

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

**Youssef, K. M.**

**Food Technology Department, Faculty of Agriculture, Suez Canal University, Ismailia 41522, Egypt**

**e-mail: [kmyoussef73@yahoo.com](mailto:kmyoussef73@yahoo.com)**

### **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 ( $\Delta E$ ), Chroma and Hue angle were affected by drying air temperature and velocity. Drying process caused a reduction in the  $\beta$ -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  $\beta$ -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 ( $C_{28}$  steroidol lactones), phenolics,  $\beta$ -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  $80.68 \pm 0.15$  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 ( $1.606 \pm 0.249$  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<sup>2</sup>). 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:

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

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):

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

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 ( $\chi^2$ ) 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):

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

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):

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

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 ( $\Delta E$ ) 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  $h_{ab} = 0^\circ$  for a red hue and  $h_{ab} = 90^\circ$  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 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 ( $32 \pm 2^\circ\text{C}$ ) 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  $4^\circ\text{C}$  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):

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

where A is the absorbance at 515 nm.

Also, the ability of the sample extract to scavenge the ABTS<sup>+</sup> 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.

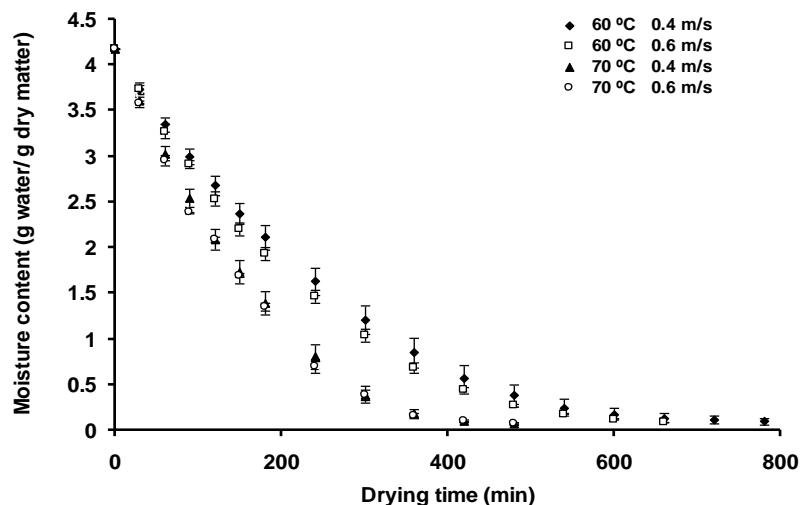
**Statistical analysis:**

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

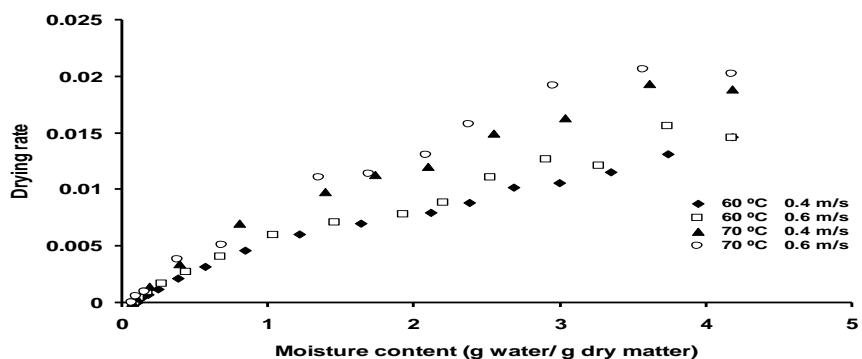
### Drying characteristics of cape gooseberry fruits and modeling of drying curves:

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 ( $0.090 \pm 0.005$ ) 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  $\pm$  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  $\chi^2$ ) 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  $\chi^2$  values. Of all model tested, the Thomson, Wand and Sigh and Page models give the highest  $R^2$  and the lowest  $\chi^2$  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	
				$R^2$	$\chi^2$
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  $4.8346 \times 10^{-8} \text{ m}^2/\text{s}$  at  $60^\circ\text{C}$  to  $7.1866 \times 10^{-8} \text{ m}^2/\text{s}$  at  $70^\circ\text{C}$  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 ( $3.6091 - 5.8853 \times 10^{-9} \text{ m}^2/\text{s}$ ,  $4.67 - 6.82 \times 10^{-10} \text{ m}^2/\text{s}$  and  $6.61 \times 10^{-11} \text{ m}^2/\text{s}$ , respectively).

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

Temperature ( $^\circ\text{C}$ )	Velocity (m/ s)	Effective moisture diffusivity ( $\text{m}^2/\text{s}$ )	Coefficient of determination ( $R^2$ )
60	0.4	$4.8346 \times 10^{-8c}$	0.9492
60	0.6	$4.9653 \times 10^{-8c}$	0.9439
70	0.4	$7.1866 \times 10^{-8b}$	0.9541
70	0.6	$7.5786 \times 10^{-8a}$	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 ( $D_0$ ) was  $6.20 \times 10^{-2} \text{ m}^2/\text{s}$  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

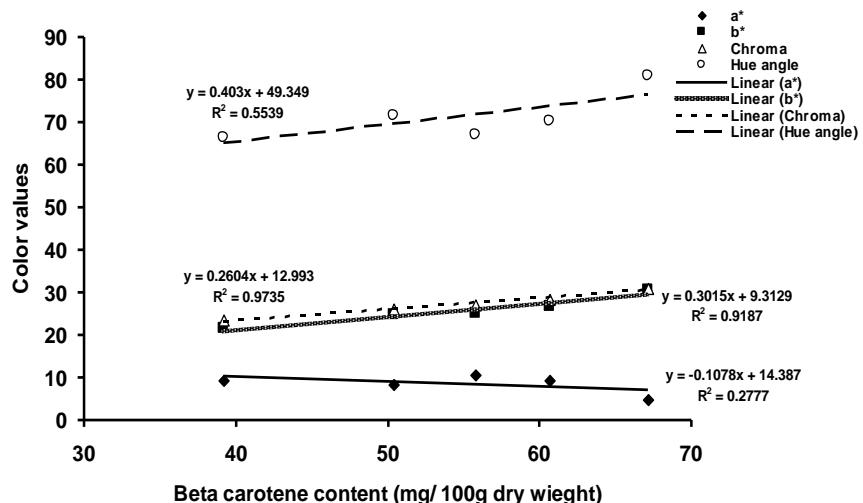
and Hue angle values of 62.50 and 76.77, respectively, indicated more clear yellow color. Drying temperature, air velocity and drying time affect significantly the color characteristics of cape gooseberry fruits. All treatments increased the  $L^*$  and  $a^*$  values and decreased the  $b^*$ , Chroma 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 ( $b^*$ ) than those dried at lower temperature (60 °C).

The effect of drying air temperature and velocity on total color difference ( $\Delta E$ ) of cape gooseberry fruits are also shown in Table (4). The highest  $\Delta E$  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 ( $\beta$ -carotene) and auto-oxidation reactions involving phenolic compounds and the formation of iron-phenol complexes (Vega-Gálvez *et al.*, 2009).

#### **$\beta$ -carotene content:**

The effect of drying air temperature and velocity on cape gooseberry  $\beta$ -carotene content are shown in Table (5). The fresh fruits contained 67.17 mg 100 g<sup>-1</sup> dry weight.  $\beta$ -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*-  $\beta$ -carotene was the major carotenoid in Cape gooseberry fruits, contributing 76.80% of the total carotenoids, followed by 9-*cis*-  $\beta$ -carotene and *all-trans*- $\alpha$ -cryptoxanthin, contributing around 3.6 and 3.4%, respectively. The degradation of  $\beta$ -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  $\beta$ -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  $\beta$ -carotene content of Cape gooseberry fruits and the measured color values. Figure (3) showed a high correlation between  $\beta$ -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  $1266.59 \text{ mg } 100 \text{ g}^{-1}$  dry weight and the total phenolics content ( $329.29 \text{ mg } 100 \text{ g}^{-1}$  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  $60 \text{ }^\circ\text{C}$  at an air velocity of  $0.6 \text{ m/s}$ , 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  $70 \text{ }^\circ\text{C}$  and  $0.4 \text{ m/s}$  air velocity. Vega-Gálvez *et al.* (2012) showed that drying apple slices at  $80 \text{ }^\circ\text{C}$ , 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 cytoplasm 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).



#### **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<sup>-1</sup> sample) and the FRAP (ferric reducing antioxidant power) assay (54.98 – 56.53 mg ascorbic acid 100 g<sup>-1</sup> 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.

## **REFERENCES**

- Abdulla, G. (2012). Effect of hot air temperature on drying kinetics of goldenberry. *Zagazig J Agric Res.*, 39:665-673.
- Akpınar, E. K. (2006). Determination of suitable thin layer drying curve model for some vegetables and fruits. *J. Food Eng.*, 73:75–84.
- AOAC (2000). Official Method of Analysis (16<sup>th</sup> Ed.). Association of Official Analytical Chemists, Washington DC.
- Arun, M. and Asha, V. V. (2007). Preliminary studies on antihepatotoxic effect of *Physalis peruviana* Linn. (Solanaceae) against carbon tetrachloride induced acute liver injury in rats. *J Ethnopharmacol.*, 111:110–114.
- Ayensu, A. (1997). Dehydration of food crops using a solar dryer with convective heat flow. *Sol. Energy*, 59: 121-126.
- Babalis, S. J. and Belessiotis, V. G. (2004). Influence of the drying conditions on the drying constants and moisture diffusivity during the thin-layer drying of figs. *J. Food Eng.*, 65:449–458.
- Balasundram, N.; Sundram, K. and Samman, S. (2006). Phenolic compounds in plants and agri-industrial by-products: Antioxidant activity, occurrence, and potential uses. *Food Chem.*, 99:191-203
- Barros, L.; Cabrita, L.; Boas, M. V.; Carvalho, A. M. and Ferreira, I. C. F. R. (2011). Chemical, biochemical and electrochemical assays to evaluate phytochemicals and antioxidant activity of wild plants. *Food Chem.*, 127:1600–1608.
- Botero, A. (2008). Aplicación de la Ingeniería de Matrices en el desarrollo da la uchuva mínimamente procesada fortificada con calcio y vitaminas C y E. Facultad de química farmacéutica, vol. Magíster en ciencias farmacéuticas énfasis en alimentos (pp. 185). Medellín: Universidad de Antioquia. Cited in: Puente, L. A.; Pinto-Muñoz, C. A.; Castro, E. S. and Cortés, M. (2011). *Physalis peruviana* Linnaeus, the multiple properties of a highly functional fruit: A review. *Food Res Inter.*, 44:1733-1740.
- Buchner, N.; Krumbein, A.; Rhon, S. and Kroh, L.W. (2006). Effect of thermal processing on the flavonols rutin and quercetin. *Rapid Commun Mass Spectro.*, 20:3229–3235.

- Chang, J. C.; Lin, C. C.; Wu, S. J.; Lin, D. L.; Wang, S. S.; Miaw, C. L. and Ng, L. T. (2008). Antioxidative and hepatoprotective effects of *Physalis peruviana* extract against acetaminophen-induced liver injury in rats. *Pharmaceut Biol.*, 46:724–731.
- Chuah, A. M.; Lee, Y-C.; Yamaguchi, T.; Takamura, H.; Yin, L-J. and Matoba, T. (2008). Effect of cooking on the antioxidant properties of coloured peppers. *Food Chem.*, 111:20-28.
- Crank, J. (1975). *The Mathematics of Diffusion*. 2<sup>nd</sup> Edition, Oxford, Clarendon Press
- Demiray, E.; Tulek, Y. and Yilmaz, Y. (2013). Degradation kinetics of lycopene, β-carotene and ascorbic acid in tomatoes during hot air drying. *LWT-Food Sci Technol.*, 50:172-176.
- DeRosso, V. V. and Mercadante, A. Z. (2007). Identification and quantification of carotenoids, by HPLC-PDA-MS/MS, from Amazonian fruits. *J Agric Food Chem.*, 55:5062–5072.
- Di Scala, K.; Vega-Gálvez, A.; Uribe, E.; Oyanadel, R.; Miranda, M.; Vergara, J.; Quispe, I. and Lemus-Mondaca, R. (2011). Changes of quality characteristics of pepino fruit (*Solanum muricatum* Ait) during convective drying. *Inter J Food Sci Technol.*, 46:746-753.
- Diamante, L. M. and Munro, P. A. (1993). Mathematical modelling of the thin layer solar drying of sweet potato slices. *Sol. Energy*, 51: 271-276.
- Doymaz, I. (2012). Evaluation of some thin-layer drying models of persimmon slices (*Diospyros kaki* L.). *Energy Convers Manage.*, 56: 199-205.
- El-Beltagy, A. E.; Naeem, M. A. and Gaafar, A. M. (2013). Optimization and quality attributes of osmotic solar drying of golden berry (*Physalis peruviana*). *J Agroalim Process Technol.*, 19: 480-489.
- Erkaya, T.; Dağdemir, E. and Şengül, M. (2012). Influence of cape gooseberry (*Physalis peruviana* L.) addition on the chemical and sensory characteristics and mineral concentrations of ice cream. *Food Res Inter.*, 45:331–335.
- Falade, K. O. and Solademi, J. S. (2010). Modelling of air drying of fresh and blanched sweet potato slices. *Int. J. Food Technol.*, 45: 278-288.
- Fang, S-T.; Li, B. and Liu, J-K. (2009). Two new withanolides from *Physalis peruviana*. *Helv. Chim. Acta*, 92:1304–1308.
- Franco, L.; Matiz, G.; Calle, J.; Pinzon, R. and Ospina, L. (2007). Anti-inflammatory activity of extracts and fractions obtained from *Physalis peruviana* L. calyces. *Biomedica*, 27:110–115.
- Henderson, S. M. and Pabis, S. (1961). Grain drying theory: I. Temperature effect on drying coefficient. *J. Agric. Res. Eng.*, 6: 169-174.
- Ihns, R.; Diamante, L. M.; Savage, G. P. and Vanhanen, L. (2011). Effect of temperature on the drying characteristics, color, antioxidant and beta-carotene contents of two apricot varieties. *Inter J Food Sci Technol.*, 46:275–283.
- Lan, Y. H.; Chang, F. R.; Pan, M. J.; Wu, C. C.; Wu, S. J.; Chen, S. L.; Wang, S. S.; Wu, M. J. and Wu, Y. C. (2009). New cytotoxic withanolides from *Physalis peruviana*. *Food Chem.*, 116:462–469.

- Larrauri, J. A.; Ruperez, P. and Saura Calixto, F. (1997). Effect of drying temperature on the stability of polyphenols and antioxidant activity of red grape. *J Agric Food Chem.*, 45:1390–1393.
- Lavelli, V.; Zanoni, B. and Zaniboni, A. (2007). Effect of water activity on carotenoid degradation in dehydrated carrots. *Food Chem.*, 104:1705–1711
- Lee, G. and Hsieh, F. (2008). Thin-layer drying kinetics of strawberry fruit leather. *Trans ASABE*, 51:1699-1705.
- López, J.; Vega-Gálvez, A.; Torres, M.; Lemus-Mondaca, R.; Quispe-Fuentes, I. and Di Scala, K. (2013). Effect of dehydration temperature on physico-chemical properties and antioxidant capacity of goldenberry (*Physalis peruviana* L.). *Chilean J Agric Res.*, 73:293-299.
- Manzocco, L.; Calligaris, S.; Mastrolcola, D.; Nicoli, M. and Lerici, C. (2001). Review of non enzymatic browning and antioxidant capacity in processed foods. *Trends Food Sci Technol.*, 11:340–346.
- McCain, R. (1993). Goldenberry, passion fruit and white sapote: Potential fruits for cool subtropical areas. In Janick, J. and Simon, J. E. (Eds.). *New Crops* (pp. 479–486). New York: Wiley and Sons.
- Mrkic, V.; Coccia, E.; Rosa, M. D. and Sacchetti, G. (2006). Effect of drying conditions on bioactive compounds and antioxidant activity of broccoli (*Brassica oleracea*, L.). *J Sci Food Agric.*, 86:1559–1566.
- Mundada, M., Hathan, B. S. and Maske, S. (2010). Convective dehydration kinetics of osmotically pretreated pomegranate arils. *Biosyst Eng.*, 107:307–316.
- Murakami, M.; Yamaguchi, T.; Takamura, H. and Matoba, T. (2004). Effects of thermal treatment on radical-scavenging activity of single and mixed polyphenolic compounds. *J Food Sci.*, 69:FCT7–FCT10.
- Nicoli, M. C.; Anese, M. and Parpinel, M. (1999). Influence of processing on the antioxidant properties of fruit and vegetables. *Trends Food Sci Technol.*, 10:94–100.
- Pinto, M. S.; Ranilla, L. G.; Apostolidis, E.; Lajolo, F. M.; Genovese, M. I. and Shetty, K. (2009). Evaluation of antihyperglycemia and antihypertension potential of native Peruvian fruits using in vitro models. *J Med Food*, 12:278–291.
- Puente, L. A.; Pinto-Muñoz, C. A.; Castro, E. S. and Cortés, M. (2011). *Physalis peruviana* Linnaeus, the multiple properties of a highly functional fruit: A review. *Food Res Inter.*, 44:1733-1740.
- Ramadan, M. F. (2011). Bioactive phytochemicals, nutritional value, and functional properties of cape gooseberry (*Physalis peruviana*): An overview. *Food Res Inter.*, 44:1830–1836.
- Ramadan, M. F. and Mörsel, J. T. (2007). Impact of enzymatic treatment on chemical composition, physicochemical properties and radical scavenging activity of goldenberry (*Physalis peruviana* L.) juice. *J Sci Food Agric.*, 87:452–460.

- Restrepo, A. (2008). Nuevas perspectivas de consumo de frutas: Uchuva (*Physalis peruviana* L.) y Fresa (*Fragaria vesca* L.) mínimamente procesadas fortificadas con vitamina E. Facultad de Ciencias Agropecuarias, vol. Magíster en ciencia y tecnología de alimentos (pp. 107). Medellín: Universidad Nacional de Colombia. Cited in: Puente, L. A.; Pinto-Muñoz, C. A.; Castro, E. S. and Cortés, M. (2011). *Physalis peruviana* Linnaeus, the multiple properties of a highly functional fruit: A review. *Food Res Inter.*, 44:1733-1740.
- RØrå, A. M. B. and Einen, O. (2003). Effects of freezing on quality of cold smoked Salmon based the measurements of physicochemical characteristics. *J. Food Sci.*, 68: 2123-2128.
- Rufino, M. S. M.; Alves, R. E.; de Brito, E. S.; Pérez-Jiménez, J.; Saura-Calixto, F. and Mancini-Filho, J. (2010). Bioactive compounds and antioxidant capacities of 18 non-traditional tropical fruits from Brazil. *Food Chem.*, 121:996–1002.
- Sakihama, Y.; Cohen, M.; Grace, S. and Yamasaki, H. (2002). Plant phenolic antioxidant and prooxidant activities: Phenolics-induced oxidative damage mediated by metals in plants. *Toxicol.*, 177:67–80.
- Salazar, M. R.; Jones, J. W.; Chaves, B. and Cooman, A. (2008). A model for the potential production and dry matter distribution of Cape gooseberry (*Physalis peruviana* L.). *Sci Horticult.*, 115:142-148.
- Singh, N. J. and Pandey, R. K. (2012). Convective air drying characteristics of sweet potato cube (*Ipomoea batatas* L.) *Food Bioprod Proc.*, 90:317-322.
- Thomson, T. L.; Peart, P. M. and Foster, G. H. (1968). Mathematical simulation of corn drying: A new model. *Trans ASAE*, 11: 582–586.
- Turkmen, N.; Sari, F. and Velioglu, Y. S. (2005). The effect of cooking methods on total phenolics and antioxidant activity of selected green vegetables. *Food Chem.*, 93:713–718.
- Valdenegro, M.; Fuentes, L.; Herrera, R. and Moya-León, M. A. (2012). Changes in antioxidant capacity during development and ripening of goldenberry (*Physalis peruviana* L.) fruit and in response to 1-methylcyclopropene treatment. *Post Biol Technol.*, 67:110–117.
- Vasco, C.; Ruales, J. and Kamal-Eldin, A. (2008). Total phenolic compounds and antioxidant capacities of major fruits from Ecuador. *Food Chem.*, 111:816-823.
- Vásquez-Parra, J. E.; Ochoa-Martínez, C. I. and Bustos-Parra, M. (2013). Effect of chemical and physical pretreatments on the convective drying of cape gooseberry fruits (*Physalis peruviana*). *J Food Eng.*, 119:648–654.
- Vega-Gálvez, A.; Ah-Hen, K.; Chacana, M.; Vergara, J.; Martínez-Monzó, J.; García-Segovia, P.; Lemus-Mondaca, R. and DiScala, K. (2012). Effect of temperature and air velocity on drying kinetics, antioxidant capacity, total phenolic content, colour, texture and microstructure of apple (var. Granny Smith) slices. *Food Chem.*, 132: 51-59.

- Vega-Gálvez, A.; Di Scala, K.; Rodríguez, K.; Lemus-Mondaca, R.; Miranda, M. and Perez-Won, M. (2009). Effects of air-drying temperature on physico-chemical properties, antioxidant capacity, colour and total phenolic content of red pepper (*Capsicum annuum*, L. var. Hungarian). *Food Chem.*, 117:647–653.
- Vega-Gálvez, A.; Puente-Díaz, L.; Lemus-Mondaca, R.; Miranda, M. and Torres, M. J. (2014). Mathematical modeling of thin-layer drying kinetics of cape gooseberry (*Physalis peruviana* L.). *J Food Proc Preserv.*, 38: 728-736.
- Wang, C. Y. and Singh, R. P. (1978). A single layer drying equation for rough rice. *ASAE*, paper no. 3001.
- Wu, S. J.; Ng, L. T.; Huang, Y. M.; Lin, D. L.; Wang, S. S.; Huang, S. N. and Lin, C. C. (2005). Antioxidant activities of *Physalis peruviana*. *Biolo Pharmaceut Bulletin*, 28:963–966.
- Wu, S. J.; Ng, L. T.; Lin, D. L.; Huang, S. N.; Wang, S. S. and Lin, C. C. (2004). *Physalis peruviana* extract induces apoptosis in human Hep G2 cells through CD95/CD95L system and the mitochondrial signaling transduction pathway. *Cancer Letters*, 215:199–208.
- Wu, S. J.; Tsai, J. Y.; Chang, S. P.; Lin, D. L.; Wang, S. S.; Huang, S. N. and Ng, L. T. (2006). Supercritical carbon dioxide extract exhibits enhanced antioxidant and anti-inflammatory activities of *Physalis peruviana*. *J Ethnopharmacol.*, 108:407–413.
- Xiao, H. W.; Pang, C. L.; Wang, L. H.; Bai, J. W.; Yang, W. X. and Gao, Z. J. (2010). Drying kinetics and quality of Monukka seedless grapes dried in an air-impingement jet dryer. *Biosyst Eng.*, 105: 233-240.

**تأثير درجة حرارة وسرعة الهواء أثناء التجفيف على حركيات تجفيف، لون، المركبات الفعالة والنشاط المضاد للأكسدة لثمار الحرنكش**  
**خالد محمد يوسف**  
**قسم الصناعات الغذائية - كلية الزراعة - جامعة قناة السويس - الاسماعيلية ٤١٥٢٢ - مصر**

تم دراسة تأثير كل من درجة حرارة (٦٠ و ٧٠ °م) وسرعة الهواء (٤٠٠ و ٦٠٠ م/ث) أثناء التجفيف بالهواء الساخن على حركيات التجفيف وبعض خصائص الجودة في ثمار الحرنكش. أوضحت النتائج أن عملية تجفيف أنصاف ثمار الحرنكش تتم في مرحلة معدل التبخير المتافق. وكانت النماذج الرياضية *Page* و *Wand and Singh*، *Thomson* والأفضل 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 والفالافونيدات 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 ومحتوها من المركبات الفعالة المدروسة ( الفينولات و الفالافونيدات الكلية و البيتا كاروتين). بناء على النتائج المتحصل عليها يمكن اعتبار ثمار الحرنكش المجففة مكونا هاما لتطوير وانتاج العديد من المنتجات الغذائية الوظيفية.

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

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

Results are mean  $\pm$  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)

( $\Delta E$ ) The total color difference

**Table 5: Phytochemicals content (mg 100 g<sup>-1</sup> dry weight) and antioxidant activity of fresh and dehydrated cape gooseberry samples**

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

DPPH : 2,2-diphenyl-1-picrylhydrazyl

ABTS : 2,2'-azino-bis (3-ethylbenzothiazoline-6-sulfonic acid) diammonium salt

Results are mean  $\pm$  standard deviation, n = 3

Different letters in the same column indicate that values are significantly different (P < 0.05)