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Evaluation of drying methods on the content of some bio-actives (lycopene, β-carotene and ascorbic acid) of tomato slices

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Tomato (*Solanum lycopersycum* L.) is one of the most important vegetables worldwide. As it is a relatively short duration crop and gives a high yield, it is economically attractive. Thus, the objective of this study was to evaluate the effect of drying method on the quality of the dried tomatoes based on three parameters viz; lycopene, ß-carotene and ascorbic acid contents. Thirty-six kilograms of tomatoes were sorted, cleaned, blanched and divided into three equal portions of 12 kg each. The tomatoes were sliced into 4, 6 and 8 mm, then sun, solar and hybrid dried, respectively. The value of lycopene content obtained for sun dried tomatoes ranged from 23.89 to 18.77 mg/100 g, solar dried ranged from 24.51 to 22.56 mg/100 g and hybrid dried ranged from 25.12 to 24.65 mg/100 g. The average value of β-carotene content obtained for sun dried tomatoes ranged from 4.12 to 3.72 mg/100 g, solar dried ranged from 4.94 to 4.25 mg/100 g and hybrid dried ranged from 4.98 to 4.65 mg/100 g. The values of ascorbic acid obtained for sun dried tomatoes ranged from 17.04 to 5.60 mg/100 g, solar dried ranged from 23.73 to 13.37 mg/100 g and hybrid dried ranged from 29.20 to 24.82 mg/100 g. Hybrid dried tomatoes slice showed higher retention of lycopene, ß-Carotene and ascorbic acid than both the solar and open sun dried methods.

Key words: Tomato, hybrid-photovoltaic dryer, solar dryer, sun drying, lycopene, β-carotene and ascorbic acid.

INTRODUCTION

Tomato (*Lycopersicon esculentum* Mill.) belongs to the family *Solanaceae*, the main vegetable grown and most widely consumed and is therefore of strategic importance (Celma et al., 2009). It is highly seasonal and available in large quantities at a particular season of the year (Lorenz and Maynard, 1997). The tomato crop is noted to be the second most important vegetable crop next to potato (FAOSTAT, 2010). Tomato fruits had a high moisture

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content (90 to 94%), makes the fruit highly perishable (Rajkumar, 2007; Al-Sananbani et al., 2013). This fruits are rich sources of potentially bioactive compounds as health functional constituents including red-coloured carotenoid lycopene, β-carotene, vitamins E and C, phenolics, organic acids and flavonoids (Kaur et al., 2002; Periago and Garcia-Alonso, 2009; Kalogeropoulos et al., 2012). Also, tomatoes are widely known for their outstanding antioxidant content, including their high concentration of lycopene and excellent amounts of other conventional antioxidants like vitamin C and tocopherols, additional carotenoids (β-carotene, lutein, and zeaxanthin), trace minerals (selenium, copper, manganese and zinc) and phytonutrients including flavonoids (naringenin, rutin, kaempferol, and quercetin) and hydroxycinnamic acids (caffeic, ferulic, and coumaric acid) (Capanoglu et al., 2010; Fernández-ruiz et al., 2011). High levels of antioxidants present in tomatoes and tomato products help prevent oxidative damage that is hazardous for humans. Moreover, it is widely recognized that the protective role of tomato consumption is due to the synergistic effect among the different classes of antioxidants. Aside from the genetic potential of the cultivar, agronomic and environmental conditions, ripening stage of fruit and post-harvest storage are known to affect the chemical composition of tomatoes (Garcia and Barrett, 2006; Hernández et al., 2007; Al-Sanabani et al., (2013).

Adejumo (2012) reported that a medium sized tomato contributes 40% of ascorbic acid (vitamin C) required in humans, which is important in forming collagen, a protein that gives structure to the bones, cartilage, muscle, and blood vessels and aids in the absorption of iron. Ascorbic acid is necessary for healthy teeth, gums and is essential for proper functioning of adrenal and thyroid glands. It is also an antioxidant and as such acts as a general de-toxicant. USDA (2010) reported that tomato fruits contained vitamin A (5%), vitamin C (17%), and vitamin E (4%), potassium (5%). Vitamin A is needed for maintenance of skin, mucous membranes, bones, teeth, hair, vision and reproduction processes. The chemical composition of the tomato fruit depends on factors such as cultivar, maturity and environmental conditions, in which they are grown (Davies and Hobson, 1981).

Recent studies have demonstrated that the regular intake of tomato, either fresh or processed, is associated with a reduced risk of inflammation, cancer, cardio-vascular diseases and obesity and can increase cell protection from DNA damage by oxidant species (Harms-Ringdahl et al., 2012; García-Valverde et al., 2013; Raiola et al., 2014). Other medicinal benefits of tomatoes include reduction of cholesterol, improvement of vision, maintenance of gut, lowering of hypertension, alleviation of diabetes, protection of the skin, prevention of urinary tract infections and gallstones. Lycopene is used in cosmetics and pharmaceutical products and is an excellent natural colorant in several food formulations (Arab and Steck, 2000; Egydio et al., 2010; Levelly and Torresani, 2011; Itziar et al., 2013).

Nigeria ranks as the 16th largest tomato producing nation in the world and has the comparative advantage and potential to lead the world in tomato production and exports (FAOSTAT, 2010). The production of tomatoes in Nigeria in 2010 was about 1.8 million metric tonnes, which accounts for about 68.4% of West Africa, 10.8% of Africa's total output and 1.28% of world output (FAOSTAT, 2010). Unfortunately, the country still experiences deficiency in critical inputs, lack of improved technology, low yield and productivity, high postharvest losses and lack of processing and marketing infrastructure. The demand for tomato and its by-products far outweighs the supply. With a population of over 170 million people, an estimated national population growth rate of 5.7% per annum, and an average economic growth rate of 3.5% per annum in the past five years, Nigeria has a large market for processed tomato products (Ugonna et al., 2015).

Again, tomato has a limited shelf life at ambient conditions and is highly perishable. The demand for a wide range of processed tomato products has increased remarkably both in the retail and the food ingredient markets (Verlent et al., 2006). To increase the shelf life of tomatoes, different preservation techniques are being employed; however the success of these methods depends on how it meets certain requirements of the product quality for consumption. Many developing countries still face enormous challenges of postharvest losses of tomatoes due to inadequate processing and storage facilities. Tomatoes produced in the peak seasons are either consumed fresh, sold at relatively cheap prices, or are allowed to go waste (Abano and Sam-Amoah, 2011).

Drying is a very common preservation method used in foodstuffs and the quality of the final products is strongly dependent on the technique and the process variables used (Doymaz, 2005). The reduction of water activity by moisture removal leads to significant reduction of weight and volume, minimizing packaging, transportation and storage costs (Okos et al., 1992). Drying also, alters other physical, biological and chemical properties of foods (Demirhan and Özbek, 2010). Hot-air drying is one of the most frequently used operations for food dehydration (Krokida and Maroulis, 1999; Youssef and Mokhtar, 2014). A major disadvantage associated with hot-air drying is that it takes long time even at high temperature, which may cause serious damage to the flavour, colour and nutrients in dried products (Jing et al., 2010; Youssef and Mokhtar, 2014). Sun drying is a well-known traditional method of drying agricultural commodities immediately after harvest since the existence of human. Adejumo (2012) reported that a large percentage of tomatoes are usually sun dried on the bear ground to avoid wastages but such methods results in products with unattractive attributes, since the

product is unprotected from the environmental factors and infestation by insects, rodents, animals etc.

It then becomes expedient to produce solar dryers that would have added advantage of longer period residence, increased productivity and reliability through its ability to augment available heat during days with limited radiation as well as ability to operate during the night. In a hybrid solar dryer, drying is continued during off sunshine hours by back-up heat energy or storage heat energy. Therefore, the product is saved from possible deterioration by microbial infestation (Hossain et al., 2010). Drying helps to extend the shelf-life, decrease product volume significantly, increase product diversity, increases product food applications and improved products qualities and increased economic benefit. However, drying can accelerate some reactions that can adversely affect the product quality too (Akanbi and Oludemi, 2004). The interest in the production of dried tomatoes is increasing because of the possibility of using them in different purposes and drying efficiencies alone may not be adequate in qualifying this dryer for acceptance, except when the quality of the dried product is comparable to other alternatives in terms of lycopene, ß-carotene and ascorbic acid. This study represents the first systematic analysis of the effects of three different drying methods (sun, solar and hybrid-photovoltaic solar drying) on lycopene, ß-carotene and ascorbic acid of tomato slices.

MATERIALS AND METHODS

Sample source and preparation

In this study, tomatoes were obtained from the Jimeta Modern Market Yola, Nigeria. Tomatoes were selected from the lot based on; firmness, colour and size uniformity. They were sorted, cleaned thoroughly by washing under tap water (Owusu et al., 2012). Thirty-six kilograms of tomatoes were washed, sorted, blanched (in boiling water 100^{o}C for 2 min to inactivate enzymes) and divided into three equal portions of 12 kg each. Then, each portion was sliced with Hand Tomato Slicer to a thickness of 4, 6 and 8 mm, respectively. The moisture content of the fresh fruits was immediately determined according to the AOAC (2000) method (number 934.01), and found to be 94.22 ± 0.21 g water per 100 g sample.

Drying method

Open sun drying method

Out of the first portion (12 kg and 4 mm thickness), 4 kg of the sliced was spread in a single layer on a four different wire meshes (1 kg on each wire mesh) and sun dried until equilibrium moisture content was achieved. The procedure was repeated for the second portion (12 kg and 6 mm thickness) and third portion (12 kg and 8 mm thickness). The drying time required to reach the equilibrium moisture content was 510, 630 and 840 min and the moisture content of the dried slices was 9.75 ± 0.21, 9.83 ± 0.10 and 9.91 ± 0.15 g water per 100 g slices dried with 4, 6 and 8 mm thickness, respectively. The average of atmospheric temperature was approximately 40 – 45^{o}C daily.

Solar drying method

The second portion (12 kg and 4 mm thickness) 4 kg of the sliced was dried in the constructed hybrid dryer (1 kg on each tray) by using solar collector as the heating source alone. This is the solar drying method; here the heating source is from solar collector alone. The heater was not working in this case but the solar energy from the panel was charging the battery. So if the weather changes with poor sun intensity especially when drying through the night, the stored energy in the battery will power the heater to generate heat to facilitate drying process. The procedure was repeated for the second portion (12 kg and 6 mm thickness) and third portion (12 kg and 8 mm thickness). The drying time required to reach the equilibrium moisture content was 420, 510 and 600 min and the moisture content of the dried slices was 8.63 ± 0.22, 9.56 ± 0.48 and 9.71 ± 0.51 g water per 100 g slices dried with 4, 6 and 8 mm thickness, respectively. The average of atmospheric temperature was approximately 40 to 45°C daily.

Hybrid-photovoltaic solar dryer

The residual quantity, (12 kg and 4 mm thickness) was also dried in the constructed hybrid dryer (1 kg on each tray) but by using both heating source together. The schematic diagram of the experimental system is shown in Figure 1. The procedure was repeated for the second portion (12 kg and 6 mm thickness) and third portion (12 kg and 8 mm thickness). The drying time required to reach the equilibrium moisture content 300, 360 and 420 min and the moisture content of the dried slices was 6.57 ± 0.32, 7.63 ± 0.60 and 8.57 ± 0.15 g water per 100 g slices dried with 4, 6 and 8 mm thickness, respectively. The average of atmospheric temperature was approximately 40 to 45°C daily.

Determination of lycopene and vitamins in the fresh and dried tomatoes

Lycopene analyses

Spectrophotometric determination of lycopene content was carried out by using Spectrophotometer (UV-VIS SPECORD Analytik Jena, Germany) as described by Alda et al. (2009). Lycopene in the fresh and dried tomatoes samples were extracted by adding 8.0 ml of the mixture of hexane–acetone–ethanol (2:1:1, v/v/v) wrapped with aluminum foil to exclude light. Tubes were cap and vortex immediately, and then incubate out of bright light. The mixture was extracted at room temperature for 30 min. This extract was reconstituted with 10 mL distilled water on a vortex mixer for 1 min. The samples were allowed to stand for 10 min so as to allow phases to separate and all air bubbles to disappear. The cuvette was rinsed with the upper layer from one of the blank samples, then using hexane as a blank to zero at 503 nm determine the A_{503} of the upper layers of the lycopene samples. Lycopene levels in the hexane extracts was calculate as follows:

$$Lycopene\,(mg/100g) = (A_{503} \times 537 \times 8 \times 0.55)/(0.10 \times 172)$$

Where: The molecular weight of lycopene = 537g/mole, The volume of mixed solvent = 8 ml, The volume ratio of the upper layer to the mixed solvent = 0.55, The weight of added tomato = 1.0 g, The extinction coefficient for lycopene in hexane = 172 mM^{-1}, The Spectrophotometer at 503nm = A_{503}.

βcarotene (Pro-vitamin A) analyses

Vitamin A determination was carried out by using the method

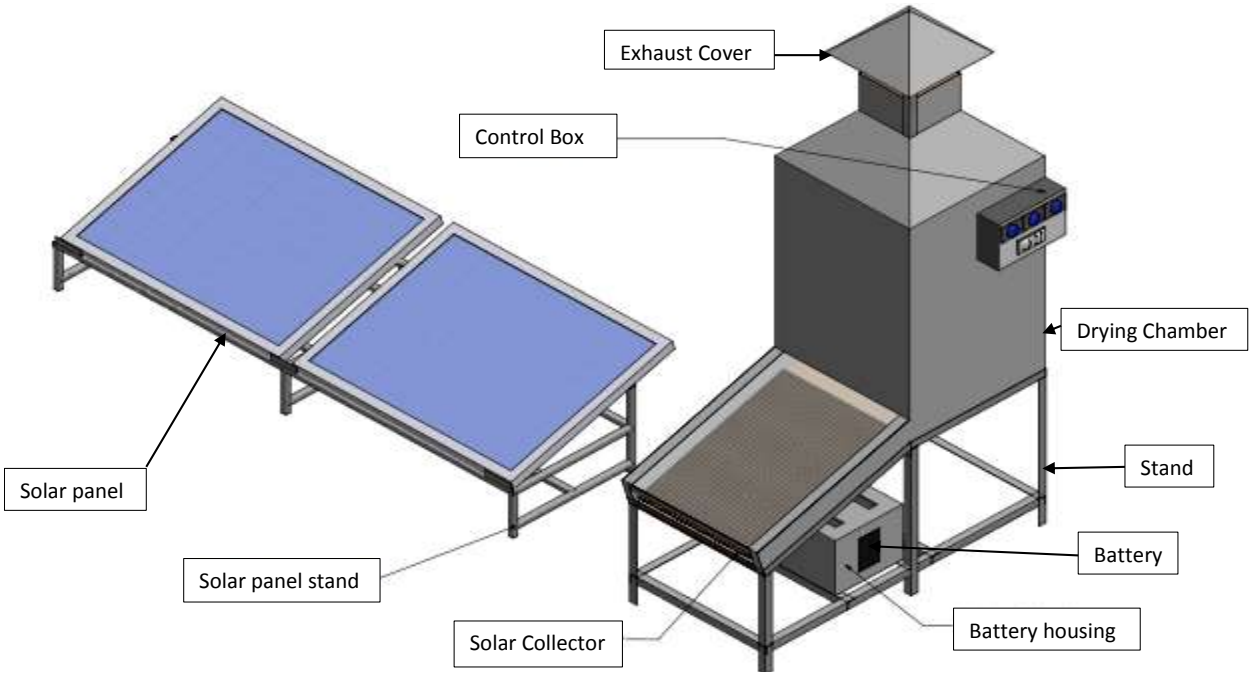

Figure 1. Isometric view of the hybrid dryer.

described by Onwuka (2005); this involves 200 µl of distilled water was placed in appropriate test tubes for blanks, samples and standard solution. Then 200 µl of alcoholic KOH was added to all tubes (including blanks) and mixed well on the vortex mixed for 10 to 20 s. Tubes were then placed in a water bath at approximately 55 to 60°C for 20 min. After 20 min, samples were cooled to room temperature and 200 µl of xylene- kerosene mixture was added. Retinol was extracted by vigorous mixing of each tube on the vortex for at least 30 s. Centrifugation was done for 5 min at 600 to 1000 xg. Xylene-Kerosene supernatant was withdrawn by means of a constriction micropipette connected to a rubber tube (for mouth sucking) and placing this sample extract in the spectrophotometer cuvettes. Readings were done at 328 nm for retinol and 460 nm for total carotenoids. Sample extract was transferred from the cuvette to glass tubes for irradiation. All the samples and blanks were irradiated for 35 min using an ultraviolet for source. The irradiated samples extract were transferred to cuvettes and their optical absorbance was read at 328 nm.

$$Retinol\ (\mu g/dl)\ =\ A^o\ (328)\ -\ A'\ X\ 637$$
$$Carotenes\ (\mu g/dl)\ =\ A^o\ (460)\ X\ 480$$

Where: A^o = Initial optical absorbance reading. A' = Optical absorbance after ultra violet irradiation.

Ascorbic acid analyses

Ascorbic acid was determined using the AOAC (2000) official titrimetry method. An aliquot (10 g) of the sample was diluted to a fixed volume (100 ml) with 3% HPO_3 and then titrated with 2, 6-dichlorophenolindophenol. A standard ascorbic acid solution of 5 mL was added to 5 mL of 3% HPO_3 and titrated with dye solution to a pink colour, which persisted for 15 s. Triplicate determinations were carried out and the result averaged. Ascorbic acid (mg/100 g) of reconstituted juice was calculated using the following formula:

$$Ascorbic\ acid\ (mg/100\ g) = \frac{T \times DF \times V_1}{V_2 \times V_3}$$

Where, T = titre; DF = Dye factor; V_1 = volume made up (100 ml); V_2 = aliquot of extract taken for estimation (10 g) and V_3= volume of sample taken for estimation (10 ml).

Statistical analysis

All experiments were performed in triplicate, and the results were expressed as means ± standard deviation (SD). Analysis of variance (ANOVA) was carried out to determine any significant differences in measurements using the SPSS statistical software (SPSS 20.0 for Windows; SPSS Inc., Chicago, IL, USA) and considering the confidence level of 95%. The significance of the difference between the means was determined using the Duncan Multiple range test, and the differences were considered to be significant at $p< 0.05$.

RESULTS AND DISCUSSION

Drying characteristics of tomato fruits

The change in moisture content (wet basis) of tomatoes slices with drying time (min) in open sun, solar and hybrid-photovoltaic solar dryer was showed in Figure 2. It was observed that the total drying time for 4, 6 and 8 mm thickness slices was 510, 630 and 840 min, respectively in open sun drying, 420, 510, 600 min, respectively; in solar drying and 300, 360, 420 min, respectively in hybrid-photovoltaic solar drying. All curves showed a clear exponential tendency with moisture content

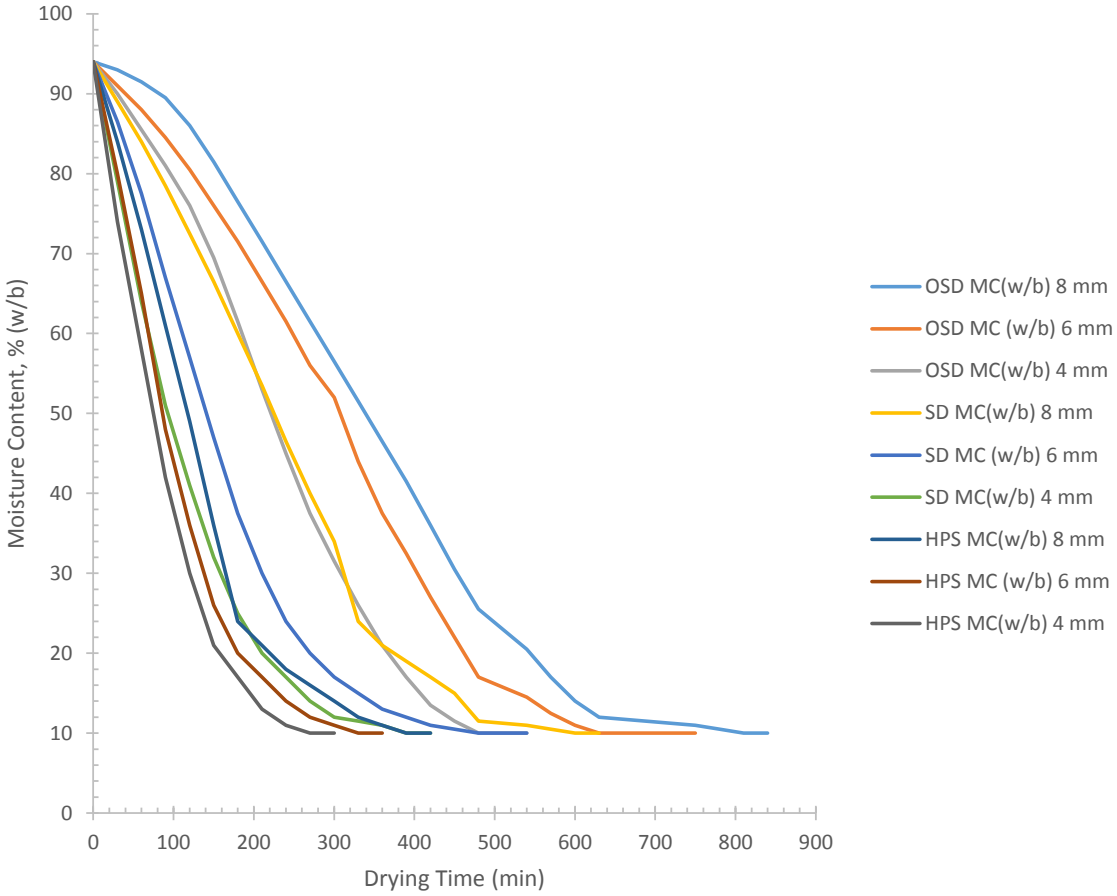

Figure 2. Drying curves for tomato slices at different thickness during for open sun, solar and hybrid-photovoltaic solar drying. OSD MC = Open Sun Drying Moisture Content, SD MC = Solar Drying Moisture Content, HPS MC = Hybrid-photovoltaic Solar Drying Moisture Content.

decreasing as the drying time increased. This shows that for a given thickness, the hybrid-photovoltaic drying method required shorter drying time when compared to solar and open sun drying. The drying followed a falling rate period and the decrease of thickness tomato slices accelerated the drying process. As thickness decreased, moisture removal also increased and ultimately resulted in the reduction in drying time. Drying time reduced from 840 to 510 min as the thickness tomato slices decreased from 8 to 4 mm (open sun-dryer), 600 to 420 min (solar dryer) and 420 to 300 min (hybrid-photovoltaic dryer). This means that there was significant savings in time as thickness decreased and type of dryer. The results agree with what reported by Sacilik et al. (2006) and Rajkumar (2007), The moisture content (wet basis, wb) of fresh tomato was 94.22 %, 9.83% (open sun dried tomato), 9.56% (solar dried) and was 7.63% (hybrid-photovoltaic dried). The results indicate that much moisture was removed in hybrid-photovoltaic drying method compared to sun and solar drying method within a short period of time. These results is in agreement with Toor and Savage (2006).

Influence of drying method on lycopene, ß-carotene and ascorbic acid content

Lycopene, the pigment of red tomatoes, determines the biological and curative value of dried tomatoes. It is a carotenoid belonging to the same group of β-carotene and gives the red colour to tomatoes. Among the most prominent phytochemicals in tomatoes are the carotenoids of which lycopene is the most abundant in the ripened fruit, accounting for approximately 80-90% of the total pigments (Helyes et al., 2009; Shi et al., 2009). This compound is not only a pigment but also a strong antioxidant, which neutralizes the free radicals, and, especially, the oxygen derived ones. Its ability to inhibit the oxidative activity of the active oxygen is twice higher than in case of β-carotene and 10 times higher than in case of α- tocopherol (Shi and LeMaguer, 2000). Lycopene is an important carotenoid from human plasma, but unlike β-carotene it does not have the activity of vitamin A. The biological role of lycopene in human body also consists in its capacity of preventing the oxidative reactions. It neutralizes the toxic compounds that are

Table 1. The effect of drying methods on the lycopene, β-carotene and ascorbic acid (mg/100g) of tomato slices.

Samples	Thickness (mm)	Lycopene (mg/100 g)	*ß*-carotene (mg/100 g)	Ascorbic acid (mg/100 g)
Fresh	-	15.51 ± 0.31^{d}	0.88 ± 0.02^{i}	40.15 ± 2.11^{a}
	4	23.89 ± 0.19^{a}	4.15 ± 0.03^{f}	17.04 ± 0.61^{e}
Sun dried	6	22.33 ± 0.90^{b}	3.96 ± 0.01^{g}	12.78 ± 1.05^{f}
	8	18.77 ± 0.77^{c}	3.72 ± 0.01^{h}	5.60 ± 0.95^{g}
	4	24.51 ± 0.30^{a}	4.94 ± 0.02^{b}	23.73 ± 1.05^{d}
Solar dried	6	24.00 ± 0.13^{a}	4.68 ± 0.01^{d}	18.25 ± 1.05^{e}
	8	22.56 ± 0.53^{b}	4.25 ± 0.01^{e}	13.37 ± 0.61^{f}
	4	25.12 ± 0.12^{a}	4.98 ± 0.02^{a}	29.20 ± 0.42^{b}
Hybrid dried	6	25.00 ± 0.14^{a}	4.79 ± 0.01^{c}	27.13 ± 0.42^{ab}
	8	24.65 ± 0.23^{a}	4.65 ± 0.01^{d}	24.82 ± 0.63^{cd}

Values are means of triplicate ±SD, Values in the same column bearing different superscripts are significantly different ($p<0.05$).

formed as a result of oxidative processes of the cell metabolism, thus protecting certain biomolecules (lipids, proteins and DNA). Lycopene in tomato is particularly effective in fighting prostate cancer, cervical cancer, cancer of the stomach and rectum as well as pharynx and oesophageal cancers (Harvard School of Public Health, 2010). The phyto-chemical composition (lycopene, beta-carotene and vitamin c content) of dried tomato slices are presented in Table 1. Fresh tomato contained lycopene, beta-carotene and vitamin C in varied concentrations as 15.51±0.31, 0.88±0.02 and 40.15±2.11 mg/100 g, respectively.

To compare the influence of drying methods (open sun, solar and hybrid-photovoltaic solar dryers) on lycopene, the dried tomato slices lycopene content were compared with that of the fresh (Table 1). The lycopene levels of the fresh tomatoes significantly ($p<0.05$) increased from 18.77±0.77 to 23.89±0.19 mg/100 g, 22.56±0.53 to 27.51±0.30 and 24.65±0.23 to 25.12±0.12 mg/100 g when dried with slice thickness 4, 6 and 8 mm, respectively. The result is similar to what was reported by Roldan-Gutierrez and Luque de Castro (2007) and Aktas et al. (2011). Studies have found consistent differences in lycopene concentrations between tomato varieties, which can be magnified by environmental conditions and agricultural practices, especially those affecting plant nutrient status (Abushita et al., 2000; Binoy et al., 2004). The content of lycopene depends on variety, cultivating area, variable climate conditions and cultivation technology. Red tomato is the richest source of lycopene and yellow tomato is rich in carotene (Butnariu and Samfira, 2012). The base phenomena, which result in changing lycopene during tomato processing, are isomerisation and oxidation. While oxidation is a process leading to lycopene decomposition, isomerisation has a positive effect. Lycopene is found in tomatoes in the *trans*-steric form. Thermal processes, including drying, lead to lycopene isomerisation and its change from *trans*-steric to *cis* form. The quantity of cis isomers grows once with the increase in temperature and duration of heat treatment. The bioassimilation of lycopene cis isomers is greater than of *trans*- isomers. Drying increases the lycopene bioassimilation by destructing the tomato cells and breaking the connection between lycopene and matrix, damaging the lycopene-protean complex and releasing free lycopene by cis isomerisation (Shi and LeMaguer, 2000). The results as presented in Table 1 shows that the lycopene and β-carotene content of fresh tomatoes increases with drying and drying method used. This could be due to concentration effect which is as a result of the reduction in the moisture content compared to the fresh tomatoes.

The lycopene content of open sun dried tomato slices was significant ($p<0.05$) with tomato slice (thickness, 4 mm) having the highest value (23.89 mg/100 g) and tomato slice (thickness, 8 mm) had the lowest value (18.77 mg/100 g). In hybrid-photovoltaic and solar-dried tomato slices (thickness 4, 6 and 8 mm) there were no significant ($p>0.05$) difference. Lavelli et al. (1999) have obtained analogical data for half tomatoes, demonstrating the insignificant difference between lycopene concentration in fresh and dried tomatoes at temperature of 80°C. This observation may be due to prolonged time of drying with uncontrolled temperature in the sun drying method, while in the hybrid-photovoltaic and solar drying methods the drying took place at temperature less than 60^{o}C with short period of drying time. The long exposure of the sun dried tomato to drying temperature might have resulted in higher degradation of its components including lycopene (Yusuf et al., 2013). This is also supported by a previous study, by Yusuf et al. (2013) which stated that increase in temperature and duration of heat treatment

caused lycopene degradation. Aktas et al. (2011) reported that the drying processes that were performed at higher temperature above 65°C may cause high loss of lycopene content, but we can also say from the result obtained that if exposure duration to drying process was long, the rate of degradation is expected to be higher too. All studied drying methods caused significant increase in β-carotene content of dried tomato slices. This result could be related to an increase in the extractability of such compounds.

The average value of *ß*-carotene content of fresh tomatoes before drying was 0.88 mg/100 g. The values obtained for sun dried tomatoes ranged from 4.12 to 3.72 mg/100 g, solar dried ranged from 4.94 to 4.25 mg/100 g and hybrid dried ranged from 4.98 to 4.65 mg/100 g. Similar results were observed by Muratore et al. (2008) and Yusuf et al. (2013). They reported that degradation of lycopene and β -carotene in tomatoes was highly influenced by the temperature and length of drying. The quantity and quality of phytochemicals detected in tomato fruits is known to depend greatly on genotype and environmental condition (Giuntini et al., 2005). The β-carotene content of open sun dried tomato slices was significant ($p<0.05$) with 4 mm thick tomato slice having the highest value follow by 6 mm thick and 8 mm thick. The same trends were also observed for hybrid-photovoltaic and solar drying methods. The β-carotene content of dried tomato decreased with increasing the period of drying and thickness of the tomatoes. Hybrid-photovoltaic dried tomatoes slices showed a higher retention of β-carotene than both the solar and open sun dried methods. This may be due to high rate of moisture loss within a short period of time. This high retention of lycopene and β-carotene by hybrid-photovoltaic drying method was suggested to retain the bright colour of hybrid-photovoltaic dried tomatoes than the solar and open sun dried ones. The selection of the drying techniques and the processing parameters seems to be essential in order to preserve high carotenoids concentrations; as carotenoids being sensitive to heat. Freeze-drying is therefore the leading candidates for this operation as it allows retaining 100% of carotenoids in the dried samples (Tran et al., 2008).

Tomatoes are a rich source of ascorbic acid (Abushita et al., 2000; Kaur et al., 2002); however, processing of tomatoes has been reported to have a very detrimental effect on their ascorbic acid content (Takeoka et al., 2001; Toor and Savage, 2006). Ascorbic acid is one of the most thermolabile components of food products, fact also confirmed at tomato drying. The value of the ascorbic acid content for the fresh sample was 40.15 mg/100 g. The values obtained for open sun dried tomatoes ranged from 17.04 to 5.60 mg/100 g, solar dried ranged from 23.73 to 13.37 mg/100 g and hybrid-photovoltaic dried ranged from 29.20 to 24.82 mg/100 g. It was observed that there was a continuous decrease in the value of ascorbic acid as the drying time and the temperature increased which was expected because of the sensitivity of ascorbic acid to heat (Rajkumar, 2007). From the results obtained, it was observed that the ascorbic acid was very sensitive to oxidative heat damages as the reduction was significant ($p < 0.05$). Hybrid-photovoltaic dried tomato slices showed a higher retention of ascorbic acid than solar and open sun dried tomatoes. Also solar dried tomato slices showed a higher retention of ascorbic acid than open sun dried tomatoes. This variation in retention of ascorbic acid was observed to due to variations in temperature, thickness and period of drying. This observation confirms with the results obtained by Giovanelli et al. (2002) that the reduction in ascorbic acid content was mainly due to the temperature, time of exposure to direct sun light, thickness and the presence of air. This reduction may also be due to leaching of the vitamin being water soluble and oxidation due to longer period of drying. This is in agreement with the works of Shi et al. (1999). Also, significant loss of ascorbic acid has been reported in the previous studies using higher temperature and longer drying time. Lavelli et al. (1999) reported about 88% losses in ascorbic acid when tomatoes were dried at 80°C for 7 h to 10% moisture content. The results of Toor and Savage (2006) have shown that drying tomatoes in quarters at 42°C during 18 h, led to ascorbic acid losses between 17 to 27%, according to tomato varieties. The increase of drying temperature results in deep decomposition of ascorbic acid.

A similar trend was also observed for tomatoes dried at 90°C for more than 8 h (Yusuf et al., 2013). This result supports the concept that nutrients are more sensitive to longer time of exposure than to higher temperature shorter times, which implies that a greater reduction in time at the cost of slight increase in temperature results in better retention of nutrients (Teixeira, 2012). Similar decline in ascorbic acid content was noticed in other studies with tomato by Kadam et al. (2012) and Qadri and Srivastava (2014). Hence, the higher drying exposure time, thickness and temperature resulted in considerable reduction in the values of nutrients in dried tomatoes.

Conclusion

Hybrid-photovoltaic dried tomatoes slice showed higher content of lycopene, ß-carotene and ascorbic acid than solar and open sun dried methods. The ascorbic acid was very sensitive to oxidative heat damages as the reduction was significant ($p < 0.05$) when the thickness of tomato slices increases for the three drying methods used. Lycopene, ß-carotene and ascorbic acid contents decreased with drying time. Therefore, hybrid drier can be ranked to be the best followed by the solar drying method for drying tomatoes in order to preserve its nutrient and prevent it from post-harvest losses.

Conflict of interests

The authors have not declared any conflict of interests.

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