and subsequently evaporated (Monhanraj et al., 2009). It was also observed in Figure 4 that there was insignificant reduction in moisture between 4.00-6.00pm in the first day and 9.00-11.00am in the second day and was attributed to low insolation during these periods.

3.3 Variation of Drying Rate with Time

The rate of moisture removal from the tomato as a function of drying time is shown in Figure 5. It is evident from Figure 5 that at the initial stage of drying process (0-3 hours), the rate of moisture removal was insignificant in both MD and UM which corresponds to 9.00-11.00am of the drying time. This was due to the low insolation and higher relative humidity during these periods. However, beyond 4 hours of drying time, significant moisture removal was observed reaching a maximum value of 9.4kg/h at corresponding time of 8 hours for MD and 6.9kg/h for UM also within the same drying time. This means that an increase in moisture removal of 2.5kg (9.4kg/h – 6.9kg/h) was recorded in the MD. These higher drying times in both dryers were attributed due to the following two reasons; 1. Attainment of peak insolation rate of about 20MJ/day which occurred between 12 noon to 3.00pm depending on the latitude, 2. The moisture removed during these drying times were mostly free moisture or unbound moisture held within the porous structure of the tomato fiber and its removal is usually governed by mass transfer process (Mu'azu et al., 2012).

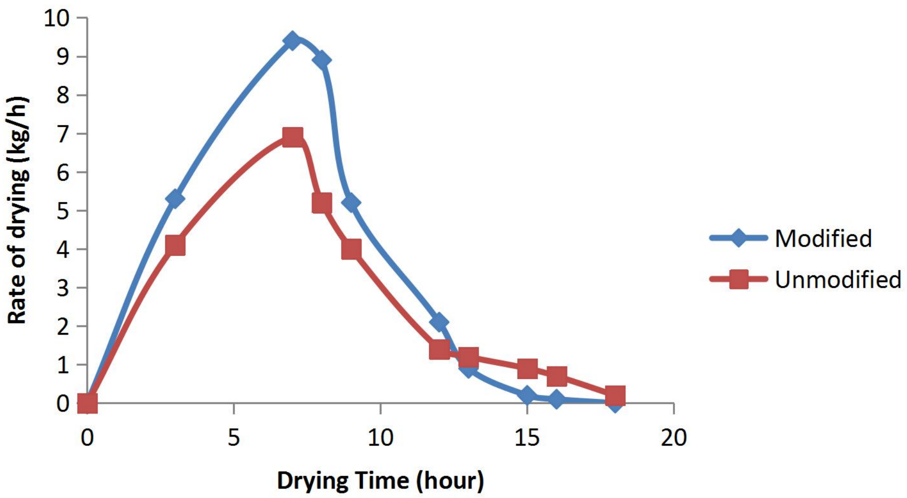

Figure 5: Rate of drying as a function of time

The decline in the rate of drying was observed after 8 hours for both MD and UM and continued until insignificant values were observed in 15.5 hours for MD and 18 hours for UM. At these times, the final moisture content achieved were 12% (wb) in UM and 13.3 % (wb) in MD implying that no further drying could take place under this drying air conditions used (Mu'azu et al., 2012). It is also important to note in Figure 5 that the rate of moisture removal from MD was generally faster than the UM which resulted in reduction of total drying time.

3.4 Proximate Chemical Composition

Comparative analysis of nutritional values of fresh and dried tomato in both UM and MD is presented in Table 2 and the fresh tomato was served as control. The values obtained for dried tomato in MD were slightly lower than those obtained in UM and fresh sample.

Table 2: Proximate analysis of both fresh and dried tomato in UM and MD

Parameter	Fresh	Dried (UM)	Dried (MD)
Proteins, %	0.78	0.76	0.69
Lipids, %	1.10	1.00	0.90
Vitamins E, %	0.089	0.083	0.080
Moisture, %	92	13.3	12
Ash, %	0.60	0.60	0.58
Crude fiber, %	1.86	1.80	1.78

The high moisture contents obtained was due to high relative humidity of the drying air compared to 8.67% (wb) obtained by Opadotun et al. (2016). There was good correlation on the nutritional values in both dryers with slight differences which could be largely attributed to the direct effect of UV light on the tomato during drying in MD. Generally, both dryers have proved to be effective in terms of preservation of these active ingredients and also agreed closely with the work conducted by other researchers (Joel, et al., 2013; Navalea et al., 2015).

4.0 Conclusions

This study showed that the temperatures in the MD were generally higher than in the UM with maximum temperature of 58°C recorded in MD and 49°C in UM at about 3 pm. The total drying time to achieved final moisture content of 12-13.3% (wb) had reduced due to modification from 18 hours to 15.5 hours representing reduction of 13.89% or 2.5 hours. Proximate analysis of some active nutrients in the dried tomato in both dryers showed good correlation when compared with the fresh tomato. This study will be useful in exploiting the concept of this modified dryer by farmers in drying vegetables instead of the traditional active solar dryer due its numerous advantages especially reduction in drying time.

References

Adelaja, AO. and Babatope, BI. 2013. Analysis and testing of a natural convection solar dryer for the tropics. Journal of Energy, 4(1): 1-8. http://dx.doi.org/10.1155/2013/479894

Adewale, O., Jumoke, I. and Ifeoluwa, A. 2018. Influence of drying temperature and storage period on the quality of cherry and plum tomato powder. Food Science and Nutrition, 6:1146-1153. https://doi.org/10.1002/fsn3.658

Corresponding author's e-mail address: kabirumuazu@yahoo.co.uk

Ajay, C., Orsunil, KS. and Deepak, DP. 2009. Design of solar dryer with turbo ventilator and fireplace. www.solarfood.org/solarfood.

Akintunde, TT. and Afolabi, TJ. 2009. Drying of chili pepper (capsicum frutscens). Journal of Food Process Engineering, 33(4): 649-660.

Bello, MO., Olabanjo, IO., Abdulhammed, M. and Okunade, TO. 2013. Characterization of domestic onion wastes and bulb (Allenion cepa L): Fatty acids and metal contents. International Food Research Journal, 20(5): 2153-2158.

Berinyuy, JE., Tangka, JK. and Weka-Fotso, GM. 2012. Enhancing natural convection solar drying of high moisture vegetable with heat storage. Agricultural Engineering Institute: CIGR Journal, 14(1): 141-148.

Bolaji, BO., Olayanju TMA. and Falade TO. 2011. Performance evolution of a solar wind - ventilated cabinet dryer. The West Indian Journal of Engineering, 33(1): 12-18.

Bukola, OB. and Ayoola, PO. 2008. Performance evaluation of a mixed-mode solar dryer. American Journal of Food Technology, 11(4): 225-231.

El-Sebali, AA. and Shalaby, SM. 2011. Solar drying of agricultural products: A Review. Renewable and Sustainable Energy Reviews, 16: 37-43.

Hussan, AB. and Tabassum, Y. 2015. Antimicrobial, phytochemical, ethno-botanical and proximate analysis of allium cepa L. Journal of Advanced Botany and Zoology, 3(1): 1-4.

Ibrahim, D. 2005. Drying characteristics and kinetics of okra. Journal of Food Engineering, 69(3): 275-279.

James, S. and Peter, S. 2012. Performance evaluation of an enhanced fruit solar dryer using concentrating panels. Energy for Sustainable Development, 16: 224-230.

Jedlicka, A. and Klimes, J. 2005. Determination of water and fat-soluble vitamins in different matrices using high-performance liquid chromatography. Chemical Processing, 59 (3): 202-222.

Joel, BK., Cisse-Camara, M., Absalom, AM., Georges, GT., Daniel, ES. and Etienne TV. 2013. Comparative study of proximate chemical composition of two varieties of okra dried by two methods: sun and electric drying. American Journal of Bioscience, 1(4): 74-79.

Kabiru, M., Mahmood, A., Bashir, I., Shittu, MU., Musa, AK. and Zakariyya, A. 2016. Design, development and performance evaluation of active solar dryer for drying moringa leave under controlled conditions. Proceeding of 6th Annual International Conference of the Renewable & Alternative Energy Society of Nigeria (RAESON).

Mohammed, MA., Gamea, GR. and Keshek, MH. 2010. Drying characteristics of okra by different solar dryers. Journal of Agricultural Engineering, 27(1): 294-312.

Mu'azu, K., Bugaje, IM. and Mohammed, IA. 2012. Performance evaluation of forced air-convection vegetable drying system. Journal of Basic Applied Science Research, 2(3): 2562-2568.

Monhanraj, M. and Chandrasekar, P. 2009. Performance of a forced convection solar dryer with gravel as heat storage material for chilli drying. Journal of Engineering Science and Technology, 4: 305-314.

Navalea, SR., Harpaleb, VM. and Mohitec, KC. 2015. Comparative study of open sun and cabinet solar drying for fenugreek leaves. International Journal of Renewable Energy Technology Research, 4(2): 1-9.

Opadotun, OO., Adekeye, SA., Ojukwu, EO. and Adewumi, AA. 2016. Comparative analysis of nutritional values of tomatoes subjected to different drying conditions. International Journal of Basic and Applied Sciences, 5(1): 6-9.

Sodha, MS., Bansal, NK., Kumar, A., Bansal, PK. and Malik, MA. 1987. Solar Crop Drying. Vol. I and II. CPR press, Boca Raton, Florida, USA.

USDA. 2007. The US and World Situation: Fresh and Processed tomatoes. USDA Foreign Agricultural Services Horticultural and Tropical Products Division.

Wankhade, PK., Sapkal, RS. and Sapkal, VS. 2012. Drying characteristics of okra slices using different drying methods by comparative evaluation. Proceedings of the world congress on Engineering and Computer Science, Vol.II, San Francisco, USA.

Wankhade, PK., Sapkal, RS. and Sapkal, VS. 2013. Drying characteristics of okra slices on drying in hot air dryer. Proceeding Engineering, 51: 371-374.

Weingberger K. and Lumpkin, TA. 2007. Diversification into horticulture and poverty reduction: A Research Agenda, 35(8):1464-1480.

Youcef -Ali, S., Messaoudi, H., Desmons, JY., Aene, A. and Le Ray, M. 2001. Determination of the average coefficient internal moisture transfer during the drying of a thin bed of potato slices. Journal of Food Engineering, 48 (2): 95-101

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