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The Effect of Ultrasound-Assisted Osmotic Dehydration Pretreatment on the Convective Drying of Apple Slices (var.Golab)

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ABSTRACT: Drying is one of the widely used methods of food preservation and it is a sensitive food processing operation due to undesirable changes in the quality of dried product. In this study the effect of osmotic dyhedration and ultrasound pretreatment prior to convective drying on quality properties of apple slices was investigated. Apple slices were pretreated by osmotic dehydration in two concentration levels of sucrose solution (30, 60ºBrix) at 25 ºC for 15 and 30 minutes and were subjected to ultrasound pretreatment modulates osmotic dehydration by ultrasonic waves in a water bath at the frequency of 60 kHz in osmotic sucrose solution (30, 60ºBrix) at 25 ºC for 15 and 30 minutes. The quality of dehydrated apple was analyzed by rehydration ratio, shrinkage and color changes. The results showed that the application of ultrasound-assisted osmotic dehydration led to a decrease in rehydration ratio as compared to the control samples and observed more decrease in the samples of ultrasound-assisted osmotic than osmotic samples. Most of shrinkage belonged to the control samples and the least shrinkage was related to the samples of ultrasound-assisted osmotic. Control samples had darker color whereas the treated samples had higher lightness (L*) and lower redness (a*), yellowness (b*) and colour intensity (ΔE) were represented. Based on the findings it can be concluded that the ultrasound-assisted osmotic dehydration led to improves in the color and shrinkage and obtained a decrease in rehydration ratio in the dried samples.

Keywords: *Hot Air Driying, Osmotic Dehydration, Quality Properties, Ultrasonic.*

Introduction

Apple is one of the most widely produced fruits in the world and it is considered as one of the most important raw material for many food products. It is consumed not only as fresh, but also in processed form such as juice, jam, paste and dried (Doymaz, 2009). Apple has been known as an excellent source of phenolic compounds with considerable antioxidant activities. However apple processing can have a destructive impact on the antioxidant properties.The composition of polyphenols present in apples are important due to their contribution to the sensory quality of fresh fruit and the processed products (Khanizadeh *et al.*, 2008). Apples play a significant role in diet as they contain appreciable amount of carbohydrate (12-14%), dietary fibre, vitamins and minerals. (Kaleta and Górnicki, 2010). Drying is a classical method of food preservation and is a sensitive food processing operation due to the undesirable changes in the quality of dried product (Unal & Sacilik, 2011; Doymaz, 2009). The basic objective in

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drying the agricultural products is the reduction of water to a certain level, at which microbial spoilage and deterioration chemical reactions are minimized and in addition, dried food has longer shelf life and lower transportation and storage costs (Unal & Sacilik, 2011; Doymaz, 2009). Convective drying is the most widely employed method due to its simplicity and cost effectiveness and on the other hand the hot air drying is considered as a highly destructive method, particularly for thermally sensitive materials like biomaterials (Kowalski and Szadzińska., 2014). Excessive temperatures lead to structural, organoleptic and nutritional changes. The extent of changes of the most important quality characteristics like colour and nutritional value usually increase by increasing temperature (Sturm *et al.*, 2014). Convective drying requires a high amount of energy and longer duration for drying because it is a simulataneous heat and mass transfer process accompanied by phase change and it could cause severe shrinkage, reduced bulk density and rehydration capacity especially at high temperatures (Onwude *et al.*, 2016; Tao *et al.*, 2016; Fernandes *et al.*, 2008). Recently, the use of ultrasounds in drying is of great interest because it does not influence the main characteristics and quality of the products. The application of alternative techniques in drying of food, such as ultrasound accelerates the moisture removal and improves nutritional aspect of bioproducts by drying at lower temperatures than in conventional methods (Kowalski and Szadzińska., 2014; Onwude *et al.*, 2016; Ricce *et al.*, 2016). Osmotic dehydration is a pretreatment process, which depends upon the phenomenon of diffusion of moisture from food materials by immersing in a hypertonic aqueos solutions. During the osmotic process a pressure difference is generated across the cellular surface, which acts as an effective semi-permeable membrane, therefore the solution of different sugars such as sucrose, glucose or fructose moves into free space of the tissue while water comes out of the cells (Ahmed *et al.*, 2016; Mavroudis *et al.*, 2012; Shukla and Singh, 2007). Osmotic dehydration is generally used for removal of water from biomaterials, but it is usually time-consuming. One of the possibilities to increase the rate of mass transfer during osmotic dehydration is the enhancement of this process with ultrasound (Nowacka *et al.*, 2014; Barman and Badwaik, 2017). Ultrasound technology is one of the non-thermal techniques, which can be used to accelerate mass transfer processes. The basis of ultrasound as a pretreatment before drying is its mechanical effect and the accompanied ultrasonic cavitation phenomenon. Specifically the propagation of ultrasound in liquid medium can cause a rapid series of alternative compression and expansion, as well as the formation of cavitation bubbles. The mechanical force can remove the moisture strongly attached to the food materials, deform porous food materials and create microscopic channels, thus enhancing the mass transfer during convective drying (Tao *et al.*, 2016; Nowacka *et al.*, 2014). Kowalski and Szadzińska (2014) reported that ultrasonic assisted osmotic dehydration could contribute to shorten drying time, improve color preservation and decline water activity. Fernandes *et al.* (2008) investigated the effect of ultrasound-assisted osmotic dehydration pretreatment on the air drying on cell structure Melon. According to the basic results, water loss and sugar gain happend due to the concentration gradient of water and sugar between the fruit and the liquid medium. The effective water diffusivity in fruits is dependent on tissue structure since the cell wall act as a semi-permeable membrane. Fernandes *et al.* (2009) described that the osmotic dehydration and ultrasonic pre-treatment induced changes on pineapple cell structure.

The ultrasonic waves created microscopic channels in the fruit that increased the effective water diffusivity because water could use these microscopic channels as an easier pathway to diffuse towards the surface of the fruit and osmotic dehydration by breaking down part of the cell walls reducing the resistance for water to diffuse through the cells. The aim of this study is to evalute the effect of osmotic dehydration and ultrasound pre-treatments on physical and chemical properties of dried apple slices, thus rehydration ratio, shrinkage and colour parameters were investigeted.

Materials and Methods

- Preparation of the samples

Fresh apple (varieties of Golab) were purchased at local market in Mahabad, Iran. The samples were cut into three mm thick slices and subjected to pre-treatments process and then were dried in an oven at 60 ºC to obtain a constant weight. The initial moisture content was determined by heating in a drying oven at 105 ºC for 48 h (AOAC, 1990). The initial moisture content of the fresh apple was found to be 85.32% (wet basis).

- Osmotic dehydration and ultrasound pre-treatments

Osmotic dehydration treatment was carried out by immersing the samples in 30 and 60% (w/w) sucrose solution for a constant period of 15 and 30 minutes. The ratio of raw material to osmotic solution was maintained at 1:4 (w/w). In order to apply the ultrasound-assisted osmotic pre-treatment, the apple slices were immersed in the osmotic solution at the concentrations of 30 and 60% (w/w) and subsequently submitted to the ultrasonic waves in a water bath at the frequency of 60 kHz for 15 and 30 minutes. After the osmotic dehydration with or without the ultrasound, the samples were removed from the osmotic medium and immediately rinsed with distilled water (30 s) to remove the excess osmotic solotion. The samples were then gently blotted out with clean tissue paper (2 min) to remove excess water and then weighed. All the experiments were performed in triplicate and at room temperature (25ºC).

- Rehydration ratio

Apple slices for rehydration ratio were obtained at the end of drying process. Rehydration experiments were performed by immersing the known weight of each sample in a glass beaker containing 50 mL of deionised water at room temperature (25ºC). Apple slabs were removed at predetermined time intervals and allowed to drip of on a screen for 1 minute then weighed and immediately returned to the same soaking water. This procedure was repeated until reached to a constant weigh. The rehydration ratio (RR) is defined as the mass ratio of rehydrated sample to that of dry sample (Ramallo and Mascheroni, 2012) and calculated using the following equation:

$$\text{Rehydration Ratio} = \frac{\text{Weight of rehydrated sample (g)}}{\text{Weight of dehydrated sample (g)}} \quad (1)$$

- Shrinkage

Percentage of shrinkage was determined from the changes of the bulk volume of the apple slices using the liquid displacement method. In this study, toluene was used because it caused reduction of liquid absorption into the dried apple (Yan *et al.*, 2008). Shrinkage (Sh) was calculated from the following equation:

$$\text{Sh} = \frac{V_0 - V}{V_0} \times 100 \quad (2)$$

where V is the apparent volume of the sample after drying and V_0 is the apparent volume of the raw sample.

- Colour measurments

The colour of the fresh and dreied apple samples were measured using colorimeter

(Colorimeter Minolta model CR-410), and recorded using L*, a* and b* values. Where L* indicates lightness, and ranges from 0 (black) to 100 (withe), a* is the measure of greenness-redness and b* is the measure of blueness-yellowness (Falade *et al.*, 2007). Chroma (C), colour intensity (ΔE) and hue angle (h) were calculated by the following equations:

$$(\Delta E) = \sqrt{(L_i - L)^2 + (a_i - a)^2 + (b_i - b)^2} \quad (3)$$

$$(C) = \sqrt{a^2 + b^2} \quad (4)$$

$$(h) = \text{arc tan}\left(\frac{b}{a}\right) \quad (5)$$

- Statistical analysis

The analysis of data were statically evaluted using SPSS software, Version 24. Tukey Test was applied to compare the means of data and concentration and immersion time varibles between the samples at t 5% level of significance.

Results and Discussion

- The effect of pretreatment on rehydration ratio

The results of statistical analysis showed that significant differences were observed between both of pretreatment at 95% confidence level ($p < 0.05$), also significant differences were observed between osmotic-ultrasound treated samples and control amples ($p<0.05$), but there were not ststistically significant differences ($p > 0.05$) between treated samples with osmotic and untreated samples (Table 1). Table 2 indicates that the highest rehydration ratio was observed in the control samples and the lowest rehydration ratio was allocated to the osmosis-ultrsonicated samples. In the osmosed and osmotic-ultrasonicated sampels lower rehydration ratio was observed as compared to the untreated samples due to the sugar gain. The intercellular spaces of the tissue was increased due to the exposed ultrasonic waves as the result of this phenomenon the water loss and solid gain were increased extremely. The impact of the osmotic-ultrasound dehydration was studied by Fernandes *et al.* (2009). The water loss and solid gain were the highest when an osmotic solution was employed in the higher concentration. They reported that this could be attributed not only to the higher osmotic pressure of the process but also to the changes that occurred in fruit tissue. The formation of micro-channels facilitated the mass transfer through the tissue and entered more sugar into the apple tissue structure in osmotic-ultrasound treated samples. Similar results were also found in the studies of other researchers who reported that by increacing the process duration and osmotic solution concentration, the rehydration ratio decreased because of cell permeabilization due to the osmotic stress, hence osmosed samples could not absorb water as much as control samples (Rastogi *et al.*, 2004; Bakalis and Karathanos, 2005; Singh *et al.*, 2007). Regading the presented results in the Table 3, the comparsion results of sugar concentration and immersion time variables showed that there was a significant influence on the osmostic process between treatmeants 1 and 4 and between treatmeants 1 and 3 ($P< 0.05$) and in ultrasound-assisted osmotic dehydration a significant influence was observed in all the pretreatments ($P < 0.05$), except the treatments 1 and 2 ($P > 0.05$). Osmotic solution concentration and immersion time had effects on rehydration ratio and by increasing the concentration of sucrose solutions and processing time, rehydration ability decreased in both of pretreatments than untreated samples. The higher concentration of sucrose leads to greater osmotic pressure gradients, thereby leading to higher solid gain and water loss throughout the osmotic treatment period (Ahmed *et al.*, 2016). The difference in osmotic potential between the solution and fruit sample resulted in a higher diffusion rate of solute and water. The water loss and solid gain of the fruit treated with the higher osmotic solution concentration were found to be higher (Ahmed *et al.*, 2016). Ispir and Toğrul, (2009) evaluated the mass transfer rate of apricot during osmotic dehydration. Apricot fruits were immersed in three different sucrose concentrations. The higher concentration of sucrose leads to greater osmotic pressure gradients, thereby leading to higher solid gain and water loss throughout the osmotic treatment period. Mundada *et al.* (2011) studied the influence of various sucrose concentrations (40, 50 and 60 °Brix) on mass transfer rate of pomegranate arils during osmotic dehydration. Pomegranate arils soaked in 60 °Brix sucrose solution showed higher solid gain and water loss as compared to the samples soaked in 40 and 50 °Brix osmotic solution. Noshad *et al.* (2012) reported that the lower rehydration ratios in the osmotic-ultrasonic convective dried quince were attributed to the added sugar, which reduced the amount of water that could be absorbed during rehydration and were found that water loss and solid gain increased with increasing cocentration and processing time. Therefore, concerned with the result of sugar uptake into the apple tissue, the water absorption decreased during rehydration in pretreated dried apple slices.

- *The effect of pretreatment on shrinkage*

Shrinkage is an important phenomenon that appears during drying process of food. The obtained results indicated that significant differences existed between osmotic and ultrasound-assisted osmotic pre-tratments at 95% confidence level ($p < 0.05$) and also between osmotic and ultrasound-assisted osmotic pre-treatmeants with control group (Table 1). Table 2 indicates that ultrasound-assisted osmotic dehydration application led to a decrease in the shrinkage. One of the most important physical changes that the food suffers during drying is the reduction of its external volume. The loss of water and heating cause stresses in the cellular structure of the food leading to changes in the shape and a decrease in dimension (Mayor and Sereno, 2004; Dehghannya *et al.*, 2015). According to the obtained results in this research less shrinkage in treated apple slices was observed than untreated apple slices and the highest shrinkage was observed in the control apple samples and the lowest

Table 1. The results obtained from the comprasion of shrinkage and rehydration ratio in treated samples with osmotic dehydration, ultrasound-assisted osmotic dehydration and untreated samples

(P-value) Shrinkage	(P-value) Rehydration	Drying method
0.001**	0.042*	Osmotic - ultrasound-assisted osmotic dehydration
0.001**	0.255	Osmotic – control dehydration
0.000**	0.009**	Ultrasound-assisted osmotic – control dehydration

* significant at confidence level of 5%, ** significant at confidence level of 1%

Table 2. The means of shrinkage and rehydration in treated samples with osmotic dehydration, ultrasound-assisted osmotic dehydration and untreated samples

Rehydration		Shrinkage (%)		Treatment
Ultrasound-assisted osmotic treatment	Osmotic treatment	Ultrasound-assisted osmotic treatment	Osmotic treatment	
5.767	6.328	79.866	82.63	Treatment 1
5.458	5.859	78.618	81.95	Treatment 2
4.807	5.434	75.401	80.373	Treatment 3
3.548	5.073	74.13	78.6	Treatment 4
6.439		87.112		Control samples (untreated)

Treatment 1 (concentration 30%, immersion time 15 min), Treatment 2 (concentration 30%, immersion time 30 min), Treatment 3 (concentration 60%, immersion time 15 min), Treatment 4 (concentration 60%, immersion time 30 min).

shrinkage appeared in the pretreated samples with ultrasound-assisted osmotic. Shrinkage depends on the temperature and time of drying and more shrinkage was observed while the temperature and drying time were increased (Sturm *et al*., 2014; Mayor and Sereno, 2004; Noshad *et al*., 2011). Osmotic dehydration reduced the moisture content with the passage of time until equilibrium condition was reached, (Ahmed *et al*., 2016; Shukla and Singh., 2007), especially when the osmotic process combined with ultrasound that induced the formation of microscopic channels which lowered the resistance to water diffusion because of these channels. Consequently the mass transfer acceleration was enhanced during drying, thus the sampels was exposed to the high temprature in shorter time (Jambrak *et al*., 2007; Cárcel *et al*., 2007). The other effect of the ultrasound application is the increase in sugar uptake, after combining the osmotic process with ultrasound as the pretreatment because of appearance of micro-channels and cell wall disruption (Fernandes *et al*., 2009), therefore as the result the shrinkage diminished after utilizing the pretreatments in comparison with the untreated apple samples. The lowest shrinkage was allocated to ultrasound-assisted osmotic processed samples. Riva *et al*. (2005) reported that added sugar during osmotic dehydration helps to decrease the volume of reduction slightly during dehydration and there is a protective effect of sugar on the roundness parameter. The osmotic dehydrated fruit cubes showed less deformation and the original shape retained the original shape better with sucrose showing a slightly higher tissue structure protection. The less shrinkage was observed in the treated samples with osmostic and ultrasound-assisted osmotic process as explained by Fernandes *et al*., 2008. Significant changes on tissue structure in osmotic-ultrasound treated samples caused the cell wall disruption and formation of microscopic channels by ultrasonic waves and consequently solid uptake into the intercellular space during the ultrasound-assisted osmotic process was increased and hence the microscopic channels and pore spaces are occupied by sugar, therefore shrinkage has been decreased. The osmotic dehydration caused changes on the cell structure by disrupting the cell walls due to the osmotic pressure gradients, thereby sugar penetrated into the apple tissue (Fernandes *et al*., 2009), but this was at lower amount than the osmosis-ultrasonicated samples. Regading Table 3 the comparsion of variables of sucrose concentration and immersion time indicated that there were significant differences in the osmose pretreatment between the tratments 1 and 4 and between the tratments 2 and 4 ($p < 0.05$) and in the pretreatment of ultrasound-assisted osmotic between the treatment 1 with treatments 3 and 4 and also between the treatments 2 and 4 ($p < 0.05$). By increasing sucrose concentration and immersion time due to the incorporeating solid gain into tissue, resistence tissue aginest shrinkage was increased, as the penetrating suger inside the created empty space and tissue channels caused the obestraction of these channels. Dehghannya *et al*. (2015) evaluated the shrinkage of Mirabelle Plum during hot air drying by ultrasound-assisted osmotic dehydration and observed that the shrinkage of pretreated plum samples was decreased by increasing ultrasonication time from 10 to 30 minutes and osmotic solution concentration from 50 to 70% at the langest period of immersion times (240 min) in osmotic solutions. Amami *et al*. (2017) observed higher shrinkage for the samples with lower osmotic solution concentrations and reported that the utilization of low osmotic solution concentration and less immersion time in osmotic process might lead to an increase in shrinkage. Similar results were obtained by Mundada *et al*. (2011) and Singh *et al*. (2007) that reported

Table 3. The comparsion of the results of concentrations and immersion times in treated samples with osmotic dehyration and ultrasound-assisted osmotic dehydration

Pretreatment		Drying with ultrasound-assisted osmotic process		Drying with osmotic process	
		Rehydration (P-value)	Shrinkage (P-value)	Rehydration (P-value)	(P-value) Shrinkage
Treatment 1	Treatment 2	0.076	0.724	0.332	0.901
	Treatment 3	0.000 **	0.023 *	0.034 *	0.185
	Treatment 4	0.000 **	0.006 **	0.005 **	0.016 *
Treatment 2	Treatment 1	0.076	0.724	0.332	0.901
	Treatment 3	0.001 **	0.099	0.406	0.437
	Treatment 4	0.000 **	0.022 *	0.062	0.04 *
Treatment 3	Treatment 1	0.000 **	0.023 *	0.034 *	0.185
	Treatment 2	0.001 **	0.099	0.406	0.437
	Treatment 4	0.000 **	0.713	0.532	0.347
Treatment 4	Treatment 1	0.000 **	** 0.006	0.005 **	0.016 *
	Treatment 2	0.000 **	0.022 *	0.062	0.04 *
	Treatment 3	0.000 **	0.713	0.532	0.347

* significant at confidence level of 5%, ** significant at confidence level of 1%; Treatment 1 (concentration 30%, immersion time 15 min), Treatment 2 (concentration 30%, immersion time 30 min), Treatment 3 (concentration 60%, immersion time 15 min), Treatment 4 (concentration 60%, immersion time 30 min).

the solid gain and water loss of the samples treated with the higher osmotic solution concentration were found to be higher.

- The effect of pretreatment on colour parametrs

The results of statistical analysis between pretreatments and control samples for redness (a*), lightness (L*), yellowness (b*), hue angle (h), chroma (C) and colour difference (ΔE) parameters at 95% confidence level showed significant difference ($p < 0.05$), except values of yellowness and chroma between the samples of osmotic-ultrasound treated and the control samples and values of lightness and colour difference between the osmotically samples and osmotic-ultrasound samples ($p > 0.05$) (Table 4). Regading the demonstrated results in Table 5 in treated samples with osmotic-ultrasound, chroma, redness and yellowness values were higher and lightness and hue angle values were lower than the treated osmotic samples. The comparison of the control samples with the osmotic and ultrasound-osmotic samples indicated that the pretreated samples had higher lightness and lower redness and yellowness than the control samples while chroma and difference colour parameters were higher in the control samples. Similar results were obtained by Amami *et al.* (2017) that investigated the effect of ultrasound – assisted osmotic dehydration pretreatment on the convective drying of strawberry and observed that chroma changes were more intense during conventional than during ultrasound – assisted osmotic dehydration and lightness and redness value were found to be better in the dried strawberries by pretreatment. According to the obtained results in this study, Krokida *et al.* (2000) investigeted the effect of osmotic dehydration on the colour characteristics of apple and banana and observed the osmotically pretreated samples kept their colour intact that the lightness decreased only a little and redness and yellowness increased slightly, while the colour of untreated samples changed significantly. The osmotic dehydration inhibited the decolourisation of fruit by inactivating the enzymes responsible for the enzymatic browning due to infusion of extensive sugars. The addition of sugar resulted in the reduction of the water activity of the samples and the non-enzymatic browning reaction was decreased. In another research, Mandala *et al.* (2005) investigeted the influence of the osmotic dehydration on apple by air drying and reported that after air drying lightness values were higher in the osmosed samples than in the untreated samples. The increases in redness and yellowness were clear and seemed to be the result of the solid uptake during the osmosis pre-treatment. The colour difference was higher for the untreated samples as compared to the osmosed samples during air drying. This occurred due to the solute uptake, which resulted in lower amount of O_2 being transferred to the surface and consequently observed the less discolouration of the osmosed samples by enzymatic browning. These samples had lower moisture content after the osmosic and this could inhibit the enzymatic oxidation. In a similar study, Garcia-Noguera *et al*. (2012) studied the effect of the ultrasonic and osmotic pre-treatments on the colour of freeze dried strawberries and founded that hue angle decreased by increasing immersion time, which is a positive and desirable result in strawberries, because of the decrease in hue angle strawberries became more colourful. The increase in lightness is also a positive contribution because it will produce bright redness in strawberry. According to another research enzymatic and oxidative browning is prevented as the fruit pieces are surrounded by sugar, thus making it possible to retain good colour (Yadav and Singh, 2014). Silva *et al*. (2014) studied the effect of osmotic dehydration on the quality of pineapple and observed that the treated samples had higher lightness and by increasing the concentration lighness decreased and chroma increased, also the same result was in papaya by Rodrigues *et al*. (2003) and in pumpkin by Silva *et al*. (2011). In this study the compasion of the results between the osmotic dehydration and osmotic-ultrasound process as pretreatments indicated that osmotically treated samples had somewhat more lightness than osmotic-ultrasound samples because of incorporated sugar throughout the created micro-channels by ultrasonic waves in the tissue structure of treated samples with the ultrasound-assisted osmotic was more than the treated samples with osmotic, thereby this process might be the cause of the darkening appearance of the ultrasound-assisted osmotic samples. The results showed that between concentrations and immersion times there was no significant difference ($P > 0.05$) on the colour parametrs in the treated samples except in the lightness parameter between the treatment 1 with 3 and 4 in treated samples with osmotic process. The results are shown in Tables 6 and 7. Based on the obtained results from the comprasion of concentrations and immersion times, it was found that the lightness and hue angle parameters decreased and the redness, yellowness and difference colour parameters increased by increasing the concentration and immersion time, hence in both of the pretreatments, treatment 1 had the more lightness while treatment 4 had more darkness than the other treatments. Silva *et al*. (2014) found that an increase in the concentration of the sucrose solution resulted in a greater water loss, which might increase the pigment concentration in the tissue and consequently enhanced the chromaticity of the product. In another study, Rodrigues *et al*. (2003) reported that Chroma values increased during osmotic dehydration processing and tended to stabilization after dehydration. The increase in redness and yellowness is clear and seems to be the result of matrix concentration and solid uptake. Azarpazhooh and Ramaswamy, (2011) reported that the increase in redness and yellowness values might be due to solid accumulation during osmotic pretratment and possible membrane plasticizing effect, which might have increased the cell membrane permeability to sucrose molecules. The comparsion of the treatment 2 and 3 indicated that the concentration difference was more effective on water loss and solid gain than the time difference but this effect was not very prominent. The treated samples with treatment 2 were slightly brighter and chroma and differance colour valuses were slightly lower than the treated samples with treatment 3, probably the enhancement of sugar penetration into the apple slices by increasing of concentration was greater than increase of time, therefore solid gain was somewhat lower in the treated samples with 30% concentration in a period of 30 minutes than the treated sampels with 60% concentreation in a period of 15 minutes. The moisture loss from the product takes place at a faster rate in the first few hours, and then the rate decreases slowly. The chemical potential difference across a semi-permeable membrane between the cellular material and osmotic solution is the driving force for mass flow. The osmotic dehydration phenomena precede until the water activity of both the solution and the sample attain the equilibrium state. Due to the permeability of the cell wall, the volume between the plasmalemma and cell wall gets filled with the osmotic solution (Ahmed *et al*, 2016; Mavroudis *et al*, 2012; Rastogi *et al*., 2002). The results of Garcia-Noguera *et al*. (2012) showed an increase in water loss by increasing osmotic solution concentration, because of the increase in the gradient between the soluble solids concentration in the fruit and in the osmotic solution. The effectiveness on the colour is more related to the concentration of solids in the fruit, which may impact the luminosity and chroma parameters. The increase in the osmotic solution concentration and immersion time had a negative effect on lightness.

Conclusion

In this study the effect of ultrasound-assisted osmotic dehydration pretreatment on the convective drying of the apple slices was investigated. The results showed that solid gain and water loss were increased by increasing concentration of sucrose solution and immersion time. The utilization of ultrasound-assisted osmotic faciliated the mass transfer by the created micro-channels intercellular tissue, consequently the solid gain and water loss were more increased than the osmotic process. The lowest shrinkage was observed in the treated samples with ultrasound-assisted while the highest rehydration rate related to the control samples. All the treated sampels represented higher lightness (L*) and lower redness (a*) yellowness (b*) and colour intensity (ΔE) than the ones of untreated sampels. The lightness in the treated samples decreased after prolonged ultrasonic exposure and the utilization of high sucrose concentrations. The highest lightness and the lowest redness, yellowness were observed in the treated samples with osmotic dehydration. Thus the application of ultrasound technology as one of the non-thermal techniques is able to improve the quality characteristics of dried food.

Table 4. The comprasion of the results of the colour parameters in treated samples with osmotic dehydration, ultasound-assisted osmotic dehydration and untreated samples

Drying method	P-value (ΔE)	P-value (h)	P-value (C)	(L*)P-value	P-value (b*)	P-value (a*)
Drying osmotic - ultrasound-assisted osmotic	0.113	0.002 **	0.024 *	0.563	0.044 *	**0.002 ****
Drying osmotic – control	0.001 **	0.000 **	0.005 **	0.003 **	0.038 *	**0.000 ****
Drying ultrasound-assisted osmotic - control	0.025 *	0.002 **	0.21	0.013 *	0.581	**0.001 ****

* Significant at confidence level of 5%, ** Significant at confidence level of 1%

Table 5. The means of the results from the colour parameters in the treated samples with osmotic dehydration, ultrasound-assisted osmotic dehydration and the untreated samples

Parameters	Control	Ultrasound-assisted osmotic process	Osmotic process
Redness (a*)	13.663	8.542	5.089
Yellowness (b*)	34.689	33.33	30.404
Lightness (L*)	44.851	52.127	53.802
Hue angle (h)	68.506	75.763	81.407
Chroma (C)	37.290	34.453	30.877
Colour intensity (ΔE)	28.705	20.491	16.17

Table 6. The comprasion of the results of concentrations and immersion times in the treated samples with osmotic dehydration

Pretreatment		P-value (ΔE)	P-value (C)	P-value (h)	P-value (L*)	P-value (b*)	P-value (a*)
Treatment 1	Treatment 2	0.98	0.991	0.949	0.976	0.991	0.981
	Treatment 3	0.616	0.872	0.877	0.485	0.87	0.91
	Treatment 4	0.3	0.618	0.525	0.267	0.656	0.531
Treatment 2	Treatment 1	0.98	0.991	0.949	0.976	0.991	0.981
	Treatment 3	0.822	0.964	0.996	0.706	0.963	0.991
	Treatment 4	0.741	0.777	0.814	0.436	0.81	0.739
Treatment 3	Treatment 1	0.616	0.872	0.877	0.485	0.87	0.91
	Treatment 2	0.822	0.964	0.996	0.706	0.963	0.991
	Treatment 4	0.913	0.959	0.905	0.957	0.974	0.876
Treatment 4	Treatment 1	0.3	0.618	0.525	0.267	0.656	0.531
	Treatment 2	0.741	0.777	0.814	0.436	0.81	0.739
	Treatment 3	0.913	0.959	0.905	0.957	0.974	0.876

The comprasion of the results of concentrations and immersion times are not significant effect ($P > 0.05$); Treatment 1 (concentration 30%, immersion time 15 min), Treatment 2 (concentration 30%, immersion time 30 min), Treatment 3 (concentration 60%, immersion time 15 min), Treatment 4 (concentration 60%, immersion time 30 min).

Table7. The comprasion of the results of concentrations and immersion times in the treated samples with ultrasound-assisted osmotic dehydration

Pretreatment		P-value (ΔE)	P-value (C)	P-value (h)	P-value (L*)	P-value (b*)	P-value (a*)
Treatment 1	Treatment 2	0.472	0.221	0.339	0.383	0.179	0.351
	Treatment 3	0.178	0.147	0.24	0.038*	0.127	0.239
	Treatment 4	0.087	0.072	0.098	0.018*	0.075	0.097
Treatment 2	Treatment 1	0.472	0.221	0.339	0.383	0.179	0.351
	Treatment 3	0.862	0.99	0.992	0.384	0.994	0.989
	Treatment 4	0.589	0.85	0.794	0.188	0.992	0.774
Treatment 3	Treatment 1	0.178	0.147	0.24	0.038*	0.127	0.239
	Treatment 2	0.862	0.99	0.992	0.384	0.994	0.989
	Treatment 4	0.952	0.955	0.912	0.942	0.982	0.91
Treatment 4	Treatment 1	0.087	0.072	0.098	0.018*	0.075	0.097
	Treatment 2	0.589	0.85	0.794	0.188	0.992	0.774
	Treatment 3	0.952	0.99	0.912	0.942	0.982	0.91

The comprasion of the results of concentrations and immersion times are not significant effect except in the lightness parameter between treatment 1 with 3 and 4 ($P > 0.05$); Treatment 1 (concentration 30%, immersion time 15 min), Treatment 2 (concentration 30%, immersion time 30 min), Treatment 3 (concentration 60%, immersion time 15 min), Treatment 4 (concentration 60%, immersion time 30 min).

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