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EFFECT OF OSMOTIC-AIR DEHYDRATION ON DRYING KINETICS AND MICROSTRUCTURE OF APPLE SLICES AND CUBES

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ABSTRACT

Osmotic dehydration (OD) is a process of water removal from a high-moisture solid food by pressure created by a surrounding liquid medium. Meanwhile, air dehydration of foods involves vaporization of water and removal of the vapor with a stream of air. Major problems associated with air dehydration are poor product quality, unfavorable changes in color, flavor and nutritive value of dried products. The process of osmotic dehydration followed by air drying of apples was studied to improve the quality of dried apples, so it could be consumed as snake foods. Apple slices and cubes were initially immersed in sucrose solutions (40 or 50%) for 12 hours, according to the results of preliminary experiments for osmotic dehydration. Kinetic studies during soaking in osmotic solution show that soaking apples in 50% of sucrose solution resulted in increasing the solid gain (SG), water loss (WL) and weight reduction (WR) comparing to those which were soaked in 40% of sucrose solution. Also, apple slices had higher values for the forementioned parameters than cube ones. Moreover, kinetic studies during drying by hot air revealed that osmotic-air dried apples which were soaked in 40% of sugar solution had less drying time, higher (WL) and higher (WR) than those which were treated with 50%. Also, apple slices had better results than the cubes. Microstructure changes using scanning electron microscope in osmotic-air dried apple tissues were studied. The concentration of the soaking sugar solution affected the microstructure of both apple slices and cubes. Osmotic dried apple slices and cubes which were soaked in 50% resulted in higher cell shrinkage than those which were treated with 40% of sucrose solution.

INTRODUCTION

Apples are a highly favored fruit, not only because of their good storage and manufacturing properties, but also owing to their unique flavor characteristics (Elss, *et al*., 2006). Egypt produces a considerable amount of apple which reached 455, 817 metric tons at 2011 (FAO, 2013).

Conventional dehydration of apple slices leads a product of dark, leathery texture, and poor flavor with a loss of nutritive values (Taiwo *et al*., 2001). It requires high temperature and velocity of drying and takes long time (Lewicki and Jakubczyk, 2004 and Miranda *et al*., 2009).

In order to improve the quality of preserved food products, researches have looked for new ways to processes foods, and one of these new methods is osmotic dehydration. Osmotic dehydration process can reduce the water content of fruits by 50% since osmotic dehydration is more economical than thermal drying, it is often used as pretreatment for drying biological material (Tortoe, 2010 and Chavan and Amarowicz, 2012).

During osmotic pre- concentration, two major counter-current flows take place simultaneously under the water and solute activity gradients across the semi-permeable cell membrane. Water flows from the product into the osmotic solution whereas osmotic solute is transferred from the solution into the product which result in an increase in water activity and effective reduction of product water content with minimal damage in fresh product attributes. A third transfer process is the leaching of product solutes (sugars, acids, minerals and vitamins) into the media, although recognized as affecting the sensory and nutritional characteristics is considered negligible (Browne and Badrie, 2006).

Water loss and solid gain are mainly controlled by the raw material characteristics, certainly influenced by the possible pretreatments. The great variability observed among the different fruits is mostly related to the tissue compactness, initial insoluble and soluble solid content, intercellular spaces, presence of gas, and ratio between the different pectin fractions (water soluble pectin and protopectin) and jellification level of pectin of the fruit (Lenart and Flink, 1984 a,b, and Torreggiani, 1993).

The geometry of sample pieces affects the behavior of the osmotic concentration due to the variation of the surface area per unit volume (or mass) and diffusion length of water and solutes involved in mass transport (Lerici *et al*., 1985; Falade and Aworth, 2005).

Bai *et al*., (2002) and Phisut *et al*., (2013) observed that, a degree of cellular collapse has occurred in all dried apple slices which were dried at different drying temperature. Moreover, the higher the drying temperature, the higher the cellular collapse. In addition, Lewicki and Pawlak (2003) observed that most of small cavities were present in layers close to the surface of the cube apple, while large cavities were spread all over the cut surface.

The microstructure of apple cubes studied by Prothon *et al*. (2001) and Lewicki and Pawlalak, (2005) using confocal laser scanning microscopy (CLSM) showed that osmotic drying did not damage the cell wall. A thickening of the cell wall can be observed possibly due to the adsorption of sugar to the components of the cell wall-cellulose, pectic substances or other polysaccharides. A decrease in cell size can also be observed. The decrease in cell size is due to the dehydration process, a significant decrease in sample size was observed after osmotic dehydration.

The general objective of this work was to study the process of osmotic dehydration followed by air – drying of apples. The influence of osmotic solution percentage and type of cut on the solid gain, water loss, weight reduction and drying time that occurred during osmotic process and after drying were studied. Moreover, the changes in the microstructure properties of apple tissues during this process was also investigated.

MATERIALS AND METHODS

Materials

Anna apple fruits (*malus doestic*) were bought from local market in Alexandria Egypt and had almost similar ripeness, skin color and format. The fruits were sorted, washed and packaged in box and stored in refrigerator at 4°C ± 1 and 90% RH until processing.

Methods

Osmotic dehydration (OD)

The fruits were washed, peeled and cut manually into cubes and slices. The thickness was approximately similar (2×2×2 cm for cube and 0.4-0.5 cm for slice). The samples were soaked in 0.5% citric acid for 5 min then rinsed. Cubes and slices were immersed in sucrose solution (40, 50 and 60%) at 4:1 (w/w) fruit to sugar ratio at room temperature for 6, 8, 10 and 12 hrs. At the end of the osmotic process, samples were drained, blotted with absorbent paper to remove excess solution. After that, samples were air dried at 70°C until the samples reached the equilibrium moisture content 2-3% .

During osmotic process and after air drying for all samples, drying curves were carried out. Solid gain % , water loss % and weight reduction % were calculated according to Nieto, *et al*., (2004) as follows:

$$\text{Weight Reduction (WR)} = \frac{\text{Initial weight of sample} - \text{weight of samples at time} \times 100}{\text{Initial weight of sample}}$$

$$\text{Water loss (WL)} = \frac{\text{Initial weight of water in the sample} - \text{weight of water in the sample at time} \times 100}{\text{Initial weight of sample}}$$

$$\text{Solid Gain (SG)} = \frac{\text{Weight of soluble solids at time} - \text{initial weight of soluble solids in the sample} \times 100}{\text{Initial weight of sample}}$$

Sensory evaluation

Sensory properties including colour, crispness, texture, odour, taste and overall acceptability for dried apples were determined by 10 staff members of Food Science and Technology Department, Faculty of Agriculture, Alexandria University, Egypt, using the hedonic scale method rating of 1-10 (1= dislike very much, 10= like very much).

Tissue structure

The different samples, fresh apples, and osmotic convective dried apple slices and cubes were examined by scanning electron microscopy (SEM). Samples were defatted and freeze-dried, and the surface and vertical cross-section of the samples were sputter-coated with gold and examined with a JEOL JSM-6300 SEM according to Shu and Hwang (2001).

Statistical analysis

Statistical analysis, standard deviation of means, analysis of variance, including the study of homogenous groups established throughout the Least Significant Difference (LSD) test, (Falade and Aworth, 2005).

RESULTS AND DISCUSSION

Preliminary experiments on the sensory sucrose attributes of osmotic-air dried apples, which were soaked in 40, 50 and 60% sugar solutions for 6, 8, 10 and 12 hrs, follow by air drying (at 70°C until the samples reached the equilibrium moisture content of 2-3% were carried out to choose the best treatments. Table (1 and 2) show that the panelists favored slice or cube samples which were soaked in 40 and 50% sucrose solutions for 12 hrs than those which were soaked in 60% of sucrose solution. Therefore, these treatments were selected for the further experiments.

Table (1): Sensory evaluation of apple slices

Concentration of osmotic solution	Soaking time (hr)	Sensory attributes				
		Color	Taste	Texture	Odour	Overall acceptability
40%	6	7.89^{ab}	7.78^{ab}	7.67^{cde}	7.00^{a}	8.11^{abcd}
	8	8.56^{ab}	7.56^{ab}	7.89^{bcd}	7.44^{a}	8.33^{abc}
	10	8.33^{ab}	8.00^{ab}	8.33^{abc}	7.22^{a}	8.11^{abcd}
	12	8.67^{a}	8.22^{a}	8.89^{ab}	8.22^{a}	8.44^{ab}
50%	6	7.67^{bc}	7.89^{ab}	8.22^{abc}	7.56^{a}	8.67^{a}
	8	8.00^{ab}	7.89^{ab}	8.11^{abc}	7.67^{a}	8.11^{abcd}
	10	7.78^{abc}	7.78^{ab}	7.33^{cde}	7.22^{a}	7.67^{bcd}
	12	8.67^{a}	8.22^{a}	9.00^{a}	8.33^{a}	8.67^{a}
60%	6	5.33^{d}	5.89^{cd}	3.56^{g}	7.33^{a}	5.33^{e}
	8	8.11^{ab}	7.67^{ab}	6.11^{f}	7.33^{a}	7.44^{cd}
	10	8.22^{ab}	7.89^{ab}	7.44^{cde}	7.56^{a}	7.89^{abcd}
	12	6.89^{c}	6.89^{bc}	7.00^{def}	7.33^{a}	7.22^{d}
L.S.D		0.96	1.23	1.09	n.s	0.94

n.s. : non significant at 0.05.

Table (2): Sensory evaluation of apple cubes

Concentration of osmotic solution	Soaking time (hr)	Sensory attributes				
		Color	Taste	Texture	Odour	Overall acceptability
40%	6	6.4^{ab}	6.7^{abc}	5.1^{abc}	6.8^{a}	6.2^{abc}
	8	6.3^{ab}	6.8^{ab}	5.3^{abc}	7.1^{a}	6.7^{ab}
	10	4.3^{c}	5.4^{bc}	3.1^{c}	6.9^{a}	4.3^{c}
	12	7.3^{a}	7.2^{a}	6.3^{ab}	7.2^{a}	7.4^{a}
50%	6	6.9^{ab}	6.6^{abc}	5.1^{abc}	7.3^{a}	7.1^{ab}
	8	6.8^{ab}	6.6^{abc}	5.0^{abc}	7.3^{a}	6.4^{ab}
	10	5.3^{bc}	6.7^{abc}	5.6^{ab}	6.8^{a}	6.9^{ab}
	12	7.2^{a}	7.6^{a}	6.4^{a}	6.6^{a}	7.3^{a}
60%	6	6.4^{ab}	6.4^{abc}	4.3^{abc}	7.4^{a}	6.9^{ab}
	8	8.0^{a}	6.9^{ab}	4.0^{bc}	7.4^{a}	5.4^{abc}
	10	6.6^{ab}	6.4^{abc}	6.2^{ab}	7.9^{a}	7.4^{a}
	12	5.2^{bc}	6.4^{abc}	5.6^{ab}	7.0^{a}	6.3^{abc}
L.S.D		1.82	1.95	2.29	n.s	2.1

n.s. : non significant at 0.05.

Kinetic studies during soaking in osmotic solution

Determination of solid gain (SG%)

Solid gain (SG%) for apple slices and cubes during osmotic process in 40 and 50% sucrose solutions are presented in Figure (1).

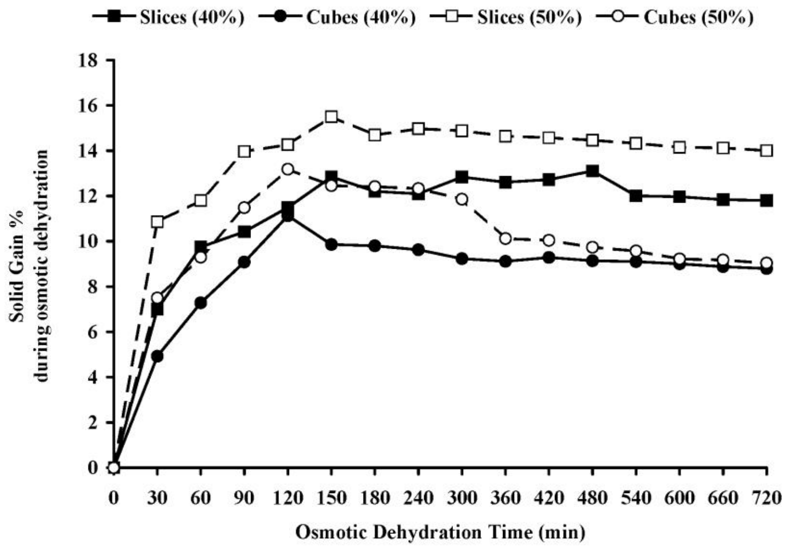


Figure (1): Effect of osmotic process during soaking in osmotic solution (40 & 50% sucrose solution concentration) on solid gain %

Generally, as shown in the forementioned figure, SG% increased, significantly, as the immersion time increased until equilibrium was reached at almost 240 min of osmotic time.

Soaking apples in sucrose solution (50%) resulted in increasing the percentage of SG comparing to those which were soaked in 40% sucrose solution. Also, apple slices had SG% more than apple cubes either soaked in 40 or 50% sucrose solution. This increase was presumably due to increasing infusion of sucrose into the tissues, which is the driving force that causes water to flow out of the tissue (Falade and Aworth, 2005 and Nimmanpipug and Therdthai, 2013).

Determination of water loss (WL%)

Water loss (WL%) expressed as water content per initial water content of the sample increased with increasing time of osmotic process in minutes (Fig. 2). Concentration of the sucrose solution affect significantly the WL% , since WL % in apple samples which were soaked in 50% sucrose solution was higher than that of apple samples soaked in 40% sucrose solution. This result is in a good agreement with that of Falade and Aworth (2005), who concluded that water loss increased as the osmotic solution concentration increased and approached equilibrium towards the termination of the process.

Also, it is cleared from (Fig. 2) that the geometry of sample pieces affected the rate of the WL%, since apple slices gave higher water loss than cube ones either treated with 40 or 50% sucrose solution.

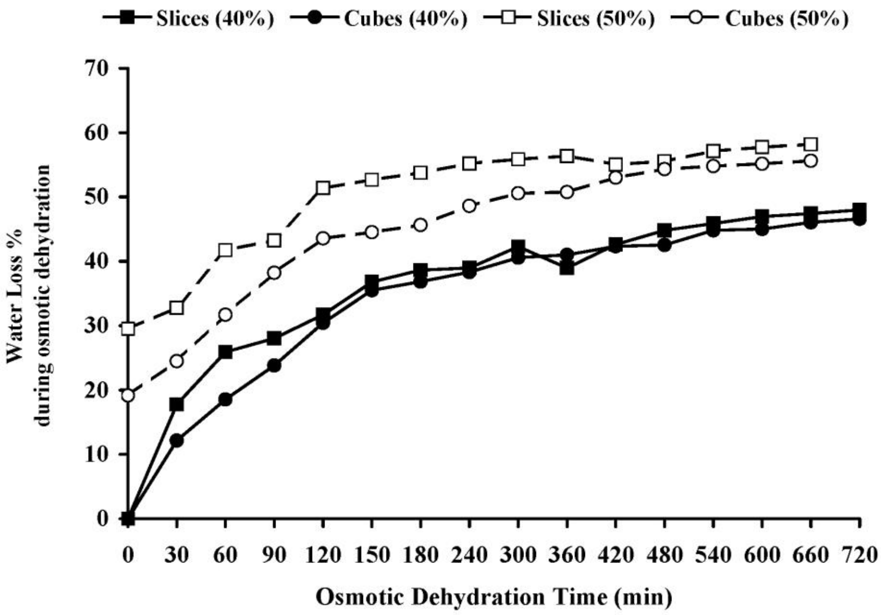


Fig. (2): Effect of osmotic process during soaking in osmotic solution (40 & 50% sucrose solution concentration) on water loss

Lerici *et al*. (1995) and Chavan and Amarowicz (2012), stated that water loss increases with the increase of the surface area of such fruit rings compared to lower surface area such as stick.

Determination of weight reduction (WR)

Weight reduction (WR%) for apple slices and cubes during osmotic dehydration in 40 and 50% sucrose solution are shown in Fig. (3). Increasing time of osmotic dehydration (min.) caused a significant increase in WR%. The WR % was increased as a result of increasing the concentration of sucrose solution for both apple slices and cubes. Falade *et al*. (2003) reported that increasing immersion time and osmotic solution concentration increased the weight reduction (%) of fruits.

Type of cut affected significantly the percentage of weight reduction, where apple slices had higher weight reduction than cube ones. Similar trend was reported by Li and Ramaswamy (2006), who, found that WR% increased when the dimension of osmotic apricot is decreased because of increasing contact area.

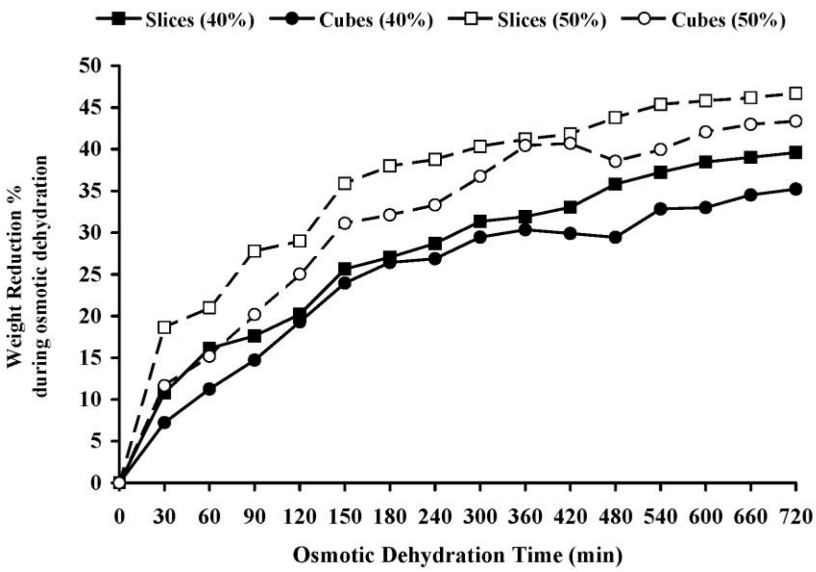


Fig. (3): Effect of osmotic process during soaking in osmotic solution (40 & 50% sucrose solution concentration) on weight reduction

Determination of drying time

Figure (4) show the drying time of osmotic-air dried apple slices and cubes. Osmotic air-dried apples with 40% sucrose solution needed 300 min. as drying time for both slices and cubes, while the drying time increased to 360 min and 420 min for apple slices and cubes which were soaked in 50% sugar solution, respectively. The slice samples dried faster than cubes.

In addition, the higher concentration of osmotic solution had higher drying time. It is clear that the internal resistance increase to mass transfer during drying due to the solute uptake in the osmosis process. Therefore, a considereable amount of water was already removed during osmosis and further water removal during drying was more difficult (Mandala *et al*., 2005).

Determination of Water Loss (WL)

Water loss (WL%) values of osmotic air dried apple slices and cubs are given in Fig. (5). The results show that using 40% of sucrose solution during the osmosis process before air drying showed rapid and higher water loss than osmotic-dried samples with 50% sucrose solution, these results are in agreement with those of Mandala *et al*. (2005), Falade *et al*. (2007) and Khan (2012). It is clear that the increase in internal resistance to mass transfer during drying is due to the increase in the solute uptake in osmosis process. Therefore, a considerable amount of water was already removed during osmosis and further water removal during drying was more difficult. Comparing the WL% of osmotic-air dried slices with apple cubes, it was found that WL% increased in the case of slice samples than that of cube ones. According to Barat et al., (1998), osmotic dehydrated papaya slices provided higher water loss than cubic which can be explained by the small thickness, which contributes for the water exit and can consequently the water loss increase.

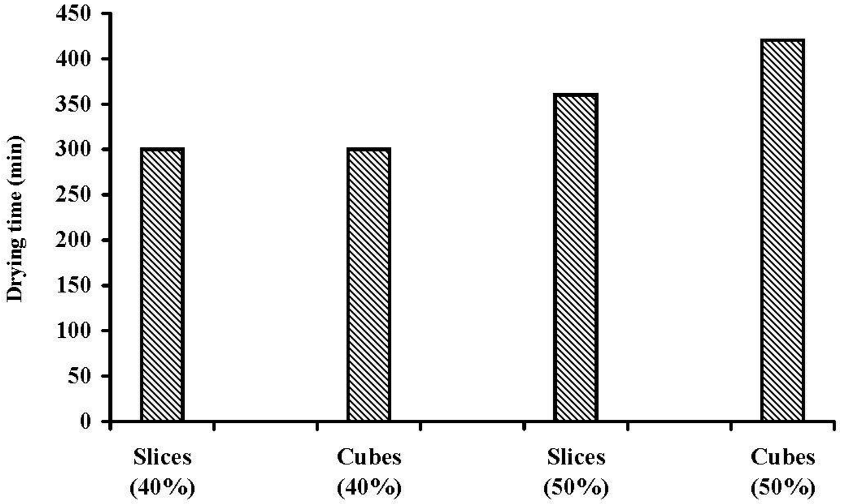


Fig. (4): Effect of sucrose solution concentration on drying time

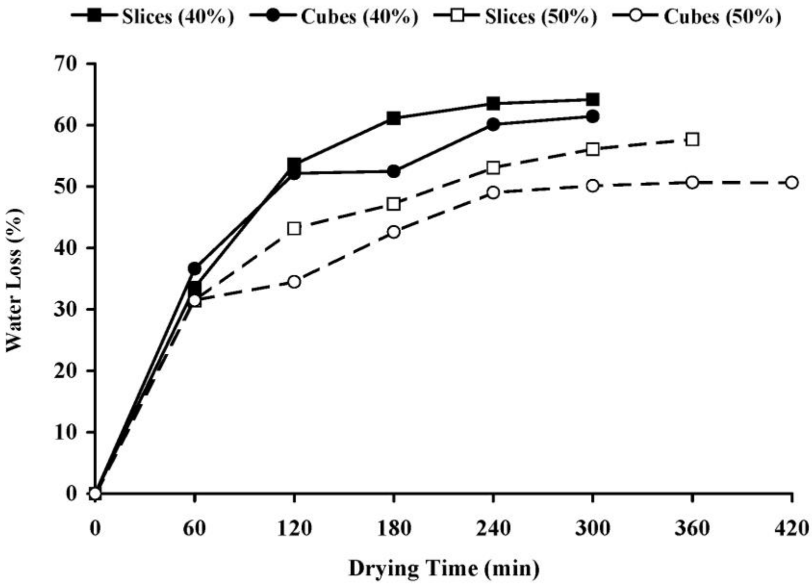


Fig. (5): Water loss (WL%) for osmotic-air dried apples (slices and cubes) in 40 and 50% sucrose solution

Kinetic studies during drying and after drying by hot air

Determination of weight reduction (WR %)

Figure (6) show that significant effect of soaking sugar solution was observed, since, WR % of osmotic-air dried apple samples were higher for apple samples soaked in 40% sucrose solution than that of apple samples soaked in 50%.

The geometry cut affected the WR % for osmotic-air dried apples, which were soaked in 40% sucrose solution but did not have any effect in case of samples which were soaked in 50% sucrose solution, since they were 49.04 %, 49.03 % for slices and cubes soaked in 50% and dried for 360 min, respectively.

The water loss and weight reduction percentages increased with increasing osmotic solution concentration and immersion time, and decreased with increasing slice thickness (Falade *et al*., 2003).

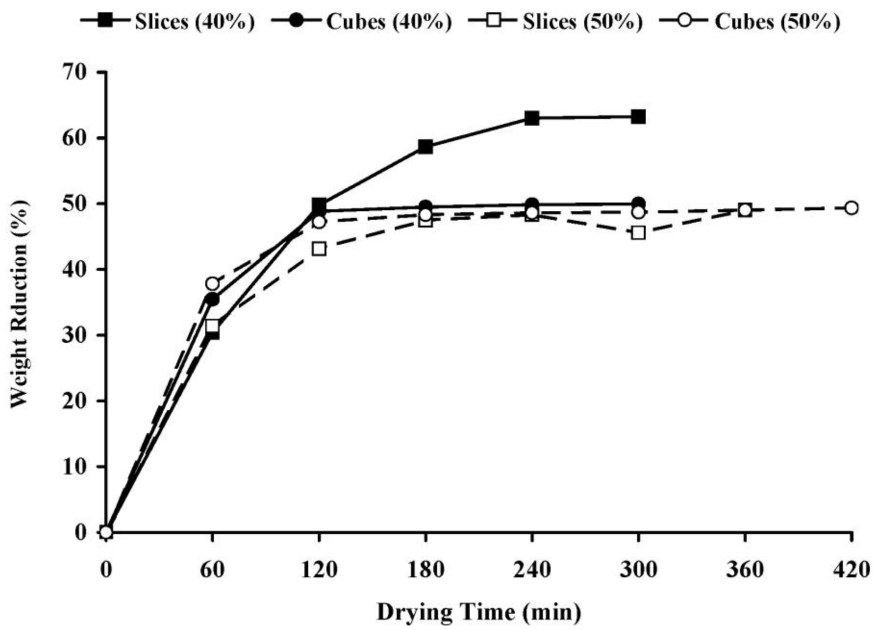


Fig. (6): Weight reduction (WR%) for osmotic-air dried apples (slices and cubes) soaked in 40 and 50% sucrose solution

Changes in the microstructure of apple tissues

Driving forces and structure are the two major forces in the understanding and control of the mass transport phenomena in food processing, in general and in osmotic processing in particular (Tortoe, 2010).

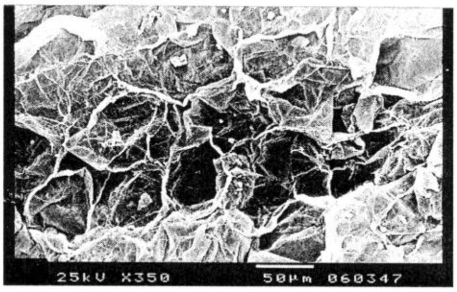
So, microstructure evaluation, using scanning electron microscope of fresh and osmotic air dried apple slices and cubes were studied. As shown in Fig. (7) fresh apple tissues have a well-organized structure consisting of cells and intercellular spaces. On the other hand, it could be seen that breakdown of cell walls and collapse of cell structure were found in all osmotic dried apple tissues, also, the turgor pressure pushes cell walls toward the center of the intercellular spaces. This possibly due to the absorption of sugar and reducing of water content.

Xiao and Gao (2012) and Phisut *et al*. (2013) reported that loss of cell turgidity and/or cell wall rupture, splitting and degradation of the middle lamella, lysis of membrane, cellular collapse and shrinkage cellular structure of plant tissues.

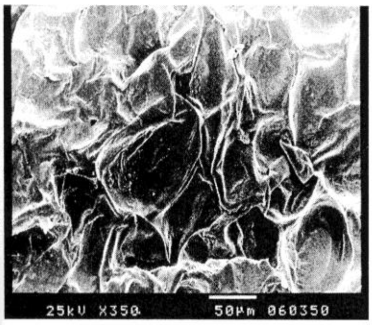
The concentration of the soaking solution affected the microstructure of both dried apple cubes and slices (Fig. 7), since the higher osmotic sucrose solution (50%) resulted in higher cell shrinkage than those which were treated with 40% of sucrose solution.

These findings are in accordance with Barat *et al*. (1998) and Tortoe (2010) who reported that the structural stress associated with cell shrinkage promoted osmotic dehydration and the higher the osmotic concentration, the higher the structural stress and thus higher cell shrinkage.

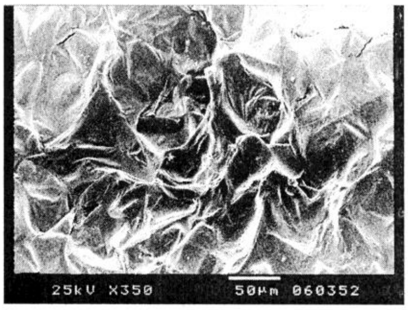
Finally, it could be concluded that the concentration of sucrose soaking solution and the geometric shap of the apples affected significantly the kinetic parameter, sensory properties and microstructure of the procced apples.



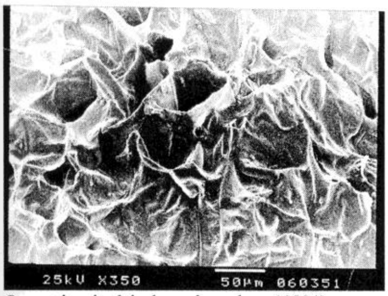
Fresh apple



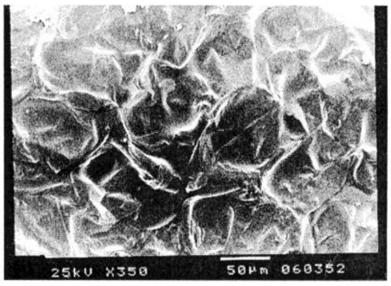
Osmotic air dried apple slices (40%)



Osmotic air dried apple slices (50%)



Osmotic air dried apple cubes (40%)



Osmotic air dried apple cubes(50%)

Fig. (7): Change in the microstructures of osmotic-air dried apple slices and cubes comparing to fresh one

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تأثير التجفيف الاسموزي متبوعا بالهواء الساخن علي الخواص الحركية والتغيرات الخلوية المجهرية لمكعبات وشرائح التفاح

مــروة خضــر قبيصــي ، ليلــي عبـد الهــادي شـكيب ، ناهـــد عبـد الحميـد الشـيمي و حميدة محمد موسي
قسم علوم وتقنية الأغـذية – كلية الزراعة – الشاطبي – جامعة الاسكندرية ٠
الرقم البريـدي ٢١٥٤٥ – الاسكندرية - مصر

التجفيف الاسموزي هو عملية إنتقال الماء من الأغذية ذات الرطوبة المرتفعة عن طريق الضغط الناتج من الوسط المائي المحيط بالغذاء وفي نفس الوقت فإن التجفيف بالهواء الساخن يؤدي الي تبخير الماء من المادة الغذائية ثم إنتقال هذا البخار الي الخارج عن طريق تيار الهواء ٠ ويؤدي التجفيف بالهواء الساخن فقط الي إنتاج منتج مجفف ذو جودة فقيرة ، وتغير غير مرغوب فيه في اللون والطعم والرائحة والقيمة الغذائية ٠ ولهذا فقد تم تجفيف التفاح باستخدام التجفيف الاسموزي يتبعه التجفيف بالهواء الساخن بهدف تحسين خواص المنتج المجفف لاستخدامه كغذاء تسالي (تصبيرة) ٠ ثم نقع شرائح ومكعبات التفاح في محلول سكري (سكروز) بنسب ٤٠ ، ٥٠% لمدة ١٢ ساعة ولقد تم اختيار هذه الظروف بعد اجراء تجارب مبدئية علي نسب مختلفة للمحلول السكري وأزمنة مختلفة ٠

وقد أجريت دراسة للتغيرات الحركية خلال النقع وتبين أن نقع التفاح في ٥٠% محلول سكري (سكروز) لمدة ١٢ ساعة تؤدي الي زيادة في كل من المادة الصلبة (solid gain %) والماء المفقود water loss %)) وانخفاض الوزن (weight reduction %) مقارنة بالعينات التي تم نقعها في محلول سكري بنسبة ٤٠% ٠ كما وجد ان الخواص الحركية السابقة لشرائح التفاح اعلي عند مقارنتها بمكعبات التفاح ٠

كما تبين أن الخواص الحركية التي تم دراستها خلال التجفيف بالهواء الساخن أوضحت أن عينات التفاح التي تم معاملتها إسموزيا بواسطة ٤٠% محلول سكري كان وقت تجفيفها أقل ونسبة فقد الماء ، نسبة الفقد في الوزن أعلي من تلك التي تم معاملتها بـــ ٥٠% محلول سكري ٠

كما وجد أن جميع نتائج شرائح التفاح بالنسبة للخواص السابقة كانت أجود من المكعبات ٠ كما تم دراسة التغيرات الخلوية المجهرية باستخدام الميكرسكوب الالكتروني لعينات التفاح بعد النقع في المحلول السكري والتجفيف النهائي بالهواء الساخن ٠ ووجد أن تركيز المحلول السكري المستخدم في النقع يؤثر تأثيرا معنويا علي التركيب الخلوي لكل من شرائح ومكعبات التفاح ٠ ووجد ان معدل الإنكماش في الخلايا كان أعلي في العينات التي تم معاملتها إسموزيا بـــــ ٥٠% محلول سكري عن تلك التي استخدم لها محلول سكري ٤٠% ٠