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IMPACT OF HOT-AIR DRYING TEMPERATURE AND VELOCITY ON DRYING KINETICS, COLOR, PHYTOCHEMICALS AND ANTIOXIDANT ACTIVITY OF CAPE GOOSEBERRY (*Physalis peruviana* l.) FRUITS

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ABSTRACT

The impact of temperature and air velocity during hot-air drying on the drying kinetics and some quality attributes of cape gooseberry fruit halves was studied. Experiments were conducted at 60 and 70 °C as well as at air velocities of 0.4 and 0.6 m/ s. Experimental drying curves showed that drying process took place in the falling rate period. Thomson, Wand and Singh, and Page models showed a better fit to describe the drying curves of cape gooseberry fruits. Effective moisture diffusion increased with increasing the temperature, air velocity and the activation energy was found to be 38.78 KJ/ mol. Chromatic coordinates (L^*, a^* and b^*) as well as total color difference (ΔE), Chroma and Hue angle were affected by drying air temperature and velocity. Drying process caused a reduction in the β–carotene, total phenolics, total flavonoids contents and antioxidant activity; either determined by DPPH and/ or ABTS assays, of the dried fruits with non-significant reduction at 70 °C as compared to fresh fruits. A high correlation was observed between fruit bioactive components (total phenolics and flavonoids as well as β–carotene) with antioxidant capacity. Thus, the dried fruits have potential for the development and production of many functional food products.

Keywords: Cape gooseberry, Drying kinetics, Phytochemicals, Antioxidant activity, Color, Quality

INTRODUCTION

Nowadays, consumers are very interested in the potential benefits of nutritional support for disease prevention through a healthy diet. There is a growing knowledge of the potential role of functional foods to reduce the health risks and/ or improve the health. In fact, fruits and vegetables contain many biologically active health-promoting components associated with a strong antioxidant activity because of free radical scavenging activities, donation of hydrogen atoms or electron, or chelate metal cations (Balasundram *et al.*, 2006; López *et al.*, 2013 and Vega-Gálvez *et al.*, 2014).

Cape gooseberry or goldenberry (*Physalis peruviana* L., Solanaceae family) is an upright herbaceous, perennial and semi-shrub plant native to tropical South America. It has been grown in North and South America, South Africa, Egypt, India, New Zealand, Australia and Great Britain. The plant is fairly adaptable to wide variety of soils and good crops are obtained on poor sandy ground. Its fruit is protected by an accrescent calyx, and is around 2 cm wide, 4-5 g weight, with a smooth, orange-yellow skin and juicy pulp containing around 100-200 small yellowish seeds (Valdenegro *et al.*, 2012). Cape gooseberry fruits are an excellent source of provitamin A, vitamin C, minerals (phosphorus, iron, potassium, calcium) and some of the vitamin B-complex, besides the presence of many bioactive health promoting components such as withanolides (C_{28} steroidal lactones), phenolics, β-carotene and dietary fiber (Wu *et al.*, 2005; Salazar *et al.*, 2008; Fang *et al.*, 2009; Lan *et al.*, 2009; Puente *et al.*, 2011 and Ramadan, 2011). The extracts of cape gooseberry exhibited high antioxidant and anti-inflammatory activities (Wu *et al.*, 2006 and Chang *et al.*, 2008), anti-hepatotoxic (Arun and Asha, 2007), anti-proliferative effects on hepatome cells (Wu *et al.*, 2004) and anticancer activity towards many types of cancers (Franco *et al.*, 2007; Fang *et al.*, 2009 and Lan *et al.*, 2009). Additionally, fruits have excellent potential as anti-diabetes and anti-hypertension solutions (Pinto *et al.*, 2009), recommending the consumption of five fruits a day. In general, the fruit is consumed fresh and it can be consumed in many ways as an interesting ingredient in salads, cooked dishes, dessert, cocktails, jams, snacks, pies, jellies, ice cream and marmalades. The whole fruit can be used in syrup or dried to raisins for use in bakeries, cereal breakfast and chocolate-covered candies (McCain, 1993; Puente *et al.*, 2011; Erkaya *et al.*, 2012 and Vásquez-Parra *et al.*, 2013).

Drying is probably the oldest, favored and the most important preservation method for fruits and vegetables practiced by human. It improves the food stability by reducing the water and microbial activity and minimizing physical and chemical changes during storage (Doymaz, 2012). Nowadays, dehydration is regarded not only as a preservation process, but also as a method for increasing value-added foods and it is one of the important unit operations used in formulating a functional food product. Selecting appropriate control parameters can lead to higher yield from the point of view of operational and capital investment and produce a high quality final product (Vega-Gálvez *et al.*, 2009; DiScala *et al.*, 2011 and López *et al.*, 2013). The drying kinetics of food is a complex phenomenon and its mathematical modeling is crucial for optimizing the process parameters and predicting the drying behavior. Many empirical and semi-empirical models have been used to describe the drying process of which thin-layer drying models have been widely used (Singh and Pandey, 2012).

Several researches have reported the effect of hot air drying conditions on the drying kinetics and quality indices of several fruits and vegetables. However, little information is reported about the effects of drying conditions on the drying kinetics (Abdulla, 2012; El-Beltagy *et al.*, 2013 and Vega-Gálvez *et al.*, 2014) and main quality characteristics (López *et al.*, 2013) of cape gooseberry.

Thus, the objective of this study was to investigate the effect of air-drying temperature (60 and 70 °C) and velocity (0.4 and 0.6 m/ s) on drying kinetics, surface color attributes, phytochemicals content and antioxidant activity of cape gooseberry fruits during convective dehydration.

MATERIALS AND METHODS

Materials

Plant material:

The fresh cape gooseberry (*Physalis peruviana* L.) fruits were purchased from a local market (Ismailia city, Egypt) during May 2012. The fruits were manually de-husked and then homogeneously selected based on color, size, and freshness measured by visual analysis. They were refrigerated at 5 °C until the drying process. The moisture content of the fresh cape gooseberry fruits was immediately determined according to the AOAC (2000) method (number 934.01), and found to be 80.68 ± 0.15 g water per 100 g sample wet basis (4.176 on dry basis). The diameter of the fresh fruits was measured using a digital caliper (Mitutoyo Corp., Japan) and an average value of 30 measurements was recorded (1.606 ± 0.249 cm).

Chemicals and Reagents:

Folin-Ciocalteu's phenol reagent, anhydrous sodium carbonate, gallic acid, aluminum chloride and sodium hydroxide were purchased from Fluka. Sodium nitrite, quercetin, 2.2-diphenyl-1-picrylhydrazyl (DPPH), 6-hydroxy-2, 5, 7, 8-tetramethylchroman-2-carboxylic acid (trolox), potassium persulfate and 2,2´-azino-bis (3-ethylbenzothiazoline-6-sulfonic acid) diammonium salt (ABTS) were purchased from Sigma-Aldrich (St. Louis, Missouri, USA). Methanol, hexane and acetone (analytical grade) were from Scharlab Company (Spain).

Methods

Drying experiments:

The conditions applied in the experimental setup used for the drying of cape gooseberry fruit halves were based on a factorial design n^m, where, n is the number of levels and m is the number of factors. The air-drying temperature and velocity were the two factors under study (m = 2), each with two levels (n = 2). Drying experiments, performed in triplicate, were carried out at two temperatures (60 and 70 °C) with a two air velocities (0.4 and 0.6 m/ s).

The Cape gooseberry samples were spread uniformly in a thin layer within stainless steel trays of size 36.5 cm x 60 cm with a load of 500 g (approximately, 2.25 Kg/ m^2). The drying process was carried out in a convective dryer (WT-binder, Type F115, Germany) at the mentioned air temperatures and velocities and ambient relative humidity (38-40%).

The dryer was switched on 30 min before drying experiments to achieve steady-state conditions. The sample under drying was weighed at regular time intervals (30 min in the first 3 hours and hourly thereafter) during the drying process using a digital balance, with an accuracy of 0.01 g. A tray with the sample was taken out from the oven, weighed and placed back into the drying chamber. The weighing process took about 10 seconds. Drying was continued until the equilibrium moisture content was reached, and a constant weight of the samples was registered (Vega-Gálvez *et al.*, 2012). The drying experiments were conducted in triplicate and the average of the moisture ratio at each value was used for drawing drying curves (Doymaz, 2012). The dried samples were kept in sealed polypropylene bags and stored at -18 °C until further analyses.

Mathematical modeling of drying curves:

The moisture content of cape gooseberry fruit halves at time "t" can be transformed to be moisture ratio (MR) using the following equation:

$$MR= (M - M_e)/ (M_o - M_e) \qquad \textbf{(Eq. 1)}$$

where M, M_o and M_e are the moisture contents at any time, initial moisture content and equilibrium moisture content, respectively.

The drying rate of the samples was calculated using Eq. (2):

$$\text{Drying rate}= (M_{t+dt} - M_t)/ (dt) \qquad \textbf{(Eq. 2)}$$

Where M_t and M_{t+dt} are the moisture content at "t" and moisture content at "t+dt" (g moisture/ g dry matter), respectively, (t) is the drying time (min) and (dt) is the time difference (min).

The drying data obtained were fitted to five thin-layer drying models that are detailed in Table (1) using the nonlinear least squares regression analysis. Regression analysis was performed using the Statistica computer program (Statistica 6.0, Statsoft Inc., Tulsa, OK, USA). The determination of correlation coefficient (R^2) is one of the primary criteria for selecting the best model to describe the drying curves of the dehydrated samples. In addition to R^2, reduced chi-square (x^2) was used to determine the quality of the fit.

Table 1: Thin-layer models applied to the cape gooseberry fruit halves drying curves

Model name	Model equation	Reference
Lewis	$MR= \exp(-kt)$	Ayensu (1997)
Page	$MR= \exp(-kt^n)$	Diamante and Munro (1993)
Henderson and Pabis	$MR= a \exp(-kt)$	Henderson and Pabis (1961)
Wang and Singh	$MR = 1 + at + bt^2$	Wang and Singh (1978)
Thomson	$t = a (\ln MR) + b (\ln MR)^2$	Thomson *et al.* (1968)

a, b, k, n are empirical constants in drying models; (t) is the drying time (min); (MR) is the moisture ratio

Calculation of the effective moisture diffusivion and activation energy:

It has been accepted that the drying characteristics of biological products in the falling rate period can be described by using Fick's diffusion equation. The solution to this equation developed by Crank (1975), and can be used for various products. For long drying period, this solution can be simplified and written in a logarithmic form as follows (Falade and Solademi, 2010):

$$\ln MR= \ln (8/ \pi^2) - (\pi^2 D_{eff}/4L^2)\, t \qquad \textbf{(Eq. 3)}$$

Where D_{eff} is the effective diffusivity (m^2/ s), (L) is the half thickness of the cape gooseberry fruit halves (m). Diffusivities are determined by plotting of ln MR versus drying time t in the equation, gave a straight line with a slope of ($\pi^2 D_{eff}/4L^2$).

To evaluate the dependence of the effective diffusivity on the temperature, an Arrhenius-type equation (Eq. 4) was used, from which the activation energy (E_a) was determined (Xiao *et al.*, 2010):

$$D_{eff} = D_o \exp(-E_a/ RT) \qquad \textbf{(Eq. 4)}$$

where E_a is the activation energy of the moisture diffusion (KJ/mol), (D_o) is the diffusivity value for an infinite moisture content (m^2/ s), (R) is the universal gas constant (KJ/mol K), and (T) is the drying air temperature (°K).

Instrumental surface color measurement:

The color of fresh and dried cape gooseberry samples was measured with a Minolta colorimeter (Minolta Co. Ltd., Osaka, Japan). Color was expressed by CIE L^* (whiteness or brightness), a^* (redness/ greenness), and b^* (yellowness/ blueness) coordinates. Measurements were replicated five times and the results were averaged. The total color difference (ΔE) was calculated by equation (5) where L_0, a_0, and b_0 are the control values for fresh fruits. The color intensity (Chroma, C^*) was calculated by equation (6) and the Hue angle (h_{ab}) by (Eq. 7), where h_{ab}= 0° for a red hue and h_{ab}= 90° for a yellow hue (RØrå and Einen, 2003 and Vega-Gálvez *et al.*, 2012):

$$\Delta E= [(a^* - a_0)^2 + (b^* - b_0)^2 + (L^* - L_0)^2]^{0.5} \quad \text{(Eq. 5)}$$

$$\text{Chroma } (C^*) = (a^{*2} + b^{*2})^{0.5} \quad \text{(Eq. 6)}$$

$$\text{Hue angle} = \tan^{-1} (b^*/a^*) \quad \text{(Eq. 7)}$$

Determination of β-carotene content:

The β-carotene content of fresh and dried cape gooseberry samples was determined with the method described by Barros *et al.* (2011) with some modifications as follows: A 500 mg of fresh or 200 mg of dried samples was vigorously shaken with 10 ml of acetone-hexane mixture (4:6) at 100 rpm on Orbital Shaker (LAB-LINE Instruments, Inc., USA) for 15 min and filtered through filter paper No. 102. The extract was adjusted to 10 ml with volumetric flask. The absorbance of the extract was measured at 453, 505, 645 and 663 nm using a spectrophotometer (6505 UV/ VIS, Jenway LTD, Felsted, Dunmow, UK). The content of β-carotene was calculated by to the following equations (Eq. 8):

$$\beta\text{-carotene (mg/ 100 ml)} = 0.216 \times A_{663} - 1.220 \times A_{645} - 0.304 \times A_{505} + 0.452 \times A_{453} \quad \text{(Eq. 8)}$$

Determination of total phenolics, total flavonoids content and antioxidant capacity of Cape gooseberry samples:

The extract used for determination the contents of total phenolics, total flavonoids and antioxidant capacity of cape gooseberry samples which prepared according to the method described by Barros *et al.* (2011) with some modifications as follows: one gram of the sample was stirred with 25 ml of methanol at 100 rpm on Orbital Shaker (LAB-LINE Instruments, Inc., USA) for 1 h at room temperature (32 ± 2 °C) and filtered through filter paper No. 102. The residue was then re-extracted with 25 ml of methanol. The methanol extracts were combined and stored at 4°C till further analyses. The extract was diluted if necessary.

Total phenolics content was estimated in the methanolic extracts, according to the Folin-Ciocalteu method with slight modifications (Chuah *et al.*, 2008). The results were expressed as mg of gallic acid equivalents per 100 g of dry weight (mg GAE/ 100 g DW). All measurements were done in triplicate and the results averaged.

Total flavonoids content was measured by colorimetric assay reported by Barros *et al.* (2011). Total extract flavonoids were expressed as mg quercetin equivalents per 100 g of dry weight.

Free radical scavenging activity of the samples was determined by the 2,2,-diphenyl-1-picryl-hydrazyl (DPPH) method (Turkmen *et al.*, 2005) with some modifications. The total antioxidant activity was expressed as the percentage inhibition of the DPPH radical and was determined by the following equation (Eq. 9):

$$\text{DPPH radical–scavenging activity (\%)} = [1-(A_{sample}/A_{control})] \times 100 \quad \text{(Eq. 9)}$$

where A is the absorbance at 515 nm.

Also, the ability of the sample extract to scavenge the $ABTS^{\cdot+}$ radical was determined using the trolox equivalent antioxidant capacity (TEAC) assay described by Rufino *et al.* (2010). Ethanolic solutions of trolox (6-hydroxy-2,5,7,8-tetramethylchroman-2-carboxylic acid) concentrations (0-10 µg per ml) were used for calibration (R^2= 0.998) and results were expressed as µmol trolox equivalents per 100 g dry weight sample.

Statistical analysis:

The data are presented as the mean of three determinations ± standard deviation. The data were analyzed by ANOVA and Duncan's multiple range test by using SPSS (ver. 17.0) at $p< 0.05$. The statistical analyses of the drying experiments for model fitting were performed by using the software package (Statistica 6.0, Statsoft Inc., Tulsa, OK, USA).

RESULTS AND DISCUSSION

Drying characteristics of cape gooseberry fruits and modeling of drying curves:

Changes of the moisture content (dry basis) with the drying time (min) for varying values of the studied parameters (air-drying temperature and velocity) have been determined. Figure (1) showed the experimental drying curves of the employing air temperatures and velocities. All curves showed a clear exponential tendency with moisture content decreasing as the drying air temperature and velocity increased. An increase in drying air temperature was accompanied by a decrease in drying time from 660 - 780 min at 60 °C to 420 – 450 min at 70 °C to achieve the equilibrium moisture content (0.090 ± 0.005) at the mentioned air velocities (a decrease of 39.34%). Also, the drying time decreased with increasing the drying air velocity from 0.4 to 0.6 m/ s by 11.03% at mentioned air temperature. These results well agree with those reported in previous studies for drying cape gooseberry (Abdulla, 2012; López *et al.*, 2013 and Vega-Gálvez *et al.*, 2014) and other fruits (Akpinar, 2006 and Mundada *et al.*, 2010).

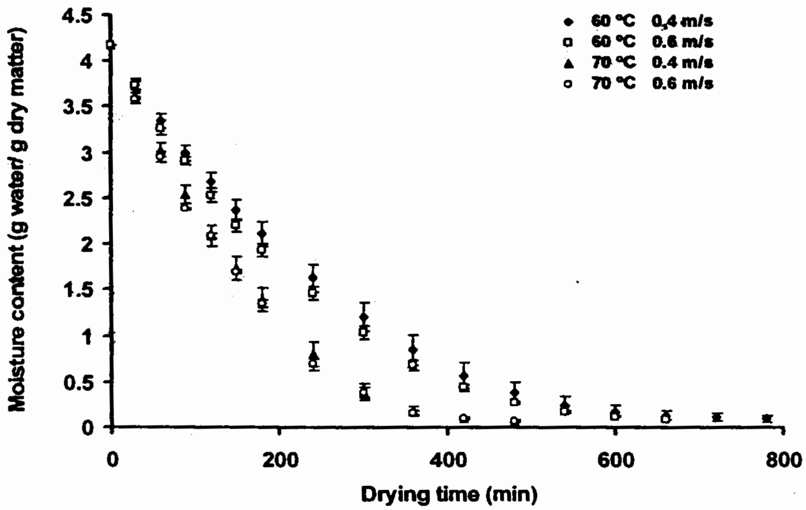

Figure (1): Experimental drying curves for cape gooseberry samples at different air-drying temperatures and velocities. Results are mean ± standard deviation, n= 3

The relation between the drying rate of cape gooseberry fruits and the moisture content (dry basis) is shown in Figure (2) for various drying air temperatures and velocities. It was clear that the drying rate decreased continuously with decreasing the moisture content during drying process. The drying rate was rapid during the initial period but it became very slow at the last stages of the drying process. As shown in Figure (2) there was no constant drying rate period and the drying process took only in the falling rate period. This showed that diffusion is the dominant physical mechanism governing moisture movement in the samples and explaining the use of the empirical models presented in Table (1) (Doymaz, 2012; López *et al*., 2013 and Vega-Gálvez *et al*., 2014).

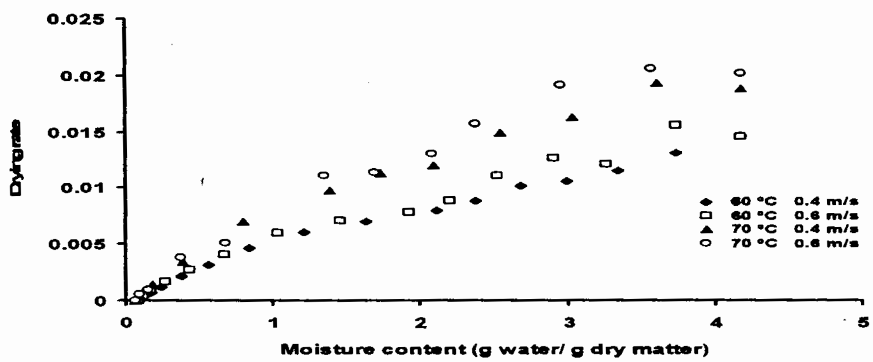

Figure (2): Experimental drying rate curves for cape gooseberry samples at different air drying temperatures and velocities

The moisture content data obtained at different air temperatures and velocities were converted to dimensionless moisture ratio and then fitted to five thin-layer drying models (Table 1) and the average values (n= 3) of the kinetic and empirical parameters obtained for all proposed models are summarized in Table (2). It was found that parameter *k* and *b* for the proposed models increased with drying air temperature. It may be assumed that these constants would be directly proportional to temperature. While, *n* and *a* (except *a* of Thomson model) values remained relatively unchanged, suggesting that, they may be most probably dependent on the characteristics of the cell tissue (Vega-Gálvez *et al.*, 2014). Table (2) showed also the results of the statistical tests (R^2 and x^2) used to analyze the goodness of fit of proposed models. The best model describing the thin-layer drying characteristics of cape gooseberry fruits was chosen as the one with the highest R^2 values and the lowest x^2 values. Of all model tested, the Thomson, Wand and Sigh and Page models give the highest R^2 and the lowest x^2 values. Accordingly, these models can be selected as suitable models to represent the thin-layer drying characteristics of cape gooseberry fruits. Similar observations were reported by Vega-Gálvez *et al.* (2014).

Table 2: Values of the kinetic and empirical parameters and results of statistical analysis on the modeling of moisture ratio and drying time for cape gooseberry fruits at different air temperatures and velocities

Model name	Temperature (°C)	Velocity (m/ s)	Model constants*	Statistics	
				R^2	x^2
Lewis	60	0.4	k= 0.0064	0.9228	0.0281
	60	0.6	k= 0.0066	0.9184	0.0520
	70	0.4	k= 0.0094	0.9231	0.0273
	70	0.6	k= 0.0098	0.8972	0.0471
Page	60	0.4	k= 0.0014, n= 1.2312	0.9857	0.0138
	60	0.6	k= 0.0015, n= 1.2321	0.9887	0.0112
	70	0.4	k= 0.0015, n= 1.3057	0.9900	0.0099
	70	0.6	k= 0.0018, n= 1.2801	0.9798	0.0198
Henderson and Pabis	60	0.4	a= 1.6094, k= 0.0074	0.9492	0.0094
	60	0.6	a= 1.4909, k= 0.0076	0.9439	0.0410
	70	0.4	a= 1.5469, k= 0.0110	0.9541	0.0280
	70	0.6	a= 1.6445, k= 0.0116	0.9324	0.0305
Wang and Singh	60	0.4	a= -0.0032, b= 3E-06	0.9981	0.0068
	60	0.6	a= -0.0036, b= 3E-06	0.9983	0.0070
	70	0.4	a= -0.0050, b= 6E-06	0.9996	0.0149
	70	0.6	a= -0.0050, b= 6E-06	0.9975	0.0083
Thomson	60	0.4	a= -240.13, b= -20.749	0.9946	0.0019
	60	0.6	a= -229.95, b= -22.544	0.9972	0.0010
	70	0.4	a= -163.08, b= -16.217	0.9933	0.0024
	70	0.6	a= -164.51, b= -16.699	0.9909	0.0032

* a, b, k, n are empirical constants in drying models

Effective moisture diffusivity and activation energy:

Moisture diffusivity is an important transport property necessary for the design and optimization of all the processes that involve internal moisture movement.

The effective moisture diffusion (D_{eff}) values of hot-air dried cape gooseberry fruits at different air temperatures and velocities are shown in Table (3). The obtained D_{eff} values confirm that the drying rate of cape gooseberry fruits increased as drying air temperature and velocity raised. Where, the D_{eff} values increased significantly with increasing temperature from 4.8346 x 10^{-8} m^2/ s at 60 °C to 7.1866 x 10^{-8} m^2/ s at 70 °C at a constant air velocity (0.4 m/ s). This may be due to that, drying the samples at high temperature, increased heating energy which increases the activity of water molecules leading to higher moisture diffusion (Xiao *et al.*, 2010). Also, increasing the drying air velocity at a constant air temperature increased the D_{eff} of the samples. The D_{eff} values obtained in this study were higher than those found by Abdulla (2012), Vásquez-Parra *et al.* (2013) and Vega-Gálvez *et al.* (2014) at the same range of drying air temperatures for cape gooseberry fruits (3.6091 – 5.8853 x 10^{-9} m^2/ s, 4.67 – 6.82 x 10^{-10} m^2/ s and 6.61 x 10^{-11} m^2/ s, respectively).

Table 3: Effective moisture diffusion (D_{eff}) obtained for cape gooseberry fruits at different drying air temperatures and velocities

Temperature (°C)	Velocity (m/ s)	Effective moisture diffusivity (m^2/ s)	Coefficient of determination (R^2)
60	0.4	4.8346 x 10^{-8c}	0.9492
60	0.6	4.9653 x 10^{-8c}	0.9439
70	0.4	7.1866 x 10^{-8b}	0.9541
70	0.6	7.5786 x 10^{-8a}	0.9324

Means of triplicates

The activation energy (E_a) was determined by plotting the natural logarithm of D_{eff} values versus the reciprocal of drying temperature (1/ T). The result showed a linear correlation due to Arrhenius type dependence (y= -4678.8x – 2.781, R^2= 0.9896). The diffusivity constant (D_o) was 6.20 x 10^{-2} m^2/ s and the activation energy was 38.90 KJ/ mol. This value was very closed to that found by Vega-Gálvez *et al.* (2014) for cape gooseberry, 38.78 KJ/ mol at the same temperature range and lower than that obtained by Abdulla (2012), 51.31 KJ/ mol, and similar to those reported for different fruits and vegetables such as 30.46 – 35.57 KJ/ mol for strawberry (Lee and Hsieh, 2008), 37.27 KJ/ mol for figs (Babalis and Belessiotis, 2004) and 30.64 – 43.26 KJ/ mol for persimmon (Doymaz, 2012).

Surface color attributes:

The effect of drying air temperature and velocity on the mean color attributes values of cape gooseberry fruits are shown in Table (4). The measured initial values of lightness (L_0), redness (a_0) and yellowness (b_0) of the fresh fruits were 48.28, 4.90 and 30.76, respectively which indicated that fresh fruits had high intensity (Chroma, 31.09) yellow color (Hue angle, 80.93). Botero (2008) studied the color of fresh cape gooseberry fruits and the chromatic coordinates were L^* (70.31), a^* (14.31), b^* (60.84) with Chroma and Hue angle values of 62.50 and 76.77, respectively, indicated more clear yellow color. Drying temperature, air velocity and drying time affect significantly the color characteristics of cape gooseberry fruits. All treatments increased the L^* and a^* values and decreased the b^*, Chroma and Hue angle values, which indicated that the dried fruits had a high luminosity and low intensity yellow color compared to fresh ones. The a^* values of dried fruits (8.24 at 60 °C and an air velocity of 0.4 m/ s) increased significantly ($p < 0.05$) with increasing the drying temperature (10.57 at 70 °C and 0.6 m/ s air velocity). The increase in a^* value denotes a redder Chroma (Hue angle, 67.18), which indicated of the enzymatic or/ and non-enzymatic reactions (Vega-Gálvez *et al.*, 2009). Fruits dried at higher temperature (70 °C) tended to have higher values of yellowness (b^*) that those dried at lower temperature (60 °C).

The effect of drying air temperature and velocity on total color difference (ΔE) of cape gooseberry fruits are also shown in Table (4). The highest ΔE value was observed at 70 °C with high air velocity (0.6 m/ s) as compared with the rest of the treatments ($p < 0.05$). This may be due to the effect of the high temperature and presence of air on some heat-sensitive components such as proteins and carbohydrates led to non-enzymatic browning reactions, destruction of pigments (β-carotene) and auto-oxidation reactions involving phenolic compounds and the formation of iron-phenol complexes (Vega-Gálvez *et al.*, 2009).

β-carotene content:

The effect of drying air temperature and velocity on cape gooseberry β-carotene content are shown in Table (5). The fresh fruits contained 67.17 mg 100 g^{-1} dry weight. β-carotene, is a fat-soluble pigment, has many physiological functions such as cell-to-cell communication, pro-vitamin A activity, UV skin protection and avoids the breakdown of chromoplasts by heat treatments and mechanical damage (Lavelli *et al.*, 2007). DeRosso and Mercadante (2007) found that *all-trans-* β-carotene was the major carotenoid in Cape gooseberry fruits, contributing 76.80% of the total carotenoids, followed by 9-*cis-* β-carotene and *all-trans*-α-cryptoxanthin, contributing around 3.6 and 3.4%, respectively. The degradation of β-carotene was more evident at 60 °C (25.04% and 41.67% at air velocity of 0.4 and 0.6 m/ s, respectively). Some authors concluded that the loss of β-carotene during drying at low temperatures was highly influenced by the length of drying (Demiray *et al.*, 2013 and López *et al.*, 2013). However, drying at 70 °C did not show any significant differences (Table 5) when compared with fresh samples ($p < 0.05$) either at 0.4 or 0.6 m/ s air velocity, with more loss at 0.6 m/ s air velocity (16.91%), which may be referred to oxidation with air (Ihns *et al.*, 2011).

Data represented in this study showed a positive correlation between β-carotene content of Cape gooseberry fruits and the measured color values. Figure (3) showed a high correlation between β-carotene content with b^* values (R^2= 0.9187) and Chroma (R^2= 0.9735). Also, showed a moderate positive correlation with Hue angle values (R^2= 0.5539).

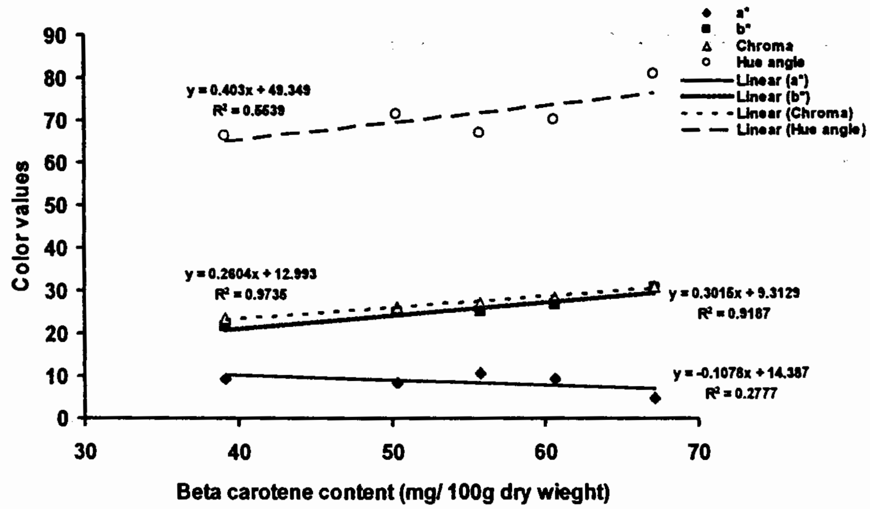

Figure (3): Correlation between beta carotene content and color values of cape gooseberry fruits

Total phenolics and flavonoids content:

Results are presented in Table (5) showed that the initial total flavonoids content was 1266.59 mg 100 g^{-1} dry weight and the total phenolics content (329.29 mg 100 g^{-1} dry weight) results were closed to this obtained by López *et al.* (2013) and in the range of values reported for other fruits such as plums, blackberries and strawberries (Vasco *et al.*, 2008). Drying process at different temperatures and air velocities caused a reduction in the fruits total phenolics and flavonoids contents. A maximum reduction of 14.60% and 35.13% in the phenolics and flavonoids contents were observed in fruits dried at 60 °C at an air velocity of 0.6 m/ s, respectively. This may be referred to the binding of phenolic compounds with other components, alterations in the chemical structure of polyphenols during the long time of drying process or by oxidation with air (Buchner *et al.*, 2006). Whereas a reduction of only 0.21% and 7.62% in phenolics and flavonoids, respectively were observed at the end of drying at 70 °C and 0.4 m/ s air velocity. Vega-Gálvez *et al.* (2012) showed that drying apple slices at 80 °C, the highest drying temperature, degradation of total phenolics was the least. This is probably due to high convective forces acting at the air-solid interface retarding heat diffusion into the solid apples. The phenolics glycosides being localized in hydrophilic regions of cell such as vacuoles and apoplasts or as other soluble phenols in the cytoplasrn seemed to get a protective heat shield by material of the cell walls (Sakihama *et al.*, 2002). The decomposition of polyphenolics during hot-air drying was proven to depend on the food matrix and the processing conditions (Larrauri *et al.*, 1997).

Table 4: Chromatic coordinates (L^*, a^* and b^*), Chroma, Hue angle and ΔE for fresh and dehydrated cape gooseberry samples

Cape gooseberry samples		L^*	a^*	b^*	ΔE	Chroma	Hue angle
Fresh		48.28 ± 1.01^{d}	4.90 ± 0.53^{d}	30.76 ± 1.40^{a}	-	31.09 ± 1.50^{a}	80.93 ± 0.03a
Temperature (°C)	Velocity (m/ s)						
60	0.4	53.25 ± 1.99^{b}	8.24 ± 0.73^{c}	24.80 ± 1.22^{c}	8.45 ± 1.00^{c}	26.13 ± 1.42^{c}	71.62 ± 0.02^{b}
60	0.6	50.79 ± 1.73^{c}	9.33 ± 1.21^{b}	21.57 ± 1.37^{d}	10.51 ± 1.37^{b}	23.44 ± 1.83^{d}	66.61 ± 0.02^{c}
70	0.4	54.28 ± 2.20^{b}	9.45 ± 0.72^{b}	26.66 ± 2.76^{b}	8.57 ± 2.74^{c}	28.23 ± 2.52^{b}	70.48 ± 0.05^{b}
70	0.6	57.28 ± 1.21^{a}	10.57 ± 0.76^{a}	25.12 ± 1.55^{bc}	12.04 ± 0.58^{a}	27.21 ± 1.63^{bc}	67.18 ± 0.03^{c}

Results are mean ± standard deviation, n = 3
Different letters in the same column indicate that values are significantly different ($P < 0.05$)
L* (whiteness or brightness), a* (redness/ greenness), and b* (yellowness/ blueness)
(ΔE) The total color difference

Table 5: Phytochemicals content (mg 100 g^{-1} dry weight) and antioxidant activity of fresh and dehydrated cape gooseberry samples

Cape gooseberry samples		Phytochemical content			DPPH	ABTS
		β-carotene	Total phenolics	Total flavonoids	(%)	(µmol trolox 100 g^{-1})
Fresh		67.17 ± 9.61^{a}	329.29 ± 12.24^{a}	1266.59 ± 63.33^{a}	36.65 ± 1.97^{a}	9.09 ± 2.60a
Temperature (°C)	Velocity (m/ s)					
60	0.4	50.35 ± 3.56^{bc}	286.70 ± 22.65^{b}	1018.80 ± 60.13^{ab}	17.69 ± 0.61^{b}	5.76 ± 0.86^{b}
60	0.6	39.18 ± 7.15^{c}	281.19 ± 8.77^{b}	821.58 ± 115.68^{b}	17.10 ± 1.18^{b}	4.19 ± 0.56^{b}
70	0.4	60.64 ± 2.89^{ab}	328.59 ± 17.28^{a}	1170.07 ± 72.19^{a}	18.12 ± 2.32^{b}	6.02 ± 2.75^{b}
70	0.6	55.81 ± 6.48^{ab}	321.40 ± 30.41^{a}	1147.19 ± 69.37^{ab}	18.09 ± 2.07^{b}	5.65 ± 0.57^{b}

DPPH : 2.2-diphenyl-1-picrylhydrazyl **ABTS : 2,2´-azino-bis (3-ethylbenzothiazoline–6-sulfonic acid) diammonium salt**
Results are mean ± standard deviation, n = 3
Different letters in the same column indicate that values are significantly different ($P < 0.05$)

Antioxidant capacity:

Fresh cape gooseberry fruits exhibited values of 36.65% and 9.09 µmol trolox equivalents per 100 g dry weight for DPPH and ABTS assays, respectively (Table 5). A high antioxidant capacity has been demonstrated for cape gooseberry juice (Ramadan and Mörsel, 2007) and the synergistic effect of different antioxidants has been suggested. Restrepo (2008) and Botero (2008) determined the antioxidant activity of cape gooseberry fruits in terms of DPPH free radical scavenger (192.51 – 210.82 µmol trolox 100 g^{-1} sample) and the FRAP (ferric reducing antioxidant power) assay (54.98 – 56.53 mg ascorbic acid 100 g^{-1} sample). The total antioxidant activity of the fruits depends on the cultivar and can be affected by many factors such as environmental conditions of growing, harvest time, ripening stage, storage and processing conditions (Valdenegro *et al.*, 2012).

Drying process led to significant decrease in the antioxidant capacity of cape gooseberry fruits, with no significant differences between drying air temperatures and velocities for both assays. Mrkic *et al.* (2006) found that during hot-air drying of broccoli, the antioxidant activity was correlated positively with both air velocity and drying temperature. The retention in the antioxidant capacity was non-significantly higher at 70 °C than 60 °C. As reported by some authors, long drying times associated with low process temperature may promote a decrease in antioxidant capacity (DiScala *et al.*, 2011; Demiray *et al.*, 2013 and López *et al.*, 2013). Drying process may be caused no change to antioxidant potential of fruit and vegetables or enhanced it depending on the nature of the substrate (Murakami *et al.*, 2004). During drying at high temperatures, oxidation reactions could take place and polyphenolics with an intermediate oxidation state can exhibit a higher radical scavenging activity than non-oxidized polyphenols (Nicoli *et al.*, 1999). Also, it can be due to a formation of novel compounds such as Maillard reaction products that could act as pro/ or antioxidants (Manzocco *et al.*, 2001).

The antioxidant capacity may be related to the content of phytochemicals such as β-carotene, phenolics and flavonoids, since both act as scavengers of the free radicals produced during oxidation reactions (Di Scala *et al.*, 2011). In this study, there were a high linear correlation between the antioxidant capacity of dried cape gooseberry fruits and its β-carotene (R^2= 0.9644 and 0.8861), total phenolics (R^2= 0.8140 and 0.4763) and flavonoids (R^2= 0.9989 and 0.8486) contents for DPPH and ABTS assays, respectively (data not shown). Generally, increasing correlation between antioxidant activity and phytochemicals content has been reported during food drying process (Vega-Gálvez *et al.*, 2009 and López *et al.*, 2013).

CONCLUSION

The drying kinetics of cape gooseberry fruits were studied at 60 and 70 °C as well as at air velocities of 0.4 and 0.6 m/ s. Drying of cape gooseberry fruits had a clear dependence on drying air temperature and velocity, showed only a falling rate period. The drying process was faster when air temperature and velocity increased, which is reflected in the values of effective moisture diffusivity obtained. Based on statistical evaluation, Thomson, Wang and Singh and Page models can be applied to estimate optimum drying conditions required to achieve a final moisture content of cape gooseberry fruits. Controlled hot-air drying process conditions (e.g., temperature and air velocity) can lead to high quality food from a sensorial and nutritional point of view (color, phytochemicals content and antioxidant capacity). A high correlation was observed, in this study between fruits phytochemicals content and their antioxidant activity determined by DPPH and ABTS assays. Dried cape gooseberry fruits could be considered as an important source of biologically active components with high antioxidant activity and can be consumed as a raisins or in many functional food products.

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تأثير درجة حرارة وسرعة الهواء أثناء التجفيف علي حركيات تجفيف، لون، المركبات الفعالة والنشاط المضاد للأكسدة لثمار الحرنكش

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تم دراسة تأثير كل من درجة حرارة (٦٠ و ٧٠ °م) وسرعة الهواء (٠,٤ و ٠,٦ م/ ث) أثناء التجفيف بالهواء الساخن علي حركيات التجفيف وبعض خصائص الجودة في ثمار الحرنكش. أوضحت النتائج ان عملية تجفيف أنصاف ثمار الحرنكش تتم في مرحلة معدل التبخير المتناقص. وكانت النماذج الرياضية Thomson، Wand and Singh و Page الأفضل في التنبؤ ووصف خصائص منحنى تجفيف ثمار الحرنكش. ازداد معدل نفاذية الرطوبة بزيادة كل من درجة حرارة وسرعة هواء التجفيف وبلغت قيمة طاقة التنشيط نتيجة لهذا التأثير ٣٨,٧٨ كيلو جول/ مول. تأثرت جميع خصائص اللون المدروسة في ثمار الحرنكش بدرجة حرارة وسرعة هواء التجفيف تحت الدراسة. أدت عملية التجفيف انخفاض محتوى الثمار من البيتا كاروتين، الفينولات الكلية والفلافونيدات الكلية وكذلك النشاط المضاد للأكسدة. كان الانخفاض الحادث عند ٧٠ °م غير معنويا مقارنة بالعينات الطازجة. أوضحت النتائج وجود علاقة قوية بين النشاط المضاد للأكسدة لثمار الحرنكش ومحتواها من المركبات الفعالة المدروسة (الفينولات و الفلافونيدات الكلية و البيتا كاروتين). بناء علي النتائج المتحصل عليها يمكن اعتبار ثمار الحرنكش المجففة مكونا هاما لتطوير وانتاج العديد من المنتجات الغذائية الوظيفية.