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Research article

Physicochemical quality of twin layer solar tunnel dried tomato slices

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ABSTRACT

The objective of this experimental study was to evaluate the effect of twin layer solar tunnel drying on physicochemical quality of tomato slices. The novelty of this dryer is that it has two layers of trays unlike Hohenheim solar tunnel dryer which makes it to have drying capacity of more than two times compare to type hohenheim solar tunnel dryer with equal collector area. The experiment consists of two (tray position and drying position) factors with two levels of tray position (upper tray (samples exposed to direct solar radiation) and lower tray (samples are exposed to only heated air)) and three levels of drying position (collector out let,middle of the dryer and dryer out let) with three replications. During the experiment 180 kg of Tomato slices of Galilea variety with 5mm thickness were dried in the twin layer solar tunnel dryer. Data on physicochemical quality of tomato were collected and analyzed using SAS (version 9.2). software. From the experimental result; an increase in lycopene and phenolic content retention along the length of the dryer was observed while Vitamin C retention showed a decreasing trend. Large retention of total phenol, lycopene and beta carotene content were observed for the lower tray dried tomato slices compared to the upper tray dried ones. The water activity and PH values of the solar tunnel dried tomatoes were within the safe range from microbial growth, enzymatic and non-enzymatic browning. Compared to sun drying; solar tunnel dried tomatoes showed a much better nutrient retention for all quality parameters which is comparable with the data reported for energy intensive mechanical dryers.

1. Introduction

Tomato (Solanum lycopersicum) is one of the fresh vegetable crops which are widely consumed in the world (Vaughan and Geissler, 2009). It is rich in lycopene, β carotene, phenolic compounds and ascorbic acid (Perveen et al., 2015). The major phytochemicals in the tomato fruit is lycopene, a red pigment in the tomato fruit, whose content increases as the fruit ripens. Additionally it contains carotenoids such as phytoeneand phytofluene phenolics such as coumaric and chlorogenic acids, quercetin, rutin (flavonoids) (Hedges and Lister, 2005). Tomato is a perishable food product that starts deteriorating 2–3 days after harvesting (Ochida et al., 2019). The field assessment results of Tomato production and postharvest loss in Dugda wereda, Ethiopia indicated that postharvest loss of tomato across the supply chain is as high as 38.7 percent starting from harvesting and happens along other chains including during transporting, storage, retailing and packing (FAO, 2019). Drying of fruits, vegetables and their products are dried to enhance storage stability, decrease transport weight and minimize packaging requirements (Sagar & Kumar, 2010). However, there are changes in quality parameters of products during dying process (Sahin et al., 2011). Therefore, it should be done in the way that will be least detrimental to the product quality (Purkayastha et al., 2013). Drying has been used for many years as a means of preservation and this processes provides an alternative way of using tomato for consumption (Kulanthaisami et et al., 2010). color, sensorial, nutritional and functional quality of tomato is affected during thermal processing (Santos-Sánchez et al., 2012). To minimize these changes during drying, drying methods such as microwave drying, heat pump drying (HPD), infrared drying,and freeze drying (FD), are used (Gaware et al., 2010). Different researchers have also proposed to use these dryers for better quality retention of tomatoes. Sahin et al. (2011) proposed freeze drying for better color and maximum lycopene content retention. Xu et al. (2016) also recommended continuous vacuum drying method for tomato to produce powders with good color and lycopene retention. During rehydration studies Gaware et al. (2010) reported highest rehydration ratio for freeze-dried samples and better

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rehydration ratio for microwave vacuum and heat pump dried tomato slices than solar cabinet and hot air dried slices.

These dryers require high capital and running cost to build and operate the facilities and also use conventional energy sources (Aravindh and Sreekumar, 2015) and they are not often viable to use in many developing countries (Ringeisen et al., 2014). In addition to this; using artificial drying methods with energy sources from fossil fuels and biomass will result in greenhouse gas emissions that contributes for global climate change. Hence, using an environmental friendly drying unit is important to promote the use of renewable energy in drying tomato to minimize its post-harvest loss while still retaining its nutrients.

In Ethiopia sun drying of crops is most widely used. However, during sun drying the quality of sun dried product is degraded and sometimes it may not be safe for human consumption. Further the required drying time is too long in sun drying (Kulanthaisami et et al., 2010). Using solar dryers can be an alternative to traditional open-air sun drying since they are viable technology which can be used to process food at farm or village level (Puri, 2016). Ther are Several designs of Solar dryers and among them Cabinet types solar drier is reported to be suitable for drying vegetables and fruits (Sharma et al., 1995).

Direct mode natural convection solar dryer which is developed by Akachukwu (2013) has a drying capacikty of 10 kg of tomato and saves 54.55 of drying time Compared to open sun drying. At a drying air temperature of about 40–50 °C solar box dryer can dry about4–5 kg of fruits, vegetables and fish in a single batch (Mohsin et al., 2011). Alternative to natural using forced convection can decrease the required collector area by 50 % and can reduce drying time by up to three times (Puri, 2016). The greenhouse solar dryer with LPG burner which is developed by Janjai (2012) was reported to be suitable for a large-scale production of quality dried fruits but use of LPG increases the drying cost.

Among active dryers Hohenheim solar tunnel dryer which was developed in the early eighties at the University of Hohenheim, Germany for small scale production of dried vegetables, fruits, fish, and spices has been widely tested and attained economic viability (Bala and Janjai, 2009). This dryer is 18 m long and 2 m wide, with a collector area of $16m^2$ and a drying area of $20m^2$ (Patil and Gawande, 2016).

Different researchers fabricated and tested different sizes of solar tunnel dryers based on the Hohenheim dryer design for drying of different agricultural products like chili, pineapple, jackfruit bulbs and leather (Bala et al., 2003; Bala et al., 2005; Hossain et al., 2005; Chowdhury et al., 2011).

Even though these all dryers gave a promising result in drying of these products their drying capacity is very small. Therefore design optimization of the solar tunnel type Hohenheim was done by the Hohenheim Engineers and developed a twin layer solar tunnel dryer having a collector area of $16m^2$ and drying area of $32m^2$. The dryer has a two layer of 60 trays loaded one over the other 30 at top and 30 at bottom each with 0.81 m^2 area. This dryer has more than two times drying area compare to type Hohenheim to dry more amount of product. In order to use this dryer; it should be tested under local climate condition with full scale drying experiments. Thus, the main objective of this experimental study was to assess the applicability of twin layer solar tunnel dryer for drying of tomato slices by evaluating its impact on the physicochemical quality of dried tomato slices under Jimma, Ethiopia weather condition.

2. Material and methods

2.1. Description of the study site

This research was conducted in Jimma zone, Ethiopia; at Jimma University College of agriculture and Veterinary Medicine which lies between 36° 5′ E longitude and 7° 42′ N latitude at an altitude of 1710 m above sea level (masl).

2.2. Twin layer solar tunnel dryer

The twin layer solar tunnel dryer is used in the drying experiment. This dryer consisted of solar collector and solar drying region, 80 W solar module and one 24 V DC (direct current) fan at the air inlet of the solar collector for providing the required air flow (Figure 1).

The dryer is 24 m long (8m long collector and 16m long drying section) and 2 m wide. It stands on 0.8m high brick plinth. UV-stabilized polythene sheet (transmittance. 88–90%) is used for covering both the collector and drying region. The collector region is painted black for absorbing solar radiation. In the dryer there are sixty $0.81m^2$ wide trays arranged in two layers loaded one over the other 30 at top and 30 at bottom for drying products on them. Hand-operated pipe and crank arrangement is used to open or close the plastic cover to easily load and unload a product to be dried.

2.3. Instrumentation

Air velocity at fun exit was measured by using anemometer (model PL-135 HAN WIRE ANEMOMETER). Data loggers (Testo, model 174, Germany) were placed at four meters interval inside the drier to measure the temperature and relative humidity in the dryer. The temperature and relative humidity measurements are taken above the surface of the upper tray. The instantaneous solar radiation was measured by using Pyrometer (model SP Lite2) Arrangements of the instruments are shown in (Figure 2).

2.4. Raw material and experimental design and procedure

Fresh tomatoes of Galilea variety were hand harvested from the field of a local farmer in mojo and transported to Jimma. Then firm fully mature tomatoes with red color were sorted and washed with water, sliced in to 5mm thickness and dried in the twin layer solar tunnel drier (Figure 3). For investigating effect of tray position and drying position on quality of tomato slices; experiments were laid out in a completely randomized complete block design (RCBD) with factorial arrangement in three replications. The drying zones (collector outlet (0m), middle of the dryer (8m) and dryer outlet (16m)) were used as the first factor and the tray position (upper and lower) were used as the second factor and drying day was used as a block. The tomato samples used for analysis were taken from 1st tray (at collector outlet), 8th tray (middle of the dryer) and 15th tray (dryer outlet) for both upper and lower trays.

2.5. Quality of dried tomato slices

2.5.1. Lycopene

Lycopene extraction from tomato samples was done using ethanol: acetone:hexane (1:1:2) (v/v) mixture as described in (Suwanaruang,

Figure 1. Twin layer solar tunnel dryer Photo.

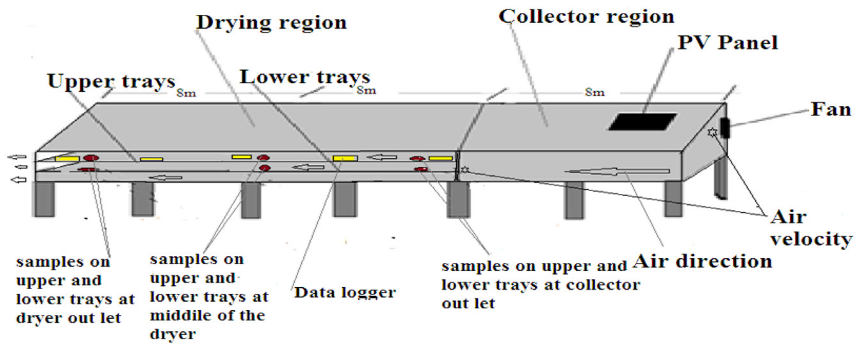

Figure 2. Arrangement of the instruments in the twin layer solar tunnel dryer.

2016). Briefly;0.1g powdered tomato sample was dissolved in 1ml of distilled water and vortexed at 30 °C for 1hr in water bath. Then, 8.0 ml of hexane, ethanol: acetone:hexane (1:1:2) (v/v)was added, capped and vortexed again, followed by incubation for 60 min in dark place. Each sample was vortexed again after adding one (1) ml of distilled water. Then the samples were allowed to stand for separation into phases. UV–Vis spectrophotometer (T80, China) were used to read the absorbance of the upper layers of the lycopene samples at wavelength of 503 nm. Lycopene content of the samples were then calculated using Eq. (1)

$$\text{Lycopene}\left(\frac{mg}{100g}dw\right) = (\text{Abs}_{503\text{nm}}) \times 537 \times 8 \times \frac{0.55}{0.1} \times 172 \qquad \text{(Eq.1)}$$

where: $\text{Abs}_{503\text{nm}}$ = the absorbance at 503nm, 537 = the molecular weight of lycopene in g/mole,8 = the volume of mixed solvent, 0.55 is the volume ratio of the upper layer to the mixed solvents in ml,0.10 = the weight of tomato added in g and 172 = the extinction coefficient for lycopene in hexane in mM^{-1}

2.5.2. Vitamin C

Determination of Vitamin C was done according to the AOAC (2005) Official Method 967.21 by 2,6-dichloroindophenol titration method, according to the AOAC (2005) Official Method 967.21. Briefly, 40 ml of HPO_3-HOAc extracting solution (*i.e.*,15 g of HPO_3 and 40 ml of HOAc in 500 ml of deionized water)was used to mix 0.2 g of dried tomato powder. Standard solution was prepared by Weighing 50 mg of L-ascorbic acid standard and diluting in 50 ml of HPO3-HOAc extracting solution and diluted to a final concentration of 10 mg of ascorbic acid/100 ml. Then ten ml of test sample,blank and Standard solution was titrated with the indophenol reagent (*i.e.*, prepared by dissolving42 mg of NaHCO3 and 50 mg of 2,6-dichloroindophenol sodium salt to 200 ml with deionized water) to a light but distinctive rose pink endpoint lasting ≥5 s. Vitamin C in mg/g of sample was then calculated using (Eq. 2).

$$\text{Vitamin C}\left(\frac{mg}{g}\right) = (A - B) \times (C|D) \times (V|Y) \qquad \text{(Eq.2)}$$

where: A = average ml for test solution titration, B = average ml for test blank titration, C = mg ascorbic acid equivalents to 1.0-ml, indophenol standard solution, D = sample weight (g) or volume V = volume of initial test solution and Y = volume of test solution titrated.

2.5.3. Antioxidant capacity

Antioxidant capacities of the Samples were determined based on the method modified by Lu & Foo (2000). Briefly, 0.1 g of dried tomato powder was mixed with 100 ml methanol and the mixture was homogenized in a homogenizer (PLTYRON®2500E, Switzerland) for 1 min and kept in a water-bath for 60 min at 20 °C. Then it was centrifuged at 2500 rpm for 15 min and 200, 400, 600, 800, 1000 μL of the supernatant was added in each test tube and the volume were made up to 1 mL with methanol. Then 2 ml of 0.1 mM DPPH was added to all the tubes and incubated in the dark at room temperature for 30 min. UV-Vis spectrophotometer, T80 China was used to measure the decrease in absorbance of the resulting solution at 517 nm. Then from the absorbance values of samples;radical scavenging activity of each sample and control was calculated using (Eq. 3).

$$\text{Radical scavenging activity}(\%) = \left(\frac{A_{c-A_t}}{A_c}\right) \times 100 \qquad \text{(Eq.3)}$$

Where:

Ac-Absorbance of control = absorbance of DDPH
At- Absorbance of test solution = absorbance of the treatments

The E_{50} value, defined as the amount of the sample to scavenge 50% of the DPPH radicals, was calculated from percentage of radical scavenging activity results by plotting the graph of DPPH free radical scavenging activity verses concentration of the sample.

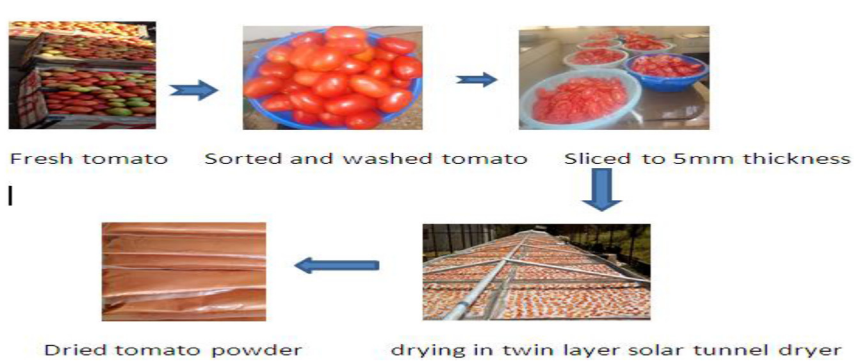

Figure 3. Pocess flow chart of tomato drying during the experiment.

2.5.4. β-carotene

β-carotene content was determined as described by Sadler et al. (1990) with minor moifications. Briefly,1 g of sample was mixed with 1 g $CaCl_2.2H_2O$ and 50 ml extraction solvent (25% acetone, 50% hexane, and 25% ethanol, containing 0.1% BHT) and gently shaken for 30 min. Then 15 ml of distilled H_2O was added to the solution and shaken again for additional 15 min. Then the organic phase, containing the beta-carotene was separated from the water phase and UV-Vis spectrophotometer, T80 China was used to measure the absorbance of the extracted sample at 450nm. Pure β-carotene standard (Sigma Aldrich) was used as a standard and the measurement was compared to a standard solution. β-carotene standard stock solution prepared by dissolving 0.01g beta-carotene standard in 100 ml solvent was used. From the stock solution a concentration of 0, 0.1, 0.2, 0.4, and 0.8 mg/L of beta-carotene standard was prepared in the same solvent. Then UV-Vis spectrophotometer, T80 China was used to read the absorbance of each was sample at 450nm. All samples were replicated three times and the average value of absorbance was obtained.

2.5.5. Total phenolic content

Total phenol determination was carried out according to (Singleton et al., 1999) using method involving Folin-Ciocalteu reagent and Gallic acid as standard. Briefly, 0.1 g of dried tomato powder was mixed with 100 ml methanol and the mixture was homogenized in a homogenizer for 1 min. Then 0.5 ml of methanolic solution of extracts was added with 2.5 ml of 2N Folin-Ciocalteau reagent. Immediately, 2.5 ml of 7.5% sodium carbonate solution were added. Then, the mixture was incubated for 45 min at 45 °C, and the absorbance was measured using UV-Vis spectrophotometer, T80 China at 765 nm. Then the absorbance of the samples were compared to a standard curve ($R^2 = 98\%$) prepared with Gallic acid solution. Finally, the total Phenolic contents were expressed as mg of Gallic acid equivalents per gram of sample (mg GAE/g sample). All The samples were replicated three times. To draw the calibration curve Gallic acid stock solution was prepared by adding 0.1g Gallic acid in to 100ml absolute methanol and the solution was made up to 100 ml with same solvent. From the stock solution samples were taken and diluted to give0,1,2,4,6,8,10,20, 40, 60, 60, 80 and 100 mg/L of Gallic acid in methanol. Then 0.5 ml of each sample were added into test tubes and mixed with 2 N Folin- Ciocalteu reagent and 2 ml of 7.5% sodium carbonate. The tubes were then allowed to stand for 30 min at room temperature after covering with aluminum foil. Then the absorbance were measured using UV/Vis spectrophotometer, T80 China at 765nm.

2.5.6. TSS

TSS of the samples was measured by refractometer (model, DR201-95, Germany).

2.5.7. TA

5 g of dried tomato powder was diluted 10 times with distilled water and filtered with filter paper № 1. and 10 ml of the solution was titrated with 0.1 N Sodium hydroxide solutions to a pink end-point. Then TA was calculated using (Eq. 4).

$$TA(\%) = \left(\frac{ml\ of\ NaOH(titre) \times 0.1N\ NaOH\ \times acid\ meq.factor}{ml\ of\ juice\ titrated}\right) \times 100 \quad \text{(Eq.4)}$$

2.5.8. Moisture content

The moisture content of the tomato slices was determined using (Eq. 5) with reference to the bone-dry weight of the slices.

$$M_{db} = \left(\frac{w_0 - wf}{w_f}\right) \times 100 \quad \text{Eq.5}$$

where: w_{db} is the moisture content (% db) at time t, w_0 is initial sample weight (g), w_f is the bone-dry weight (g) of the sample.

2.5.9. Water activity

The water activity of both dried and fresh tomato slices were measured using a water activity meter (model Novasina AG, CH-8853 Lachen) at room temperature (23.4 ± 1 °C).

2.5.10. Rehydration ratio (RR)

Rehydration ratio of the dried tomato samples was determined according to (Lewicki et al., 1998). First 1g of dried tomato slices were immersed in 100 mL of deionized water at room temperature for 50 min. Following this the excess water was drained and the slices were re weighted. Rehydration ratio was then calculated as the ratio of the weight of absorbed water over the initial sample weight.

2.5.11. PH

PH meter was used to measure PH value of the samples.

2.5.12. Color

To determine the Color parameters digital photographs of the samples were taken in a special chamber under Controlled conditions and the analyses of the photographs were done via Color Analyzer HTWG software. Photographs were taken inside a chamber with a black background. Once the parameters (L, a and b) were extracted, total color change (ΔE), chroma (C), and hue angle (h^0) was calculated using equations described by Wrolstad and Smith (2010) as follows using (Eqs. (6), (7), and (8)).

$$\Delta E = \left[(L - L_0)^2 + (a - a_0)^2 \ + (b - b_0)^2\right]^{\frac{1}{2}} \quad \text{(Eq.6)}$$

$$Chroma(C) = \left[a^2 + b^2\right]^{\frac{1}{2}} \quad \text{(Eq.7)}$$

$$Hue\ angle(h^0) = tan^{-1}\left(\frac{b}{a}\right) \quad \text{(Eq.8)}$$

The parameter L* represents the lightness of the color, a* the hue range of the colors red (+) and green (-) and b*hue range of colors yellow (+) and blue (-).

Total color difference (ΔE) indicated the magnitude of color difference between fresh and dried tomato slices. Fresh tomatoes were used as the reference (L_o, a_o, b_o) and a larger ΔE denotes greater color change from the reference material (Purkayastha et al., 2013). Hue angle ($h°$) values represent the degree of redness, yellowness, greenness, and blueness; the maximum is at 0, 90, 180, and 270, respectively (Wrolstad and Smith, 2010).

2.6. Statistical analysis

Procedures described by Gomez and Gomez (1984) was used in doing Analyses of Variance (ANOVA)for each quality parameter. SAS (Version 9.2) statistical software was used for ANOVA, in RCBD with three replications. The difference between treatment means was compared for characters having significant mean differences using Tukey's test at probability level Of 5%.

3. Result and discussions

3.1. Solar intensity, temperature, relative humidity and air velocity

The maximum solar radiation recorded during the experimental drying was 954 W/m^2 and the maximum air velocity recorded at collector inlet was 1.6 m/s. Maximum drying air temperature in the twin layer solar tunnel dryer were 53.3 °C, 58.2 °C and 61.2 °C at collector outlet, middle of the dryer (8m), and at dryer out let (16m) respectively and 38.2 °C for ambient air (Figure 4). The minimum relative humidity values were 7.4, 6.2, and 7.7 % at collector outlet, middle of the dryer (8m), and at dryer out let (16m) respectively and 14.3 % for ambient air (Figure 5).

3.2. Quality of dried tomato slices

3.2.1. Lycopene

Lycopene content of tomato slices were decreased after drying (Tables 1 & 2). The lycopene content of fresh tomato was 283.63 mg per 100g DM and of solar tunnel dried tomato ranges from 98.78 to 106.99 mg per 100 g DM (Tables 1 & 2). From the result it was observed that lycopene content of the dried tomatoes significantly decreased after drying compared to the fresh samples. Exposure of tomato to oxygen and heat results in the lycopene destruction (Shi et al., 1999) and this result may be obtained due to lycopene oxidation during drying.

Statistically significant differences ($p < 0.05$) were observed in lycopene content of tomato slices dried at different positions and tray of twin layer solar tunnel dryer (Tables 1 & 2). Increasing trend in lycopene content retention of dried tomato slices were observed along the length of the dryer. This may be due to increase of drying temperature along the length of the dryer which minimizes oxidation of lycopene as a result of short drying time and heat exposure. Similar results were observed by Purkayastha et al. (2013) for tomato slices dried at 50, 60, 65 and 70 °C of drying air temperatures, and reported that maximum amount of lycopene was found in the slices dried at 60 °C, and decrease of lycopene content beyond this temperature. Higher lycopene content was obtained in dried tomato slices on the lower tray than the upper tray. This may be due to degradation of lycopene by direct exposure to sun light.

Lycopene content retention of (34.82%–37.7%) were obtained from twin layer solar tunnel dryer and for tomato slices dried in open sun lycopene content retention of 24.44% were obtained (Tables 1 & 2). This lower retention in lycopene content of tomatoes dried in the open sun than the solar dried one may be due to long time exposure of the sun dried samples to oxygen and heat which resulted in the lycopene destruction. Coelho et al. (2013) reported 34.26–59% lycopene content retention of tomatoes dried with Convective Drying at 60 °C, 70 °C and 80 °C with 3,5 and 7 mm thickness. Retention of 52% and 67% was reported by Chang et al. (2006) in two varieties of freeze-dried tomatoes. For oven dried tomatoes lycopene retention in the range of 33.05–58.11% was reported by Mwende et al. (2018) in drying four different varieties of tomatoes to 13% final moisture content at drying temperature of 50, 60 and 70 °C. This result indicates that drying tomatoes in solar tunnel dryer can result in high retention of lycopene which is comparable with expensive methods like oven drying of tomato.

3.2.2. Vitamin C

Vitamin C is one of a group of organic complex compounds that the body needs in small quantities and which must be supplied from outside, as the human body cannot synthesize them (Rahmawati and Bundjali, 2012). Tomato is an important source of vitamin C for humans

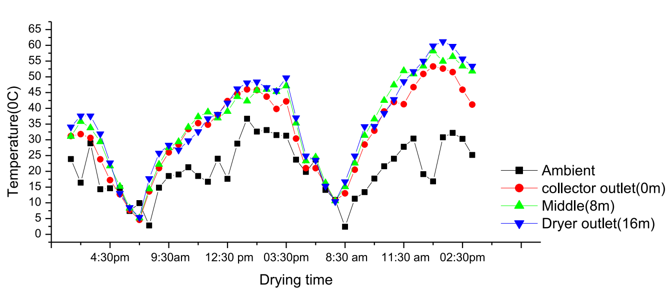

Figure 4. Variation of temperature of air at different positions of twin layer solar tunnel dryer and ambient air with time during load test on (22 Nov, 2018–24 Nov, 2018).

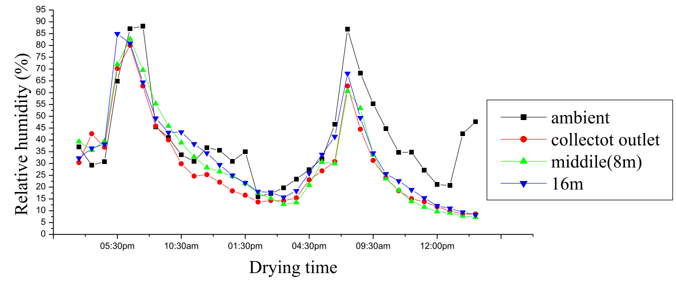

Figure 5. Variation of relative humidity of air at different positions of twin layer solar tunnel dryer and ambient air with time on (22 Nov, 2018–24 Nov, 2018).

(Villanueva Gutierrez, 2018). Since fruits and vegetables have a high content of Vitamin C, it is commonly used as a quality marker (Raponi et al., 2017). In this work vitamin C was determined in fresh and dried tomato slices dried at different drying positions of twin layer solar tunnel dryer. The vitamin C content in fresh tomatoes decreased after drying and Significant differences ($p < 0.05$) were observed among the samples dried at different positions (Table 1). A maximum Vitamin c loss was detected in the samples dried at dryer out let (16m) at which there is higher drying temperature. Relatively low vitamin C loss was observed at collector outlet (0m) of the twin layer solar tunnel dryer and this may be due to short drying time and low drying temperature. Due to high sensibility of vitamin C to heat, the combination between temperature and time during drying determines its retention (Santos and Silva, 2008). Similar results were observed by Purkayastha et al. (2013) for tomato slices dried at 50, 60, 65 and 70 °C of drying air temperatures, with constant drying air velocity of 1.1 m/s and reported that highest reduction in vitamin C occurred at 70 °C and lowest at 50 °C. Higher decrease of vitamin C was also observed in sun dried tomatoes. Loss of vitamin C increases with the increase of the heating time (Jacob et al., 2010). The higher loss of vitamin C content of the sun dried ones may be due to longer drying time during sun drying.

Vitamin C retention of 20.77 %–27.26% were obtained from twin layer solar tunnel dryer while for sun dried slices vitamin C retention of 20.9% was obtained (Table 1). These results of vitamin C retention are better than the data from the literature for vitamin C retention during heat processing of tomato products. Jacob et al. (2010) found 10% retention of vitamin C after preparation of tomato pastes at 110 °C for 15 min, and at 110 °C for 30 min Georgé et al. (2011) reported a 19% retention of vitamin C in processing of tomato to puree.

3.2.3. Antioxidant capacity

Thousands of phytochemicals in plants have been shown to act as antioxidants and contribute to human health. The major antioxidant phytochemicals in plants are phenolic compounds carotenoids, and glucosinolates (Li et al., 2012). Tomato has high antioxidant capacity both fresh and processed due to the composition of phytochemical compounds. The E_{50} value of fresh tomato was 0.1 mg/ml and was increased after drying. The E_{50} value of the twin layer solar tunnel dried tomatoes ranges from 0.085 to 0.145 mg/ml. Lower E_{50}value indicates higher antioxidant activity (Tables 1 & 2). This decreased antioxidant capacity may be related with the decrease of vitamin c, lycopene and phenolic content of the tomatoes after drying.

Tray position showed statistically significant difference ($p \leq 0.05$) on the E_{50} values of dried tomato slices (Table 2). Comparable value of antioxidant capacity of the solar tunnel dried tomatoes was observed with the fresh tomatoes. This may be due to high antioxidant capacity of bound phenolics released from the cell wall as a result of heat treatment and cis-isomers of lycopene and beta carotene formed during thermal processing of tomato through isomerization process. It was reported that bound phenolics extracts has better radical scavenging activity than the free extracts (Begum et al., 2015). With thermal processing Lycopene

Table 1. Analysis of variance (ANOVA) table for Physicochemical quality of twin layer solar tunnel dried tomato slices (Pr > F) values.

Parameters	Lycopene	Beta-carotene	Vitamin C	E_{50} value	Total soluble solids (TSS)	Titrable acidity TA	Log of Total phenolic content	Water activity (wa)	Moisture content (wb)	PH	Rehydration ratio (RR)
Rep	0.8955	0.9968	0.9607	-	0.7438	0.5439	-	0.6777	-	0.8859	0.4218
block	0.0056	<.0001	0.0001	0.0072	0.0623	0.1151	0.0276	<.0001	0.0120	<.0001	0.7922
Tray	0.0122	0.0001	0.772	**0.0402**	0.4835	**0.0444**	0.4728	<.0001	**0.0289**	0.0036	0.1000
Drying zone	**<.0001**	0.0018	**<.0001**	0.9698	**<.0001**	0.5827	0.1567	0.1571	0.5920	<.0001	0.2236
Tray* zone	0.1494	**0.0020**	0.6085	0.0947	0.1126	0.1055	0.5650	**<.0001**	0.0854	**0.0338**	**0.0389**

* The significant factors are written in bold.

Table 2. Effect of drying position on Lycopene Vitamin C and E_{50} value of twin layer solar tunnel dried tomato slices (means ± standard deviation).

Drying position	Lycopene (mg/100g DM)	Vitamin C (mg/100g DM)	E_{50} value (mg/ml)	Total soluble solids (TSS)
Collector out let (0m)	$98.78^{c} \pm 1.4$	$100.55^{a} \pm 12.3$	$0.11794^{a} \pm 0.037$	$8.46^{a} \pm 0.32$
Middle of the dryer (8m)	$101.73^{b} \pm 3.8$	$83.27^{b} \pm 15.5$	$0.11532^{a} \pm 0.036$	$8.08^{b} \pm 0.21$
Dryer out let (16m)	$106.99^{a} \pm 2.4$	$76.60^{b} \pm 4.6$	$0.11825^{a} \pm 0.040$	$7.68^{c} \pm 0.16$
sun	69.32601	77.07172	0.176	7.91
fresh	283.63	368.86	0.10	5.86
cv	2.23	11.26	15.66	2.87
Lsd	1.92	8.19	0.0334	0.19

*Means with the same letter are not significantly different ($p \geq 0.05$) according to Tukey's (significance difference) test.

undergoes isomerization in tomatoes and results in conversion of the all-trans isomers to the cis-isomers (Shi et al., 1999). Studies revealed that cis-isomers has a higher antioxidant potency than that of the all-trans isomer (Dewanto et al., 2002). In addition to this; the lower water activity of the solar tunnel dried tomatoes may have contributed to the reduction in occurrence of chemical reactions and enzyme activity thus improving the retention of phenolic compounds that contributes to increase in the antioxidant capacity.

The observed higher antioxidant capacity of lower trays dried tomatoes may be due to relatively higher phenolic, lycopene and beta-carotene contents of lower tray dried tomatoes in the solar tunnel dryer. According to literature data, phenolic compounds, vitamins, carotenoids, etc., show different antiradical kinetic action (Savatović et al., 2012); therefore it can be concluded that the different kinetic behavior of these compounds (phenols, vitamins, carotenoids etc.)Present in tomato, determined the antiradical activity of this natural source of antioxidants.

The anti-oxidant capacity of sun dried tomatoes were lower than the twin layer solar tunnel dried tomatoes with $E_{50\ value}$ of (0.176 mg/ml) and this may be comparatively due to the larger decrease in vitamin c, lycopene and total phenolic content of the tomato slices during sun drying. For the solar tunnel dried tomatoes a minimum retention of 68.9% to a maximum increase of 25% antioxidant activity measured by DPPH was obtained. Lutz et al. (2015) reported 16.4% retention of antioxidant capacity during tomato drying in the temperature range of 40 °C–130 °C which is much less than the minimum value obtained in tomatoes dried in twin type solar tunnel dryer.

3.2.4. Moisture content

Statistically no significant difference was observed among the moisture content of tomato slices dried at different positions of the dryer. But significant differences in moisture content of the samples were observed for the upper and lower tray dried tomato slices (Table 1). It was observed that relatively lower moisture content was obtained for upper tray tomato slices than the lower tray dried tomato slices (Table 3). this may be due to direct exposure of the upper trays to the solar radiation than the lower tray dried ones. This variation indicates existence of some variation between the relative humidity and temperature of the drying air on upper and lower trays.

3.2.5. β-carotene

β-carotene content of twin layer solar tunnel dried tomato slices showed statistically significant ($P \leq 0.05$) variation with drying position and tray position (Table 3). The β-carotene content of fresh sample was 17.05mg/100gDM and a decrease of β-carotene content was observed after drying for all samples. β-carotene is very unstable and degrades easily in heat and light and needs monitoring during the drying process (Ihns et al., 2011). The observed reduction in β – carotene contents in tomato slices after drying in this study is similar with previously reported works (Azeez et al., 2019) reported a decrease in beta carotene content of tomatoes after drying.

The highest value of β-carotene content (7.84 mg/100g DM) was obtained from the sample dried at dryer out let (16m) lower tray and the least amount of β-carotene was (5.52%) was obtained from the sample dried at middle of the dryer (8m) upper tray. It is observed that tomato slices dried on the lower tray resulted in higher beta carotene content

Table 3. Effect of tray position on Lycopene content and E_{50} value of twin layer solar tunnel dried tomato slices (means ± standard deviation).

Drying position	Lycopene (mg/100g DM)	$E_{50\ value}$ (mg/ml)	Titrable acidity (%) (TA)	Moisture content (%Wb)
Upper tray	$101.47^{b} \pm 4.7$	$0.13175^{a} \pm 0.037$	$0.848^{a} \pm 0.08$	5.52
Lower tray	$103.52^{a} \pm 3.8$	$0.10259^{b} \pm 0.026$	$0.801^{b} \pm 0.04$	6.27
sun	69.32601	0.176	0.725	7.34
fresh	283.63	0.10	0.0512	94.01
cv	2.23	15.66	8.06	7.34
Lsd	1.56	0.0272	0.046	0.64

*Means with the same letter are not significantly different ($p \geq 0.05$) according to Tukey's (significance difference) test.

than the upper tray dried ones and this may be due to direct exposure of the samples to sun light for the upper tray dried ones. Increase in the beta carotene content of the sample is observed along the length of the drier and this may be due to increase in drying temperature which shortens the light and heat exposure of the samples. Compared to sun drying higher β-carotene content was observed in solar tunnel dried slices than sun dried (3.68 mg/100g DM) ones.

β-carotene content retention of 32.37 %–45.9% were obtained from twin layer solar tunnel dryer while for sun dried slices β-carotene retention of 21.5% was obtained. Idah et al. (2010) reported 20 % retention of beta carotene in oven drying tomatoes of 10mm thickness at 90 °C.

Mwende et al. (2018) also reported 4.3–22.56 % beta carotene retention after oven drying of different tomato varieties to final moisture content of 13% at 50 °C, 60 °C, and 70 °C .The β-carotene retention obtained in this work is far better than the result obtained from oven drying of tomatoes at different drying temperature.

Beta-carotene retention of 32.37 %–45.98% was obtained from twin layer solar tunnel dryer dried slices while for sun dried slices Beta-carotene retention of 21.5% was obtained (Table 3). This lower retention of the sun dried ones could be due to long drying time in sun drying. These results of Beta-carotene retention are better than the data from the literature for Beta-carotene retention during heat processing of tomato products. Percentage β carotene retention values in the range of 4.30–22.56% was reported by Mwende et al. (2018) in drying four different varieties of tomatoes at drying temperature of 50,60 and 70 °C to 13% final moisture content by oven drying. Azeez et al. (2019) also reported 57.65, 56.61 and 58.83% retention of beta carotene after drying for 5 h at 50, 60 and 70 °C using vacuum oven drying and this indicates further drying could also lead to more degradation of beta-carotene.

3.2.6. Total phenol

Table 3. Presents the total phenolic content of tomato slices dried at different positions of solar tunnel dryer, under the sun and of fresh sample. The drying treatment greatly decreased the total phenolic content of the tomato samples. The total phenolic content of fresh sample were 586.26mg of GA/100gDM while of the solar tunnel dried ones are in the range of 259.96–362.95 mg GA/100gDM and 169.51 mg GA/100gDM for the sun dried ones. Sun dried tomatoes had lower phenolic content than Twin layer solar tunnel dried tomatoes. This low phenolic content of sun dried tomatoes could be due to the long time drying which has been reported to destroy some phenolic compounds (Azeez et al., 2019).

Statistically no significant difference ($P \geq 0.05$) were observed among tomato slices dried at different positions of solar tunnel dryer and on upper and lower tray. But variation in total phenolic content was observed among the tomato slices dried along the length of the dryer and on upper and lower try dried samples. It was observed that the total phenolic content of the tomato samples increased along the length of the dryer and this may be due to increase in the drying temperature along the length of the dryer. Different studies revealed that total phenolic content of tomato increases with increasing drying temperatures. Azeez et al., 2019 reported high phenolic contents in tomatoes dried at higher temperature than low temperature dried ones using vacuum oven drying at different temperatures (50, 60 and 70 C) with 0.1 m/s air velocity. Kim and Chin (2016) reported increase in the phenolic content of tomato as drying temperature increase from 60 to 100 °C. Santos-Sánchez et al. (2012) reported a 21.6% total phenolic content loss of tomato during drying at 45 °C and 1.2 m/s velocity whereas 2.1% total phenolic content loss of tomato during drying at 60 °C and 0.6 m/s air velocity. This high phenolic contents of high temperature dried tomatoes could be related to the increase in the release of bound phenolic from the cell wall as a result of heat treatment that breaks down the ester between phenolic and cell wall (Azeez et al., 2019).

Generally Total phenolic content retention of 44.34 %–61.9% was obtained from twin layer solar tunnel dryer dried slices while for sun dried slices Total phenolic content retention of 28.9% was obtained (Table 3). These results of total phenolic content retention are comparable with the data from the literature for total phenolic content retention during tomato processing. Georgé et al. (2011) reported 57% retention of red tomatoes after heat processing to produce tomato purée. Total phenolic content retention value of 60% was reported by Mwende et al. (2018) in drying four different varieties of tomatoes to 13% final moisture content at drying temperature of 50,60 and 70 °C by oven drying .

3.2.7. TSS

Total soluble solids (TSS) is mainly composed of a blend of hexose, sucrose, malate and citrate that all together reach 78% of the total content (Villanueva Gutierrez, 2018). In this study Significant differences ($p \leq 0.05$) were observed in total soluble solids content of tomato slices dried at different positions of twin type solar tunnel dryer (Table 2).

The value of TSS significantly ($P \leq 0.05$) increased after drying compared to the fresh sample and decrease as drying temperature increase along the length of the dryer. The solar tunnel dried samples resulted in higher TSS value (7.68–8.46)than the sun dried samples (7.91) and this may be due to long time dying of the samples. Yusufe et al. (2017) also reported an increase in TSS of Tomato slices after oven drying of tomato at 70, 80 and 90 °C and reported that TSS decreases as drying temperature increase. Similar results were observed by Purkayastha et al. (2013) for tomato slices dried at 50, 60, 65 and 70 °C of drying air temperatures. It is reported that highest amount of TSS was found in the slices dried at 50 °C; and further rise in drying temperature caused a reduction in total sugar content.

3.2.8. TA

Titratable acidity (TA) is a type of measurement that deals with total acid concentration in any food (Villanueva Gutierrez, 2018). The value of TA of dried tomatoes increased after drying (Table 3). The solar tunnel dried samples resulted in higher value TA (0.8–0.84) than the sun dried samples (0.72) and this may be due to high temperature drying of solar tunnel which may result in formation of different organic acid by milliard reaction. These values were in agreement with Abreu et al. (2011) who reported an increase of the TA in tomatoes submitted to drying. Similar results were reported by Purkayastha et al. (2013) for tomato slices dried at 50, 60, 65 and 70 °C of drying air temperatures. Yusufe et al. (2017) also reported an increase in TA of tomato slices after oven drying of tomato at 70 80 and 90 °C. This elevation of the TA promoted by the dehydration can be associated to the tendency of the fall of the pH of the dried tomatoes (Abreu et al., 2011). Significant differences ($p \leq 0.05$) were observed between TA of slices dried on the upper and lower tray of the solar tunnel dryer. Higher TA values were obtained for slices dried on the upper tray than the lower tray.

3.2.9. Water activity (aw)

Water activity, aw, is the term which indicates the availability of free water in a product for growth of microorganisms, chemical reactions, and spore germinations (Vijayan et al., 2017). It does play a pivotal role in stability of products obtained from vegetables due to the direct involvement of water in practically chemical and biochemical reactions (Schiraldi et al., 2012). Lowering the water activity of food is among the most common and the oldest forms of food preservation (Bourdoux et al., 2016). In this study statistically Significant differences ($p \leq 0.05$) were observed in Water activity values of tomato slices dried at different positions of twin layer solar tunnel dryer (Tables 1 & 4). Water activity of the twin layer solar tunnel dried tomato slices ranges from (0.288–0.32) Quality of food products is mainly affected by yeasts, moulds, bacteria and other microorganisms if the water activity is more than 0.7 (Vijayan et al., 2017). Foods with water activity in the range 0.5–0.8 are more susceptible to non-enzymatic browning and values under 0.2 results in Lipid oxidation (Guiné and Barroca, 2017). The result obtained in this work is in the safe range from microbial growth,enzymatic and non-enzymatic browning and Lipid oxidation. Therefore; these water

Table 4. Interaction effect of drying position and tray position on Beta-carotene, total phenol, water activity PH and Rehydration ratio of twin layer solar tunnel dried and sun dried tomato slices (means ± standard deviation).

Drying position	Tray position	Beta-carotene (mg/100g DM)	Log of Total phenolic content (mg of GA/100gDM)	Water activity (wa)	PH	(Rehydration ratio) RR
Collector out let(0m	upper	$6.27^{bc} \pm 0.64$	$2.4^{a} \pm 0.023$	$0.298^{ab} \pm 0.01$	$4.16^{b} \pm 0.05$	$3.85^{a} \pm 0.21$
	Lower	$6.06^{bc} \pm 1.3$	$2.46^{a} \pm 0.08$	$0.30^{ab} \pm 0.01$	$4.23^{ab} \pm 0.06$	$3.43^{b} \pm 0.13$
Middle of the dryer (8m)	upper	$5.52^{c} \pm 0.15$	$2.45^{a} \pm 0.03$	$0.2895^{b} \pm 0.01$	$4.26^{ab} \pm 0.02$	$3.75^{ab} \pm 0.17$
	Lower	$7.21^{ab} \pm 1.53$	$2.51^{a} \pm 0.09$	$0.32^{a} \pm 0.00$	$4.29^{a} \pm 0.09$	$3.77^{ab} \pm 0.17$
Dryer out let (16m)	upper	$6.45^{abc} \pm 0.25$	$2.54^{a} \pm 0.11$	$0.288^{b} \pm 0.02$	$4.32^{a} \pm 0.03$	$3.59^{ab} \pm 0.34$
	Lower	$7.84^{a} \pm 0.37$	$2.55^{a} \pm 0.11$	$0.312^{a} \pm 0.00$	$4.32^{a} \pm 0.04$	$3.61^{ab} \pm 0.22$
sun		3.68	2.22	0.324	4.206333	3.15
fresh		17.05	2.768	0.95	4.359167	-
cv		9.5	2.18	1.899	0.73	6.16
Lsd		1.56	0.18	0.02	0.09	0.39

*Means with the same letter are not significantly different ($p \geq 0.05$) according to Tukey's (significance difference) test.

activity values of all tomato slices dried at different positions of twin type solar tunnel dryer make the dried tomatoes safer and shelf-stable with respect to microbial growth and chemical reactions though the storage conditions also play an important role.

3.2.10. Rehydration ratio (RR)

Rehydration ratio is important parameter in effective dehydration. The rehydration ratio of twin layer solar tunnel dryer were in the range of (3.43–3.85) and of the sun dried ones was 3.15. Statistically significant ($P \leq 0.05$) difference was observed among the Rehydration ratio of solar tunnel dried tomato slices (Table 4). Relatively higher rehydration ratio was observed in tomato slices dried at collector out let upper tray. Statistically no significant variation ($P \geq 0.05$) was observed for the Rehydration ratio of slices dried at middle and dryer out let of both upper and lower tray dried ones. Compared to the tomato slices dried in open sun the tomato slices dried in solar tunnel drier showed the highest rehydration ratio than sun dried ones and this may be due to long time drying. Similar results were reported by Kulanthaisami et al. (2010) for rehydration ratio of tomato slices dried in Cabinet solar dryer with 4,6 and 8mm thickness to be 3.25, 3.56 and 3.61 respectively when compared to open sun dried (2.95, 3.15 and 3.24) slices. Moisture content of 58% were reported by Lopez-Quiroga et al. (2020) as a maximum rehydration capacity at 50 °C for freeze-dried tomatoes. But the rehydration capacity in this work is in the range of 78.73%–81.57% moisture content for twin layer solar tunnel dried tomato slices and 77.5% for sun dried tomato slices.

3.2.11. PH

A decrease in PH value of the of twin layer solar tunnel dried tomato slices were observed after drying and, statistically significant differences ($p \leq 0.05$) were observed among the samples dried at different positions of the dryer (Table 4). slices dried in middle and dryer out let had higher PH value than slices dried at collector out let. Slices dried on the upper tray showed lower PH value than the slices dried on the lower tray. The average pH values of fresh tomato samples were 4.36 and of the solar tunnel dried tomato slices were in the range of (4.16–4.32) and a PH value of 4.2 was observed for the Sun dried tomato slices. Tomatoes and tomato products are classified as an acidic food ($pH < 4.6$) (Lucci et al., 2016). PH below 4.5 is an advantageous attribute, since it stops production of microorganisms (Tigist et al., 2013). The PH value of both fresh and dried tomatoes dried in the tunnel drier and in the sun fall in this category.

3.2.12. Color

Color Values of tomato slices dried at different positions of twin layer solar tunnel dryer is shown in Table 5. Decrease in the L value (lightness) was observed in dried tomato samples dried at middle and collector out let of the dryer. This is in agreement with a previous study by Ashebir et al. (2009); who reported decrease in brightness of tomato slices after hot-air drying for different tomato cultivars. It was observed that darkening of tomatoes increases with increase in temperature and relative humidity of the drying air at high moisture content. Purkayastha et al. (2013) also reported a decreased L-value of the dried tomato slices with increase in drying temperature. Decrease in '+a' and '+b' values of tomato slices were also observed in dried tomato samples and high decrease was observed in the slices dried at middle and dryer out let. This may be due to higher drying temperature at middle and dryer out let of the dryer. This is also in agreement with Purkayastha et al. (2013) who reported decrease in Hunter '+a' value and '+b' values of tomato slices at higher drying temperature (700C) compare to low drying temperatures (60 and 500C). Increasing trend of overall color change (ΔE) was observed along the length of the dryer. This may be due to Maillard reaction and conversion of trans-lycopene to cis-form at high drying temperatures. Sahin et al. (2011) reported ΔE values of 25, 16.62, 37.85, and 22.84 for Sun drying, Hot air drying at 65 °C, Vacuum drying at 75 °C and Freeze drying of tomato slices respectively. The overall color change

Table 5. Color Values of fresh and dried tomato slices dried at different positions of twin layer solar tunnel dryer.

Drying position	Fresh tomato slices					Dried tomato slices					
	L_0	a_0	b_0	$h^0{}_0$	C_0	L	a	b	h^0	C	ΔE
0 up	20.64	19.97	8.47	22.98	21.69	20.89	14.87	3.25	12.32	15.22	7.30
0 low	21.84	18.85	7.36	21.33	20.24	30.97	22.11	9.89	24.09	24.22	10.02
8 up	38.38	21.15	10.79	27.04	23.74	28.35	17.22	-0.22	-0.73	17.22	15.41
8 low	38.07	23.26	14.05	31.13	27.18	23.49	17.97	3.95	12.40	18.40	18.51
16 up	23.63	21.62	9.05	22.71	23.43	13.88	10.70	0.60	3.254	10.71	16.90
16 low	23.85	21.67	8.51	21.44	23.29	17.56	13.53	0.83	3.533	13.56	12.84

Where: L_0 = lightnes of the fresh sample, L = lightness of the dry sample, $h^0{}_{0=}$ hue angle of the fresh sample,h^0 = hue angle of the dry sample, $C_{0=}$Chroma of the fresh sample, C= Chroma of the dry samples.

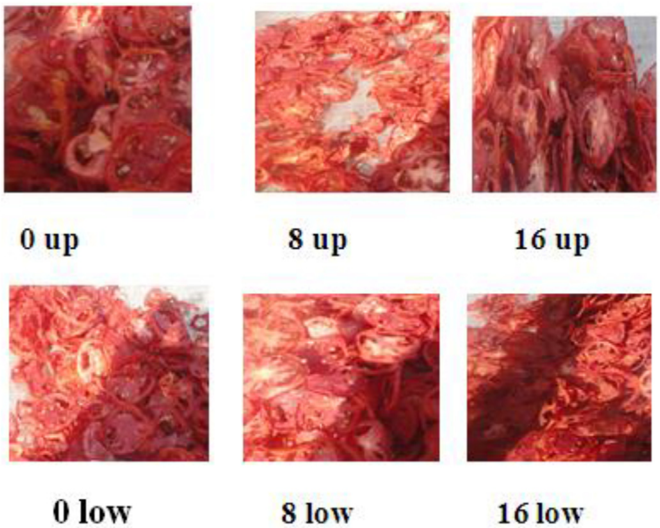

Figure 6. Twin layer solar tunnel dried tomatoes (0up = collector outlet upper tray, 0low = collector outlet lower tray, 8up = middle upper tray 8low = middle lower tray 16up = dryer outlet upper tray 16l0w = dryer outlet lower tray).

Figure 7. Dried tomatoes on the twin layer solar tunnel dryer.

(ΔE) obtained in this work is much better than the most expensive method of drying such as Vacuum and freeze drying. Figures 6 and 7 shows dried tomatoes at different positions of twin layer solar tunnel dryer. But ΔE* indexes, which is given for comparing with other indexes, is not a good indicator to define color differences If there is significant total color difference, total color differential index is not sufficient to define which color parameters (L*, a* and/or b*) caused this (Anonymous, 1996).

Tomato color changes occur due to Maillard reaction or non-enzymatic browning (Cernîşev, 2010), conversion of the all-trans-lycopene to a less strongly colored, less intensely absorbing cis-form,and lycopene degradation (Coelho et al., 2013) during drying. Lycopene contributes to characteristic red color to tomato and it is the predominant carotenoid pigment of tomato (Sacilik, 2007). When changes of color are only due to the diminishment of trans-lycopene Color values are best related to lycopene. In the hot air drying; other contributions, such as non-enzymatic browning, affects color changes (Xu et al., 2016).

The hue angle (h^0) and Chroma values of the dried tomatoes were decreased for all twin layer solar tunnel dried tomatoes and decreasing trend was observed along the length of the dryer. The decrease in hue angle (h^0) along the length of the dryer may be due to higher retention of lycopene content of the slices dried at the middle and dryer out let. Chroma reflects color purity or saturation. It is an expression of the purity or saturation of a single color (different colors may have the same Chroma values) (López Camelo and Gómez, 2004).

4. Conclusions and recommendations

Twin layer solar tunnel dryer was tested for drying tomato slices under jimma, Ethiopia weather condition by loading with 180 kg of 5mm tomato slices. The quality of dried tomato slices were compared with the fresh and sun dried ones. From the result the twin layer solar tunnel dried tomatoes showed a good retention of lycopene, total phenol, beta-carotene and antioxidant capacity which is comparable with the reported data of energy intensive mechanical drying methods and much more better than sun drying. The water activity and PH values of the solar tunnel dried tomatoes were within the safe range from microbial growth, enzymatic and non-enzymatic browning. Comparatively from the two layer of trays (upper layer and lower layer trays) lower try showed higher retention of lycopene, total phenol and beta-carotene and better TSS and RR value than the upper layer tray dried ones and no significant difference was observed in vitamin C content of upper and lower layer tray dried tomatoes. But Tomato slices dried on the upper layer tray showed better color values than the lower layer tray dried ones. Based on the result, twin layer solar tunnel dryer can be used for tomato drying; to maintain high percentage of the original quality of the tomato slices after drying which is comparable with the most expensive drying methods. Furthermore; it is recommended to study microbial quality of the solar tunnel dried tomatoes together with its shelf life in different packaging materials.

Declarations

Author contribution statement

Lelise Tilahun Dufera: Conceived and designed the experiments; Performed the experiments; Analyzed and interpreted the data; Wrote the paper.

Werner Hofacker, Albert Esper, Oliver Hensel: Conceived and designed the experiments; Wrote the paper.

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Data availability statement

Data will be made available on request.

Declaration of interests statement

The authors declare no conflict of interest.

Additional information

No additional information is available for this paper.

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