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Effect of Pretreatments and Air Temperatures on Drying Characteristics and Color Changes of Ziziphus Fruits

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Abstract: The aim of this study was to investigate the effect of pretreatments and hot air temperature on drying kinetics and color changes of Ziziphus fruits dried in an oven drier. The average weight of *Ziziphus spina-christi* (ZS) fruits was 4.12g, while that of *Ziziphus mauritiana* (ZM) fruits was 41.02g. Drying curves of ziziphus fruits were affected by the applied pretreatments and hot air temperature. No constant drying rates were observed which indicate that moisture removal was carried out principally by moisture diffusion from pulp to fruit outer surface. Consecutive dipping in solutions of sodium hydroxide, citric acid and sodium metabisulfite followed by drying at 90°C shortened the drying time to an average of 6.2h for ZS fruits and 5.27h for ZM slices. Page-model was better than Newtonian-model for mathematical representation of drying curves for ziziphus fruits. Drying process caused reduction in lightness (L-values), increase in redness (a-values), decrease in yellowness (b-values) and increase in browning index (BI-values). Color saturation (chroma) of the dried fruits was higher than that of fresh fruits, while Hue-angles were radically changed from yellow region towards orange-red region upon drying.

Key words: Ziziphus fruits · Drying · Color · Fruits pretreatments · Drying rate

INTRODUCTION

Ziziphus spina-christi is one of the most important evergreen trees in the dry regions of sub-tropical Arabia, especially in west Asia and east Africa including Egypt, Saudi Arabia, Yemen and south of Iran with edible, fresh fruits [1]. The fruits are round in shape, red-yellow to yellow-green colored and have a non-separating stone which is not eaten with the fruits. They have sweet taste, highly nutritious and rich in vitamin C [2]. The fruits are eaten fresh or dried and can be made into a floury meal, butter or a cheese-like paste used as a condiment and for candy making. It's also a good source of carotene, vitamin A and C. The dry fruits (i.e. per 100g) contains in average 9.3% moisture, 4.8% protein, 0.9% fat, 80.6% total carbohydrates, 4.4% ash, 140 mg Ca, 3 mg Fe, 0.04 mg thiamin, 0.13 mg riboflavin, 3.7 mg niacin, 30 mg ascorbic acid and have an energy value of 314 calories [3]. Fresh fruits of ZS deteriorate fast and cannot be kept for more than 10-14 days under ambient conditions without serious deterioration [4]. Research on processing and preservation technologies and marketing opportunities for the fresh ziziphus fruits are limited locally as well as internationally. Cooling, freezing and moisture reduction are the most important tools for extending the shelf life of fruits and vegetables [5] and can ensure its availability throughout the year. Drying is a classical method of food preservation and dried fruits are widely used as a component in much formulation of foods [6, 7]. Pretreatment processes blanching and dipping are used before drying of most vegetables and fruits in order to prevent the development of off flavor and excess browning upon drying and subsequent storage. The treatment aims also to facilitate drying and to preserve the physical, chemical, nutritional and organoleptic characteristics of the dried product [8-11]. Few attempts had been trialed to extend the shelf life and preserve the fruits of ZS by cooling [4, 12] and by drying [13]. However, there is a lack of information about the effect of dipping pretreatments on the drying rate and color

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characteristics of these fruits. Therefore, the aim of this investigation is to determine the effect of pretreatments and drying temperature on the drying rate and color changes of dried Ziziphus fruits grown in Egypt and those marketed in Saudi Arabia.

MATERIALS AND METHODS

Fresh ziziphus fruits (Ziziphus *spina-christi* (ZS) and *Ziziphus mauritiana* (ZM)) were obtained from a local market in Egypt and Saudi Arabia, respectively. Fruits were washed and subjected to different treatments before drying. These pretreatments were set up according to Femenia *et al.* [14] and own preliminary experiments. The pretreatments were performed on duplicate samples of ziziphus fruits as follows: (0) served as a control; (1) immersion in a 0.3% sodium hydroxide solution at 100°C for 30 s with ZS and 60 s with ZM followed by washing in distilled water at 25°C for 5 min, (2) pretreatment as in (1) followed by washing in distilled water, then the fruits were dipped in 3% a citric acid solution for 5 min with ZS and 10 min with ZM at room temperature; (3) subsequent dipping in a sodium hydroxide solution and citric acid solution as in treatment (2), followed by dipping in 4% potassium metabisulphite solution for 10 min with ZS and 20 min with ZM at room temperature.

Proximate Analysis: Major compositions (crude protein, crude fat and ash) were analyzed on dry matter basis using the recommended methods of the A.O.A.C. [15]. Total carbohydrates were calculated by difference, while moisture content was determined by air oven and vacuumed oven according to A.O.A.C. [15].

Physical Properties: One hundred fruits were selected randomly and tested for their physical parameters such as length, width, thickness, weight, volume, true density, bulk density, geometrical mean diameter, sphericity and surface area. Vernier caliper and digital balance with accuracy of 0.01mm and 0.001g, respectively were used according to the methods described by Jahromi *et al.* [16], Ahmadi *et al.* [17] and Akhijahani and Khodaei [18]. The pH-values were determined by pH meter (HANNA-instrument, USA).

The Drying Operation: A laboratory scale hot-air dryer (WF binder, 7200 Tuttlingen/Germany) was used for drying process in a thin layer pattern. Before starting each experiment, the dryer was turned on for 30 minutes in order to achieve the desirable steady-state conditions. Experiments were conducted at three levels of temperatures: 70, 80 and 90°C and the air velocity were in the range of 1-1.5 m/s in parallel follow. Dried samples were manually weighed using an electronic balance with an accuracy of ±0.01, (AND GF-600, Japan). Weighing of the samples was continued at time intervals until no change was observed between two consecutive measurements.

Modeling of Drying Rate: Experimental drying data were fitted to two drying kinetics models widely used in drying fruits and vegetables [4, 8]. The equations use a relationship between moisture ratios (MR) as a dependent variable with drying time (Equation 1).

$$MR = \frac{Mt}{M_o} \quad (1)$$

The applied drying models were Newton (Equation 2) and Page (Equation 3) models.

$$MR = \exp(-k.t) \quad (2)$$

$$MR = \exp(-k.t)^n \quad (3)$$

where:

- Mt = Moisture content at any time during drying experiment Kg H_2O/Kg DM.
- M_o = Initial moisture content Kg H_2O/Kg DM.
- t = Drying time
- k = Drying rate constant Kg H_2O/Kg DM h.
- n = Exponent value representing the deviation of the drying characteristics of a food material from evaporation of water vapor from a plan water surface.

The fit quality of the applied mathematical models was evaluated by the coefficient of determination (R^2), sum squared errors (SSE, Equation 4) and root mean sum of errors (RSME, Equation 5). The values closest to 1.0 for R^2 and those closest to zero for SSE and RMSE are commonly considered as optimum criteria to evaluate the fit quality of the applied models.

$$SSE = \frac{1}{N}\sum_{n-1}^{n}(MRe - MRc)^2 \quad (4)$$

$$RMSE = \sqrt{SSE} \quad (5)$$

where:

N = Number of experiments.

MRe = Experimental values of moisture ratio.

MRc = Calculated value of experimental ratio.

Color Measurements: Sample color was measured before drying and at time intervals during drying period by Spectrophotometer (MOM, 100 D, Hungary). For each sample at least three measurements were performed and the measured values are mean values. Total color difference, chroma and hue angle were calculated using the following equations [19]:

$$\Delta E = (a^2+L^2+b^2)^{1/2}, \text{ Chroma} = (a^2+b^2)^{0.5} \text{ and Hue Angle} = \tan^{-1}(b/a) \quad (6)$$

where L is degree of lightness to darkness, a is degree of redness to greenness, b is degree of yellowness to blueness. Browning index (BI) represents the purity of brown color and is considered as an important parameter associated with browning. Browning index was calculated from the following equations [20]:

$$BI = \frac{[100(x-0.31)]}{0.17} \quad (7)$$

where:

$$x = \frac{(a+1.75L)}{2(5.645L+a-3.012b)} \quad (8)$$

Statistical Analysis: Experimental data for drying experiments were fitted to two kinetic models (Newton and page) and processed by using SAS-linear regression program [21]. Kinetic rate constants were calculated from linear regression. Correlation coefficient and RMSE were used as the basis to select the best fitting for estimation of the parameters of models.

RESULTS AND DISCUSSION

Chemical Composition and Physical Properties of the Ziziphus Fruits: Table 1 shows the chemical composition of the tested ziziphus fruits. The moisture content of ZM is higher than that of ZS being 85.68% for the first and 76.70% for the latter. The major component of the two cultivars is carbohydrates, which makes 83.3 to 85.72% of the dry weight of the fruits. However, the fruits contain a considerable amount of crude protein and ash being 6.73 to 8.42% (for protein) and 5.93 to 6.82% (for ash). The fruits are poor in fat, where its percentage is lower than 2% of the dry matter. The major chemical composition of the tested ziziphus fruits are in agreement with those reported by Ramulu and Rao [22] and Feyssa *et al.* [23]. The physical properties of fresh ziziphus fruits are given in Table 2. The appearance of ZS is yellow to reddish with a hue angle value of 57.8°, while that of ZM is light green-yellow with a hue angle of 82.27°. The linear dimensions of ZS varied from 16.5 to 20.5 mm for length, 16 to 20 mm for width and 16.5 to 20 mm for thickness with a sphericity factor of 93.7%. On the other side, the major dimensions of ZM ranged from 35.5 to 48.5 mm for length, 33 to 40.5 mm for width and 30.5 to 45 mm for thickness with a sphericity factor of 99.15%. The fruit weight of ZS ranged from 2.902 to 5.334g with a variation of 21.18%, while that of ZM was in the range 21.64 to 60.40g with a variation of 33.1% (based on mean and standard deviation values of the fruit weight). The average volume of ZS is to a great extent lower than that of ZM with 4.35 cm^3 for the first and 34.77 cm^3 for the latter. The pulp/stone ratio and surface area were 2.7 and 250 mm^2 for *ZS*, 12.6 and 1135 mm^2 for ZM. The true and bulk densities of ZS were 848 and 656 kg/m^3, respectively with a porosity value of 22.64%, while those of ZM were 1013 and 722 kg/m^3, respectively with a porosity value of 28.73%. The pH-value of the fruit pulp was 4.36 and 5.15 for ZS and ZM, respectively. These results are in agreement with those reported by Pareek *et al.* [12]. The low pH-value of ZS make the pulp suitable for juice processing with pasteurization temperatures lower than 100°C, which minimize the damage of its functional components.

Drying Characteristics of the Ziziphus Fruits: Both tested varieties of ziziphus fruits were subjected to three pretreatments, as described before, in order to facilitate the drying process. The pretreated samples were subjected to drying process in a cabinet dryer at three air temperature levels: 70, 80 and 90°C.

Drying Curves and Drying Time: Fig. 1 show the drying curves of ziziphus fruits as affected by the applied pretreatment and drying air temperature. The drying curves show that the moisture content of ziziphus fruits decreased with increasing drying time under various drying conditions. As shown in Fig. 1, the constant

Table 1: Chemical composition (%) of fresh Ziziphus fruits.

Proximate analysis	*Ziziphus spina-christi* (ZS)	*Ziziphus mauritiana* (ZM)
Dry matter	23.30	14.32
Moisture	76.70	85.68
Crude protein	8.42	6.73
Carbohydrates	83.3	85.72
Crude fat	1.46	1.62
Ash	6.82	5.93

Table 2: Physical characteristics of fresh Ziziphus fruits.

Properties	*Ziziphus spina-christi* (ZS)	*Ziziphus mauritiana* (ZM)
Appearance	Yellow to reddish-yellow	Light green-yellow
Hue-angle (º)	57.8	82.27
Length (mm)	16.5-20.5 (0.1241)*	35.5-48.5(0.4169)
Width(mm)	16-20 (0.1232)	33-40.5(0.4138)
Thickness(mm)	16.5-20 (0.1362)	30.5-45(0.46128)
Sphericity (%)	93.70	99.15
Volume (cm^3)	4.35	34.77
Fruit weight (g)	2.902-5.334 (0.7807)	21.64-60.40 (11.66)
Pulp/stone ratio	2.7	12.6
Surface area(mm^2)	250	1135
True density (Kg/m^3)	848	1013
Bulk density (Kg/m^3)	656	722
Porosity (%)	22.64	28.74
pH	4.36	5.15

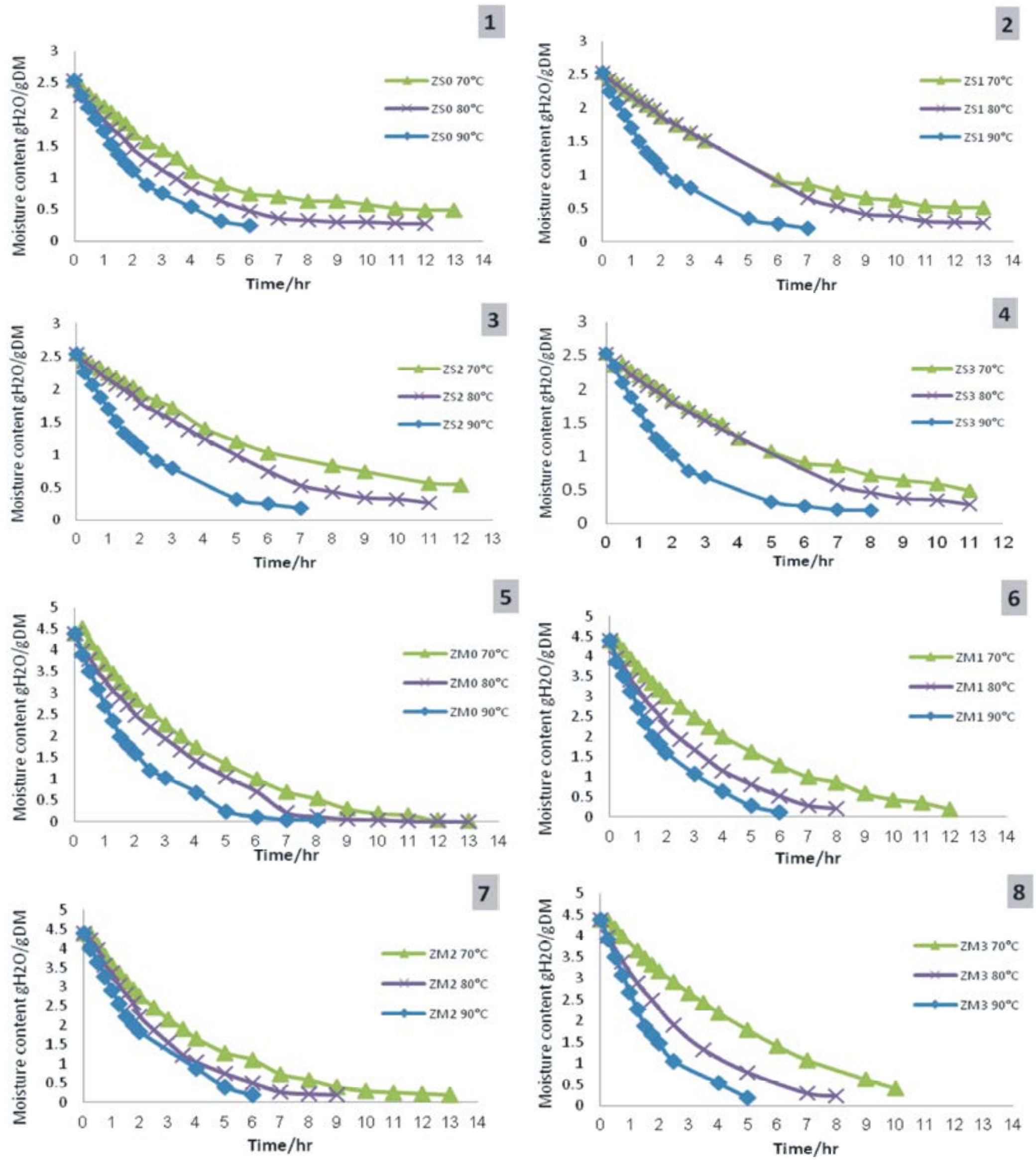
* Values in parentheses are standard deviation

Table 3: Drying time of ziziphus fruits as affected by pretreatment and drying temperature

		Ziziphus spina-christi (ZS)		*Ziziphus mauritiana* (ZM)	
Pretreatment (PT)	Drying temperature (°C)	Equilibrium moisture content gH_2O/g DM	Drying time (h)	Equilibrium moisture content gH_2O/g DM	Drying time (h)
Control	70	0.489	> 13	0.2158	9.83
	80	0.274	13	0.2148	7
	90	0.1949	7	0.2144	5.16
PT (1)	70	0.516	> 13	0.2456	11.66
	80	0.285	13	0.229	7.66
	90	0.230	6.5	0.232	5.33
PT (2)	70	0.537	> 13	0.2581	11
	80	0.2456	12.5	0.2489	7.33
	90	0.222	6	0.2459	5.75
PT (3)	70	0.4649	11.66	0.2461	11.33
	80	0.264	7.66	0.2508	7.66
	90	0.249	5.33	0.2369	4.83

PT (1): pretreatment with NaOH, PT (2): pretreatment with NaOH + citric acid, PT (3): pretreatment with NaOH + citric acid+ $Na_2S_2O_5$.

drying rate phase is not seen in all pretreatments and the drying curves showed an exponential course during the whole of the drying period. This indicates that the moisture movement is controlled by diffusion and that diffusion is dependent on the moisture content of the fruits, the applied pretreatment and the drying air temperature. It is clearly seen that ziziphus fruits lost most of its moisture content within the first two hours of drying, while a long time is required to remove the remaining moisture. Table 3 shows the drying time and the achieved final equilibrium moisture content under different drying treatments. In general, it could be observed that the drying time for ZM was shorter than that required for whole fruits of ZS. Furthermore, the effect of pretreatments on shortening drying time and facilitating drying process was only remarkable at drying temperature of 90°C and it was negligible at 70°C. The shortest drying time was 5.33 and 4.83 h, respectively for ZS and ZM fruits pretreated by consecutive dipping in solutions of NaOH, citric acid and sodium metabisulfite



Pretreatment of *Ziziphus spina-christi* (ZS), 1,2,3,4 and *Ziziphus mauritiana* (ZM), 5,6,7,8. ZS0 and ZM0: control treatment, ZS1 and ZM1: pretreatment with NaOH, ZS2 and ZM2: pretreatment with NaOH + citric acid, ZS3 and ZM3: pretreatment with NaOH + citric acid+ $Na_2S_2O_5$.

Fig. 1: Effect of the applied pretreatment and drying air temperature on drying curves of ziziphus fruits

and dried at 90°C. Drying time at 90°C was shortened by 52 to 54% to that obtained at 70°C and by 30 to 52% that obtained at 80°C. It seems that the small size of ZS fruits and the presence of seeds inside the fruits have complicated the drying process compared with ZM fruits, which was dried in slices. Regardless of the applied pretreatment, drying ZS fruits at 70°C was ineffective, since the final equilibrium moisture content was in the range of 0.465 to 0.537 g H_2O/g DM, which is higher than the safe moisture content of dried fruits (0.22 – 0.25 g H_2O/g DM). According to Femenia *et al.* [14] and Serratosa *et al.* [24] pretreatments by consecutive dipping in NaOH, citric acid and $Na_2S_2O_5$ solutions helped to reduce the drying time of grapes by solubilizing large amount of pectic substances in cell walls and creating fissures in the fruit surfaces.

Kinetic of Drying Process: The relationship between the change in moisture ratio (MR) and drying time (τ) was statistically analyzed to find out the suitable applied model and to calculate the drying rate (k-value) and the results are given in Tables 4a and 4b. Based on the levels

Table 4a: Drying rate constants of ziziphus fruits calculated according to Newton –equation

Pretreatment and drying air temp.	*Ziziphus spina-christi* Drying rate constant k (h^{-1})	Predicted intercept (MR at time zero)	R^2	Root MSE	*Ziziphus mauritiana* Drying rate constant k (h^{-1})	Predicted intercept (MR at time zero)	R^2	Root MSE
Control								
70°C	0.32533	0.9082	0.905	0.4914	0.3093	0.8384	0.985	0.1347
80°C	0.45524	0.8210	0.982	0.2584	0.3625	0.8845	0.929	0.2188
90°C	0.63313	0.7710	0.959	0.2845	0.5501	0.9407	0.970	0.1503
PT (1)								
70°C	0.38637	0.7052	0.905	0.5161	0.3263	0.7527	0.897	0.4321
80°C	0.39725	0.6895	0.928	0.4698	0.4200	0.8907	0.975	*0.1474*
90°C	0.58359	0.8730	0.987	0.1277	0.6058	0.9052	0.980	0.1534
PT (2)								
70°C	0.33278	0.7657	0.903	0.3741	0.3833	0.7547	0.970	0.2651
80°C	0.35735	0.7630	0.958	0.2393	0.5078	0.7737	0.973	0.3662
90°C	0.59186	0.8632	0.985	0.1381	0.5590	0.9032	0.972	0.1551
PT (3)								
70°C	0.2906	0.8707	0.987	0.1078	0.2938	0.8243	0.950	0.1822
80°C	0.35008	0.7900	0.971	0.2026	0.5401	0.8437	0.940	0.3421
90°C	0.72604	0.7506	0.952	0.3729	0.6338	0.9368	0.998	0.0382

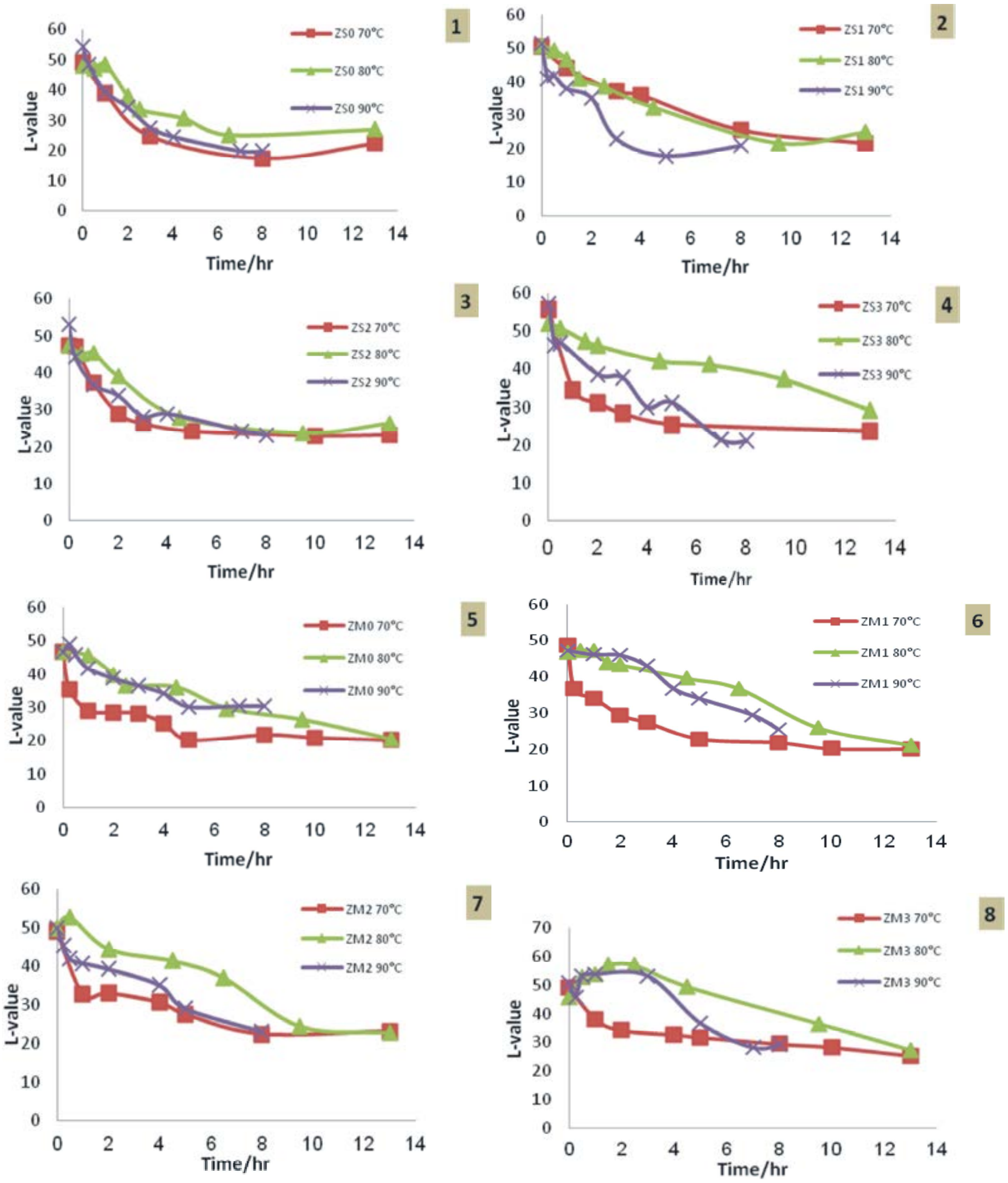
PT (1): pretreatment with NaOH, PT (2): pretreatment with NaOH + citric acid, PT (3): pretreatment with NaOH + citric acid+ $Na_2S_2O_5$.

Table 4b: Drying rate constants of ziziphus fruits calculated according to page-equation

Pretreatment and drying air temp.	*Ziziphus spina-christi* Drying rate constant k (h^{-1})	Constant (n)	R^2	Root MSE	*Ziziphus mauritiana* Drying rate constant k (h^{-1})	Constant (n)	R^2	Root MSE
Control								
70°C	0.2329	1.175	0.991	0.1271	0.1714	1.237	0.991	0.1322
80°C	0.3391	1.093	0.986	0.1489	0.3018	0.990	0.980	0.1404
90°C	0.4398	1.116	0.991	0.1021	0.4935	1.045	0.995	0.0704
PT (1)								
70°C	0.1828	1.222	0.988	0.1608	0.0958	1.574	0.892	0.6187
80°C	0.1776	1.218	0.973	0.2426	0.3529	1.019	0.890	0.1011
90°C	0.4710	1.055	0.992	0.0893	0.5106	1.059	0.994	0.0782
PT (1)								
70°C	0.1666	1.199	0.988	0.1493	0.1456	1.445	0.946	0.3907
80°C	0.1958	1.165	0.980	0.1782	0.2777	1.319	0.995	0.0910
90°C	0.4703	1.059	0.992	0.0892	0.4433	1.107	0.995	0.0726
PT (1)								
70°C	0.2100	1.072	0.963	0.2263	0.1083	1.531	0.956	0.3463
80°C	0.2000	1.145	0.980	0.1796	0.3789	1.071	0.983	0.1640
90°C	0.4613	1.192	0.996	0.0789	0.5371	1.135	0.998	0.0390

PT (1): pretreatment with NaOH, PT (2): pretreatment with NaOH + citric acid, PT (3): pretreatment with NaOH + citric acid+ $Na_2S_2O_5$.

of correlation coefficient (R^2-values) and the values of root of mean sum squares of error (RMSR), it could be concluded that the Page equation is more suitable than the Newton equation to represent the drying curves of Ziziphus fruits, since Page equation showed the highest R^2-values and the lowest RMSE-values. The n-constant of page equation showed always values higher than unity, indicating the complexity of moisture removal during drying of Ziziphus fruits, especially at 70°C. The drying rates (K-values) of ZM fruits, in general, were higher than those calculated for ZS. Also the pretreatments with NaOH solution alone or in series with citric acid and $Na_2S_2O_5$ had enhanced the drying rate values of the fruits. The same effect was also achieved by increasing drying air temperature from 70° to 90°C. The reason for the higher drying rate of the big size ZM compared to the small size ZS fruits could be attributed to the difference in vapor pressure inside the fruits during drying. The larger fruits contain more water but have less specific surface area than the small ones, resulting in higher vapor pressure potential, which facilitate the water loss from the fruits to the environment and increasing



Pretreatment of *Ziziphus spina-christi* (ZS), 1,2,3,4 and *Ziziphus mauritiana* (ZM), 5,6,7,8. ZS0 and ZM0: control treatment, ZS1 and ZM1: pretreatment with NaOH, ZS2 and ZM2: pretreatment with NaOH + citric acid, ZS3and ZM3: pretreatment with NaOH + citric acid+ $Na_2S_2O_5$.

Fig. 2: Changes in Lightness (L-value) of Ziziphus fruits in relationship to pretreatment, drying temperature and drying time

moisture diffusivity and K-values. On other side, the long drying time and low K-values of *Ziziphus* fruits dried at 70°C could be referred to the long time required at this temperature to heat the fruit – by conduction – to the evaporation temperature.

In addition, the drying begins from the external fruit surface leading to hardening and lowering the permeability of the surface. The hardened layers, from one side and the low heat drying force at this temperature, from other side, prevents moisture diffusion and prolongs the time needed for moisture removal from the fruits, especially during the second part of the falling drying curve, where the moisture transport from inside to the surface of the fruits is carried out by liquid and vapor diffusion which requires high heat energy to achieve vapor motion towards the surface, which could not be achieved enough at 70°C. With increasing temperature to 90°C, drying rate increased as a result of increase in

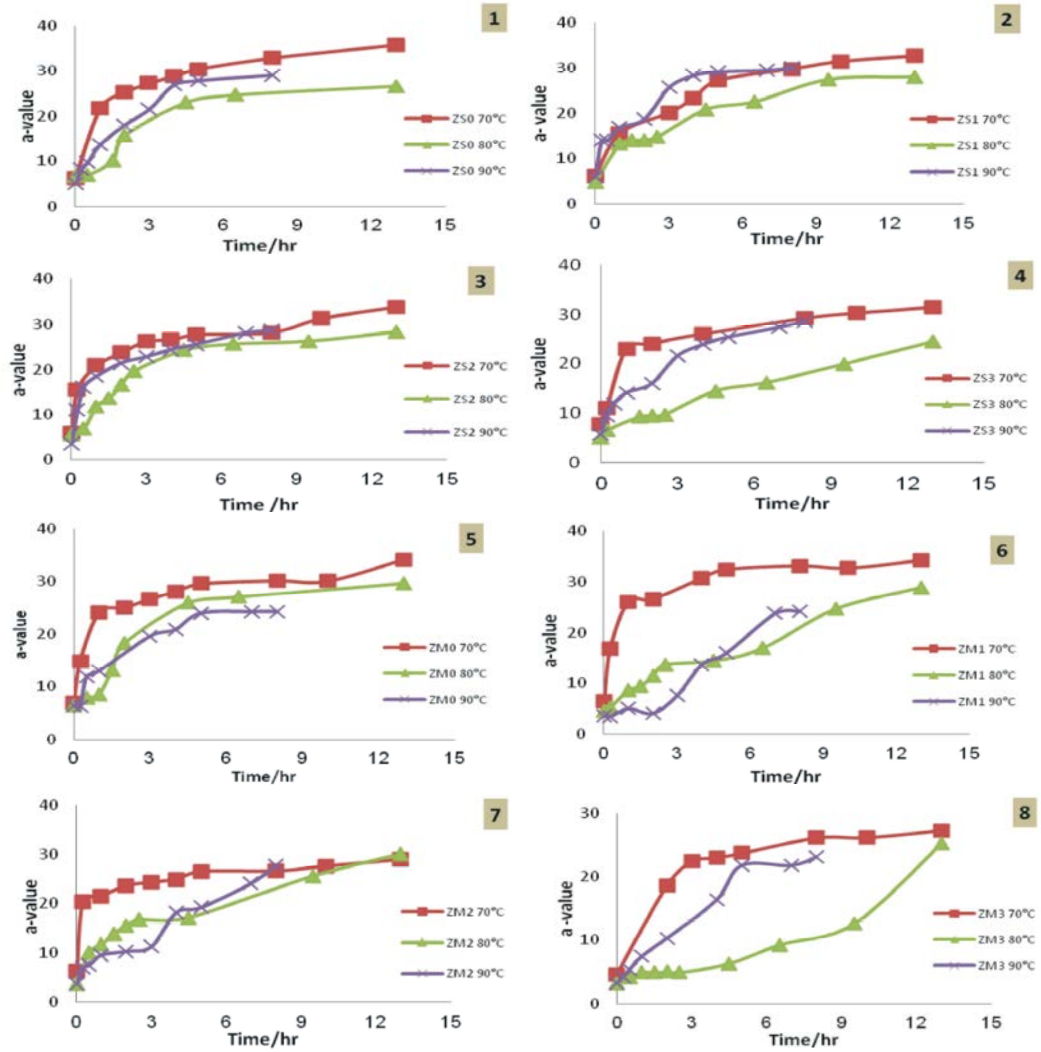


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Fig. 3: Change in redness (a-value) of Ziziphus fruits in relationship to pretreatment, drying temperature and drying time

thermal gradient inside the fruits. The obtained results are in agreement with those reported by Motevali *et al*. [13], Femenia *et al*. [14], Serratora *et al*. [24], Shi *et al*. [25], Vega-Galvez *et al*. [26] and Gorjian *et al*. [27], they found that drying of alkali pretreated fruits at 60°C and 70°C was ineffective compared with 80°C and that the n-value of page equation increases with the existence of hardened outer skin.

Effect of Drying Process on Color Parameters of Ziziphus Fruits: Figures 2, 3 and 4 show the change in color parameters; Lightness (L-value), redness (a-value) and yellowness (b-value) of Ziziphus fruits in relationship to pretreatment, drying temperature and drying time. The initial L-value of the fresh fruits was 48 to 51.37 and 46.64 for ZS and ZM, respectively. The a-values of fresh ZS and ZM were 6.013 and 6.593, respectively, while the initial b-values were 40.556 and 36.226, respectively. The pretreatment with sodium hydroxide followed by citric acid and sodium metabisulfite has enhanced the L-values of the fresh fruits, which was increased to average L-values of 55.026 and 48.633 for ZS and ZM, respectively. The a-values of the fresh fruits were not remarkably affected by the applied pretreatments but the b-values of ZS were remarkably decreased to an average of 35.8, while b-value of ZM was not remarkably affected by the applied pretreatments. As shown in Fig. 2, 3 and 4, the hot air drying process has decreased the lightness

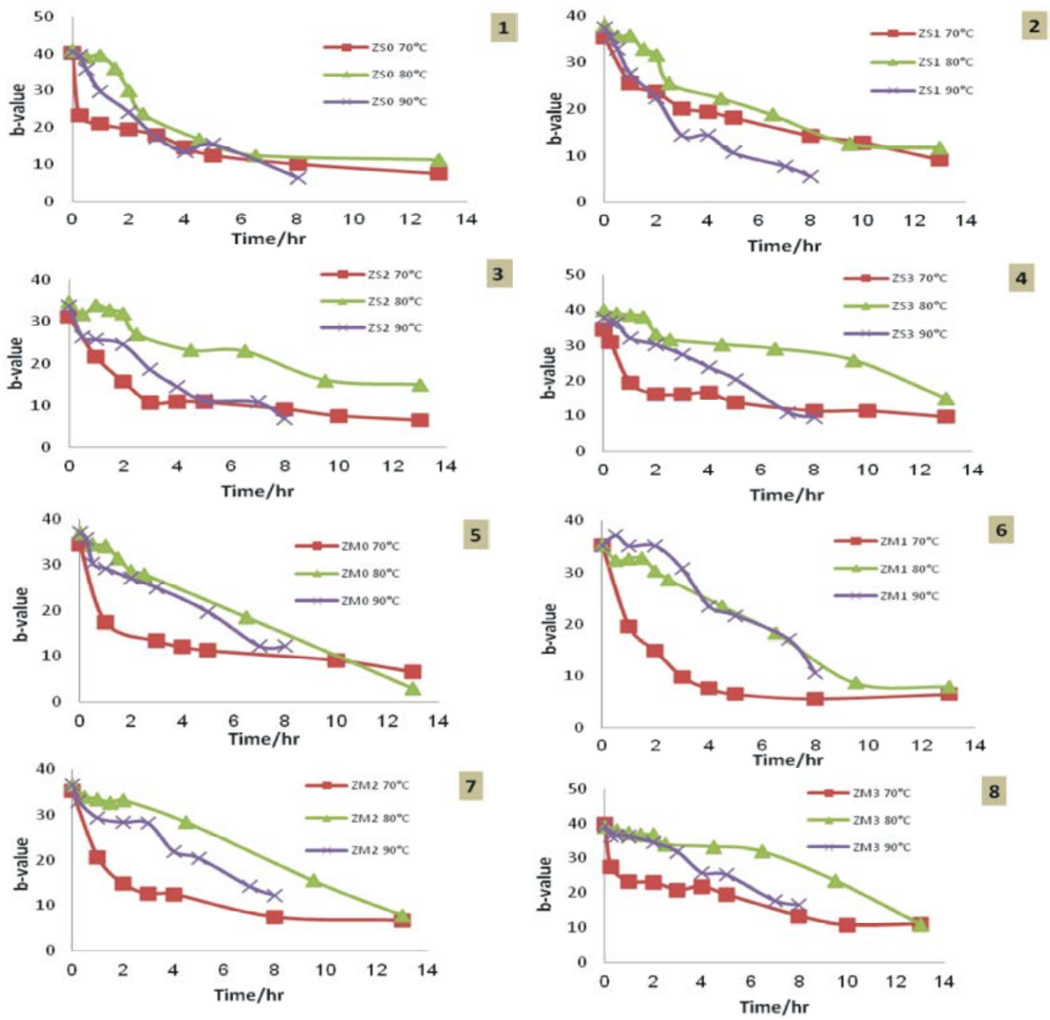

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Fig. 4: Change in yellowness (b-value) of Ziziphus fruits in relationship to pretreatment, drying temperature and drying time

(L-values) of Ziziphus fruits due to the darkening of the fruits during drying. The final L-value was temperature dependent; whereby the final L-value of fruits dried at 90°C were higher than those dried at 70 and 80°C. This inversely effect of temperature on the L-value of the dried fruits is related to the time of drying, whereby longer drying time, for example at 70 and 80°C caused more darkening compared with shorter drying time at 90°C. The limits of the L-values for dried ziziphus fruits pretreated with sodium hydroxide, citric acid and sodium metabisulfite were higher than those untreated or those treated with sodium hydroxide only or with sodium hydroxide and citric acid. Redness (a-values) of the dried fruits were higher than those of fresh fruits and the a-values of fruits dried at 70°C were always higher than those dried at 80 and 90°C, may be for the same reason mentioned before. All applied pretreatments; especially the treatment with sodium hydroxide, citric acid and sodium metabisulfite has reduced the levels of final a-values in the dried fruits compared with untreated control samples. On contrary to a-values, the yellowness (b-values) were decreased during drying and this reduction was temperature dependent, whereby the loss in b-values was more drastically at 90°C compared with those at 70ºC and 80°C. However, the loss in b-value of ziziphus fruits pretreated with NaOH, citric acid and sodium metabisulfite was lower than those of control samples and samples of other applied pretreatments.

Table 5a: color parameters changes of *ziziphus spina-christi* (ZS) as affected by different pretreatments solutions and different drying temperatures

		Color parameters							
		Chroma		Hue angle		Δ E		BI	
Pretreatment (PT)	Temp. °C	Fresh	Dried	Fresh	Dried	Fresh	Dried	Fresh	Dried
Control	70	40.68	35.39	81.16	11.74	62.54	42.84	151.81	164.71
	80	41.47	28.85	80.69	22.77	63.43	39.55	156.82	166.82
	90	40.86	29.73	82.86	11.94	65.66	35.74	140.67	191.98
PT (1)	70	35.90	33.35	80.14	15.75	61.69	40.16	118.21	144.49
	80	38.22	30.28	82.70	22.61	63.65	39.27	128.10	147.03
	90	37.88	30.63	80.78	14.63	63.88	38.43	127.76	154.76
PT (2)	70	32.89	31.97	79.03	10.79	57.07	41.51	117.08	129.49
	80	33.64	31.07	82.02	27.66	59.06	41.43	117.96	142.35
	90	33.94	28.89	84.01	21.02	59.31	38.63	119.25	144.98
PT (3)	70	35.70	32.53	77.35	17.16	66.02	40.42	100.74	138.22
	80	40.16	30.11	82.02	31.67	65.89	40.97	124.06	142.01
	90	37.71	29.76	84.01	21.97	68.72	36.41	123.00	146.38

PT (1): pretreatment with NaOH, PT (2): pretreatment with NaOH + citric acid, PT (3): pretreatment with NaOH + citric acid+ $Na_2S_2O_5$.

Table 5b: Color parameters changes of *ziziphus mauritiana* (ZM) as affected by different pretreatments solutions and different drying temperatures

		Color parameters							
		Chroma		Hue angle		Δ E		BI	
Pretreatment (PT)	Temp. °C	Fresh	Dried	Fresh	Dried	Fresh	Dried	Fresh	Dried
Control	70	35.27	32.28	78.78	10.71	58.48	40.21	131.28	138.52
	80	36.38	28.63	80.11	5.36	59.91	36.19	137.63	157.59
	90	36.94	29.48	80.11	26.78	59.91	40.72	141.20	151.20
PT (1)	70	35.83	33.28	79.62	10.96	60.58	40.21	124.88	130.23
	80	35.57	29.70	82.48	15.34	58.70	36.65	126.19	140.37
	90	35.29	26.22	84.06	23.50	59.55	41.60	124.28	149.68
PT (2)	70	35.83	29.60	79.03	12.81	60.69	37.64	123.53	132.01
	80	36.73	28.88	84.12	14.56	61.96	38.47	123.05	142.77
	90	36.73	27.05	84.12	24.83	61.96	40.34	123.05	152.23
PT (3)	70	39.33	28.82	83.50	21.85	63.36	38.84	133.53	137.54
	80	39.15	27.51	85.19	23.24	60.30	38.67	122.74	140.32
	90	39.33	27.25	85.99	36.52	64.28	39.78	129.84	147.67

Tables 5a and 5b shows the calculated chroma, hue angle, total color intensity and browning index of ziziphus fruits. Chroma values of the fresh fruits of ZS were higher than those of fresh ZM. However, all pretreatments led to reduction in chroma values of the fresh fruits of ZS may be due to the reduction in b-values. For fresh fruits of ZM, the chroma values were remarkably increased through the triple pretreatment, due to the increase in b-values of the fruits. Drying led to reduction in chroma values although a-value was increased. The lowest chroma values were recorded for ziziphus fruits dried at 90°C. Similar results were obtained by Mohammadi *et al.* [20], they reported losses in L, b and chroma values during drying of sliced Kewi fruits and referred the loss in b-value to decomposition of chlorophyll and caroteneoid pigments of the fruits, whereby the loss in chroma closely followed the loss of b-value. The Hue-values of the fresh fruits were, in average, 81.57 and 79.66 for ZS and ZM, respectively, which mean that the color is tending to be yellow. Pretreatments led to a slight increase in the Hue-values of the fresh fruits, may be due to expelling trapped air in the surface layer of the fruits, which improve the light reflection beside the bleaching effect of sodium metabisulfite. However, Hue-values were drastically decreased to a level of 11 to 20 upon drying due to the formation of dark brown pigments. The loss in Hue-values was more pronounced in the control dried fruits, compared with those who undergone pretreatments. This reflects the importance of pretreatments, especially with sodium metabisulfite in reducing the pigmentation and keeping the yellowness of the dried ziziphus fruits. The total color intensities (ΔE) of the fresh fruits were, in average, 63.88 and 59.43 for ZS and ZM, respectively. All pretreatments has enhanced ΔE values for fresh ziziphus fruits, except the double pretreatment, which led to reduction in ΔE values of ZS, may be due to the reduction observed in L and b-values of these fruits upon pretreatments with citric acid. Drying process has, in average, decreased the ΔE-value by 37.2% due to the reduction in L and b-values. Also, Diamante *et al.* [28] reported reduction in L, b, chroma values and Hue-angle of dried golden yellow kiwi fruits.

Browning index (BI) represents the purity of brown color and it is considered as an important parameter associated with browning. As shown in Table 5a, browning index of the fresh fruits of ZS was higher than those of ZM (Table 5b) and all pretreatments, especially the triple pretreatment, which led to reduction in BI- values of the fresh fruits. Drying ziziphus fruits without pretreatments led to a drastic increase in BI-values, especially at 90°C. On the other side, pretreatments led to moderate increase in BI-values. According to Valdenegro *et al.* [29], L-value is also an indicator of the oxidative browning reaction and changes in browning may be well represented by the decrease in L and b-values. They also indicated that an increase in drying duration led to reduction in the chroma values and to an increase in browning index of the dried fruits, regardless of the drying method. The undesired brown color of the dried fruits could be attributed to the evaporation of surface water as well as enzymatic and non-enzymatic browning reactions. The obtained results are in agreement with those reported by Mohammadi *et al*. [20], Serratora *et al*. [24], Valdengro *et al.* [29] and Serratosa *et al*. [30]

CONCLUSION

Drying of the ziziphus fruits is essential to prevent their deteriorations during long storage periods. Pretreatments of the fruits prior drying by consecutive dipping in solution of sodium hydroxide, citric acids and sodium metabisulfite facilitate the drying process. Drying at hot air temperature of 90°C shorten the drying time necessary to achieve the safe final moisture content and to minimize the losses in color parameters of the fruits.

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