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# Influence of Pretreatments on Microwave Vacuum Drying Kinetics, Physicochemical Properties and Sensory Quality of Apple Slices

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The objective of this study was to determine and compare the effect of five different pretreatments including sulfite treatment (ST), osmotic dehydration (OD), steam blanching (SB), steam blanching plus osmotic dehydration (SB+OD), and ultrasound treatment (UT), on the microwave vacuum drying (MVD) kinetics, the physicochemical properties, and sensory quality of the apple slices. The results showed that the pretreatments prior to MVD could reduce the drying time of apple slices by 25–45% as compared to the non-pretreated apple slices, and the drying time in the SB+OD apple slices sample was shortest. Whether pretreated or not, MVD process was controlled by diffusion and characterized by a two-stage falling-rate drying. As calculated according to the Fick's law of diffusion, the moisture diffusivities ($D_{eff}$) ranged from $1.64 \times 10^{-8}$ to $3.46 \times 10^{-8}$ m²/s. Different pretreatment methods had a significant influence on the physicochemical properties and sensory qualities of the dried products ($p < 0.05$). The SB+OD-pretreated apple slices showed the lowest shrinkage (59.5%) and the highest total sugar content (77.90 g/100 g dry matter). Besides, the OD-pretreated apple slices showed the highest density (0.953 g/cm³) and the lowest titratable acidity (1.67 g/100 g dry matter). In addition, the ST-pretreated samples showed the highest titratable acidity (3.21 g/100 g dry matter) and vitamin C content (12.74 mg/100 g dry matter), while the sample pretreated by SB showed the highest total phenolics content (18.37 mg/g dry matter). Non-sulfite-pretreated samples were superior to the sulfite treatment or the control in flavor but inferior to the sulfite treatment in color. Results of preference sensory evaluation showed that the dried apple slices were preferred by the panelists in the following order: SB+OD>SB>UT>OD>ST>the control.

## INTRODUCTION

Apple, the most important temperate fruit of the world, is regarded as one of the most important raw material in the food industry and is processed into a variety of products such as juice, jam, marmalade, and variously dried products [Beigi, 2016]. China is the largest country in the world, which cultivates and consumes apples. According to the Food and Agriculture Organization (FAO), the production amount of apple in China was more than 40 million tons in 2015, which accounted for about half of the global production [Xiao *et al*., 2018]. Currently, apples are mostly consumed fresh and the processing markets only account for 33% in China, which is extremely lower than above 70% in the developed countries; moreover, the intensively processed products are mainly the concentrated juice exported to the European and American markets [Bi *et al*., 2015]. There are some obvious problems such as simple processing production types, low processing rate as well as low value-added products in the postharvest processing of apples, which are restricting the healthy development of the apple industry in China.

Dried apples are rich in dietary fiber and bioactive components, and are convenient to handle, store, and utilize [Pasławska *et al*., 2017; Blanda *et al*., 2008]. They are a part of numerous prepared foods including snack preparations, integral breakfast foods, and so on [Vega-Gálvez *et al*., 2012]. In addition, drying fruits and vegetables into low water content provides new product formulas, such as fruits and vegetables crisps with unique texture and physical properties [Bi *et al*., 2016; Xiao *et al*., 2018; Velickova *et al*., 2014]. Furthermore, apple snacks play an important role in eating habits change, may substitute potato snacks and solve obesity problems among children or adults [Pasławska *et al*., 2017]. Therefore, apples dehydration process would be a promising path to deal with the problems as above mentioned.

The convective drying is still the most widely used drying method, which is applied to apples on the industrial production scale for its little capital, simple equipment and low energy input [Farias Aires *et al*., 2018; Velickova *et al*., 2014]. The main disadvantage of hot air drying is long drying time for exposure of the heat-sensitive materials to high temperature and aerobic environment, which may generate low quality dried products [Zhang *et al*., 2006]. Freeze drying (FD) under vacuum conditions is the best water removal method for all kinds of foods including apples, while it requires long drying time that would lead to high energy consumption and high capital investment. Therefore, FD is applied only with the high added-value products [Wang *et al*., 2018]. Microwave-vacuum drying (MVD) is increasingly used in food science research and in commercial food products drying

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[Zhang *et al*., 2006]. Numerous studies have confirmed that MVD yields high-quality dehydrated products that are similar to or better than those dried by FD [Nimmanpipug *et al*., 2013; Chong *et al*., 2013]. Besides, MVD possesses advantages including shortened drying time, improved energy efficiencies, and reduced energy consumption [Zhang *et al*., 2006].

Pretreatments prior to drying are often used to reduce the initial moisture content, accelerate the drying process, improve quality of dried products, modify the physicochemical properties of dried material, and influence the heat and mass transfer during drying [Doymaz *et al*., 2010]. Some common pretreatments include blanching, osmotic dehydration, sulfite treatment or a combination of the above treatments [Camel *et al*., 2019; Wang *et al*., 2018; Doymaz *et al*., 2010]. The sulfiting at low concentration is the most commonly used pretreatment method for apples and other fruits for its features of simple operation and well preserved color of products. Due to chemical residues in the final product, which may cause asthmatic reactions in some sensitive individuals and other health problems, there is an increasing demand to produce sulfur-free dried fruits [Igual *et al*., 2012; Krokida *et al.*, 2000]. Some novel pretreatments including ultrasound [Rodríguez *et al*., 2015; Nowacka *et al.*, 2012; Mothibe *et al*., 2014], microwave [Zielinska *et al*., 2018; Mothibe *et al*., 2014; Liu *et al*., 2015], vacuum [Blanda *et al*., 2008], have been developed to satisfy the growing health-conscious consumers. Ultrasonic wave has been used to enhance mass transfer since it can create microscopic channels in solid material by unique mechanical fluctuation and cavitation effect [Rodríguez *et al*., 2015; Nowacka *et al.*, 2012]. It is reported that ultrasonic wave pretreatment could reduce drying time by 10–30% [Zhao *et al*., 2017; Horuz *et al*., 2017]. Ultrasound pretreatment of apples resulted in dried products with greater rehydration ratios and softer texture due to disruption of the cell walls and would be preferred when dried fruits of low calories are required because of its high sugar loss [Nowacka *et al*., 2012; Mothibe *et al*., 2014].

In recent years, both pretreatments and drying methods of the apples have been widely studied in order to obtain high quality dehydrated apple products. However, little was known about the effects of different pretreatments on microwave vacuum drying kinetics, physicochemical properties and sensory quality of the apple slices. This study was aimed to compare the effects of five types of pretreatments (sulfite treatment (ST), osmotic dehydration treatment (OD), steam blanching (SB), steam blanching followed by osmotic dehydration (SB plus OD), and ultrasound treatment (UT)) on the drying kinetics, physicochemical properties, and sensory quality in microwave vacuum drying (MVD) apple slices.

## MATERIALS AND METHODS

### Sample preparation

The fresh Red Fuji apples used in this study were purchased from a local market in Qingyang (Gansu, China) and stored in a refrigerator at 4~8ºC until the experiments were started.

Before each experiment, the apples were taken out and left to stand for 2 h in room to reach the environment tempera-ture. Then, the apples were washed, peeled, cored, and cut into half circular shape of 10 mm thickness using a multi-functional apple peeler (DM-6; Deming, BeJing, China), for further use.

### Pretreatments

Five pretreatments were applied to the apple slices before drying and an untreated sample was used as control. The pretreatments used were sulfite treatment (ST), osmotic dehydration (OD), steam blanching (SB), steam blanching plus osmotic dehydration (SB+OD), and ultrasound treatment (UT). All the pretreatment experiments were conducted in duplicate and details of each treatment were described as follows:

Control: A batch of 200 g fresh apple slices without any pretreatment were used for drying.

Sulfite treatment (ST): A batch of 200 g apple slices was dipped in 2% sodium bisulfite solution for 2 min, and then the surface water was removed using a filter paper prior to drying [Krokida *et al.*, 2000].

Osmotic dehydration (OD): A batch of 200 g apple slices were immersed in 60º Brix sucrose solution at 25ºC for 180 min. The ratio of material to liquid was 1:8 (w/v) and a stirring was done with a glass rod every 30 min. After the osmotic dehydration was finished, the samples were taken out and the surface sucrose solution was removed using a filter paper prior to drying [Nimmanpipug *et al.*, 2013].

Steam blanching (SB): A batch of 200 g apples slices were leant on a stainless grid and blanched using 100ºC steam for 180 s. After blanching treatment, they were cooled with air and the surface water was removed before drying.

Steam blanching plus osmotic dehydration (SB+OD): Apple slice samples of 200 g were blanching using 100ºC steam for 180 s and then immersed in 60º Brix sucrose solution for 180 min. The other pretreated conditions were the same as the ones in the osmotic dehydration mentioned above. After the combined treatment, the samples were taken out and the surface sucrose solution was removed using a filter paper prior to drying.

Ultrasonic treatment (UT): According to a method described by Mothibe *et al*. [2014] with slight modifications, 200 g apple slices were immersed in distilled water and subjected to ultrasound waves for 10 min in an ultrasonic bath (KH-250DE; Kunshan Ultrasonic Instruments Ltd. Co., Kunshan, China). The water-to-fruit ratio was maintained at 4:1. The pretreatment was carried out at room temperature (25ºC). The ultrasonic frequency was 25 kHz and the power was maintained at 200 W, and no mechanical stirring was used in the ultrasonic process. After ultrasonic treatment, the apple slices were blotted with filter paper and used for drying.

### Microwave-vacuum drying (MVD)

Both the non-pretreated and pretreated apple slices were dried in a lab-scale microwave-vacuum dryer (ORW1.2S-5Z; Orient Microwave Co., Ltd, Nanjing, China). The samples to be dried were arranged in a single layer on a tray and the microwave-vacuum dryer was operated at 5 kPa (absolute pressure) and the power intensity for each drying test was 2.5 W/g (of original mass 200 g of fresh sample). The temperature

of the drying material to be dried was controlled at 50°C using an automatic on–off controller to avoid local charring. During the drying process, moisture loss was measured by periodically taking out using a digital balance (JH2102, Shanghai Precision & Scientific Instrument Co. Ltd., China) with 0.01 g precision. Each periodical interval was 5 min. After each weighing, the weight of the material and total drying time were recorded. The batch of weighed samples was abandoned and another batch of prepared original samples was dried until the next time interval. The samples were dehydrated until a moisture content of 0.76 kg water/kg dry matter (15%) was reached. Each drying experiment was conducted in triplicate. After the drying process was completed, the dried products were cooled down to room temperature and packed into a sealed polyethylene bag for further analyses.

*Calculation of drying rate and moisture ratio*

During MVD process, drying rate was determined as follows:

$$\text{Drying rate} = \frac{X_t - X_{t+\Delta t}}{\Delta t} \quad (1)$$

where: $X_t$, $X_{t+\Delta t}$ was moisture content (kg water/kg dry matter) at time $t$ and $t+\Delta t$, respectively, $\Delta t$ was time interval (min).

The change of moisture content in time was defined as a dimensionless parameter and expressed as the following equation:

$$MR = \frac{X - X_e}{X_0 - X_e} \quad (2)$$

where: $MR$ was the dimensionless moisture ratio, $X_0$, $X$ and $X_e$ stood for the initial moisture content, the moisture content at time $t$ and the equilibrium moisture content, respectively. The parameter $t$ was the drying time (min). All results were expressed per dry basis (kg water/kg dry matter). The $MR$ can be simplified to $\frac{X}{X_0}$ instead of $\frac{X - X_e}{X_0 - X_e}$ because of the value of dynamic equilibrium moisture content $X_e$ which was very small in comparison with $X$ and $X_0$ [Kaya *et al.*, 2007].

*Calculation of moisture diffusivity*

Drying process was proven to occur mostly in the falling rate period, and moisture transfer during drying was controlled by internal diffusion [Kaya *et al.*, 2007]. The Fick's second diffusion law (Equation 3) had been widely used to describe the drying process in the falling rate period for most biological materials [Vega-Gálvez *et al.*, 2012; Schoessler *et al.*, 2012].

$$\frac{\partial X}{\partial t} = D_{eff} \frac{\partial^2 X}{\partial x^2} \quad (3)$$

where: $D_{eff}$ was the effective moisture diffusion coefficient (m²/s), which was a mass diffusion property of the product, and $x$ was the diffusion path (m).

Assuming unidirectional and constant moisture diffusion, negligible shrinkage and temperature change during drying, analytical solutions of Equation 4 for an infinite slab geometry were expressed as Equation 4 [Crank, 1975]:

$$\frac{X - X_e}{X_0 - X_e} = \frac{8}{\pi^2} \sum_{n=0}^{\infty} \frac{1}{(2n+1)^2} \cdot \exp\left(-\frac{(2n+1)^2 \pi^2 \cdot D_{eff}}{4L^2} \cdot t\right) \quad (4)$$

where: $L$ was the thickness of the apple slices (m).

For long drying periods, the first term of the series solution in Equation 4 can be used as stated in Equation 5.

$$MR = \frac{8}{\pi^2} \exp\left(\frac{\pi^2 \cdot D_{eff}}{4L^2} \cdot t\right) \quad (5)$$

Equation 5 can be simplified to a straight-line equation as follows:

$$\ln MR = \ln\left(\frac{8}{\pi^2}\right) - \frac{\pi^2 \cdot D_{eff}}{4L^2} \cdot t \quad (6)$$

Plotting experimental drying data in terms of ln(*MR*) *versus* time, a straight line can be obtained, $D_{eff}$ were calculated according to the slop of the straight line.

**Moisture content determination**

Moisture was determined by oven drying (101-A; Kewei, Beijing, China) at 105°C to the constant weight [AOAC, 1995].

**Total sugar (TS) content determination**

Total sugar in fresh and dried apples was analyzed with the Fehling's method [GB/T 5009.7–2016]. Appropriate amount of ground sample (2.5–5.0 g) was put into a 250 mL volumetric flask. Next, 50 mL water, 5 mL zinc acetate solution (219 g/L), and 5 mL potassium ferrocyanide solution (106 g/L) were added to the sample, and then water was added to 250 mL. The mixture was mixed well, stood for 30 min, filtrated, and the clear filtrate was collected. The filtrate (50 mL) was absorbed and transferred to a 100 mL volumetric flask and 5 mL 50% HCl were added. They were kept in a water bath at 70°C for 15 min and then neutralized with a sodium hydroxide solution (200 g/L). The prepared solution was titrated with a calibrated Fehling g's solution. The assay was performed in triplicate. The results were expressed as g of glucose per 100 g of dry matter of sample.

**Titratable acidity (TA) determination**

Titratable acidity in fresh and dried apples was determined according to a titrimetric method [GB/T 12456–2008]. An appropriate amount of the sample (about 5 g) was put in a mortar and the boiled water of the same weight as the sample was added, then the sample was grounded and transferred to a 250 mL volumetric flask with the boiled water having the temperature of 80°C. The total amount of the sample and the water in the flask was controlled to about 150 mL. After boiling for 30 min in a hot bath, the sample was cooled to room

temperature, dilluted to 250 mL, and then filtered. The filtrate (20 mL) was absorbed and transferred to a 250 mL Erlenmeyer flask. Distilled water (40 mL) and 1% phenolphthalein indicator (0.2 mL) were added to the flask, then titration was done with 0.01 M or 0.05 M NaOH. The assay was repeated twice. The results were expressed as g of malic acid equivalents per 100 g of dry matter of sample.

### Total phenolics content (TPC) determination

A 3 g ground sample was extracted subsequently by a methanol:water solution acidified with HCl (50:50 v/v, pH 2, 25 mL/g sample) and an acetone:water solution (70:30 v/v, 25 mL/g sample) with continuous stirring at room temperature for 60 min. The extracts were filtered through a Whatman No.1 filter paper, then the supernatants were combined and centrifuged at 3000×*g* for 15 min (TDL-40B; Anting, Shanghai, China) [Ovando-Martinez *et al*., 2009]. The total phenolics content was determined with the Folin-Ciocalteau reagent [Singleton *et al*., 1999]. The obtained supernatant (0.5 mL, diluted if necessary) was mixed with 0.5 mL of the Folin-Ciocalteu reagent in a 25 mL glass-stopped tube. After 3 min, 10 mL of a sodium carbonate solution (75 g/L) were added and mixed. Additional distilled water (14 mL) was added up to make a final volume of 25 mL, and then the sample was mixed thoroughly by inverting the tubes several times. After 1 h, the absorbance at 750 nm was recorded with a spectrophotometer (751-UV–VIS; Shanghai analytical Instrument Factory, Shanghai, China). Gallic acid (Sigma Chemical Co., St. Louis, MO, USA) (0–50 mg/L) was used as a standard for the calibration curve. The tests were performed in triplicate. The total phenolics content was expressed as mg GAE per g of dry matter.

### Vitamin C (V$_c$) content determination

*L*-ascorbic acid content was determined by the 2,6-dichlorophenol-indophenol (Merck KGaA, Darmstadt, Germany) titrimetric method [GB/T 5009.86–2016]. A 5 g ground sample was transferred to a 100 mL volumetric flask with the oxalic acid solution (20 g/L) and diluted to the scale. After shaking well and filtering, 10 mL filtrate was accurately absorbed and transferred to a 50 mL Erlenmeyer flask. Titration was done with the calibrated 2, 6-dichloroindophenol solution until the solution became pink and did not fade after 15 seconds, taking 10 mL oxalic acid solution as the control. All assays were done in triplicate; the vitamin C content was expressed as mg/100 g dry matter.

### Color analysis

A chroma meter CR-400 (Onica Minolta, Tokyo, Japan) calibrated with a white standard board was used to determine the color of sample surface. Readings were expressed in the CIE1976 *L*a*b*scale, where *L** meant lightness, with 100 being very white and 0 being dark; the *a** value represented green (-60) to red (+60), and *b** value represented blueness (-60) to yellowness (+60). The hue angle (*h*$^o$), the chroma (*C**), and the total color difference (Δ*E* ) were calculated according to the values of *L**, *a** and *b** as follows:

$$h^\circ = \mathrm{arctg}(b^*/a^*)(a^* > 0, b^* > 0)$$
$$\text{or } h^\circ = 180^\circ + \mathrm{arctg}(b^*/a^*)\ (a^* < 0, b^* > 0) \tag{7}$$

$$C^* = \sqrt{(a^*)^2 + (b^*)^2} \tag{8}$$

$$\Delta E = [(L^* - L_0^*)^2 + (a^* - a_0^*)^2 + (b^* - b_0^*)^2]^{\frac{1}{2}} \tag{9}$$

where: $L_0^*$, $a_0^*$ and $b_0^*$ were initial values of fresh apple slices; *L**, *a**, and *b** were dried sample values. The h$^o$ revealed the color nuance; the values were defined as follows: red-purple: 0$^o$, yellow: 90$^o$, bluish-green: 180$^o$, and blue: 270$^o$. The C* represented chromaticity and denoted the purity or the saturation of the color. The measurements were carried out with 5 slices for each treatment.

### Rehydration property analysis

Rehydration property analysis was performed according to the method reported by Vega-Gálvez *et al.* [2012] with small modification. Two dried apple slices were rehydrated by soaking in 25°C distilled water. The samples were withdrawn from the flask at 30 min interval, drained on the filter paper and weighed. This step was repeated until the difference between two consecutive recordings was smaller than 0.001 g. For all experiments, the solid-liquid ratio was kept at 1:50. The rehydration ratio ($RR_t$) was defined as the ratio of the mass of rehydrated samples to the mass of the sample and calculated as follows:

$$RR_t = \frac{W_t}{W_d} \tag{10}$$

where: $W_d$ and $W_t$ were the masses (g) of samples before rehydration and time (*t*), respectively. Each experiment was conducted in triplicate and the results were expressed as the mean values.

### Shrinkage and density analysis

The volume of both raw and dried slices was measured by the displacement method using toluene [Schoessler *et al*., 2012].

Five dried apple slices were randomly selected from each sample lot and weighed ($W_1$) with the accuracy of 0.0001 g. The slices were put into an empty 150 mL flask, filled up with toluene and weighed again ($W_2$). The corresponding volume of dried samples ($V_{ds}$) was calculated as follows [Beigi, 2016]:

$$V_{ds} = 150 - \frac{W_2 - W_1}{\rho_{\text{toluene}}} \tag{11}$$

The density of toluene ($\rho_{\text{toluene}}$) is 0.87 g/mL at 20°C. After determination of the volume of dried slices, the shrinkage of the samples was calculated as follows:

$$S\% = (1 - \frac{V_{ds}}{V_{fs}}) \times 100 \tag{12}$$

where: *S* – shrinkage (%), $V_{ds}$ – the final volume of dried apple slice (mL), and $V_{fs}$ – the volume of apple slice before drying (mL).

The density (ρ) of the dried material was calculated as follows:

$$\rho=\frac{m}{V} \tag{13}$$

where: $m$ (kg) was the mass of dried slices, and $V$ (L) was the volume of dried slices. Five analyses were carried out for each test.

### Sensory evaluation

A descriptive quantitative method was used to determine the sensory profile of the non-pretreated and pretreated dried apple slices. In this analysis, in order to understand the sensory attributes of the dried apple slices, which include color, texture, aroma, sweetness and sourness, a 15-number panel was trained with the fresh apple. The samples were evaluated in groups of 4 per session. They were coded with three digits and presented randomly. A categorized 20-point scale, anchored with "nothing" for number 1 and "very intense" for number 20, was used to measure attributed intensity [González-Herrera, *et al*., 2016]. In order to evaluate the preference of the non-pretreated and pretreated dried apple slices, the 15 panelists who frequently consume such products were asked to rate their liking of overall acceptability within a balanced nine-point hedonic rating where 9 denoted "like very much", 5 neither like nor dislike, and 1 indicated "dislike very much" [Velickova *et al*., 2014]. Three samples for each treatment were provided to each panelist; each sample consisted of five slices. All the prepared samples were coded with three-digit random numbers and presented in random order to the panelists.

### Statistical analysis

Differences among mean values were estimated within an analysis of variance (ANOVA) with the application of Duncan's tests by SPSS 17.0.1. Mean values were considered significantly different when p≤0.05.

### RESULTS AND DISCUSSIONS

### Drying characteristics

The original moisture content in the fresh apple sample was determined to be 89.8% (Table 1). The initial mois-

ture contents of the apple slices submitted to ST, OD, SB, SB+OD, and UT were found to be 87.9%, 63.5%, 88.6%, 68.8%, and 88.7%, respectively. As compared with the fresh sample, both OD and SB+OD pretreatments resulted in a significantly lower moisture content of the apple slices due to osmotic dehydration in sugar liquid ($p<0.05$).

Figure 1 revealed the variation of moisture content of the non-pretreated and pretreated apple slices with drying time during MVD. As shown in Figure 1, the moisture content decreased sharply at the initial drying stage and subsequently reduced slowly as the drying proceeded. In a relative short duration of less than 60 min, all the apple samples were dehydrated to the desired moisture content of 0.17 kg water/kg dry matter (d.m.) in the MVD. The total drying time was 45, 37, 40, 33, and 36 min for ST, OD, SB, SB+OD, and UT apple slices, respectively. The pretreatment had a significant influence on the total drying time and the various pretreatments used could reduce the drying time by 25–45%. The SB+OD apple slices had the shortest drying time, which indicated that SB+OD could reduce the drying time by 45% as compared with the one (about 60 min) of the no-pretreated apple slices. The decrement in the total drying time was associated with the reduction in the original moisture content and the change in water transfer in the samples to be dried. Nowacka *et al.* [2012] reported that the drying time of apple slices dried by hot air after ultrasonic pretreatment was 31% shorter than that of untreated apple slices due to the appearance of microscopic channels within the fruit tissue structure. Dandamrongrak *et al*. [2002] found that the freezing and the combined blanching with freezing pretreatment were the most effective methods of improving the drying rate when drying banana because heating as well as freezing leads to cell disruption.

Drying rate, a function of drying time and moisture content, was a fundamental parameter that was computed from the drying data by estimating geometric derivation occurring in each consecutive time interval, and was expressed as kg water/(kg dry matter min). Figure 2 depicts the variation of drying rate with moisture content in the apple slices submitted to different treatments. The entire drying process in all the samples underwent a transient warm-up period at the beginning, followed by a falling rate period for a long

TABLE 1. Contents of moisture (%), total sugar (TS), titratable acidity (TA), vitamin C ($V_C$), and total phenolics (TPC) in microwave-vacuum dried (MVD) apple slices subjected to different pretreatments.

| Treatment | Moisture (%) | TS (g/100 g dry matter) | TA (g/100 g dry matter) | $V_C$ (mg/100 g dry matter) | TPC (mg/g dry matter) |
|---|---|---|---|---|---|
| Fresh | 89.8±0.20[a] | 65.84±1.05[c] | 3.52±0.05[a] | 19.24±0.05[a] | 17.65±0.05[a] |
| Untreated | 15.3±0.11[b] | 63.85±2.16[d] | 3.21±0.16[b] | 8.56±0.16[d] | 9.90±0.06[e] |
| ST | 14.2±0.06[c] | 61.02±0.18[e] | 3.10±0.18[bc] | 12.74±0.18[b] | 12.98±0.07[c] |
| OD | 15.8±0.15[b] | 71.74±1.45[b] | 1.67±0.05[f] | 10.56±0.45[c] | 10.54±0.09[de] |
| SB | 13.7±0.15[d] | 62.89±3.25[de] | 2.93±0.25[c] | 6.89±0.25[e] | 18.37±0.08[a] |
| SB+OD | 14.2±0.21[c] | 77.90±2.25[a] | 1.72±0.15[e] | 5.91±0.45[f] | 14.21±0.10[b] |
| UT | 15.7±0.04[b] | 51.45±3.55[f] | 1.93±0.55[d] | 6.45±0.55[e] | 11.90±0.11[d] |

Each value is expressed as mean value ± standard derivation (n=3). Different letters in the same column indicate significant differences at p<0.05. ST: sulfite treatment; OD: osmotic dehydration treatment; SB: steam blanching; SB+OD: steam blanching followed by osmotic dehydration; UT: ultrasound treatment.

time. The drying rates in the falling rate stages of the drying process in the non-pretreated, ST, SB, and UT apple slices were quite high for high moisture content in the apple slices. It showed that drying rate decreased continuously as the moisture content decreased. There was no discernible constant rate period of drying in all samples, which suggested that the internal moisture diffusion played a decisive role in the drying process of apple slices and determined the drying characteristics of raw materials.

### Effective moisture diffusivity

The graph of experimental values of *ln(MR)* of the apple slices against drying time was plotted, and the effective moisture diffusivity ($D_{eff}$) of the apple slices was calculated according to Equation 6 and presented in Figure 3. The $D_{eff}$ values in MVD for ST, OD, SB, SB+OD, and UT were in the range of 1.64–3.46×10$^{-8}$ m$^2$/s, respectively. It was observed that the moisture diffusivity in the ST samples was significantly higher than in the control samples ($p<0.05$), while the moisture diffusivities in the other pretreated samples were significantly lower than in the control samples ($p<0.05$). The lowest value was found in the SB+OD samples. The values of $D_{eff}$
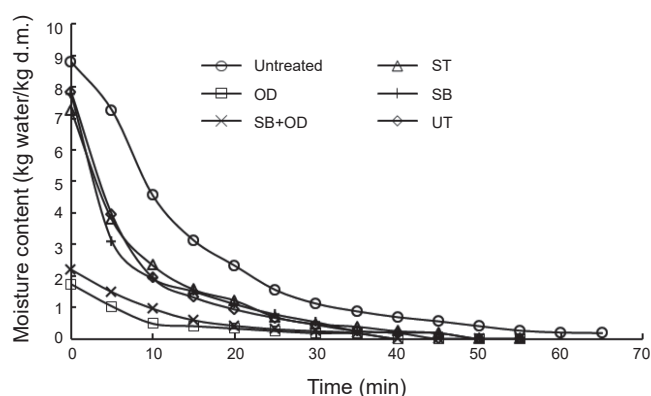


FIGURE 1. Microwave vacuum drying curves of apple slices as affected by different pretreatments. Note: ST: sulfite treatment; OD: osmotic dehydration treatment; SB: steam blanching; SB+OD: steam blanching plus osmotic dehydration; UT: ultrasound treatment.
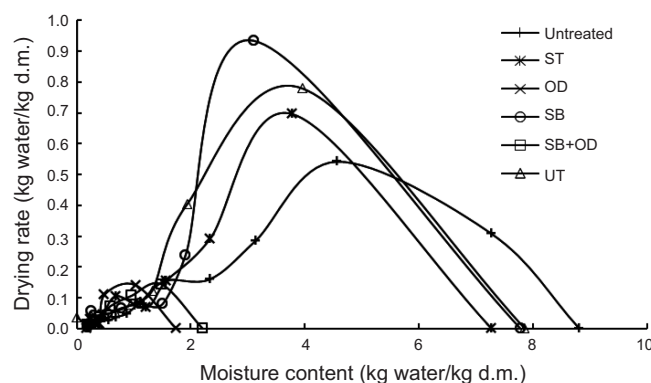
obtained from this study were in range of 10$^{-11}$ to 10$^{-6}$ m$^2$/s for food materials drying [Beigi, 2016]. The differences in the values may be caused by the differences in the initial moisture content, moisture state, and the cell disruption induced by different pretreatments.

### Chemical characterization

The contents of chemical and bioactive components in the fresh, the non-pretreated, and pretreated dried apple slices were determined, and respective results were listed in Table 1. As shown in Table 1, the contents of TS, TA, $V_C$, and TPC in fresh apple sample were 65.84 g/100 g d.m., 3.52 g/100 g d.m., 19.24 mg/100 g d.m., and 17.65 mg/g d.m., respectively. Pre-drying pretreatments used in this research strongly affected contents of the chemical and bioactive components in the dried products.

TS content in the dried samples ranged from 51.45 g/100 g d.m. to 77.90 g/100 g d.m. As expected, as compared with the fresh sample, both OD and SB+OD pretreatment led to an increase of 8.96–18.3% in TS content in the dried apple slices due to sugar uptake during OD, while lower TS content was observed in the non-pretreated, SB, UT, and ST pretreated dried apple slices. The highest TS content was observed in OD and SB+OD treatment (71.74 g/100 g d.m. and 77.90 g/100 g d.m.) while UT samples had the lowest TS content (51.45 g/100 g d.m.) because of sugar loss during ultrasound treatment process. Mothibe *et al.* [2014] found that ultrasound pretreatment resulted in a 24.7% loss of sugars of the apple cubes.

TA of the dried samples was in the range of 1.67 to 3.21 g/100 g d.m. and the significant differences in the dried apple slices were also observed ($p<0.05$). As compared with the fresh sample, MVD resulted in a decrease of 8.8–52.6% in TA content in all the dried products. The TA contents in the OD and SB+OD samples were lower than in the no-pretreated and the other pretreated dried apple slices. The lowest value was observed in OD samples while the highest value was observed in ST samples. Pasławska *et al.* [2017] and Kowalska *et al.* [2018] reported similar phenomenon of TA value decrease after fruit immersion in a sugar solution.



FIGURE 2. Microwave vacuum drying rate curves of apple slices as affected by different pretreatments. Note: ST: sulfite treatment; OD: osmotic dehydration treatment; SB: steam blanching; SB+OD: steam blanching followed by osmotic dehydration; UT: ultrasound treatment.
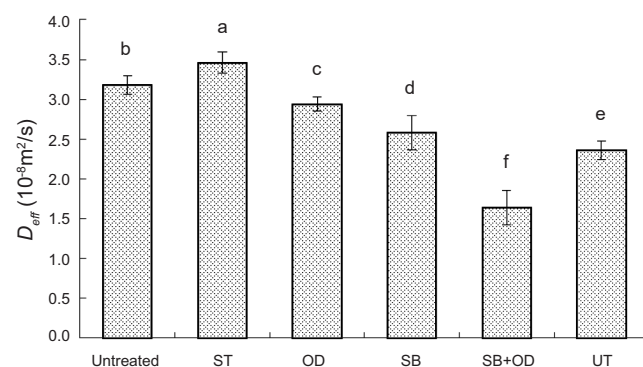


FIGURE 3. Effective moisture diffusion coefficient of dehydrated apple slices as affected by different pretreatments. Note: ST: sulfite treatment; OD: osmotic dehydration treatment; SB: steam blanching; SB+OD: steam blanching plus osmotic dehydration; UT: ultrasound treatment. Different letters indicate a significant difference ($p\leq0.05$).

The changes in TA may be attributed to the elution of organic acids from tissue during OD process [Kowalska *et al*., 2018].

Ascorbic acid and phenolics are important nutritional or bioactive compounds in apples, and these chemicals are well-known antioxidants that play an important role in promoting health [Loncaric *et al*., 2014; Blanda *et al*., 2008]. As expected, drying treatment had an adverse effect on the content of $V_C$ and TPC in all the dried samples. As compared with the fresh apples, MVD resulted in a decrease of 33.8–69.3% in ascorbic acid content in all dried products. The ascorbic acid content in the OD and ST samples was significantly higher than in the non-pretreated sample and the opposite tendency was observed in the SB, SB+OD, and UT samples. The loss in $V_C$ was attributed to the thermal disruption and leakage of water-soluble $V_C$ during pretreatment [Wang *et al*., 2018; Horuz *et al*., 2017]. However, it was reported that the presence of sugar would stabilize vitamin C in fruits [Pasławska *et al*., 2017].

With regard to the total phenolics, MVD resulted in a significant decrease (19.5–43.9%) in the total phenolics content in all the other dried products as compared with the fresh sample ($p<0.05$) except for a slight increase of 4% in the SB--pretreated samples. Moreover, the total phenolics content in the pretreated dried products was significantly or slightly higher than in the non-pretreated samples depending on which pretreated method was used. The highest TPC value was observed in the SB-treated samples (18.37 mg/g d.m.) followed by the SB+OD samples (14.21 mg/g d.m.), then followed by the ST samples (12.98 mg/g d.m.). The TPCs of OD and UT samples were comparable and were the lowest one (about 11 mg/g d.m.) due to the increment in dry matter induced by the leaching process. Processing including soaking, osmosis, heating and drying, may lead to the loss of phenolics in the food systems due to the leaching process, thermal degradation and the dilution effect [Mejia-Meza *et al*., 2010; Khandelwal *et al*., 2010]. At the same time, the amount of non-extractable phenolics was almost double of the extractable phenolics in the plant, and these non-extractable phenolics may release from the tissue in acid and high temperature environment as well as upon long-term ultrasonic treatment, which could cause an increase of phenolics con-

tent in the dried samples [Faller & Fialho, 2010; Horuz *et al*., 2017]. Additionally, sugar addition before processing was found to reduce phenolics loss in frozen and freeze-dried apple purée [Loncaric *et al*., 2014]. Obviously, the differences in the total phenolics content of the dried samples are ascribed to the multiple factors as mentioned above.

## Color

Color is an important quality attribute of dried foods, which is the first parameter customers use to judge the quality of dried products [Chong *et al*., 2013]. Desirable dried products are the closest to the fresh fruit in color. The color parameters including *L\**, *a\**, *b\**, *C\**, $\Delta E$ and $h^o$ of both the fresh and the dried apple samples were determined and the results were listed in Table 2. Both drying and pretreatments applied in this research greatly changed the original color of the flesh in fresh apples. As compared with the fresh samples, dehydration resulted in a significant decrease in the *L\** and $h^o$ values and a significant increase in *a\**, *b\**, and *C\** values in the non-pretreated and pretreated dried apple slices ($p<0.05$). The $\Delta E$ values of all the dried samples were in the range from 2.82 to 27.64, and the non-pretreated sample had the greatest $\Delta E$ value, followed by the UT and OD samples; the lowest $\Delta E$ value was observed in the ST dried products. Obviously, the pretreatment prior to drying inhibited these changes in color to a different extent. It is noteworthy that the individual value of color parameter for the ST apples slices was closer to that of the fresh samples, followed by SB and SB+OD samples. The most remarkable change in color was observed in the dried product submitted to OD and UT, indicating that the severe browning occurred in both of them. The browning in fruits may commonly attribute to the oxidation of phenolics and to caramelization [Rodríguez *et al*., 2015; Nimmanpipug *et al*., 2013]. Various methods including lowering pH, applying citric acid as a metal chelator, and avoiding exposure to oxygen have been studied for inhibiting PPO or slowing the browning reaction, and the sulfur dioxide treatment is still the most effective method and has been widely used in the food industry [Krokida *et al*., 2000; Igual *et al*., 2012].

The $h^o$ of the fresh sample was about 92.08°, while those of all the dried samples were in the range of 68°–89°, which

TABLE 2. Effect of different pretreatments on the color parameters of microwave-vacuum dried (MVD) apple slices.

| Treatment | L* | a* | b* | ΔE | C* | h° |
|---|---|---|---|---|---|---|
| Fresh | 70.84±0.06[a] | -0.56±0.12[g] | 15.08±0.15[d] | – | 15.09 ±0.15[e] | 92.08±0.13[a] |
| Untreated | 45.34±1.09[f] | 8.22±0.18[a] | 21.12±0.35[a] | 27.64±0.16[a] | 22.66±0.34[a] | 68.77±0.12[g] |
| ST | 68.34±1.08[b] | 0.23±0.15[f] | 16.12±0.25[c] | 2.82±0.14[f] | 16.12±0.15[d] | 89.23±0.05[b] |
| OD | 52.91±1.21[e] | 4.46±0.19[b] | 15.58±0.18[d] | 18.63±0.21[c] | 16.21±0.25[d] | 74.06±0.35[f] |
| SB | 57.84±0.6[d] | 2.49±0.12[d] | 18.07±0.15[b] | 13.68±0.12[d] | 18.24±0.31[c] | 82.20±0.25[d] |
| SB+OD | 60.56±1.01[c] | 1.71±0.11[e] | 17.57±0.35[bc] | 10.82±0.05[e] | 17.65±0.25[cd] | 84.48±0.15[c] |
| UT | 53.56±1.01[e] | 3.71±0.21[c] | 20.17±0.29[a] | 21.79±0.11[b] | 20.51±0.09[b] | 79.63±0.23[e] |

Each value is expressed as mean value ± standard derivation (n=3). Different letters in the same column indicate significant differences at p<0.05. ST: sulfite treatment; OD: osmotic dehydration treatment; SB: steam blanching; SB+OD: steam blanching followed by osmotic dehydration; UT: ultrasound treatment. *L\** : white 100 to 0 dark; *a\**: green (-60) to red (+60) ; *b\**: blueness (-60) to yellowness (+60); $h^o$ :hue angle; *C\**: chroma; $\Delta E$: total color difference.

represented an early yellow nuance. The ST products provided the highest $h^o$ value, followed by the SB+OD and SB products. The lowest $h^o$ value was observed in the non-pretreated dried products.

### Rehydration characteristics

Rehydration is a determination of damage to the material caused by drying process. Additionally, most dehydrated products need to be rehydrated before usage; a rapid and complete rehydration is needed when immersion in water is desirable. Figure 4 presents the variation of the rehydration ratio *versus* time for the non-pretreated and pretreated dried apple slices during rehydration. The rehydrated rate sharply increased with rehydration time in the initial rehydration stage, then gradually decreased to zero; the high rate of the water uptake at the beginning stage can be explained by the capillaries and cavities near the material surface, which are rapidly filled up with water [Horuz *et al.*, 2017].

The rehydration rate of dehydrated apple slices treated by SB was the fastest, followed by UT, ST, SB+OD, and OD
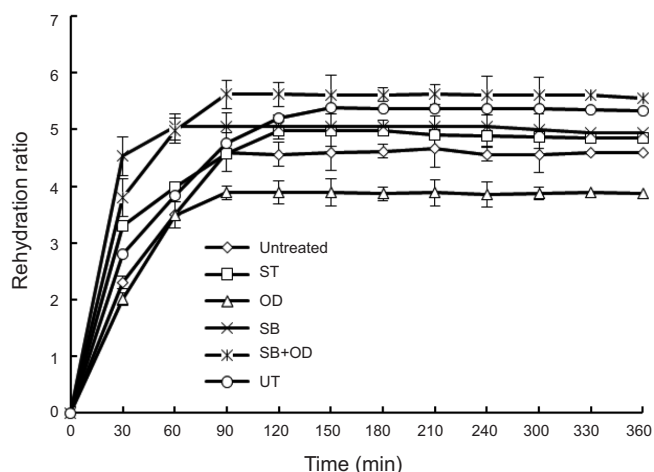


FIGURE 4. Effect of different pretreatments on the rehydration ratio of dried apple slices. Note: ST: sulfite treatment; OD: osmotic dehydration treatment; SB: steam blanching; SB+OD: steam blanching followed by osmotic dehydration; UT: ultrasound treatment.
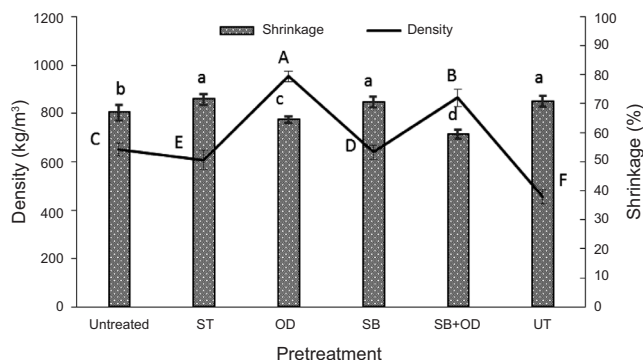


FIGURE 5. Effect of different pretreatments on shrinkage and density of dried apple slices. Note: ST: sulfite treatment; OD: osmotic dehydration treatment; SB: steam blanching; SB+OD: steam blanching followed by osmotic dehydration; UT: ultrasound treatment. Different letters indicate a significant difference ($p \leq 0.05$) in the same legend.

samples, while the rehydration rate of untreated dried products was the slowest. The stabilized rehydration ratio for SB, OD, SB+OD, untreated groups, ST and UT was 5.05, 3.89, 5.62 and 4.6, 4.98 and 5.38, respectively. The apple slices pretreated by SB+OD had the highest rehydration ratio. Ultrasound and thermal treatments destroyed the structure of the material to be dried, and formed many micro-channels on the surface of the material, thus resulting in faster rehydration rate but lower rehydration ratio during drying [Vega-Gálvez *et al.*, 2012; Horuz *et al.*, 2017].

### Shrinkage and density

Figure 5 presents the shrinkage and apparent density of the non-pretreated and pretreated dried apple slices. Compared with the non-pretreated samples, the three pretreatments including ST, SB and UT increased the shrinkage of the samples while the other two pretreatments, *i.e.* OD and SB+OD, contributed to shrinkage decrease. There were no significant differences among the ST, SB and UT in shrinkage percent ($p > 0.05$), and their shrinkage was about 70%, which was significantly higher than the one in the non-pretreated samples ($p < 0.05$). The dried samples pretreated by OD had the lowest shrinkage percent (59.5%) followed by the SB+OD pretreated samples, which was significantly lower than the one in the non-pretreated samples ($p < 0.05$). It was reported that shrinkage was associated with the moisture content of the samples to be dried during MVD. When moisture was removed from tissues, a pressure imbalance was created between the inside and outside of the tissue, which may generate compressive stress and lead to shrinkage [Nahimana & Zhang, 2011].

The apparent density of the non-pretreated and pretreated dried apple slices was found out in the range of 455––953 kg/m³ and the pretreatment methods had a significant influence on the apparent density of the dried samples ($p < 0.05$). The apparent density of the non-pretreated dried sample was 652 kg/m³, which was significantly higher than in the dried samples pretreated by UT, ST and SB, but lower than in the dried samples pretreated by OD and SB+OD ($p < 0.05$). The dried samples pretreated by OD and SB+OD obtained a relatively higher apparent density while the dried samples pretreated by UT had the lowest value of this parameter due to their lower shrinkage and sugar loss [Nowacka *et al.*, 2012; Mothibe *et al.*, 2014].

### Sensory evaluation

The results of sensory evaluation for the non-pretreated and pretreated dried apple slices are listed in Table 3. It revealed that the pretreatment had a significant influence on sweetness, texture, aroma, sourness, color, and over acceptability of apple slices ($p < 0.05$). The dried apple slices pretreated by ST had the best color, but the poorest aroma. Both OD and UT pretreatments were the best with regard to maintaining the original aroma of the fresh apple in the dried apple slices which also had a softer texture. The dried samples submitted to SB+OD and OD had a harder texture, were more sweet, and had weaker sourness than the other samples. As for the overall acceptability, the five selected pretreatments could improve the sensory quality of the dried apple slices

TABLE 3. Effect of different pretreatments on sensory qualities of microwave-vacuum dried (MVD) apple slices.

| Treatment | Sweetness | Texture | Aroma | Sourness | Color | Overall acceptability |
|---|---|---|---|---|---|---|
| Untreated | 10.8±0.9[c] | 15.4±0.8[c] | 16.3±1.2[a] | 14.7±0.7[a] | 8.3±0.7[e] | 5.6±0.9[e] |
| ST | 10.3±0.9[c] | 14.3±0.7[d] | 12.7±0.6[c] | 14.6±0.4[a] | 19.3±1.1[a] | 6.1±1.7[d] |
| OD | 18.3±1.1[a] | 19.1±0.9[a] | 15.7±0.7[a] | 5.3±0.7[d] | 10.9±0.3[d] | 5.5±0.8[e] |
| SB | 12.2±0.6[b] | 14.9±0.7[cd] | 14.2±0.8[b] | 12.9±1.5[b] | 13.2±0.6[c] | 8.1±1.2[a] |
| SB+OD | 19.0±0.7[a] | 16.9±1.1[b] | 14.5±0.4[b] | 4.9±0.7[d] | 16.5±0.7[b] | 7.6±2.5[b] |
| UT | 7.9±0.8[d] | 11.2±0.7[e] | 15.8±0.7[a] | 6.8±0.9[c] | 13.9±0.8[c] | 7.1±2.7[c] |

The results are mean ± standard deviation (n=3).Values with different superscript letters in the same column are significantly different (p<0.05).ST: sulfite treatment; OD: osmotic treatment; SB: steam blanching; SB+OD: steam blanching followed by osmotic dehydration; UT: ultrasound treatment.

in comparison with the non-pretreated samples to a different extent. The overall acceptability score of the dried apple products submitted to different pretreatments was decreased in the following order: SB> SB+OD> UT> ST>OD.

## CONCLUSION

Based on the results of the present investigation, we concluded that the pretreatments applied had a profound influence on the microwave vacuum kinetics and the quality of the dehydrated apple products. Five selected pretreatments could shorten the microwave vacuum drying time of the apple slices, and the effective moisture diffusivity ($D_{eff}$) ranged from $1.64 \times 10^{-8}$ to $3.46 \times 10^{-8}$ m²/s under different pretreatment conditions. As compared with the non-pretreated dried apple slices, different pretreatments significantly changed contents of the chemical and bioactive components and improved sensory quality of the dried apple products in a specific way. With the enhancement of consumers' health awareness, non-sulfur pretreatments including SB, OD, UT as well as their combinations are recommended in producing the dried apples. The selection of a reasonable pretreatment method prior to drying depends on the different specific demand and the investment cost of the industry. For example, the advantages of the sulfur-related pretreatment include a relatively low production cost and a cheap product price; while the ultrasound pretreatment would be preferred when dried fruits of low calories are required since it results in a high sugar loss.

## CONFLICT OF INTERESTS

The author(s) declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

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