

## Effect of Hot Air Drying Variables on Phytochemicals and Antioxidant Capacity of Jew's Mallow (*Corchorus olitorius* L.) Leaves

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**Abstract:** Jew's mallow (*Corchorus olitorius* L.) is an important vegetable in Egypt. Fresh or dried Jew's mallow leaves have a wide use and is great demand for domestic as well as export markets. The effects of hot air drying variables including: air temperature (50, 60 and 70 °C), air velocity (0.2, 0.4 and 0.6 m/ s) and trays load (125 – 500 g/ 0.22 m<sup>2</sup>) on the antioxidant capacity and some phytochemicals content of Jew's mallow leaves were studied. The fresh Jew's mallow leaves exhibited high antioxidant activity (52.29% and 139.55 µmol trolox/ g dry weight, measured by DPPH and ABTS assays, respectively). The leaves had high contents of chlorophyll a and b (649.4 and 317.4 mg/ 100 g), total phenolics (16.54 mg GAE/ g) and total flavonoids (117.88 mg quercetin equivalent/ g). Drying process resulted in drastic decreases in all studied properties except the β-carotene content. Antioxidant activity and phytochemicals compounds contents decreased as air drying temperature and velocity decreased, relating to long drying times. Drying at 60 °C and air velocity 0.6 m/ s had the lowest negative effect on the leaves antioxidant activity. Leaves dried at the highest trays load (500 g/ 0.22 m<sup>2</sup>) also, showed the highest antioxidant activity and phytochemicals contents.

**Keywords:** Jew's mallow, air drying, antioxidant capacity, phenolics, flavonoids, chlorophylls

### INTRODUCTION

*Corchorus olitorius* L. (known by several names such as Jew's mallow, Molokhia or Egyptian spinach) is a leafy summer vegetable that grows in subtropical and tropical regions (Handoussa *et al.*, 2013). It has been produced as a very important vegetable in Egypt, Japan, China and Middle East countries. Although, it is an important leafy vegetable cultivated in many countries, no statistical data on the production and trading are available. Fresh leaves and tender shoots are essential parts (Phuwapraisirisan *et al.*, 2009). The leaves are nutritious, rich in beta-carotene, chlorophylls, phenolics, minerals, protein, folate, vitamins, fatty acids and dietary fiber. The health benefits have been reported in antitumor promotion (Furumoto *et al.*, 2002), antioxidant properties (Azuma *et al.*, 1999), antibacterial activity (Zakaria *et al.*, 2006), decrease serum and liver cholesterol (Innami *et al.*, 1995), managing diabetes and hypertension (Obboh *et al.*, 2012). Its' cold infusion found to be restore the appetite and strength (Adegoke and Adebayo-Tayo, 2009).

Phytochemicals are substances found naturally in plant foods, including vegetables. Increased consumption of vegetables rich in phytochemicals correlates with increased cardiovascular health and reduced the risk of several age-related diseases such as cancer, stroke, cataract, degenerative diseases, loss of functionality and Alzheimer's disease. Levels of individual antioxidants in food do not necessarily reflect their antioxidant capacity, which could depend on synergic and redox interactions among the different antioxidant molecules present in the food (Hunter and Fletcher, 2002; Dai *et al.*, 2006; Murcia *et al.*, 2009 and Pappas and Schaich, 2009). Phenolic compounds are a category of phytochemicals that exert strong antioxidant properties. They can be classified into simple phenols, phenolic acids, hydroxycinnamic acid derivatives,

lignans, lignins and flavonoids (Decker, 1995). Flavonols and flavones are located predominantly in the leaves and outer parts of the plants (Hertog and Hollman, 1996). The antioxidant activity of phenolics is based on the redox properties of their hydroxyl groups, which allow them to act as reducing agents, hydrogen donors, single oxygen quenchers and metal chelators (Obboh and Rocha, 2007). Two new flavonol glycosides named corchorusides A and B were isolated from leaf extract of *Corchorus olitorius*. Corchoruside A comprises a kaempferol moiety connected with caffeic acid, glucose and a rare methyl glucuronate. Caffeoyl moiety occurred in corchoruside A enhanced its inhibitory effect toward α-glucosidase (Phuwapraisirisan *et al.*, 2009).

Dehydration is one of the most widely used methods for vegetables preservation. The marketing of dehydrated vegetables has increased over recent years to provide long-shelf life products which are easy to handle and store and used in formulation of nutraceutical products. Food products are sensitive to drying conditions such as temperature, air velocity and relative humidity, which can cause physical, structural, chemical and nutritional changes that, can affect quality attributes of products (Vega-Gálvez *et al.*, 2009). The drying of Jew's mallow leaves is necessary and commonly used to preserve it. Many studies investigated the changes in the quality parameters of Jew's mallow leaves during different drying methods (Ali and Sokr, 1982; Hussein, 1983 and Bahlol *et al.*, 2000). But, there is no data on the effect of drying process on the antioxidant properties and phytochemical compounds content of Jew's mallow leaves. Thus, the objective of this study was to investigate, for the first time, the effect of hot air drying conditions (air temperature, air velocity and trays load) on the antioxidant activity and phytochemical compounds of Jew's mallow leaves.

## MATERIALS AND METHODS

### Materials:

#### Plant material:

Fresh harvested Jew's mallow (*Corchorus olitorius* L.) was purchased from a local market (Ismailia Governorate, Egypt) during August and September 2013. Green leaves were separated from plant, washed with tap water and then drained and left to dry on a cheese cloth for 15 min at room temperature ( $31 \pm 2^\circ\text{C}$ ). The moisture content of the fresh Jew's mallow leaves was immediately determined according to the AOAC (2000) method (number 934.01), and found to be  $87.0 \pm 0.1$  g water per 100 g sample.

#### 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 obtained from Sigma-Aldrich CO. Methanol, hexane and acetone (analytical grade) were from Scharlab.

### Methods:

#### Drying treatments:

To study the effect of drying air temperature on the antioxidant activity and phytochemical compounds of the dried product, 250g of Jew's mallow leaves were spread uniformly onto stainless steel trays of size 36.5 cm x 60 cm. The leaves were dried in a convective dryer (WT-binder, type F115, Germany) at 50, 60 and  $70^\circ\text{C}$ . The air velocity was set at 0.6 m/s as measured with digital anemometer (VWR, Ireland) and ambient relative humidity (32%). The drying time required to reach the equilibrium moisture content was  $405 \pm 8$ ,  $300 \pm 15$  and  $195 \pm 8$  min and the moisture content of the dried leaves was  $9.35 \pm 0.45$ ,  $8.75 \pm 0.95$  and  $8.15 \pm 0.95$  g water per 100 g leaves dried at 50, 60 and  $70^\circ\text{C}$ , respectively.

To study the effect of air velocity, 125 g of Jew's mallow leaves were spread onto stainless steel trays and dried in an oven at 0.2, 0.4 and 0.6 m/s at a constant air temperature ( $60^\circ\text{C}$ ) and ambient relative humidity. The drying time required to reach the equilibrium moisture content was  $270 \pm 8$ ,  $225 \pm 0$  and  $195 \pm 8$  min and the moisture content of the samples was  $9.25 \pm 0.15$ ,  $9.25 \pm 0.35$  and  $9.00 \pm 0.30$  g water per 100 g leaves dried at 0.2, 0.4 and 0.6 m/s, respectively.

To study the effect of trays load, 125, 250, 375 and 500 g of fresh Jew's mallow leaves were spread uniformly onto stainless steel trays of size 36.5 cm X 60 cm and dried at  $60^\circ\text{C}$ , an air velocity of 0.6 m/s and ambient relative humidity (32%). The drying time was  $240 \pm 8$ ,  $300 \pm 15$ ,  $345 \pm 15$  and  $420 \pm 30$  min and the moisture content of the dried samples was  $8.90 \pm 0.70$ ,  $8.75 \pm 0.95$ ,  $8.60 \pm 0.80$  and  $8.40 \pm 1.10$  g water per 100 g leaves at 125, 250, 375 and 500 g trays load, respectively.

The drying experiments were conducted in triplicate. All samples were ground and passed through 250  $\mu\text{m}$  sieve previous to analyze.

#### Determination of Pigments:

The  $\beta$ -carotene, chlorophyll a and b contents were determined with the method described by Barros *et al.* (2011) with some modifications as follows: A 200 mg of minced fresh or dried leaves powder was vigorously shaken with 10 ml of acetone-hexane mixture (4:6) for 5 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). Contents of  $\beta$ -carotene, chlorophyll a and b were calculated according to the following equations:

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

$$\text{Chlorophyll a (mg/ 100 ml)} = 0.999 \times A_{663} - 0.0989 \times A_{645};$$

$$\text{Chlorophyll b (mg/ 100 ml)} = -0.328 \times A_{663} + 1.77 \times A_{645},$$

and further expressed in mg per 100 g dry weight.

#### Preparation of total phenolics, total flavonoids and antioxidants extracts:

Recent studies reported that the yield of extractable compounds was highest in methanol extract in comparison with the solvents such as ethyl acetate and water (Hossain and Rahman, 2011). Furthermore, the extraction of total phenolic compounds from the plant samples is commonly achieved with methanol or aqueous methanol (Antolovich *et al.*, 2000). Thus, methanol was used as a solvent to prepare the antioxidants and bioactive compounds extract according to the method described by Barros *et al.* (2011) with some modifications as follows: one gram of minced fresh Jew's mallow leaves or fine dried powder was stirred with 25 ml of methanol at 100 rpm on Orbital Shaker (LAB-LINE Instruments, Inc., USA) for 1 h at room temperature ( $35 \pm 1^\circ\text{C}$ ) and then filtered through filter paper No. 102. The residue was re-extracted with 25 ml of methanol. The methanol extracts were combined and stored at  $4^\circ\text{C}$  until further analyses. The extract was diluted if necessary.

#### Determination of total phenolics content:

Total phenolics content was calculated in the methanolic extract, according to the Folin-Ciocalteu assay with slight modifications (Barros *et al.*, 2011). One ml aliquot of the extract (diluted 1:5 with water) was mixed with 5 ml of Folin-Ciocalteu phenol reagent (diluted with water 1:10 v/v) and 4 ml of sodium carbonate (75 g/L). The tubes were vortexed for 30s and allowed to stand for 60 min at room temperature ( $30 \pm 1^\circ\text{C}$ ) for color development. The absorbance was measured at 765 nm by spectrophotometer. A calibration curve ( $R^2 = 0.9979$ ) of gallic acid (0 – 0.10 mg/ml) was prepared and treated in similar conditions. The results were expressed as mg of gallic acid equivalents per gram of dry weight (mg GAE/g DW).

### Determination of total flavonoids content:

Total flavonoids content was determined by technique modified by Dewanto *et al.* (2002) and reported by Barros *et al.* (2011). Briefly 0.5 ml aliquot of the extract was mixed with 2 ml of distilled water followed by addition of 0.15 ml of NaNO<sub>2</sub> (5%) solution. After 6 min, 0.15 ml of AlCl<sub>3</sub> solution (10%) was added and allowed to stand for another 6 min before 2 ml of NaOH solution (4%) was added. The mixture was brought to 5 ml with distilled water. Then the mixture was mixed well and allowed to stand for 15 min. The absorbance was measured at 510 nm. A calibration curve of quercetin was prepared and total flavonoids content was determined from the linear regression equation ( $R^2 = 0.9996$ ) of the calibration curve. The results were expressed as mg quercetin equivalents per gram of dry sample.

### Determination of DPPH radical-scavenging activity:

The antioxidant activity of the extract was determined by DPPH method described by Lee *et al.* (2003) and modified by Ravichandran *et al.* (2013). Shortly, 0.1 ml of a 5-fold dilution of the methanol extracts was mixed for 30 s with 3.9 ml of DPPH solution ( $6 \times 10^{-5}$  M), and left to react for 30 min, after which the absorbance of the mixture was measured at 515 nm. The DPPH solution without extract was analyzed as blank. The antioxidant activity was calculated as follows:

DPPH radical-scavenging activity (%) =  $[(A_{\text{blank}} - A_{\text{sample}})/A_{\text{blank}}] \times 100$ , where A is the absorbance at 515 nm.

### ABTS<sup>++</sup> assay (trolox equivalent antioxidant capacity, TEAC):

Additionally to DPPH investigations, the ability of the samples extract to scavenge the ABTS<sup>++</sup> radical was determined using the trolox equivalent antioxidant capacity (TEAC) assay. The method modified by Rufino *et al.* (2010) was used. Briefly, ABTS<sup>++</sup> radical cations were produced by reacting 7 mM ABTS stock solution with 145 mM potassium persulfate and allowing the mixture to stand in the dark at room temperature for 12 h before use. The ABTS<sup>++</sup> solution was diluted with ethanol to an absorbance of  $0.720 \pm 0.022$  at 734 nm. After addition of 20  $\mu$ l of the sample extract or trolox standard to 4 ml of diluted ABTS<sup>++</sup> solution, absorbance was recorded after 6 min of mixing. Ethanolic solutions of known trolox concentrations (0-10  $\mu$ g per ml) were used for calibration ( $R^2 = 0.9988$ ) and results were expressed as  $\mu$ mol trolox per gram dry sample.

### Statistical analysis:

Each experiment was done in triplicate. The results were expressed as mean  $\pm$  standard deviation and were analyzed by SPSS (version 17.0 SPSS Inc). One-way analysis of variance was performed using ANOVA procedures. Significant differences between the means were determined by Duncan's Multiple Range test.  $P < 0.05$  was considered as a level of significance.

## RESULTS AND DISCUSSION

### Effect of hot air drying variables on chlorophyll a, b and $\beta$ -carotene contents of Jew's mallow leaves:

Chlorophylls a and b are the major pigments of green vegetables, and they are usually present at a ratio of 2-3: 1 (von Elbe and Schwartz, 1996). Fresh Jew's mallow leaves contained  $649.4 \pm 22.2$ ,  $317.4 \pm 23.9$  and  $91.4 \pm 12.1$  mg/100 g (dry weight) of chlorophyll a, chlorophyll b and  $\beta$ -carotene, respectively (Table 1). Labib *et al.* (1997) found that the minced Jew's mallow leaves without any treatment contained 207 and 130 mg/100 g (dry weight) of chlorophyll a and b, respectively. Also, Bahlol *et al.* (2000) found that the fresh Jew's mallow leaves contained 281.6, 225.6 and 150.8 mg/100g (dry weight) of chlorophyll a, b and total carotenoids, respectively. These differences may be due to the variety, environmental conditions and extraction or method of determination.

Drying process variables (temperature, air velocity and trays load) led to significant decrease in the contents of chlorophyll a and b of the leaves (Table 1). The temperature had the main effect on these pigments. The decrements reached about 84.00 and 92.03 % in the case of drying at 50°C with constant air velocity (0.6 m/s) and trays load ( $250\text{g}/0.22\text{ m}^2$ ) for chlorophyll a and b, respectively. This may be due to the effect of heat or to the partial activity of native chlorophyllases (Labib *et al.*, 1997). Matile *et al.* (1999) found that, chlorophyllase catalyzes the first step in chlorophyll catabolism to form chlorophyllide. Also, chlorophyll is degraded by peroxidases or chlorophyll-degrading peroxidase (Martínez *et al.*, 2001) or by lipoxygenase through the oxidation of linolenic acid (Matile *et al.*, 1999). The retained chlorophyll a and b contents of the dried leaves significantly increased with increasing drying temperature. Moreover, the retained contents not significantly increased with increasing either air velocity or trays load. This may be due to combined effect of air velocity, drying time and drying air temperature. Chlorophyll retention during processing depends on the heating temperature and length of heat treatment. High-temperature short time processing has been made to preserve chlorophylls during heat processing (Schwartz and Lorenzo, 1991).

Carotenoids, including  $\beta$ -carotene, are known to be more stable during heating compared to chlorophylls (Lee *et al.*, 2001). Carotenoids are not only important vitamin A precursors, but display a considerable level of antioxidant activity. There were no significant differences in  $\beta$ -carotene of fresh or dried Jew's mallow leaves at different air temperatures, air velocities and trays loads (Table 1). Hot air drying at low temperature (50 °C) and trays load ( $125\text{g}/0.22\text{ m}^2$ ) caused the highest  $\beta$ -carotene losses (14.33 and 3.72%, respectively). Elevated temperatures provided less decreased in  $\beta$ -carotene content of the samples. Ihns *et al.* (2011) observed that the retained  $\beta$ -carotene content of dried apricot increased with increasing temperature from 80 to 100°C. They suggested that this is probably because the solubility of  $\beta$ -carotene increased at high temperature. Karabulut *et al.* (2007) ascribed the decrease in  $\beta$ -carotene due to oxidation with air; hence,

samples dried for a longer drying time and lower temperatures, air velocities resulted in lower  $\beta$ -carotene contents. The samples dried with a lower trays load (125 g/0.22 m<sup>2</sup>) resulted in lower pigments contents due to the more exposure to oxidation with air during drying process.

#### Effect of hot air drying variables on total phenolics and total flavonoids contents of Jew's mallow leaves:

Results in Table (2) showed that the initial contents of total phenolics and total flavonoids of fresh Jew's mallow leaves were  $16.54 \pm 0.63$  mg GAE and  $117.88 \pm 1.34$  mg QE per g (dry weight) sample, respectively. Similarly, Bahlol *et al.* (2000) found that the polyphenols content of fresh Jew's mallow leaves was 18.60 mg/ g (dry weight).

Hot air drying process led to decrease the total phenolics and flavonoids contents of Jew's mallow leaves (Table 2). A maximum reduction of 16.99 and 59.60% in comparison with fresh leaves in the total phenolics and flavonoids contents was shown in leaves dried at 50°C, respectively. Increasing temperature led to increase the retention of the total phenolics and flavonoids contents. The lowest reduction in the total phenolics (12.58%) and flavonoids (55.21%) was observed in leaves dried at 60°C (Table 2). The differences between total phenolics content in leaves dried at 60 and 70°C were not significant ( $P < 0.05$ ). A probable reason for the high reductions observed at 50°C could be the long drying time required to achieve the equilibrium moisture content. The drying at low temperature did not inactivate the oxidative enzyme, resulted in oxidation of the phenolic compounds (Mrad *et al.*, 2012). While, at 60 °C, the increasing of retained contents could be due to the increase in release of compounds from the matrix that is more accessible in the extraction. This also, may be attributed to the inactivation of polyphenol oxidase enzyme, leading to the inhibition of polyphenols degradation (Yamaguchi *et al.*, 2003) or because of the availability of precursors of phenolics by non-enzymatic inter-conversion between phenolic molecules (Que *et al.*, 2008).

The insignificant decrease occurred at 70°C could be due to the oxidation and degradation, where the degradation of total phenolics was temperature dependent. Also, it can be attributed to the interaction of polyphenols with proteins or to alterations in the chemical structure which cannot be extracted or determined (Martín-Cabrejas *et al.*, 2009 and Qu *et al.*, 2010).

All thermal drying methods such as microwave, sun and oven drying resulted in a decrease in the total phenolic compounds of ginger leaves (Chan *et al.*, 2009). The longer drying times resulted in higher degradation of phenolics in orange by-products and apple tissues (Garau *et al.*, 2007 and Devic *et al.*, 2010). Viña and Chaves (2008) found that drying celery at 48°C for one hour led to a 60% decrease in total flavonoids.

Drying Jew's mallow leaves at high air velocities led to an increase in the retained total phenolics and flavonoids contents (Table 2) in the dried product. This may be due to the reduction in drying times and thermal stress (Mrkic *et al.*, 2006).

Table (2) showed also, the effect of trays load on the total phenolics and flavonoids contents of Jew's mallow leaves. There were significant increase in the retention of both contents with increasing the trays load; the higher the trays load, the higher the total phenolics and flavonoids contents retention. This result seems inconsistent with those obtained with air temperature and velocity. Where, longer drying time led to increasing of phenolics and flavonoids degradation. This could be attributed to the complex relationships between drying air temperature, velocity, trays load and drying time. The degradation of flavonoids during heat treatment is not only a function of temperature. It may depend on other parameters such as the presence of oxygen and other phytochemicals. The presence of oxygen induces high reductions in quercetin and rutin. Also, the presence of other phytochemicals such as chlorogenic acid plays a protective role (Ioannou *et al.*, 2012).

**Table (1):** Effect of hot air drying variables on the main pigments contents (mg/100g dry weight) of Jew's mallow leaves

Drying variable	Chlorophyll a		Chlorophyll b		$\beta$ -carotene	
	Content	Retention %	Content	Retention %	Content	Retention %
Fresh	649.4 $\pm$ 22.2 <sup>a</sup>	100	317.4 $\pm$ 23.9 <sup>a</sup>	100	91.4 $\pm$ 12.1 <sup>a</sup>	100
<b>Air temperature (°C)</b>						
50	103.9 $\pm$ 15.8 <sup>d</sup>	16.00	25.3 $\pm$ 6.8 <sup>c</sup>	9.97	78.3 $\pm$ 29.0 <sup>a</sup>	85.67
60	234.3 $\pm$ 8.0 <sup>c</sup>	36.80	54.2 $\pm$ 27.0 <sup>bc</sup>	17.08	122.5 $\pm$ 47.2 <sup>a</sup>	134.03
70	327.7 $\pm$ 5.7 <sup>b</sup>	50.46	83.6 $\pm$ 35.4 <sup>b</sup>	26.34	141.4 $\pm$ 59.1 <sup>a</sup>	154.70
<b>Air velocity (m/ s)</b>						
0.2	155.9 $\pm$ 27.8 <sup>b</sup>	24.01	30.0 $\pm$ 14.0 <sup>b</sup>	9.45	96.1 $\pm$ 26.2 <sup>a</sup>	105.14
0.4	160.9 $\pm$ 41.5 <sup>b</sup>	24.78	29.6 $\pm$ 11.4 <sup>b</sup>	9.33	101.1 $\pm$ 22.5 <sup>a</sup>	110.61
0.6	163.3 $\pm$ 15.9 <sup>b</sup>	25.15	34.5 $\pm$ 14.6 <sup>b</sup>	10.87	99.5 $\pm$ 37.7 <sup>a</sup>	108.86
<b>Trays load (g/ 0.22 m<sup>2</sup>)</b>						
125	184.4 $\pm$ 39.3 <sup>c</sup>	28.40	42.5 $\pm$ 7.3 <sup>b</sup>	13.39	88.0 $\pm$ 29.5 <sup>a</sup>	96.28
250	234.3 $\pm$ 8.0 <sup>b</sup>	36.08	54.2 $\pm$ 27.0 <sup>b</sup>	17.08	122.5 $\pm$ 47.2 <sup>a</sup>	134.03
375	261.8 $\pm$ 42.6 <sup>b</sup>	40.31	54.7 $\pm$ 20.4 <sup>b</sup>	17.23	131.9 $\pm$ 38.2 <sup>a</sup>	144.31
500	239.5 $\pm$ 38.1 <sup>bc</sup>	36.88	47.9 $\pm$ 20.9 <sup>b</sup>	15.09	125.2 $\pm$ 35.8 <sup>a</sup>	136.98

Values are means  $\pm$  standard deviation of triplicate analyses.

Means within a column (for each variable) marked with different letters are significantly different at ( $p < 0.05$ ).

**Table (2):** Effect of hot air drying variables on total phenolics and total flavonoids contents (mg/g dry weight) of Jew's mallow leaves

Drying variable	Total phenolics		Total flavonoids	
	Content	Retention %	Content	Retention %
<b>Fresh</b>	16.54 ± 0.63 <sup>a</sup>	100	117.88 ± 1.34 <sup>a</sup>	100
<b>Air temperature (°C)</b>				
50	13.73 ± 0.19 <sup>c</sup>	83.01	47.62 ± 2.30 <sup>b</sup>	40.40
60	14.46 ± 0.08 <sup>b</sup>	87.42	52.80 ± 2.40 <sup>b</sup>	44.79
70	14.20 ± 0.16 <sup>bc</sup>	85.85	52.12 ± 5.99 <sup>b</sup>	44.21
<b>Air velocity (m/ s)</b>				
0.2	15.51 ± 0.20 <sup>b</sup>	93.77	50.77 ± 6.19 <sup>b</sup>	43.07
0.4	15.21 ± 0.31 <sup>b</sup>	91.96	48.74 ± 7.08 <sup>b</sup>	41.35
0.6	16.28 ± 0.34 <sup>a</sup>	98.43	52.30 ± 3.11 <sup>b</sup>	44.37
<b>Trays load (g/ 0.22 m<sup>2</sup>)</b>				
125	14.36 ± 0.19 <sup>c</sup>	86.82	50.28 ± 5.20 <sup>c</sup>	42.65
250	14.46 ± 0.08 <sup>c</sup>	87.42	52.80 ± 2.40 <sup>c</sup>	44.79
375	15.51 ± 0.03 <sup>b</sup>	93.77	59.06 ± 0.99 <sup>b</sup>	50.10
500	15.82 ± 0.82 <sup>ab</sup>	95.65	60.93 ± 3.87 <sup>b</sup>	51.69

Values are means ± standard deviation of triplicate analyses.

Means within a column (for each variable) marked with different letters are significantly different at ( $p < 0.05$ ).

#### Effect of hot air drying variables on the antioxidant activity of Jew's mallow leaves:

Results are presented in Table (3) showed the DPPH-radical scavenging activity and average antioxidant capacity (TEAC assay) of fresh and dried Jew's mallow leaves under different drying variables. Fresh Jew's mallow leaves exhibited high DPPH radical scavenging activity (52.29%, dry weight) and antioxidant capacity (139.55 µmol trolox/ g, dry weight). Leaves dried at 50 and 70 °C exhibited the lowest DPPH and TEAC scavenging activities. Meanwhile, leaves dried at 60 °C had the highest ones. The increase in the retained antioxidant activity after drying at 60 °C may be attributed to the release of phenolic compounds by the breakdown of cellular

constituents (Chan *et al.*, 2009), and the formation of new compounds such as Maillard reaction products, which having antioxidant activity (Manzocco *et al.*, 2001). Drying at low temperature (such as 50 °C) led to decrease the antioxidant activity. This behavior could be related to the long drying time that may be cause a decrease of antioxidant activity (Garau *et al.*, 2007). Drying time was the critical factor in broccoli dehydration. Short drying times, through use of high temperature and increased air flow maximized the antioxidant activity (Mrkic *et al.*, 2006). The negative effect of high temperature (70 °C) on antioxidant activity could be ascribed to its depleting effect via oxidation or degradation on phytochemicals (Katsube *et al.*, 2009).

**Table (3):** Effect of hot air drying variables on DPPH and ABTS<sup>++</sup> scavenging activities of Jew's mallow leaves.

Drying variable	DPPH radical-scavenging activity		ABTS <sup>++</sup>	
	(%, dry weight)	Retention %	(µmol trolox/ g dry weight)	Retention %
<b>Fresh</b>	52.29 ± 2.84 <sup>a</sup>	100	139.55 ± 7.48 <sup>a</sup>	100
<b>Air temperature (°C)</b>				
50	36.11 ± 0.74 <sup>c</sup>	69.06	42.16 ± 0.34 <sup>b</sup>	30.21
60	42.59 ± 0.27 <sup>b</sup>	81.45	44.79 ± 3.68 <sup>b</sup>	32.10
70	37.30 ± 0.24 <sup>c</sup>	71.33	37.77 ± 1.72 <sup>b</sup>	27.07
<b>Air velocity (m/ s)</b>				
0.2	42.17 ± 0.54 <sup>c</sup>	80.65	41.71 ± 0.80 <sup>b</sup>	29.89
0.4	42.41 ± 1.92 <sup>bc</sup>	81.11	41.72 ± 2.04 <sup>b</sup>	29.90
0.6	46.23 ± 2.20 <sup>b</sup>	88.41	43.34 ± 0.01 <sup>b</sup>	31.06
<b>Trays load (g/ 0.22 m<sup>2</sup>)</b>				
125	41.87 ± 1.69 <sup>b</sup>	80.07	41.52 ± 1.71 <sup>b</sup>	29.75
250	42.59 ± 0.27 <sup>b</sup>	81.45	44.79 ± 3.68 <sup>b</sup>	32.10
375	43.23 ± 0.68 <sup>b</sup>	82.67	45.80 ± 2.41 <sup>b</sup>	32.82
500	44.41 ± 1.21 <sup>b</sup>	84.93	50.56 ± 7.92 <sup>b</sup>	36.23

Values are means ± standard deviation of triplicate analyses.

Means within a column (for each variable) marked with different letters are significantly different at ( $p < 0.05$ ).

Data presented in Table (3) showed that the antioxidant activity of dried Jew's mallow leaves correlated positively with air velocity. This could be due to the reduction in drying time. Also showed the

positive correlations between trays load and antioxidant activity of dried Jew's mallow leaves. This result seemed inconsistent with those obtained in air temperature and velocity, where shorter drying times

enhanced the antioxidant activity. In this case, the highest load and longer drying time, the highest antioxidant activity. This could be related to generation and accumulation of different antioxidant compounds developing antagonistic or synergistic effects with other constituents or with themselves (Zielinski and Kosłowska, 2000).

Many studies have reported on the relationships between phytochemicals, especially phenolics and antioxidant activity. Increasing correlation between antioxidant activity and total phenolics content has been reported during food dehydration. A plot of antioxidant activity measured by DPPH or TEAC assay versus phytochemical compounds studied showed a strong positive correlation with chlorophyll a ( $r^2 = 0.791 - 1.00$ ), chlorophyll b ( $r^2 = 0.848 - 1.00$ ), total phenolics ( $r^2 = 0.823 - 0.955$ ) and total flavonoids ( $r^2 = 0.868 - 0.999$ ) (data not shown). This indicating that these compounds are useful predictors of antioxidant activity of Jew's mallow leaves.

### CONCLUSION

The results of the present study showed the importance of Jew's mallow leaves as a good source of natural antioxidants. Drying process variables had significant effects on the antioxidant activity and phytochemical compounds of Jew's mallow leaves. Optimizing the drying process of Jew's mallow is important to maintain its desirable properties. From nutrition point of view, dried leaves can be used in many food products such as snacks or extrudates (article in preparation) to enhance their nutritional properties.

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## تأثير عوامل التجفيف بالهواء الساخن في المركبات الحيوية والنشاط المضاد للأكسدة لأوراق الملوخية

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تعتبر الملوخية من محاصيل الخضار الهامة في مصر، والتي يتعاطم الطلب عليها سواء في صورة طازجة أو مجففة محليا وخارجيا. يهدف هذا البحث إلى دراسة تأثيرات عوامل التجفيف بالهواء الساخن مثل درجة الحرارة (٥٠، ٦٠ و ٧٠ °م)، سرعة الهواء (٠.٢، ٠.٤ و ٠.٦ م/ث) وحمولة الصواني (١٢٥ – ٥٠٠ جم/م<sup>٢</sup>) على محتوى أوراق الملوخية من المركبات الحيوية والنشاط المضاد للأكسدة. أوضحت النتائج أن لأوراق الملوخية الطازجة نشاط مضاد للأكسدة مرتفع (٥٢.٢٩% و ١٣٩.٥٥ ميكرومول trolox لكل جرام مادة جافة مقدره بطريقتي DPPH و ABTS، على الترتيب). كما احتوت الأوراق الطازجة على محتوى مرتفع من كلورفيل أ و ب (٦٤٩.٤ و ٣١٧.٤ مجم/١٠٠ جم على الترتيب) والفينولات الكلية (١٦.٥٤ مجم/جم) والفلافونيدات الكلية (١١٧.٨٨ مجم/جم). أدت عملية التجفيف عموما إلى انخفاض واضح في محتوى أوراق الملوخية الناتجة من المركبات الحيوية والنشاط المضاد للأكسدة باستثناء محتوى البيتا كاروتين. أدى التجفيف على درجات حرارة وسرعة هواء منخفضة إلى انخفاض معنوي في المركبات الحيوية تحت الدراسة والنشاط المضاد للأكسدة نظرا لطول فترة التجفيف، بينما كان أقل تأثير سلبي على درجة حرارة ٦٠ °م وسرعة هواء ٠.٦ م/ث. كما احتوت الأوراق المجففة تحت حمولة صواني تجفيف مرتفعة (٥٠٠ جم/م<sup>٢</sup>) على أعلى محتوى من المركبات الحيوية وكان لها أعلى نشاط مضاد للأكسدة عن تلك المجففة على حمولات صواني تجفيف منخفضة.