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 (C28 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 ºC 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 ºC) 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:

\[ MR = \frac{(M - M_e)}{(M_o - M_e)} \quad (Eq. 1) \]

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):

\[ \text{Drying rate} = \frac{(M_t + dt - M_t)}{(dt)} \quad (Eq. 2) \]

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

<table>
<thead>
<tr>
<th>Model name</th>
<th>Model equation</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lewis</td>
<td>( MR = \exp(-kt) )</td>
<td>Ayensu (1997)</td>
</tr>
<tr>
<td>Page</td>
<td>( MR = \exp(-kt^*) )</td>
<td>Diamante and Munro (1993)</td>
</tr>
<tr>
<td>Henderson and Pabis</td>
<td>( MR = a \exp(-kt) )</td>
<td>Henderson and Pabis (1961)</td>
</tr>
<tr>
<td>Wang and Singh</td>
<td>( MR = 1 + at + bt^* )</td>
<td>Wang and Singh (1978)</td>
</tr>
<tr>
<td>Thomson</td>
<td>( t = a \ln(MR) + b \ln(MR)^2 )</td>
<td>Thomson et al. (1968)</td>
</tr>
</tbody>
</table>

\( a, b, k, n \) 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):

\[ \ln MR = \ln \left( \frac{8}{\pi^2} \right) - \left( \frac{\pi^2 D_{eff} 4L^2}{4} \right) t \quad (Eq. 3) \]

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

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):

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

$$\Delta E = \sqrt{(a^* - a_0)^2 + (b^* - b_0)^2 + (L - L_0)^2}$$  \hspace{1cm} (Eq. 5)

$$\text{Chroma} (C) = (a^2 + b^2)^{0.5}$$  \hspace{1cm} (Eq. 6)

$$\text{Hue angle} = \tan^{-1} (b^*/a^*)$$  \hspace{1cm} (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):

$$\beta-\text{carotene (mg/100 ml)} = 0.216 \times A_{663} - 1.220 \times A_{645} - 0.304 \times A_{505} + 0.452 \times A_{453}$$  \hspace{1cm} (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):

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

where \( A \) is the absorbance at 515 nm.

Also, the ability of the sample extract to scavenge the ABTS\(^+\) 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 \( \mu \)g per ml) were used for calibration (\( R^2 = 0.998 \)) and results were expressed as \( \mu \)mol 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

<table>
<thead>
<tr>
<th>Model name</th>
<th>Temperature (ºC)</th>
<th>Velocity (m/ s)</th>
<th>Model constants $^*$</th>
<th>Statistics</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>$k$, $n$, $a$, $b$</td>
<td>$R^2$, $x^2$</td>
</tr>
<tr>
<td>Lewis</td>
<td>60</td>
<td>0.4</td>
<td>$k$ = 0.0064</td>
<td>0.9228, 0.0281</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>$k$ = 0.0066</td>
<td>0.9184, 0.0520</td>
</tr>
<tr>
<td></td>
<td>70</td>
<td>0.4</td>
<td>$k$ = 0.0094</td>
<td>0.9231, 0.0273</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>$k$ = 0.0098</td>
<td>0.8972, 0.0471</td>
</tr>
<tr>
<td>Page</td>
<td>60</td>
<td>0.4</td>
<td>$k$ = 0.0014, $n$ = 1.2312</td>
<td>0.9857, 0.0138</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>$k$ = 0.0015, $n$ = 1.2321</td>
<td>0.9887, 0.0112</td>
</tr>
<tr>
<td></td>
<td>70</td>
<td>0.4</td>
<td>$k$ = 0.0015, $n$ = 1.3057</td>
<td>0.9900, 0.0099</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>$k$ = 0.0018, $n$ = 1.2801</td>
<td>0.9798, 0.0198</td>
</tr>
<tr>
<td>Henderson and Pabis</td>
<td>60</td>
<td>0.4</td>
<td>$a$ = 1.6094, $k$ = 0.0074</td>
<td>0.9492, 0.0094</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>$a$ = 1.4909, $k$ = 0.0076</td>
<td>0.9439, 0.0410</td>
</tr>
<tr>
<td></td>
<td>70</td>
<td>0.4</td>
<td>$a$ = 1.5469, $k$ = 0.0110</td>
<td>0.9541, 0.0280</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>$a$ = 1.6445, $k$ = 0.0116</td>
<td>0.8324, 0.0305</td>
</tr>
<tr>
<td>Wang and Singh</td>
<td>60</td>
<td>0.4</td>
<td>$a$ = -0.0032, $b$ = 3E-06</td>
<td>0.9981, 0.0068</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>$a$ = -0.0036, $b$ = 3E-06</td>
<td>0.9983, 0.0070</td>
</tr>
<tr>
<td></td>
<td>70</td>
<td>0.4</td>
<td>$a$ = -0.0050, $b$ = 6E-06</td>
<td>0.9996, 0.0149</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>$a$ = -0.0050, $b$ = 6E-06</td>
<td>0.9975, 0.0083</td>
</tr>
<tr>
<td>Thomson</td>
<td>60</td>
<td>0.4</td>
<td>$a$ = -240.13, $b$ = -20.749</td>
<td>0.9946, 0.0019</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>$a$ = -229.95, $b$ = -22.544</td>
<td>0.9972, 0.0010</td>
</tr>
<tr>
<td></td>
<td>70</td>
<td>0.4</td>
<td>$a$ = -163.08, $b$ = -16.217</td>
<td>0.9933, 0.0024</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>$a$ = -164.51, $b$ = -16.699</td>
<td>0.9909, 0.0032</td>
</tr>
</tbody>
</table>

$a$, $b$, $k$, $n$ 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 ($D_{\text{eff}}$) values of hot-air dried cape gooseberry fruits at different air temperatures and velocities are shown in Table (3). The obtained $D_{\text{eff}}$ values confirm that the drying rate of cape gooseberry fruits increased as drying air temperature and velocity raised. Where, the $D_{\text{eff}}$ values increased significantly with increasing temperature from $4.8346 \times 10^{-8}$ m$^2$/s at 60 ºC to $7.1866 \times 10^{-8}$ m$^2$/s at 70 ºC 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 $D_{\text{eff}}$ of the samples. The $D_{\text{eff}}$ 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 ($3.6091 – 5.8853 \times 10^{-9}$ m$^2$/s, $4.67 – 6.82 \times 10^{-10}$ m$^2$/s and $6.61 \times 10^{-11}$ m$^2$/s, respectively).

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

<table>
<thead>
<tr>
<th>Temperature (ºC)</th>
<th>Velocity (m/s)</th>
<th>Effective moisture diffusivity (m$^2$/s)</th>
<th>Coefficient of determination ($R^2$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>60</td>
<td>0.4</td>
<td>4.8346 x 10^{-8}</td>
<td>0.9492</td>
</tr>
<tr>
<td>60</td>
<td>0.6</td>
<td>4.9653 x 10^{-8}</td>
<td>0.9439</td>
</tr>
<tr>
<td>70</td>
<td>0.4</td>
<td>7.1866 x 10^{-8}</td>
<td>0.9541</td>
</tr>
<tr>
<td>70</td>
<td>0.6</td>
<td>7.5786 x 10^{-8}</td>
<td>0.9324</td>
</tr>
</tbody>
</table>

Means of triplicates

The activation energy ($E_a$) was determined by plotting the natural logarithm of $D_{\text{eff}}$ 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 $6.20 \times 10^{-2}$ m$^2$/s and the activation energy was 38.90 KJ/mol. This value was very close 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 (\( \Delta E \)) 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\(^{-1}\) 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-a-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 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 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⁻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 ºC than 60 ºC. 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 ºC 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,
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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


Youssef, K. M.


تأثر درجة حرارة وسرعة الالوأ أثناء التجهيف على حركيات تجفيف، لون،
المركبات الفعالة والنشط المضاد للأكسدة لثمر الحرقش
خالد محمد يوسف
قسم الصناعات الغذائية – كلية الزراعة – جامعة قنات السويس – الإسماعيلية ٤١٥٢٤ – مصر

تم دراسة تأثير كل من درجة حرارة (٢٠ و ٣٥)°C وسرعة الالوأ (٤ و ٠٠٦) ٢/ث أثناء التجهيف بالهواء الساخن على حركيات تجفيف وبعض حمضات الوجود في ثمار الحرقش. أوضحت النتائج أن عملية تجفيف أصاب ثمار الحرقش تم في المرحلة معدل التجفيف المتشابه. وكانت النتائج الرياضية الأفضل في التدريع ووصف حمضات متواجدة في ثمار الحرقش. أعاد معدل نفادities الرطوبة زيادة كل من درجة حرارة وسرعة الالوأ. وت了好多 حمضات الوجود في ثمار الحرقش بدرجة حرارة وسرعة الالوأ. التدريع هذه الثمار ٣٨٨ كيلو جول/مول. تأثرت جميع حمضات الوجود في ثمار الحرقش بدرجة حرارة وسرعة الالوأ. هذه النتائج تشجع على عملية التجهيف تحث الدراسة. أدى تدريع حركة تجفيف خصائص محتوى الالم من البيتا كاروتين، الفيتوالات الكلية والفلافونيدات الكلية وكذلك النشط المضاد للأكسدة كأنالافحاص الحادة عند ٦٠ م. غير معناها مقارنات البيديات وأقوم النتائج جودة علاقة كبيرة بين النشط المضاد لأكسدة لثمار الحرقش وملحوظا من النتائج المحملة مع الحرقش المجففة مكونا هاما لتطوير وأنتاج العدد من المنتجات الغذائية الوطنية.
Table 4: Chromatic coordinates ($L^*$, $a^*$ and $b^*$), Chroma, Hue angle and ΔΕ for fresh and dehydrated cape gooseberry samples

<table>
<thead>
<tr>
<th>Cape gooseberry samples</th>
<th>$L^*$</th>
<th>$a^*$</th>
<th>$b^*$</th>
<th>ΔΕ</th>
<th>Chroma</th>
<th>Hue angle</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fresh</td>
<td>48.28 ± 1.01$^*$</td>
<td>4.90 ± 0.53$^*$</td>
<td>30.76 ± 1.40$^*$</td>
<td>-</td>
<td>31.09 ± 1.50$^*$</td>
<td>80.93 ± 0.03$^*$</td>
</tr>
<tr>
<td>Temperature (°C)</td>
<td>Velocity (m/ s)</td>
<td>$L^*$</td>
<td>$a^*$</td>
<td>$b^*$</td>
<td>ΔΕ</td>
<td>Chroma</td>
</tr>
<tr>
<td>60</td>
<td>0.4</td>
<td>53.25 ± 1.99$^*$</td>
<td>8.24 ± 0.73$^*$</td>
<td>24.80 ± 1.22$^*$</td>
<td>8.45 ± 1.00$^*$</td>
<td>26.13 ± 1.42$^*$</td>
</tr>
<tr>
<td>60</td>
<td>0.6</td>
<td>50.79 ± 1.73$^*$</td>
<td>9.33 ± 1.21$^*$</td>
<td>21.57 ± 1.37$^*$</td>
<td>10.51 ± 1.37$^*$</td>
<td>23.44 ± 1.83$^*$</td>
</tr>
<tr>
<td>70</td>
<td>0.4</td>
<td>54.28 ± 2.20$^*$</td>
<td>9.45 ± 0.72$^*$</td>
<td>26.66 ± 2.76$^*$</td>
<td>8.57 ± 2.74$^*$</td>
<td>28.23 ± 2.52$^*$</td>
</tr>
<tr>
<td>70</td>
<td>0.6</td>
<td>57.28 ± 1.21$^*$</td>
<td>10.57 ± 0.76$^*$</td>
<td>25.12 ± 1.55$^*$</td>
<td>12.04 ± 0.58$^*$</td>
<td>27.21 ± 1.63$^*$</td>
</tr>
</tbody>
</table>

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)

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

<table>
<thead>
<tr>
<th>Cape gooseberry samples</th>
<th>Phytochemical content</th>
<th>DPPH (%)</th>
<th>ABTS (μmol trolox 100 g$^{-1}$)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>β-carotene</td>
<td>Total phenolics</td>
<td>Total flavonoids</td>
</tr>
<tr>
<td>Fresh</td>
<td>67.17 ± 9.61$^*$</td>
<td>329.29 ± 12.24$^*$</td>
<td>1266.59 ± 63.33$^*$</td>
</tr>
<tr>
<td>Temperature (°C)</td>
<td>Velocity (m/ s)</td>
<td>β-carotene</td>
<td>Total phenolics</td>
</tr>
<tr>
<td>60</td>
<td>0.4</td>
<td>50.35 ± 3.56$^*$</td>
<td>286.70 ± 22.65$^*$</td>
</tr>
<tr>
<td>60</td>
<td>0.6</td>
<td>39.18 ± 7.15$^*$</td>
<td>281.19 ± 8.77$^*$</td>
</tr>
<tr>
<td>70</td>
<td>0.4</td>
<td>60.64 ± 2.89$^*$</td>
<td>328.59 ± 17.28$^*$</td>
</tr>
<tr>
<td>70</td>
<td>0.6</td>
<td>55.81 ± 6.48$^*$</td>
<td>321.40 ± 30.41$^*$</td>
</tr>
</tbody>
</table>

DPPH : 2,2-diphenyl-1-picrylhydrazyl
ABTS : 2,2’-azino-bis (3-ethylbenzthiazoline-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)