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original scientific paper

## Properties of Dried Apricots Pretreated by Ultrasound-Assisted Osmotic Dehydration and Application of Active Coatings

**Running head:** Dried Apricots Pretreated by Ultrasound-Assisted Osmosis and Active Coating

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### SUMMARY

*Research background.* The worldwide demand for healthy and sulphur-free dried vegetables and fruits has grown. Combined ultrasound-assisted osmotic dehydration (UOD) and application of active coatings incorporating natural preservatives represents an attractive alternative for sulphuring process to preserve the sensorial and nutritional quality of dried fruits. The aim of this study was to investigate the effect of osmotic dehydration (OD) and UOD and the use of pectin coatings (alone or with citric acid, CA or ascorbic acid, AA) on physical, textural and microstructural properties of hot air-dried apricot.

*Experimental approach.* Fresh apricot cubes (1 cm<sup>3</sup>) were pre-treated with either OD at a temperature of 55 °C for 30 and 45 min or UOD at two ultrasonic frequencies of 25 and 35 kHz for 30 and 45 min followed by application of active coatings with pectin alone, pectin + CA or pectin + AA for 10 min. All pre-treated coated samples were then hot-air dried at a temperature of 60 °C until a final moisture content of 20 % (wet basis) was reached. Physical (shrinkage, apparent and bulk densities), chemical (browning value, water activity), textural (firmness and shrinkage), microstructure and microbial load of dried apricot was studied.

*Results and conclusions.* Application of OD and UOD improved physical and textural properties of the dried apricots. Moreover, apparent and bulk densities, rehydration capacity of OD and UOD pre-

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treated samples were increased. While, shrinkage, water activity and microbial load were decreased. Firmness of UOD pre-treated samples was significantly ( $p < 0.05$ ) lower than that of OD ones. Likewise, increasing ultrasound frequency from 25 to 35 kHz led to a significant decrease in  $F_{max}$  values of dried apricots. Furthermore, coating of the OD and UOD processed samples with pectin + CA increased  $F_{max}$  and decreased rehydration capacity of dried apricots. Scanning electron microscopy of both OD and UOD samples illustrated improvement of textural properties. The utilization of both OD pre-treatment and pectin edible coatings resulted in a decrease in browning values. However, UOD increased browning values of the dried apricots. Coating of UOD samples with pectin + AA resulted in substantial discoloration in hot air-dried apricot.

*Novelty and scientific contribution.* This study advances the knowledge in the field of fruit drying by combined application of OD or UOD pre-treatments with post-treatments with active edible coatings on different properties of hot-air dried apricot.

**Key words:** apricot, hot air drying, osmotic dehydration, ultrasound-assisted osmotic dehydration, active coating, physical properties

## INTRODUCTION

Nowadays, there is a growing demand for healthy and nutritive foods. Apricot contains a high amount of polyphenol compounds, carotenoids, minerals, and vitamins, which is nutritionally valuable compounds (1). Nutritional content in fruits and vegetables such as apricot not only depends on size, variety, and ripeness (2) but also is affected by processing conditions (3). The small amounts of apricot are consumed in the fresh state, and its processing is necessary to extend its shelf life. Hot air drying is most commonly process to increase the shelf life of fruits, but it causes irreversible changes in nutritional and physical properties of apricots such as colour and textural variations and nutritional value decline (3). Textural damages created in air-dried fruits and vegetables include extreme shrinkage, low rehydration capacity, and texture firmness. Colour changes in hot air-dried apricot drives from ascorbic acid oxidation, enzymatic, and non-enzymatic browning reactions. Sulphur dioxide gas is normally used as a synthetic antioxidant before drying to preserve colour and to protect carotenoids, polyphenol compounds and vitamin C (4,5). However, its use in fresh fruits and vegetables is restricted by food and drug administration (FDA) regulations because of its role in the initiation of asthmatic reactions in sensitive people.

OD pre-treatment can substitute sulphite application before drying. This process improves nutritional value, texture properties, reduces shrinkage, and prevents colour deterioration during the drying of fruits and vegetables (6). Concerning low mass transfer rate in OD process, the use of high-power ultrasound can enhance mass transfer rate of the process (7). Combining power ultrasound in

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OD processing creates cavities in the liquid phase and enhances the rate of mass transfer by forming micro agitation and reducing the thickness of the solid diffusion boundary layer. In the solid phase, alternating compressions and expansions result in a sponge-like effect and creates microchannels that facilitate the flow of water out from the solid medium (8).

Coatings of fruits and vegetables by edible carbohydrate-based coatings before drying is another pre-treatment that can decline oxidation and nutritional compound loss during hot air drying. Furthermore, coatings can minimize colour changes in the dried materials due to having gas barrier properties (9). Garcia *et al.* (10) reported the application of edible coatings on papaya before drying increased retention of vitamin C content compared with non-coated dried papaya. Moreover, Silva *et al.* (9) found that coating of pineapple samples by pectin and WPI-LBG coatings decrease the loss of vitamin C content in coated samples during drying. They showed that the lowest colour change among samples happened in pectin coated ones. Ghasemzadeh *et al.* (11) represented that the use of pectin coating on raisin before drying resulted in better colour, flavour, and texture.

There are many published papers about the use of UOD and its effect on quality parameters of fruits and vegetables. To our best knowledge, no study has been done combining UOD process and the application of active edible coatings. Thus, the novelty of the paper is about combined application of UOD and active edible coatings with different antioxidant agents before hot air drying. Thus, the effect of such processes on physical (shrinkage, apparent and bulk densities), chemical (browning value, water activity), textural (maximum force and shrinkage), microstructure and microbial properties of dried apricot was studied.

## MATERIALS AND METHODS

### *Chemicals*

Liquid sorbitol (70 °Brix) (Foodchem, Shanghai, China) was used as osmotic solution. Low methylated amidated pectin (GRINDSTED® LA210; the degree of methoxylation = 0.44; degree of amidation = 0.18, DANISCO, Copenhagen, Denmark), ascorbic acid (Northeast Pharmaceutical, Shenyang, China) and citric acid (Union Biochemical Co., Yixing city, China) were used for the preparation of polysaccharide-based active edible coatings. Glycerol (Sigma-Aldrich, Munich, Germany) was applied as plasticizer agent.

### *Fruit sample preparation*

Fresh apricots (*Prunus armeniaca*) cultivar of Asgarabad (Harostar-HW 436) were directly taken from the Urmia (Iran) garden region and transported to the laboratory in wooden boxes. Mature fruits with average weights of 25 g and average diameters of 3 cm were selected. The apricots were

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refrigerated (Samsung refrigerator, Samsung Electronics Ltd, Seoul, South Korea) at 4 °C and 80-90 % relative humidity for maximum seven days until they were used. The initial moisture content of the fruits was 80 % (wet basis). Before each experiment, apricots were removed from the refrigerator and left for equilibrium at room temperature. They were then washed, halved, de-stoned, and cut to 1 cm<sup>3</sup> cubes by a household tool.

#### *Osmotic dehydration*

The sliced cubes (1 cm<sup>3</sup>) of fresh apricots (100 g) were immersed in sorbitol solution (35°Brix) (400 g) providing a fruit to osmotic solution ratio of 1/4 (*m/m*). Osmotic dehydration was carried out at a temperature of 55 °C for 30 and 45 min. To maintain this temperature constant the glass beaker containing apricot cubes immersed in the osmotic solution was placed in a water bath kept at 55 °C. The process temperature was controlled by a thermometer during osmosis. Using high OD temperature ensured the inactivation of polyphenol oxidase enzyme (PPO) as confirmed by Cheng *et al.* (12). Short treatment times below 45 min also limit solute uptake by fruit samples due to the fact that "water loss" to "solid gain" ratio stays high at the early stages of the process (13,14). OD-treated apricot cubes were removed from the sorbitol solution and their excess liquid was taken using an absorbent paper.

#### *Ultrasound assisted osmotic dehydration*

Fresh apricot cubes at the conditions mentioned above for OD treatment were subjected to power ultrasound using a 1.71 kW ultrasound processor probe (VC 1710, BANDELIN SONOPULS, Darmstadt, Germany) with an ultrasound intensity of 4.3 W/g. The probe was put in the centre of a glass beaker containing sorbitol solution and apricot cubes at the height of 25 mm from the base of the container. Two levels of 25 and 35 kHz ultrasonic frequencies were applied for 30 and 45 min. To avoid temperature fluctuation during ultrasound processing ice packs were placed around the glass beaker containing samples and the process temperature was controlled by a thermometer. Osmotic solution was stirred every 2 min by a glass agitator to ensure a homogenous osmotic treatment. The fruits were removed from the sorbitol solution, and the excess osmotic solution was removed through an absorbent paper.

#### *Active coating application*

Following OD or UOD treatments, apricot samples were coated using a solution of low methylated amidated pectin (2 %) prepared according to the method explained by Garcia *et al.* (10). For this purpose, 0.2 g glycerol (as plasticizer) and 2 g citric acid (CA) or ascorbic acid (AA) (as

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antioxidants) were added to every 100 mL of pectin solution. Apricot cubes were dipped in pectin, pectin + CA or pectin + AA solutions for 10 min, followed by rinsing and removing their excess coating liquid, and hot-air drying.

#### *Convective hot air drying*

Apricot cubes were dried using a laboratory convective tray-dryer (Armfield Ltd., Hampshire, UK) with a total capacity of ca. 3 kg (wet solids) using four sample trays, which were suspending from a digital balance mounted on the dryer top. The dryer was previously heated to the set-point temperature for about 30 min and then loaded with 0.4 kg (2 kg/m<sup>2</sup>) pre-treated and coated apricot cubes. Drying was performed at a temperature of 60 °C with an air velocity of 1.5 m/s. Changes of the samples mass during drying were continuously recorded until a final moisture content of 19-20 % (wet basis) was reached (15).

#### *Moisture content measurement*

The moisture content was estimated by vacuum drying (vacuum oven, Vacutherm VT6025, Thermo Fisher Scientific Inc., Branchburg, NJ, USA) at 60 °C until a constant weight was reached (16).

#### *Soluble solids measurement*

The total soluble solids of the liquid phase of the fruit ( $Z_s$ , in g soluble solids per g fruit liquid phase) were estimated by a refractometer (ATAGO, Pal ALFA, Tokyo, Japan). For fresh apricot, the liquid phase was directly obtained by pressing the fruit. In the case of the dried fruit, a controlled amount of distilled water (ca. 20 g) was added to each sample and the mix was homogenized to obtain the liquid phase, which was directly measured in the refractometer. The soluble solid content of the dried fruit was obtained by using Eqs. 1 and 2:

$$Z_s = \frac{X_s}{X_s + X_w} \quad /1/$$

$$X_s = (m_d \cdot X_{wd} + m_w) \text{Brix} / (100 - \text{Brix}) m_d \quad /2/$$

where  $Z_s$  is the soluble solids mass fraction (in g soluble solids per g fruit liquid phase) referred to the fruit liquid phase,  $X_s$  is the soluble solids mass fraction (in g soluble solids per g fruit),  $X_w$  is a mass fraction of water,  $m_d$  and  $m_w$  are the mass of the dried fruit and the added water used on the analysis, respectively, and  $X_{wd}$  is the water content of the dried fruit.

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### *Measurement of water activity*

A hygrometer (NOVASINA, Lab Master, Lachen, Swiss; 0.003 accuracy) was applied to determine water activity of samples after calibration by  $K_2SO_4$  standard solution ( $a_w = 0.972$ ).

### *Determination of shrinkage, apparent and bulk densities*

Shrinkage ( $\Phi$ ) of samples was estimated by measuring the volume of apricot samples before and after drying. For this purpose, five apricot cubes were selected randomly, and their volume was measured by toluene displacement method. Shrinkage and apparent density ( $\rho_a$ ) of samples were calculated according to Eqs. 3 and 4, respectively.

$$\Phi = \frac{V_0 - V}{V_0} \times 100 \quad /3/$$

$$\rho_a = \frac{m}{V} \quad /4/$$

where  $\Phi$  is shrinkage (%),  $V_0$  and  $V$  are the initial and final volumes of apricot ( $cm^3$ ), respectively,  $\rho_a$  is the apparent density ( $g/cm^3$ ), and  $m$  is the apricot mass (g).

Bulk density ( $\rho_b$ ) was calculated according to Eq. 5, which is a function of mass fraction of water in samples:

$$\rho_b = \frac{1}{\frac{X_w}{1000} + \frac{1-X_w}{1590}} \quad /5/$$

where  $\rho_b$  ( $g/cm^3$ ) is the bulk density and  $X_w$  is the mass fraction of water (g/g).

### *Determination of rehydration capacity*

To measure rehydration capacity (RC), dried samples were weighed and then were placed in a glass beaker containing 150 mL distilled water at room temperature for 6 h. Samples were then removed from the distilled water and placed on a paper tissue to eliminate residual water before weighing. Rehydration capacity was calculated according to Eq. 6 (17):

$$RC = \frac{m}{m_0} \quad /6/$$

where  $RC$  is rehydration capacity,  $m_0$  and  $m$  are the initial and final mass of samples (g), respectively.

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### *Measurement of browning value*

Apricot samples firstly were rehydrated in distilled water, and then rehydration water was clarified by centrifugation at 3200 ×g for 10 min. The supernatant was diluted with an equal volume of 95 % ethanol and centrifuged again at 3200 ×g for 10 min. The browning value of the clear extracts was determined in quartz cell using a UV-visible spectrophotometer (Thermo Electron Corporation, Rosemount, MS, USA) at an absorbance of 420 nm (5).

### *Texture analysis*

A Texture Analyzer (H5KS-Hounsfield, Redhill, England) was used to measure the maximum tolerable force, which is related to the firmness of the dried apricots. The test parameters were set to a pre-test speed of 0.1 cm/s, test speed of 0.2 cm/s, distance of 0.3 cm using cylindrical puncture flat-head probe with a diameter of 0.2 cm (18).

### *Microstructure analysis*

A scanning electron microscope (XL-30; Philips, Amsterdam, The Netherlands) was used to analyse the microstructural changes after OD and UOD pre-treatments. SEM images of freeze-dried samples were obtained after coating of sample strips (thickness of 0.1 cm) with a very thin layer of gold under high vacuum (19).

### *Microbiological analysis*

For all microbiological counts, 10 g of sample was aseptically weighed and transferred into 90 mL ringer solution and homogenized. A dilution series of each sample was prepared from  $10^{-1}$  to  $10^{-6}$ . The total number of mesophilic aerobic microorganisms, yeasts, and moulds were estimated by PCA (Merck KGaA, 64271, Darmstadt, Germany) and YGC (Merck KGaA, 64271, Darmstadt, Germany) agars, respectively. The PCA plates were incubated at 35 °C for two days, whereas YGC plates were incubated at 25 °C for five days. The results of all counts were recorded as the mean value of three parallels (2).

### *Experimental design and statistical analysis*

In this study, a set of 3.2.3 factorial experiments in a completely randomized way with three replicates were applied. Two ultrasound frequency levels (25 and 35 kHz), Two immersion duration (30 and 45 min), and three edible coatings (pectin + CA, pectin + AA, and only pectin) were used.

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Physical properties including shrinkage, apparent and bulk densities, texture, microstructure, water activity, microbial load, and browning value were studied. The data obtained from experiments were analysed using Design-Expert software (Version 6.0.1, Stat-Ease Inc., Minneapolis, MN, USA) (20). To evaluate the difference between mean values of responses, Duncan's multiple range test was performed, and significant differences were defined at  $p < 0.05$ . The Pearson correlation test was also used to determine any correlations among responses.

## RESULTS AND DISCUSSION

### *Hot-air drying curves*

The variation in moisture content of apricot cubes during hot-air drying is shown in Fig. 1. The moisture content of in fresh apricot was decreased from 4.0 kg/kg to an average of 3.4 kg/kg for OD-treated samples. UOD(25) at both temperatures reduced the moisture content to 2.8 kg/kg, while UOD(35)-T45 showed the highest moisture decline (2.3 kg/kg dry solids) in dry matter. Control sample required a drying time of 9 h to reach a constant moisture content of 0.2 kg/kg dry solids, while it was 8 and 7 h for OD-T(35) and OD-T(45) treatments, respectively. Drying times were 6 h for UOD(25) and 5 h for UOD(35) samples at both temperatures. The higher rate of moisture loss for UOD samples was due to the effect of power ultrasound in the formation of fractures and micro-channels in the apricot tissue, which enhances drying rate and decreases drying time (7).

### *Browning value*

Fig. 2 represents the effect of OD, UOD, and the use of different pectin-based coatings on the browning values of hot air-dried apricots. Application of pectin and pectin + CA coatings followed by OD treatment reduced browning values in the hot-air dried samples. This can be explained through the effect of OD treatment on inactivation of PPO (21) and the effect of active coatings in inhibition of oxidation during hot air-drying. We specifically show that pectin + CA coating have an effective role on browning inhibition in OD-treated samples. Moreover, no significant differences ( $p > 0.05$ ) was observed between browning value of OD samples that coated with either pectin or pectin + AA. Browning values of UOD-treated samples was higher than OD-treated samples. This may be attributed to the effect of power ultrasound in the breakdown of cell walls leading to possible exposure of amino acids and sugars that can participate in Maillard reaction during drying. For this reason, increasing ultrasound frequency from 25 to 35 kHz increased browning value in UOD samples. Moreover, UOD samples with pectin + AA coating showed higher browning values compared to pectin



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+ CA and pectin alone coatings. Oxidation of L-ascorbic acid to L-dehydroascorbic acid and its participation in Maillard reaction during drying can play a role here (22).

Fig. 3. demonstrates photograph images concerning browning behaviour of OD and UOD samples coated with different coatings compared to control. OD-treated samples for 30 min or 45 min showed similar browning effect. Likewise, OD samples coated with either pectin or pectin + AA had comparable browning behaviour. However, OD-T45 samples coated with pectin + CA showed better colour preservation and decreased browning. Also, UOD (35 kHz) treated for 30 min or 45 min with pectin + AA coating showed the highest browning effect. The lowest browning belonged to UOD samples with pectin + CA coating treated for 30 min. These observations confirmed results presented in Fig. 2.

### *Firmness*

Fig. 4 shows firmness results of dried apricot samples expressed as  $F_{max}$  values for OD, UOD, and coating (pectin, pectin + CA, and pectin + AA) treated samples. OD-treated coated samples had higher firmness values than control. The results showed that the composition of active coatings significantly ( $p < 0.05$ ) affected  $F_{max}$  values. There was no significant ( $p < 0.05$ ) differences between  $F_{max}$  of control and the OD-coated with only pectin sample. However, pectin + CA or pectin + AA coatings exhibited higher  $F_{max}$  values compared to pectin only coating and control samples. This is possibly due to the acidic conditions in pectin coatings containing CA or AA, which influenced the firmness values of these samples. Ben-Shalom *et al.* (23) studied the effect of acidification following blanching on the firmness of the carrot tissue. Blanching the carrot tissue at pH = 6.2 caused a significant reduction (about 70 %) in the firmness of the carrot tissue. Acidifying and blanching the tissue at pH = 4.4 increased (about 50 %) the firmness, as compared with blanching the tissue at pH = 6.2. Our results also show that pectin + CA coated OD samples had significantly ( $p < 0.05$ ) higher firmness values than that of pectin + AA coating. OD treatment combined with power ultrasound (UOD) led to the firmness decline in these samples. There are two explanations here:

(1) Fractures and micro-channels, which is formed through power ultrasound cavitation effect in the apricot tissue, results in a decrease of maximum force. These structural changes are seen well in SEM images (Figs. 5G-I). Increase of ultrasound frequency from 25 kHz to 35 kHz led to a significant ( $p < 0.05$ ) decrease in  $F_{max}$  values of UOD samples. As is seen in Fig. 5, larger cavities and fractures were formed in UOD samples in the frequency of 35 kHz. Shamaei *et al.* (18) also reported a decrease of  $F_{max}$  values in air-dried samples by increasing ultrasound frequency from 35 to 130 kHz in UOD pre-treatment of cranberries.

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(2) UOD pre-treatment of apricot in sorbitol solutions at 55 °C resulted in more destruction of pectin inside apricot tissue, which causes softer texture for these samples. Xu *et al.* (24) reported that the simultaneous application of heat (60 °C) and power ultrasound on grapefruit skin facilitated the extraction of pectin and induced more destruction and depolymerization of pectin molecules. Liu *et al.* (25) also reported that application of power ultrasound on citrus pectin decreased the molecular weight of the pectin immediately after pre-treatment with ultrasound waves.

### *Microstructural analysis*

SEM images of dried apricots are shown in Fig. 5. SEM image of dried apricot with no pre-treatment (control) showed destruction in cell walls and structure collapse in apricot tissue. This observation is similar to the reported microstructure of dried Rabbiteye blueberries, which dried without any retreatment (26). SEM images of OD samples showed swollen inner tissue compared to that of control. Sponge-like tissue formed by cavities, fractures, and microchannels were observed in the SEM images of UOD pre-treated samples. Fernandes & Rodrigues (27) found that using ultrasound before drying of pineapple caused more destruction to cellular structure and created microchannels in the internal tissue of pineapple. Garcia-Noguera *et al.* (19) reported that observed changes in the texture of strawberry after application of UOD was due to the cavitation and the effects of induced osmotic pressure generated by ultrasound waves. Stojanovic & Silva (26) reported an extensive collapse in the external surface and cavities which were distributed uniformly in the internal tissue of the pre-treated berries by UOD. As is seen in the SEM images in Fig. 5, increasing ultrasound frequency from 25 kHz to 35 kHz created large cavities in the internal tissue of apricot, which was non-uniformly distributed. More destruction of inner tissue concurrent with the formation of more micro-channels and large cavities have been reported by Shamaei *et al.* (18) when the frequency of ultrasound increased from 35 to 130 kHz during UOD retreatment of cranberry. Obtained SEM images showed that pectin coatings with different composition did not affect the microstructure of both OD and UOD pre-treated apricot samples. Garcia *et al.* (10) used TEM imaging to study the microstructure of coated and non-coated dried papaya and reported that the coating itself did not protect tissue structure changes during drying.

### *Measurement of rehydration capacity*

Fig. 6 shows rehydration capacity of OD and UOD pre-treated samples coated by pectin, pectin + CA and pectin + AA coatings. OD pre-treated coated samples had slightly higher RC compared to control. Although this difference is not significant ( $p > 0.05$ ). Higher RC can be attributed

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to open internal tissue structure of OD samples, as can also be seen in SEM images (Fig. 5). Erba *et al.* (28) showed that the use of sugar alcohols such as sorbitol as the osmotic solution in pre-treatment of fruits could lead to products with good rehydration properties, which can be used in bakery products and ice creams. Application of power ultrasound in UOD samples produced dried apricots with significantly ( $p < 0.05$ ) higher RC compared to those of OD and control samples. This can be explained by fractures, cavities, and microchannel that is created in apricot tissue during UOD pre-treatment (can also be seen in Fig. 5). Increasing ultrasound frequency waves from 25 to 35 kHz had no significant ( $p > 0.05$ ) effect on the rehydration capacity of UOD pre-treated samples. We also show that the coating of OD and UOD pre-treated apricots by different pectin coatings affected the RC of samples. RC of both OD and UOD treated samples coated with pectin + CA was significantly ( $p < 0.05$ ) lower than that of coated with pectin + AA. These findings are in agreement with those reported by Doymaz (29).

Table 1 compares apparent and bulk densities, and shrinkage values of control sample with those of OD and UOD pre-treated apricots, which are differently coated. Control had the lowest apparent and bulk densities the highest shrinkage compared to those of OD and UOD pre-treated samples. Application of OD before drying resulted in a significant ( $p < 0.05$ ) increase in bulk and apparent densities. These results are consistent with earlier studies reported the effect of OD of apple slices in increasing the bulk density of hot air-dried apples (30,31). Udomkun *et al.* (32) reported that osmotic treatment of papaya slices before freeze-drying increased apparent density and solid density of freeze-dried papaya. Shrinkage decreased in OD pre-treated coated samples compared to control. This is attributed to the filling of spaces between cells by soluble solids of the osmotic solution and reducing any structure collapse in apricot tissue (33). SEM images in Fig. 5 display extensive swollen internal tissue in osmotically pre-treated samples that can prevent shrinkage of samples during hot air drying. Reppa *et al.* (34) found that osmotic pre-treatment of apple slices decreases the shrinkage of dried samples, and there is a direct relationship between the reduction of shrinkage and mass transfer of soluble solid from osmotic solution to fruit tissue. As can be seen in Table 1, UOD pre-treatment significantly ( $p < 0.05$ ) reduced shrinkage and increased apparent and bulk densities of dried apricots. The created cavities and micro-channels in fruit tissue of UOD pre-treated samples (Fig. 5) facilitate penetration of soluble solids from osmotic solution into tissue during UOD pre-treatment. Moreover, these structural changes enhance drying speed, and therefore, decrease the shrinkage of UOD pre-treated samples during hot air-drying. This effect was even more enhanced when ultrasound frequency increased from 25 to 35 kHz. Stojanovic & Silva (26) reported an increase in the bulk density of UOD pre-treated Rabbiteye blueberries. UOD pre-treated samples in frequency of 35 kHz for 45 min had the lowest shrinkage and the highest apparent density. Samples with higher bulk density had higher rehydration capacity and lower shrinkage.

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Table 2 shows the average values of water and soluble solid contents for the fresh and pre-treated dried apricot samples. The initial water mass fraction declined from 82 to 21-27 g/100 g fruit in pre-treated dried apricot. Therefore, the soluble solid content increased from 18 to around 79-73 g/100 g fruit liquid phase in these samples. The amount of water activity was 0.929 in fresh samples, which decreased to 0.628 in non-pretreated dried apricot. Sugar content increase due to osmotic dehydration pre-treatment (with or without ultrasound) affects water activity in the pre-treated dried apricot. Water activity was within the range of 0.547-0.560 in OD pre-treated coated samples. Created cavities and microchannels in UOD pre-treated apricot tissue, as is seen in SEM images (Fig. 5), increased sugar gain during UOD pre-treatment in addition to accelerating water loss. As is seen in Table 2, increasing the mass fraction of soluble solid from 0.641-0.644 in OD pre-treated samples to 0.672-0.724 in UOD pre-treated ones proved sugar content gain in UOD pre-treated samples. This matter significantly affected water activity in these samples as the amount of water activity in UOD pre-treated samples is less than that of OD pre-treated ones. Kowalski *et al.* (35) reported that ultrasound-assisted osmotic dehydration of cherry created lower water activity in intermittent dried cherries. Also, an increase of ultrasound frequency from 25 to 35 kHz, significantly ( $p < 0.05$ ) increased mass fraction of soluble solid in these samples and led to significant ( $p < 0.05$ ) reduction in water activity of UOD pre-treated apricot. The water activity of UOD pre-treated coated apricots was 0.546-0.522. UOD pre-treated samples in the frequency of 35 kHz had the lowest water activity among UOD pre-treated samples. Shamaei *et al.* (18) indicated that increasing ultrasound frequency from 35 to 130 kHz in ultrasound-assisted osmotic dehydration of cranberry decreased water activity of the dried cranberries. Statistical analysis indicated that coatings and their compositions did not have any significant ( $p > 0.05$ ) effects on water activity of dried apricot. Immersion duration in both OD and UOD pre-treated samples did not change dried samples water activity significantly.

Table 3 demonstrates the microbial load of non-pretreated and OD/UOD/coating treated air-dried apricots. The number of total mesophilic aerobic count and total yeast and mould count in non-pretreated air dried apricot was measured  $11.5 \times 10^1$  and  $4.0 \times 10^1$  CFU/g, respectively. As is seen in Table 3, the number of total mesophilic aerobic count and yeast and mould counts reduced significantly ( $p < 0.05$ ) in OD pre-treated coated dried apricot. This reduction can be attributed to a reduced water activity of these samples (Table 2). As is known, in water activity less than 0.6, activities of bacteria, moulds, and yeasts are almost decreased (8,35). Water activity was 0.629 in control sample, which was reduced to 0.547-0.560 in OD pre-treated coated samples. Indeed, this reduction provided a substantial decrease in the microbial load of OD pre-treated coated dried apricot. Also, the evaluation of microbial load in UOD pre-treated coated dried apricot indicated that UOD pre-treatment had a positive effect in microbial load reduction in these samples compared to OD pre-treated ones. The number of total mesophilic aerobic count decreased 0.29-0.52 log cycles in the UOD pre-treated

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coated dried samples compared to the control. Villalobos *et al.* (36) reported that UOD pre-treated figs indicated the lowest microbial load compared to traditional dried samples. UOD pre-treated apricot samples in the frequency of 35 kHz for 45 min had the lowest total mesophilic aerobic count and total yeast and mould count number. There was no significant ( $p < 0.05$ ) difference between the microbial load of OD or UOD pre-treated coated dried apricot by pectin, pectin + CA and pectin + AA coatings.

## CONCLUSIONS

The application of UOD pre-treatment in sorbitol solutions before hot air-drying of apricot results in improvement of physical properties such as shrinkage, apparent density, bulk density, rehydration capacity, and texture of the dried apricot. When ultrasound frequency increased from 25 to 35 kHz, firmness decreased, and rehydration capacity increased. While pre-treatment of apricot samples through the UOD process increased browning value in air-dried apricot, OD process resulted in better colour preservation. Upon increasing ultrasound frequency from 25 to 35 kHz, discoloration increased in UOD pre-treated samples. Coating of both OD and UOD pre-treated samples by pectin + CA coatings increased firmness and declined rehydration capacity. Application of UOD pre-treatment led to water activity and microbial load reduction.

## CONFLICT OF INTEREST

This research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest. The authors declare no conflict of interest.

## AUTHOR CONTRIBUTION

R. Sakoei-Vayghan performed sample synthesis, analysis and collected test data and drafted the manuscript. S.H. Peighambardoust designed and supervised the research, interpreted the results and revised the manuscript critically. J. Hesari contributed in analysing and interpreting the results and discussions. M. Soltanzadeh assisted in interpreting results, improving English grammar and fluency and in the revised manuscript. D. Peressini assisted in analysing and interpreting the results in final format reading, and improved English grammar. All authors approved the final version of the manuscript and agreed to be accountable for all aspects of the work.

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Table 1. Variation of bulk and apparent densities, and shrinkage\* in non-treated (control) and air-dried apricot by different pre-treatment: osmotic dehydration (OD) for 30 and 45 min, ultrasound-assisted osmotic dehydration (UOD) at 25 and 35 kHz for 30 and 45 min, and application of pectin, pectin + CA, and pectin + AA coatings.

Pre-treatments	$\rho_b$ (bulk density)/(g/cm <sup>3</sup> )	$\rho_a$ (apparent density)/(g/cm <sup>3</sup> )	$\Phi$ (shrinkage)/%
Dried, non-treated (control)	(1.358±0.000) <sup>g</sup>	(1.260±0.000) <sup>g</sup>	(84.5±0.87) <sup>f</sup>
OD-T30-Coated (P+CA)	(1.368±0.002) <sup>f</sup>	(1.266±0.002) <sup>efg</sup>	(83.2±0.09) <sup>ef</sup>
OD-T30-Coated (P+AA)	(1.366±0.000) <sup>f</sup>	(1.262±0.004) <sup>fg</sup>	(83.1±0.20) <sup>ef</sup>
OD-T30-Coated (P)	(1.366±0.000) <sup>f</sup>	(1.259±0.003) <sup>g</sup>	(83.0±0.53) <sup>ef</sup>
OD-T45-Coated (P+CA)	(1.367±0.000) <sup>f</sup>	(1.268±0.002) <sup>defg</sup>	(80.4±0.68) <sup>abcd</sup>
OD-T45-Coated (P+AA)	(1.367±0.000) <sup>f</sup>	(1.268±0.000) <sup>defg</sup>	(81.1±0.26) <sup>bcde</sup>
OD-T45-Coated (P)	(1.367±0.000) <sup>f</sup>	(1.268±0.001) <sup>defg</sup>	(81.3±0.97) <sup>cde</sup>
UOD(25)-T30-Coated (P+CA)	(1.405±0.000) <sup>d</sup>	(1.279±0.002) <sup>bcdef</sup>	(82.4±1.62) <sup>de</sup>
UOD(25)-T30-Coated (P+ AA)	(1.399±0.020) <sup>e</sup>	(1.273±0.002) <sup>cdefg</sup>	(81.5±0.69) <sup>cde</sup>
UOD(25)-T30-Coated (P)	(1.403±0.000) <sup>cd</sup>	(1.279±0.003) <sup>bcdef</sup>	(81.8±0.52) <sup>cde</sup>
UOD(25)-T45-Coated (P+CA)	(1.404±0.002) <sup>bcd</sup>	(1.283±0.001) <sup>bcde</sup>	(79.9±1.91) <sup>abc</sup>
UOD(25)-T45-Coated (P+AA)	(1.402±0.002) <sup>d</sup>	(1.283±0.000) <sup>bcde</sup>	(81.2±0.10) <sup>cde</sup>
UOD(25)-T45-Coated (P)	(1.405±0.000) <sup>abcd</sup>	(1.286±0.007) <sup>abc</sup>	(81.0±0.29) <sup>bcde</sup>
UOD(35)-T30-Coated (P+CA)	(1.404±0.001) <sup>bcd</sup>	(1.283±0.004) <sup>bcde</sup>	(81.6±0.53) <sup>cde</sup>
UOD(35)-T30-Coated (P+AA)	(1.405±0.002) <sup>abcd</sup>	(1.284±0.003) <sup>abcd</sup>	(80.6±0.77) <sup>abcd</sup>
UOD(35)-T30-Coated (P)	(1.405±0.002) <sup>abcd</sup>	(1.284±0.009) <sup>bcd</sup>	(80.6±0.78) <sup>abcd</sup>
UOD(35)-T45-Coated (P+CA)	(1.407±0.000) <sup>a</sup>	(1.301±0.013) <sup>a</sup>	(79.0±0.96) <sup>ab</sup>
UOD(35)-T45-Coated (P+AA)	(1.407±0.000) <sup>ab</sup>	(1.296±0.006) <sup>ab</sup>	(79.0±1.28) <sup>ab</sup>
UOD(35)-T45-Coated (P)	(1.406±0.000) <sup>abc</sup>	(1.291±0.006) <sup>ab</sup>	(78.7±1.17) <sup>a</sup>

\*Data are mean of triplicate measurements ± standard deviation. Different letters in each column correspond to significant ( $p < 0.05$ ) differences between means.

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Table 2. Variation of the mass fraction of soluble solids ( $X_s$ ), mass fraction of water ( $X_w$ ) and water activity\* ( $a_w$ ) in non-treated (control) and air-dried apricot by different pre-treatment: osmotic dehydration (OD) for 30 and 45 min, ultrasound-assisted osmotic dehydration (UOD) at 25 and 35 kHz for 30 and 45 min, and application of pectin, pectin + CA, and pectin + AA coatings.

Pre-treatments	$X_s$ (soluble solids mass/fruit mass)/(g/g)	$X_w$ (water mass/fruit mass)/(g/g)	$a_w$ (water activity)
Fresh apricot	(0.186±0.002) <sup>k</sup>	(0.824±0.000) <sup>a</sup>	(0.929±0.003) <sup>e</sup>
Dried (No pre-treatment)	(0.622±0.000) <sup>i</sup>	(0.294±0.000) <sup>b</sup>	(0.628±0.004) <sup>d</sup>
OD-T30-Coated (P+CA)	(0.641±0.001) <sup>h</sup>	(0.275±0.002) <sup>c</sup>	(0.548±0.000) <sup>b</sup>
OD-T30-Coated (P+AA)	(0.642±0.001) <sup>h</sup>	(0.278±0.000) <sup>c</sup>	(0.561±0.003) <sup>c</sup>
OD-T30-Coated (P)	(0.642±0.000) <sup>h</sup>	(0.278±0.000) <sup>c</sup>	(0.549±0.002) <sup>b</sup>
OD-T45-Coated (P+CA)	(0.643±0.000) <sup>h</sup>	(0.277±0.000) <sup>c</sup>	(0.547±0.001) <sup>b</sup>
OD-T45-Coated (P+AA)	(0.644±0.001) <sup>h</sup>	(0.276±0.000) <sup>c</sup>	(0.548±0.000) <sup>b</sup>
OD-T45-Coated (P)	(0.643±0.000) <sup>h</sup>	(0.277±0.000) <sup>c</sup>	(0.549±0.005) <sup>b</sup>
UOD(25)-T30-Coated (P+CA)	(0.672±0.007) <sup>g</sup>	(0.227±0.007) <sup>e</sup>	(0.531±0.001) <sup>a</sup>
UOD(25)-T30-Coated (P+ AA)	(0.681±0.003) <sup>f</sup>	(0.232±0.003) <sup>d</sup>	(0.546±0.001) <sup>b</sup>
UOD(25)-T30-Coated (P)	(0.682±0.002) <sup>f</sup>	(0.226±0.002) <sup>ef</sup>	(0.541±0.002) <sup>b</sup>
UOD(25)-T45-Coated (P+CA)	(0.703±0.006) <sup>de</sup>	(0.225±0.006) <sup>ef</sup>	(0.540±0.002) <sup>b</sup>
UOD(25)-T45-Coated (P+AA)	(0.698±0.007) <sup>e</sup>	(0.227±0.007) <sup>e</sup>	(0.542±0.003) <sup>b</sup>
UOD(25)-T45-Coated (P)	(0.695±0.009) <sup>e</sup>	(0.223±0.010) <sup>efg</sup>	(0.542±0.005) <sup>b</sup>
UOD(35)-T30-Coated (P+CA)	(0.716±0.007) <sup>abc</sup>	(0.225±0.007) <sup>efg</sup>	(0.527±0.002) <sup>a</sup>
UOD(35)-T30-Coated (P+AA)	(0.713±0.010) <sup>bc</sup>	(0.223±0.010) <sup>efg</sup>	(0.522±0.004) <sup>a</sup>
UOD(35)-T30-Coated (P)	(0.708±0.005) <sup>cd</sup>	(0.223±0.005) <sup>efg</sup>	(0.526±0.008) <sup>a</sup>
UOD(35)-T45-Coated (P+CA)	(0.724±0.010) <sup>a</sup>	(0.220±0.000) <sup>h</sup>	(0.531±0.001) <sup>a</sup>
UOD(35)-T45-Coated (P+AA)	(0.720±0.002) <sup>ab</sup>	(0.220±0.002) <sup>gh</sup>	(0.529±0.009) <sup>a</sup>
UOD(35)-T45-Coated (P)	(0.722±0.000) <sup>a</sup>	(0.222±0.000) <sup>fgh</sup>	(0.531±0.002) <sup>a</sup>

\*Data are mean of triplicate measurements ± standard deviation. Different letters in each column correspond to significant ( $p < 0.05$ ) differences between means.

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Table 3 – Microbial load\* of in non-treated (control) and air-dried apricot by different pre-treatment: osmotic dehydration (OD) for 30 and 45 min, ultrasound-assisted osmotic dehydration (UOD) at 25 and 35 kHz for 30 and 45 min, and application of pectin, pectin + CA, and pectin + AA coatings.

Pre-treatments	Total Mesophyll Aerobic Count (CFU/g)	Total Yeasts & Moulds (CFU/g)
Dried (No pre-treatment)	(115±7) <sup>a</sup>	(40±7) <sup>a</sup>
OD-T30-Coated (P+CA)	(65±7) <sup>cde</sup>	(25±0) <sup>cd</sup>
OD-T30-Coated (P+AA)	(75±7) <sup>bc</sup>	(30±7) <sup>bc</sup>
OD-T30-Coated (P)	(85±7) <sup>b</sup>	(35±7) <sup>ab</sup>
OD-T45-Coated (P+CA)	(60±1) <sup>def</sup>	(20±0) <sup>de</sup>
OD-T45-Coated (P+AA)	(70±14) <sup>cd</sup>	(20±14) <sup>def</sup>
OD-T45-Coated (P)	(75±7) <sup>bc</sup>	(20±7) <sup>de</sup>
UOD(25)-T30-Coated (P+CA)	(50±0) <sup>fgh</sup>	(10±0) <sup>h</sup>
UOD(25)-T30-Coated (P+ AA)	(55±7) <sup>efg</sup>	(15±0) <sup>fg</sup>
UOD(25)-T30-Coated (P)	(60±0) <sup>def</sup>	(15±0) <sup>fg</sup>
UOD(25)-T45-Coated (P+CA)	(45±7) <sup>ghi</sup>	(10±7) <sup>hi</sup>
UOD(25)-T45-Coated (P+AA)	(50±0) <sup>fgh</sup>	(10±0) <sup>h</sup>
UOD(25)-T45-Coated (P)	(55±7) <sup>efg</sup>	(15±7) <sup>fgh</sup>
UOD(35)-T30-Coated (P+CA)	(40±0) <sup>hi</sup>	(0±0) <sup>j</sup>
UOD(35)-T30-Coated (P+AA)	(45±7) <sup>ghi</sup>	(0±0) <sup>j</sup>
UOD(35)-T30-Coated (P)	(50±0) <sup>fgh</sup>	(5±3.5) <sup>i</sup>
UOD(35)-T45-Coated (P+CA)	(35±7) <sup>i</sup>	(0±0) <sup>j</sup>
UOD(35)-T45-Coated (P+AA)	(40±0) <sup>hi</sup>	(0±0) <sup>j</sup>
UOD(35)-T45-Coated (P)	(50±0) <sup>fgh</sup>	(0±0) <sup>j</sup>

\*Data are mean of duplicate measurements ± standard deviation. Different letters in each column correspond to significant ( $p < 0.05$ ) differences between means.

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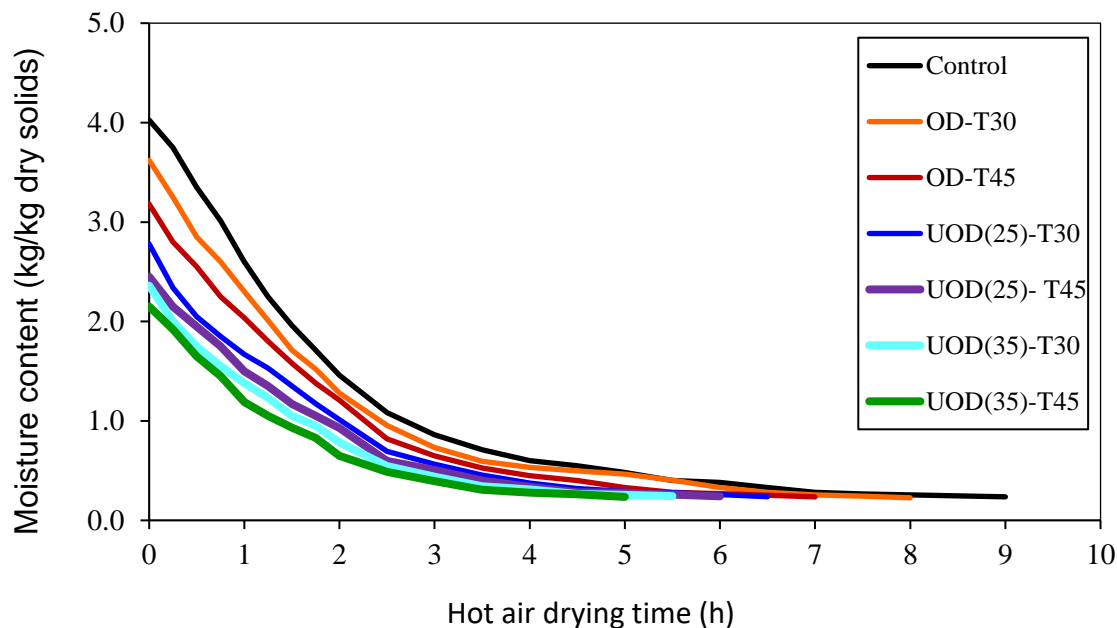


Fig. 1. Drying curves of apricot samples treated by osmotic dehydration (OD) for 30 (OD-T30) and 45 min (OD-T45); ultrasound–assisted osmotic dehydration (UOD) at frequencies of 25 [UOD(25)] and 35 kHz [UOD(35)] for 30 and 45 min.

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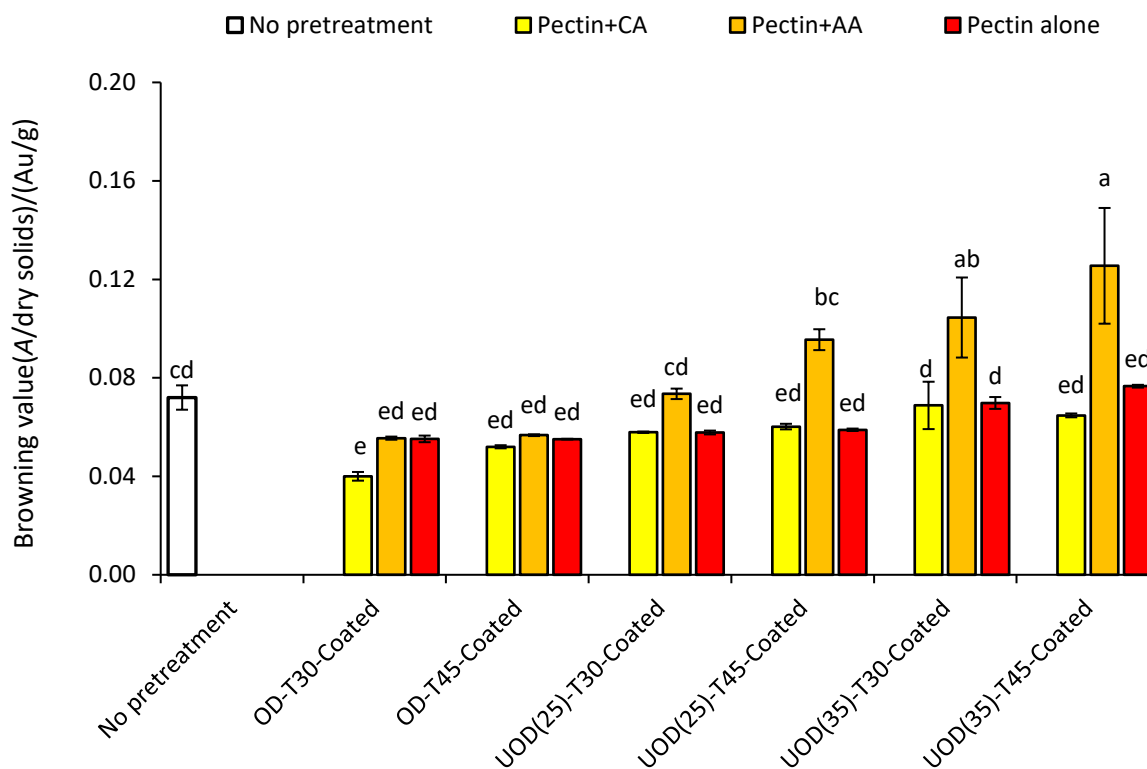


Fig. 2. Effect of different osmotic treatments (OD for 30 and 45 min, UOD at 25 and 35 kHz for 30 and 45 min), and the application of pectin, pectin + CA, and pectin + AA coatings on browning values of hot air-dried apricots. Data are mean of triplicate measurements. Error bars indicate SD values. Different letters correspond to significant ( $p < 0.05$ ) differences between means.

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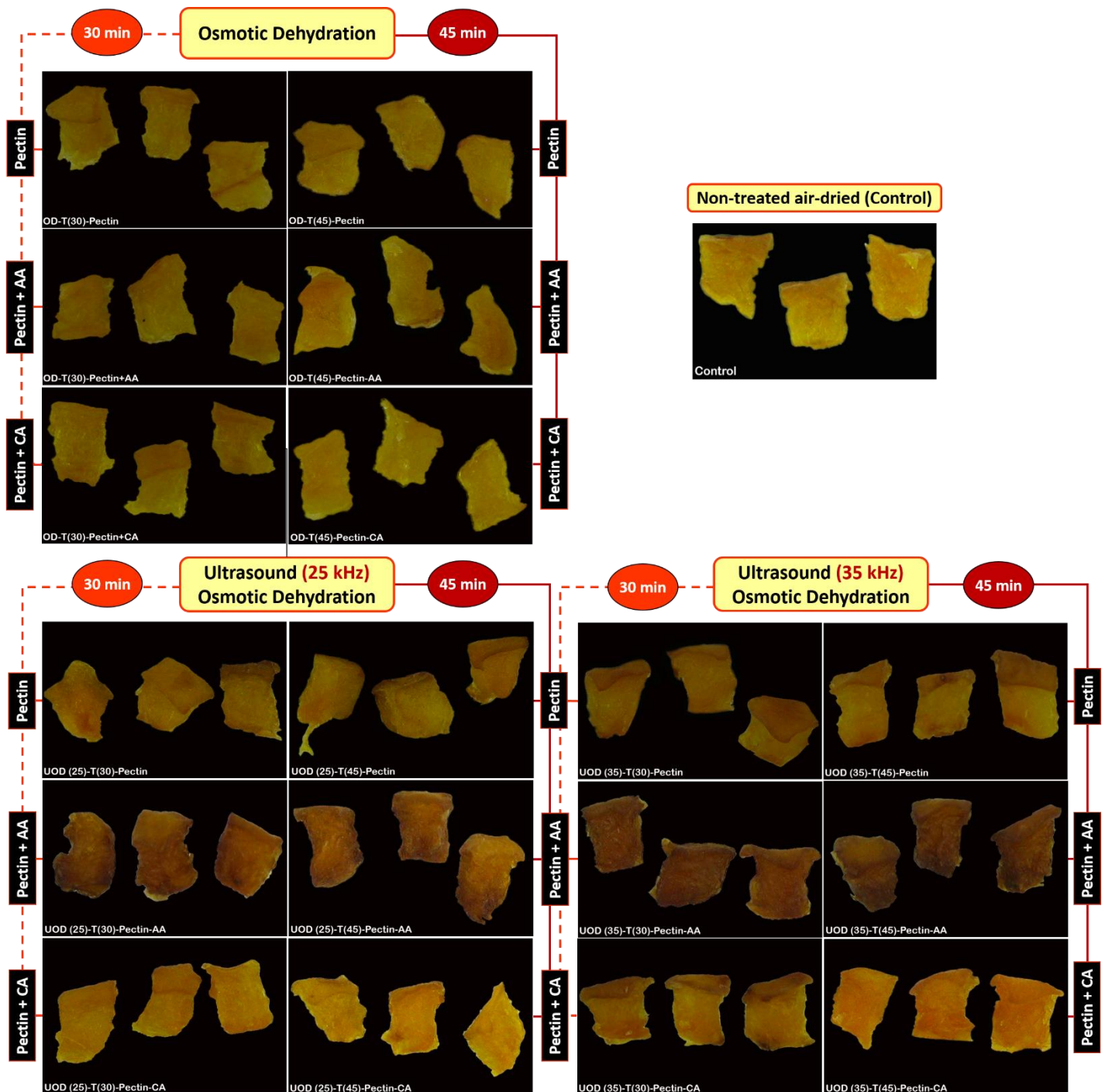


Fig. 3. Images of non-treated apricot (control) and samples treated by osmotic dehydration (OD) for T30 and T45 min, ultrasound-assisted osmotic dehydration (UOD) at frequencies of 25 and 35 kHz for T30 and T45 min, followed by the application of pectin, pectin + CA, and pectin + AA coatings.

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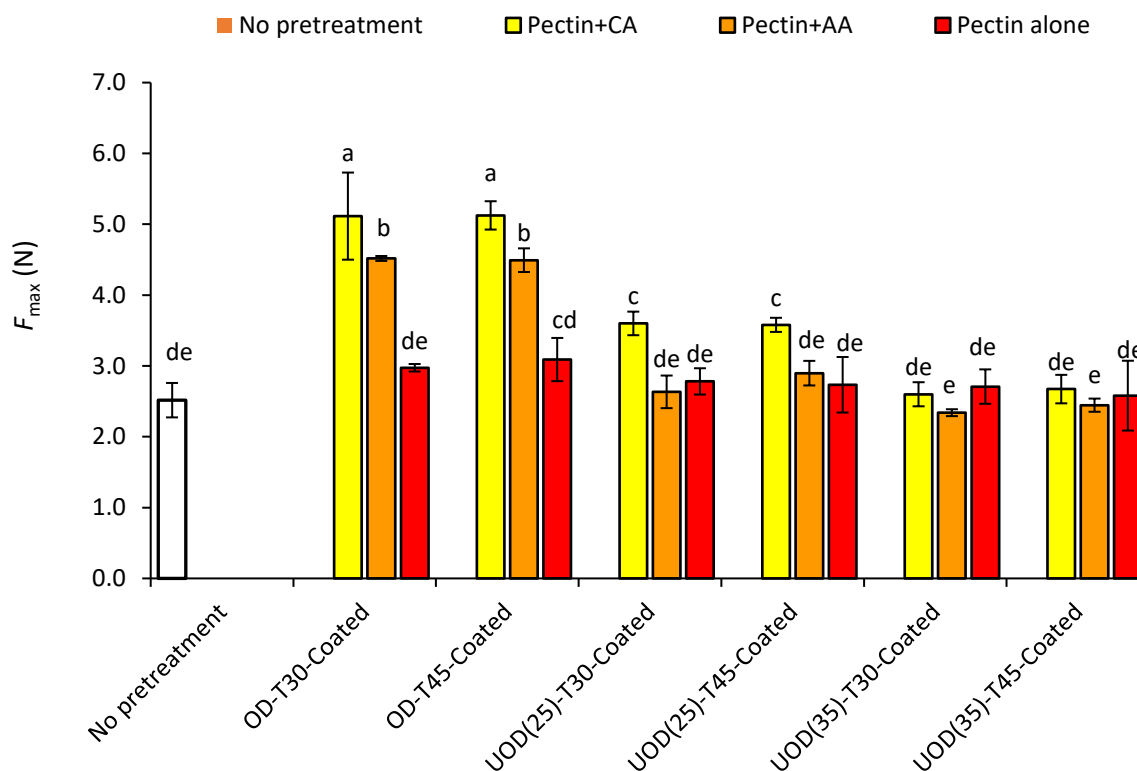
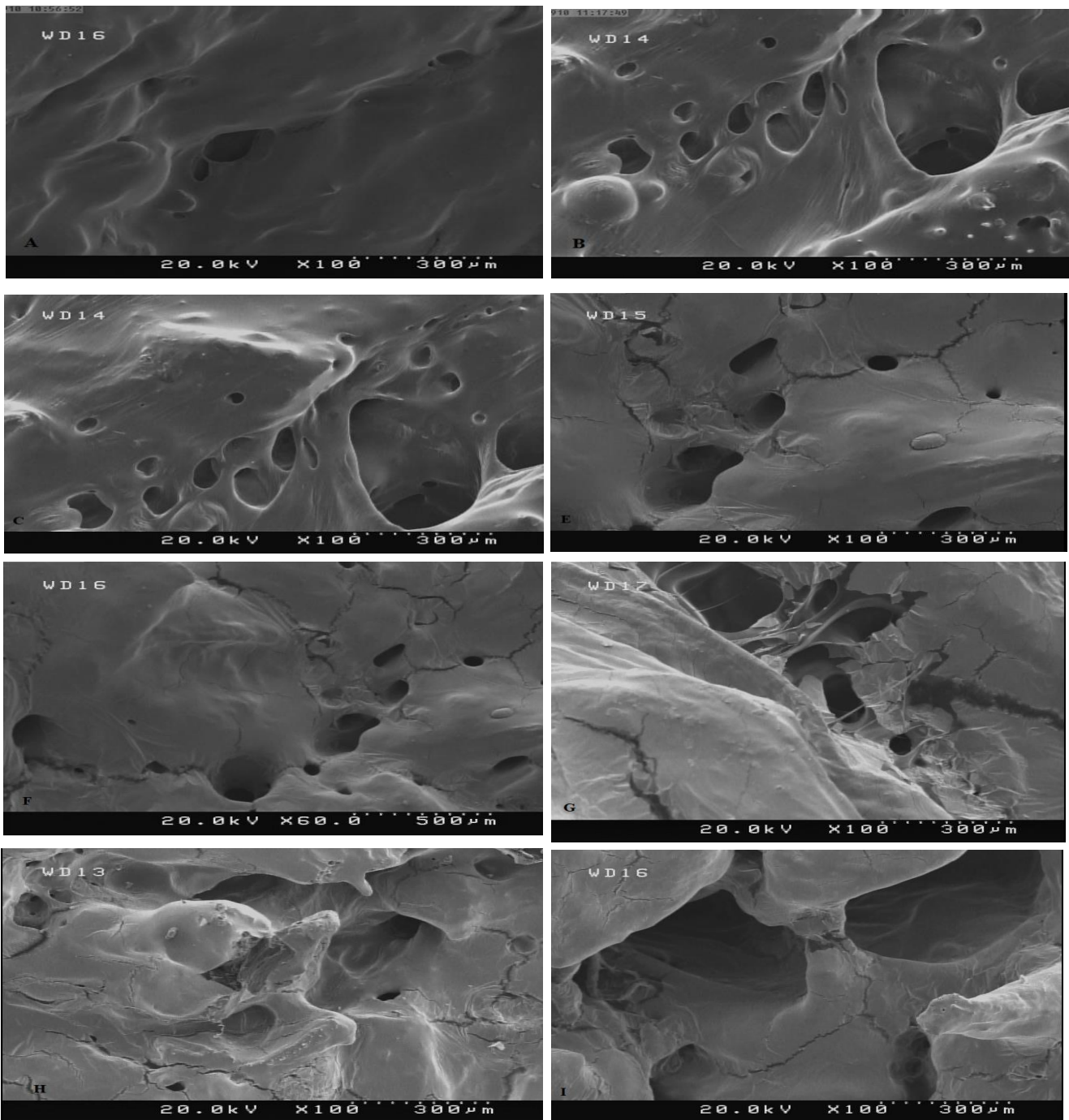


Fig. 4. Effect of different osmotic treatments (OD for 30 and 45 min, UOD at 25 and 35 kHz for 30 and 45 min), and the application of pectin, pectin + CA, and pectin + AA coatings on maximum force ( $F_{max}$ ) of hot air-dried apricots. Data are mean of triplicate measurements. Error bars indicate SD values. Different letters correspond to significant ( $p < 0.05$ ) differences between means.

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Fig. 5. Scanning electron microscopy (SEM) images of control (A), OD-treated coated by pectin+ CA (B), OD-treated coated by pectin (C), UOD-treated at 25 kHz coated by pectin + CA (E), UOD-treated at 25 kHz coated by pectin (F), UOD-treated at 35 kHz coated by pectin + CA (G), UOD-treated at 35 kHz coated by pectin+ AA (H), UOD-treated at 35 kHz coated by pectin.

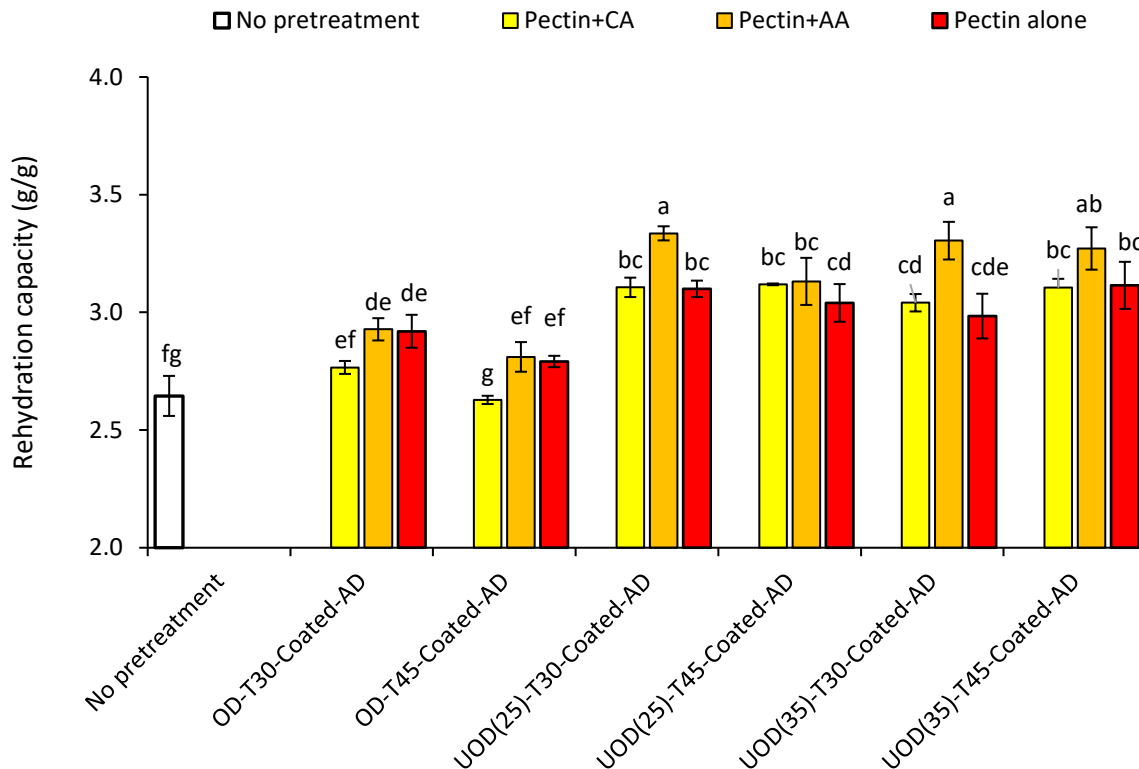


Fig. 6. Effect of different osmotic treatments (OD for 30 and 45 min, UOD at 25 and 35 kHz for 30 and 45 min), and the application of pectin, pectin + CA, and pectin + AA coatings on rehydration capacity (RC) of hot air-dried apricots. Data are mean of triplicate measurements. Error bars indicate SD values. Different letters correspond to significant ( $p < 0.05$ ) differences between means.