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Effects of osmotic pretreatment on quality and physical properties of dried quinces (*Cydonia oblonga*)

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Summary

The aim of this study was to examine the effects of osmotic pretreatment on some physical properties of quinces. Osmotic drying was performed in a saccharose and water solution. The temperatures of osmotic solution were 40 °C and 60 °C, and the initial concentrations were 50 °Bx and 65 °Bx. All four combinations were used in the experiment. High values of the total colour change ΔE^* were recorded following the treatment of quince samples with the osmotic solution of 65 °Bx. Lower values of the total colour change were recorded in the same samples after convective drying. Slighter changes in colour after convective drying were caused by a greater amount of solute retained on the surface of the fruit, forming barriers between the fruit tissue and the surrounding air. Mechanical properties of quinces during osmotic drying expressed by the force ratio $f = (F_0 - F_i)/F_0$ and modulus of elasticity showed dependence on the temperature of the osmotic solution. At 60 °C, the osmotic solution caused softening of the quince tissue. Thermal softening had a positive influence on the naturally hard quince tissue. The results of the study demonstrate positive effects of osmotic drying on physical properties and quality of dried quinces.

Keywords

quince; osmotic drying; convective drying; mechanical properties; colour

Quince fruits are usually processed into preserves, compotes, jellies, jams, juices and brandies. Quince fruits contain phenolic compounds, which contribute to sensory properties such as bitterness and astringency [1]. Astringency is one of the reasons why quinces are not consumed fresh. The fruits are also very firm due to a large presence of brachysclereids (stone cells) and a higher content of cellulose. Quinces are famous in the fruit-processing industry for their characteristic aroma and chemical composition. The osmotic dehydration process involves the partial removal of water from a given food using a hypertonic solution consisting of one or more solutes [2]. The difference in osmotic pressure obtained from the system leads to a flow of water from the food to the solution and an opposite flow of solutes from the syrup to the product, although in smaller proportions. Furthermore, a third flow of solids may take place from the food to the solution, which, although on a much smaller scale, may lead to a considerable loss of quality of the product [3].

Colour is one of the most important properties of food products. The first quality assessment of a product is based on its colour, it is the first thing a consumer notices and it can determine the acceptability of a product. Exposing fruits to high temperatures during drying may have detrimental effects on their quality [4–7]. Significant changes in colour often occur during convective drying [8]. Some authors claim that osmotic drying reduces the colour changes caused by enzymatic activities. However, osmotic drying is not efficient enough to prevent the tissue browning of certain fruit species.

Mechanical properties of products change during drying. KROKIDA et al. [9] studied mechanical properties of osmo-convectively dried bananas

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and apples. They found that osmo-convectively dried samples were more resistant to rupture than those convectively dried. These properties were explained by the more plastic structure caused by the sugar uptake during the osmotic treatment. Mechanical properties of fruits are determined by the characteristics of the cells [10]. Exposing fruits to fluids of high-temperatures causes the chemical changes that affect the structure of the fruit tissue. Water loss decreases the pressure in the cell thus decreasing the firmness of fruit tissues [11]. Microstructural changes entail the changes in cell structure, cell chemical composition, cell wall properties, cell pressure etc. Except for microstructural changes, mechanical properties are often explained on the higher structural level. Macrostructural changes involve the changes in tissue structure, tissue type, plant fibre orientation, etc. [12, 13]. Changes in the texture and structure of fruits and vegetables during processing are often explained by changes in pectin. Changes in pectin are enzymatic and chemical: enzymatic degradation by the successive demethoxylation and depolymerization by pectin methylesterase (PME) and polygalacturonase (PG), respectively, and chemical degradation via a β-elimination reaction or acid hydrolysis [14]. Many studies dealt with the research of physical properties of fruits such as colour [15–17] and mechanical properties of fruits [15, 17].

The aim of this study was to characterize the effects of osmotic drying on physical properties and quality of quinces. The changes in colour, mechanical, sensory and chemical properties of quinces were examined. The paper also provides a platform for launching a new quince product.

MATERIALS AND METHODS

The native quince variety "Leskovačka" was used in the experiment. Fruits of this variety are apple-shaped and characterized by intense aroma. Previous research showed that this variety is suitable for drying from the perspective of shape and dimension preservation [18]. Quinces were obtained from a farm in the region of Fruška gora (the Province of Vojvodina, northern Serbia). After harvesting, the fruits were stored in a refrigerator at 4 °C. All the experiments were conducted within the period of next 10 days after harvesting. The samples were pre-treated with sulfur dioxide. The amount of 1.0 g of technical sulfur (sulfur powder extra pure > 98%) per 1 kg of fruit material was used.

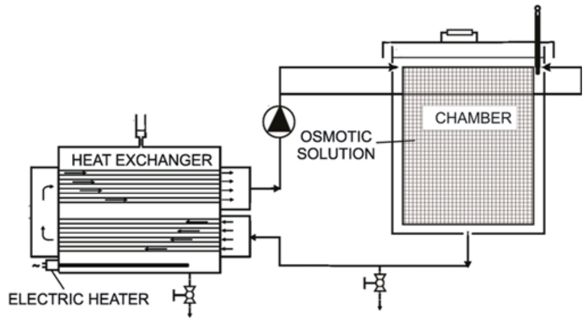

Fig. 1. Self-designed osmotic dryer.

Osmotic and convective drying

The osmotic drying was performed in a saccharose and water solution in an experimental self-designed osmotic dryer (Fig. 1) [19]. The device provided agitation of the solution. Weight ratio material : solution was higher than 1:30. The temperatures of the osmotic solution were 40 °C and 60 °C, and the initial concentrations were 50 °Bx and 65 °Bx. The combinations of these factors will be referred to as treatments in the further course of the paper, treatments being named first, second, third and fourth. Explicitely, the first, second, third and fourth treatment had the parameter combinations of 50 °Bx – 40 °C, 50 °Bx – 60 °C, 65 °Bx – 40 °C, 65 °Bx – 60 °C, respectively. The solution temperature of 60 °C was used in the experiment due to the hardness of quince fruits. The osmotic drying lasted for 180 min and it was used as pretreatment. Kinetics of osmotic drying was evaluated on samples of quince of dimensions 15 × 15 × 15 mm. The convective drying of quince sixths lasted for 23 h at a temperature of 50 °C and air velocity of 1 $m \cdot s^{-1}$. Drying was conducted in a self-designed experimental convective dryer [20]. The moisture content of fruits was determined using the standard hot air oven method keeping the fruit in the oven for 24 h at 105 °C. Solid gain (SG) was determined by measuring the mass of quince cubes before, during and after osmotic drying. SG was obtained by using the following relation:

$$SG = \frac{s_0 - s}{m_0} \quad (1)$$

where m_0 is the initial mass, s is the dry mass after time (t) of osmotic dehydration, s_0 is the initial dry mass.

Mechanical properties

The mechanical properties were examined by the compression and texture profile analysis test (TPA). The compression test was done on the cubes with the dimensions of 10 × 10 × 10 mm. Initial shape of samples used in osmotic pretreatment were sixths (sixth parts of the fruit). Five cubes were cut from the quince sixths every 20 min during osmotic drying. One piece was enough for five cubes. Sixths were used because they should be the form of the final product, dried quinces. The testing was done after the temperatures of the samples and the surroundings were equilibrated. Measurement of mechanical properties for each treatment was repeated twice.

The TMS-PRO Texture Analyzer (Food Technology Corporation, Sterling, Virginia, USA) was used for the measurement of mechanical properties. Cylindrical plate with a diameter of 40 mm was used for compression. The speed of deformation was 30 mm·min^{-1}. The rupture force represented the first peak on the force-deformation curve. Since the texture of fruits was anisotropic, the results of each treatment were expressed by the force ratio in order to minimize the biological variability.

The force ratio is formulated as follows:

$$f = \frac{F_0 - F_i}{F_0} \qquad (2)$$

where F_0 is the rupture force of fresh fruit samples, F_i is the rupture force at a certain moment of drying. It indicates the intensity of fruit tissue softening.

At interpretation of the results on the destructive force, error may be caused by the fact that the rupture force of two different samples may be the same for different values of deformation.

Modulus of elasticity in the field of elastic deformations defined Young by the following equation [21]:

$$E = \frac{\sigma}{\varepsilon} \qquad (3)$$

where E is modulus of elesticity, σ is stress and ε is extensional strain.

Dimensions of each sample were measured using a vernier scale. Based on the calculated values of stress and strain, diagrams were produced for each measurement. For the initial part of the stress, strain curve, linear relationship with a high coefficient of determination was determined. It was therefore decided that the modulus of elasticity was identical with the constant of the linear function [22]. Lewicki and Lukaszuk [23] suggested that the stress-strain dependence of the apple was non-linear. Deviation of the curve from linearity is due to plastic deformation at micrometer level [22].

The TPA test of double compression was done after osmo-convective drying [24]. The samples were cut from the osmo-convectively dried quince sixths. The cut samples were in the form of cubes with dimensions of 10 × 10 × 10 mm. The samples were deformed by up to 70% of their initial height. The test speed was 30 mm·min-1. A cylindrical plate with a diameter of 40 mm was used. The TPA test can be performed on final products because this process simulates food mastication.

Colour

The colour was measured at the beginning and after every 20 min of osmotic drying, and after combined drying. The samples were in the form of cubes with the initial dimensions of 15 × 15 × 15 mm. The same surface of the sample was always measured. The colorimeter CR-400 (Konica Minolta, Tokyo, Japan) was used for the measurements. The colour of the same samples was also measured after convective drying. The measured values of quince colour during osmotic drying were expressed in the CIE $L^*a^*b^*$ colour system. Within the system, L^* indicated lightness, the parameters $-a^*$ and $+a^*$ indicated green and red colours, and the parameter $-b^*$ and $+b^*$ were for yellow and blue colours. The total colour change ΔE^* was used for the assessment of sample colour change. The total colour change is [25]:

$$\Delta E^* = \sqrt{(L_0{}^* - L^*)^2 + (a_0{}^* - a^*)^2 + (b_0{}^* - b^*)^2} \qquad (4)$$

where L_0^*, a_0^* and b_0^* designate the initial values of fresh fruit samples, and L^*, a^* and b^* the values after osmotic drying.

The kinetics of quince colour change during osmotic drying can be described by mathematical modelling using Eq. 5 as proposed by Krokida et al. [8]. The proposed model describes the change in each of the colour parameters (L^*, a^*, b^*) during drying.

$$\frac{C - C_e}{C_0 - C_e} = \exp(-k_c t) \qquad (5)$$

where C designates the colour parameter (L^*, a^*, b^*), C_0 and C_e are the values of the colour parameters at the beginning and at the end of drying, k_c is the function coefficient, and t is the drying time.

The values of colour change are defined as:

$$\Delta b^* = b^* - b_0{}^* \qquad (6)$$

$$\Delta L^* = L^* - L_0{}^* \qquad (7)$$

where b^* and L^* indicate the values of parameters at a certain time, b_0^* and L_0^* are the values of parameters at the beginning of drying.

Total phenolics and pectin content

The total phenolics content was determined using a modified Folin-Ciocalteu colorimetric method [26]. Mass of 10.0 g of dry quince sample was transferred to a volumetric flask, and 100 ml of methanol, the as extraction solvent, was added. The samples were shaken (GFL 3015, GFL, Burgwedel, Germany) in the dark for 24 h at room temperature and then filtered. The total content of phenolic compounds in the prepared extracts was determined by absorbance measurement at 765 nm, using gallic acid as standard compound. Content of total phenolic compounds was expressed as milligrams of gallic acid equivalents per kilogram of dry matter.

The carbazole method was used for the determination of pectins [27]. Pectin was precipitated twice with 95% and 63% ethanol in order to get rid of monosaccharides that otherwise could be also determined. The precipitated hydrocolloid was re-dissolved, and carbazole reagent and concentrated sulfuric acid were added to the solution. The solution was heated at 85 °C for l5 min. The colour developed was measured at 525 nm. Galacturonic acid was used for standard curve preparation.

Sensory analysis

Sensory properties of four dried quince samples were evaluated by a panel of eight trained assessors (trained in accordance with ISO 8586 : 2012) from the Institute of Food Technology, University of Novi Sad (Novi Sad, Serbia). The sensory analysis was performed using a quantitative descriptive analysis and the assessors evaluated only the sensory properties that were the most relevant for fresh quinces according to Szychowski et al. [28]. The assessors evaluated the intensities of sweetness, bitterness, sourness, astringency, off-taste and quince flavour by linear numerical scale, where 0 represented no intensity while 10 represented extremely strong intensity of evaluated sensory properties. The evaluation of quince samples was carried out in individual booths with controlled temperature and humidity. All the samples were coded with three random numbers and presented randomly to assessors in odour-free covered plastic cups. Distilled water was used to clean mouth between the samples. The samples were evaluated in duplicate.

Statistical analysis

The measured and computed data were statistically compared by the analysis of variance (ANOVA). The analysis was done with the probability of 5%. The results of different treatments during a specific type of drying (osmotic and convective) were compared, as well as the results of different treatments of fresh (raw) fruits and fruit samples after osmotic and convective drying. The analysis of the means was performed by Tukey's test. The data were analysed by Statistica 12 software (StatSoft, Tulsa, Oklahoma, USA).

RESULTS AND DISCUSSION

Dehydration kinetics

The experimental data on osmotic dehydration kinetics and solid gain of quinces under different process conditions are shown in Fig. 2 and Fig. 3. The most intensive changes in the moisture content were determined in the first 20 min of the process. After 20 min, the reduction of moisture content decreased between each measurement. The samples dehydrated in the saccharose solution of 65 °Bx had lower moisture content at the end of the process. The moisture contents of samples after 180 min of the osmotic process in saccharose solutions at 50 °Bx – 40 °C; 50 °Bx – 60 °C and 65 °Bx – 40 °C; 65 °Bx – 60 °C were 62,1%; 58,7%; 53,6% and 45,3% (wet basis), respectively. The results indicated that the most intensive decrease in moisture content occurred with an increase in concentration of the osmotic solution. Similar results were obtained by Falade and Shogaolu [29] when using saccharose solutions for osmotic dehydration of pumpkins. Kadam and Dhingra [30] also obtained similar results by using saccharose solutions for osmotic dehydration of banana.

Fig. 3 displays the influence of osmotic parameters on solid gain during 180 min of the drying process. Changes in the solid gain were similar to moisture content changes. The solid gain increased with an increase in concentration of the osmotic solution. The highest solid gain of 9.3% was determined at the saccharose solution of 60 °C and 65 °Bx. The lowest solid gain of 5.5% was determined at the saccharose solution of 40 °C and 50 °Bx. Some authors reported that higher concentrations did not increase solid gain. Giraldo et al. [31] found that water transfer increased during osmotic drying of mango at a solution concentration of 45 °Bx. The water transfer decelerated between 55 °Bx and 65 °Bx, probably due to high viscosity of the saccharose solution. Those measurements were conducted at a solution temperature of 30 °C.

Mechanical properties

The effect of osmotic drying on the rupture force can be expressed by comparing the rup-

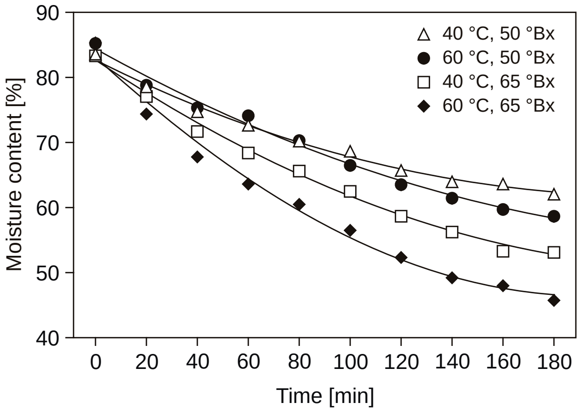

Fig. 2. Effects of osmotic pre-treatment on quince moisture content.

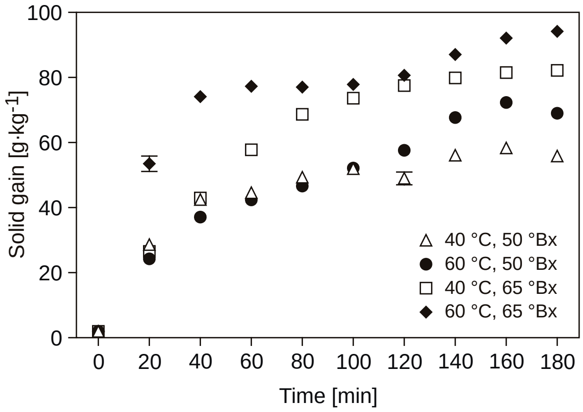

Fig. 3. Effects of osmotic pre-treatment on quince solid gain.

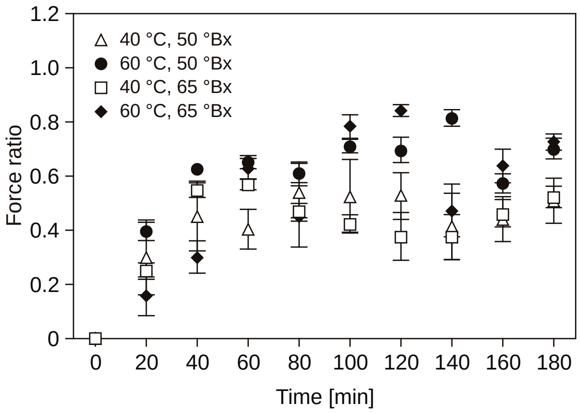

Fig. 4. Force ratio of quince samples during osmotic drying.

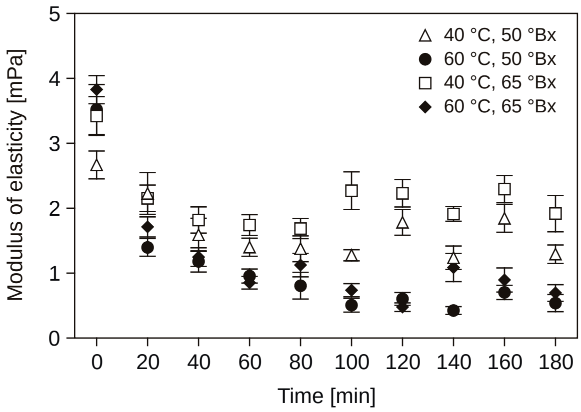

Fig. 5. Modulus of elasticity of quince samples during osmotic drying.

ture force value of fresh samples and the samples during osmotic drying (Eq. 2). Due to the anisotropy of fruit tissue, the results are expressed by the value *f* in order to reduce the biological differences between the studied samples. In Fig. 4, changes in the parameter *f* during osmotic drying of quince samples are shown. Increasing *f* values were recorded in all the treatments within the initial 60 min of the process. Following the initial period, the values increased and decreased separately. These results can be explained by the influence of turgor (water content) and physicochemical properties of cells and tissues. Quince tissue is characterized by a high content of fibres and large presence of brachysclereids (stone cells). A large amount of fibres and their orientation (anisotropy) in some samples can results in high tissue strength. This may be the reason for the variability of force ratio values and significant deviations. These changes occur due to internal heterogenity of the fruit tissue.

Major changes in the *f* values and slighter deviations were determined for the treatment with the solution of a temperature of 60 °C. Greater softening of quince cubes was determined as well. Some authors recorded an increase in the hardness of melon cubes at 60 °Bx compared to 40 °Bx. They also determined a lower water loss and a higher solid gain at 40 °Bx (the solution temperature was 30 °C). The authors explained those results by the high solution viscosity, which formed a layer of solution and stopped the mass transfer [32].

The values of modulus of elasticity are shown in a diagram (Fig. 5). Decreasing modulus of elasticity were recorded in all treatments within the initial 40 min of the process. After this period, the values increased and decreased separately. In the treatment at 50 °C, the final values did not differ from values at 40 min or 60 min. In the treatment at 60 °C, if variability of the values is neglected, there was a decline by the end of the process.

Major changes of elastic modulus were determined the in treatment with the solution of a temperature of 60 °C. However, these could be also a result of thermal softening. Variability of the results and a slighter deviation in treatments at 60 °C may be explained in the same way as the changes of rapture force. Changes of modulus of elasticity showed similar behaviour as force ratio (rupture force) during osmotic drying. MAYOR et al. [13] stated that mechanical properties of osmotically pre-treated pumpkin cylinder showed no dependence on concentration (30–60 °Bx) and temperature (12–38 °C) of the osmotic solution. Based on the results on rupture force and modulus of elasticity, it can be concluded that higher temperatures of the osmotic solution (60 °C) could affect the mechanical properties of fruit tissue. The increase in temperature and concentration of the osmotic solution leads to intensification of moisture transfer from cells to the solution. The consequence of the cellular water loss is the decrease in the cell pressure (turgor). The strength of such tissues is determined by mechanical properties of cell walls, internal turgor pressure, moisture content and physicochemical structure [14].

In order to study the effect of the examined parameters of the osmotic solution on the relative change of the rupture force of quinces, f values were established for the samples of similar moisture contents. The mean values of f are shown in Fig. 6. The average moisture content of samples during four treatments and the standard deviation were 68.7% ± 0.3%, which were based on data determined at different moments of osmotic drying. During the first treatment (40 °C, 50 °Bx), this point was reached after 180 min, during the second treatment (40 °C, 65 °Bx) after 120 min, during the third treatment (60 °C, 50 °Bx) after 100 min, and during the fourth treatment (60 °C, 65 °Bx) after 60 min.

Higher f values were determined in the samples with the same moisture contents exposed to a longer heat treatment with the osmotic solution. These results differ from the assumption that the moisture content in fruit cells affects the tissue firmness. Depending on the temperature of the osmotic solution and the duration of treatment, changes in the cell structure take place, which affect the firmness of fruit tissues [12]. The analysis of variance revealed the effect of the temperature of osmotic solution on the quince rupture force. The effect of the concentration of osmotic solution and the interaction of the temperature and concentration were not statistically confirmed ($p < 0.05$).

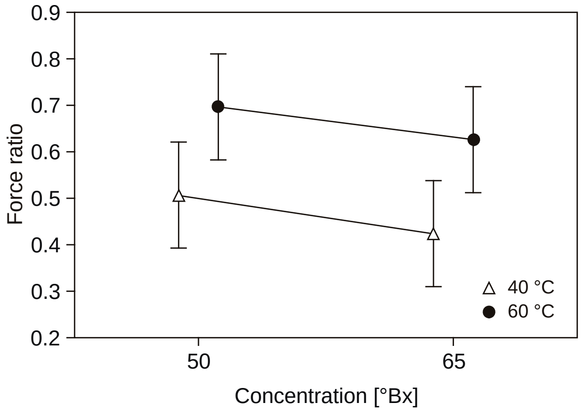

Fig. 6. Force ratio of quince samples with similar moisture contents.

Vertical bars denote 0.95 confidence intervals.

HARKER et al. [33] explained three mechanisms of tissue failure: cell fracture, cell rupture and cell-to-cell debonding. In our study, failure of the fruit tissue was clearly visible in all samples. This mechanism of failure can be described as a combination of cell rupture and cell debonding, similar to BABIĆ et al. [22]. Fig. 7 displays parameters of quince samples after the compression test and

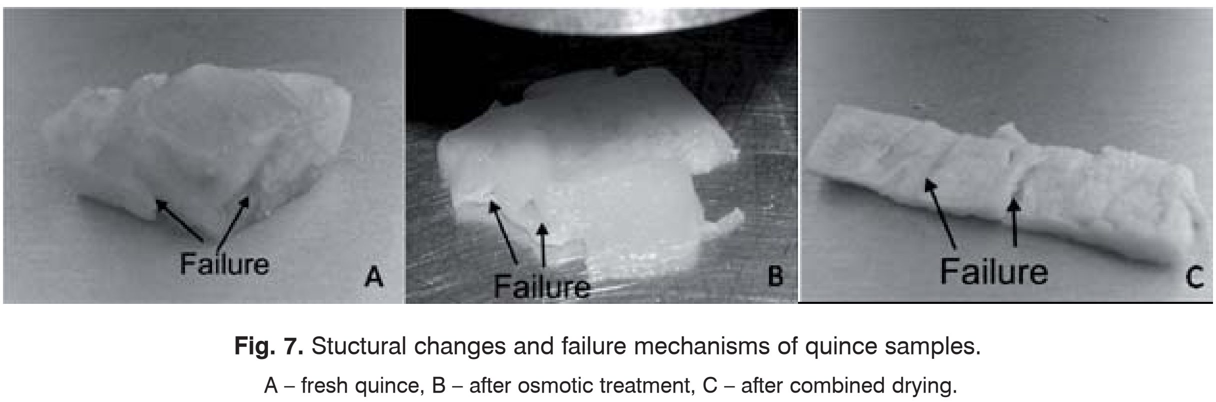

Fig. 7. Stuctural changes and failure mechanisms of quince samples.

A – fresh quince, B – after osmotic treatment, C – after combined drying.

Tab. 1. Texture profile analysis parameters of dried quinces.

Treatment	Parameters	Moisture content [%]	Hardness [N]	Cohesiveness	Springiness [mm]	Gumminess [N]	Adhesiveness [mJ]
1	40°C;50°Bx	35.7	145.62 ± 26.42 ^{b}	0.40 ± 0.16 ^{ab}	2.15 ± 0.11 ^{a}	57.94 ± 25.38 ^{b}	0.22 ± 0.04 ^{a}
2	60°C;50°Bx	33.8	89.60 ± 17.04 ^{a}	0.37 ± 0.05 ^{ab}	2.97 ± 0.71 ^{b}	32.65 ± 6.10 ^{ab}	0.71 ± 0.12 ^{b}
3	40°C;65°Bx	34.6	84.26 ± 9.87 ^{a}	0.43 ± 0.04 ^{b}	2.61 ± 0.44 ^{ab}	47.32 ± 26.38 ^{ab}	0.26 ± 0.18 ^{a}
4	60°C;65°Bx	36.7	66.05 ± 28.45 ^{a}	0.25 ± 0.07 ^{a}	2.17 ± 0.27 ^{a}	17.61 ± 11.13 ^{a}	0.51 ± 0.30 ^{ab}

The values are expressed as mean ± standard deviation. Different small letters in superscript indicate significant differences (p < 0,05).

it can be seen that disintegration always occured along the fruit fibre direction. Mayor et al. [13] did not find dependence between the fibre orientation and the mechanical properties of pumpkins and also concluded that, in the case of pumpkins, the rupture and debonding failure mechanisms can occur.

The effects of osmotic drying parameters on mechanical properties of final products are very important. Tab. 1 shows mean values of quince hardness after combined drying, as determined by TPA test [34], which can be applied to consumable food products because it simulates the process of mastication. The highest force value 145.62 N ± 26.42 N was determined for the first treatment. Hardness decreased from the first to the fourth treatment. The lowest force value 66.05 N ± 28.45 N was determined for the fourth treatment. The lowest and highest values of the parameters (temperature and concentration) led to the lowest and highest forces. All the samples had similar moisture contents, which had no influence on the hardness of quinces. At higher temperatures of the osmotic solution, tissue softening but no shape changes were observed. Thermal softening has a positive influence on osmo-convectively dried quinces. Several authors studied the changes in mechanical properties of food materials during convective drying and reported that soft (fresh) products transformed to stiff (dried) products during drying. Products changed their behaviour from plastic to more elastic, while a change to viscoelastic behaviour occured between fresh and dried products [35]. The dried quince samples expressed viscoelastic behaviour at moisture contents shown in Tab. 1.

The effects of osmotic pre-treatment on mechanical properties after convective drying can be expressed by such indicators as cohesiveness, springiness, gumminess, chewiness and adhesiveness (Tab. 1) [34]. Cohesiveness is the energy necessary for food mastication. The measured cohesiveness is in accordance with hardness. The lowest values were determined for the fourth treatment (60 °C; 65 °Bx). Springiness is correlated with the moisture content of materials, and increasing the moisture content increases the springiness. The highest value was determined at the lowest moisture content of quince, and the smallest at the highest moisture content. Springiness depends on the properties of the fruit tissue and the moisture content of samples.

Adhesiveness depends on the effects of adhesive and cohesive forces, viscosity and elasticity [36]. The obtained results depend on the moisture content of the samples and the amount of solution retained in the samples. Adhesiveness values were similar at the solution temperature of 40 °C. Gumminess is the energy necessary for disintegrating food to the swallowing point, its value being obtained by multiplying hardness and cohesiveness. Due to slight changes in cohesiveness, the changing trend was similar to the change in hardness. The results of TPA analysis indicated that some parameter values did not follow the changing trend of the most important factors (temperature and concentration). These results indicated a very complex texture of the dried quince tissue.

Total phenolics and pectin contents

Amount of pectin measured in fresh quince was 2.5%. The determined content of pectin in dried quinces was 0.8%, 1.1%, 0.9% and 0.9%, from first to fourth treatment (Tab. 2). The content of pectin in dried quinces was reduced compared to fresh quince. The enzymatic system of the fruit is generally rich in pectolytic enzymes, which serve as catalysts for pectin hydrolysis. It is generally known that these enzymes reach the maximum activity at temperatures of 40–50 °C, and an increase in ambient temperature reduces their activity. Therefore, it can be assumed that the treatment temperature of 60 °C reduced the activity of pectolitic enzymes, and the content of separate fractions of pectin substances was higher in comparison with the samples treated at 40 °C. Sharma et al. [37] also found lower contents of pectin in the quince jam (1.2%) and jelly (1.3%) in relation to its content in fresh quinces (1.8%).

The contents of phenolic compounds (expressed as gallic acid equivalents), which are responsible for astringency, ranged in dried quince samples from 5.58 $g\cdot kg^{-1}$ to 8.41 $g\cdot kg^{-1}$ (Tab. 2). The highest content was determined in sample 4 (8.41 $g\cdot kg^{-1}$), the lowest content was determined in sample 1 (5.58 $g\cdot kg^{-1}$). The contents in the samples 2 and 3 were similar, 6.53 $g\cdot kg^{-1}$ and 6.76 $g\cdot kg^{-1}$ respectively. The contents of phenolic compounds were higher than found in dried apricots 2.48 $g\cdot kg^{-1}$, peaches 2.83 g kg^{-1}, raisins 3.72 $g\cdot kg^{-1}$, but lower or similar compared to dried pears 6.79 $g\cdot kg^{-1}$, plums 7.88–11.95 $g\cdot kg^{-1}$, dates 6.61 $g\cdot kg^{-1}$, cranberries 8.70 $g\cdot kg^{-1}$ [38, 39] and sour cherries 3.14–11.80 $g\cdot kg^{-1}$ [40]. These products are intended for direct consumption. In comparison with the above mentioned dried fruits, the amount of phenolics in dried quinces will not affect the astringency and the product can be considered suitable for consumption. The second factor affecting the reduction in astringency of dried quinces is the amount of solution that is retained in the product after osmotic dehydration. The dried quinces studied in this paper are already available on the market in the Republic of Serbia.

Tab. 2. Contents of pectin and total phenolics in dried quinces.

Treatment	Parameters	Pectin [%]	Total phenolics [$g\cdot kg^{-1}$]
1	40°C;50°Bx	0.8	558
2	60°C;50°Bx	1.1	653
3	40°C;65°Bx	0.9	676
4	60°C;65°Bx	0.9	841

Colour

After osmotic drying, a small increase in the parameter L^* was recorded followed by a decrease after convective drying (Fig. 8). In the treatment with a 65 °Bx solution, the increase was somewhat larger ranging from 8 to 10. Increase of L^* values was probably caused by the higher aggregation of solution on the surface of the fruit due to the greater absorption at higher concentrations. The osmotic process caused structural changes on the surface of the fruit tissue, which allowed easier retention of the osmotic solution. Changes taking place during the drying process, which significantly affect colour, are therefore considered as the major quality determining factor, and their levels strongly depend on temperature-moisture-time parameters. Based on the results (Fig. 8), there was no influence of the solution temperature on L^* values. By interpreting the changes in the L^* value, it can be concluded that they were small, and that the application of sulfur dioxide and osmotic pretreatment could successfully preserve the lightness of quince. After convective drying, increase in this value was recorded only in the second treatment, and the increase was only very small. The values in other treatments displayed a small decrease. The changes in L^* after convective drying were slight and within the range from 1 to 2. The analysis of variance determined significant differences in the change in L^* values among the fresh samples and the samples after osmotic and convective drying

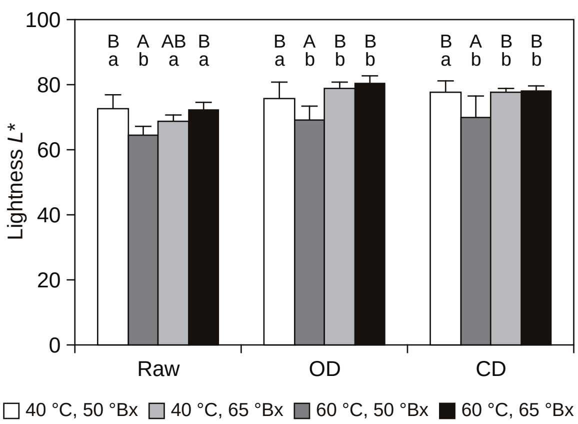

Fig. 8. Changes in the lightness (L^*) of quince samples.

OD – after osmotic drying, CD – after convective drying. Different letters (small: different samples in the same treatment; capital: different treatment of the same case) indicate significant differences ($p < 0.05$).

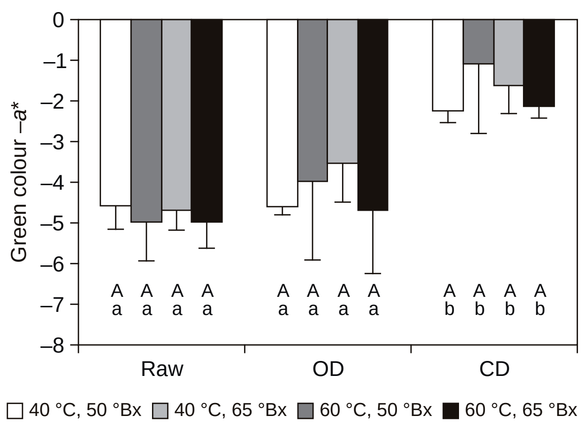

Fig. 9. Changes in the green parameter ($-a^*$) of quinces.

OD – after osmotic drying, CD – after convective drying. Different letters (small: different samples in the same treatment; capital: different treatment of the same case) indicate significant differences ($p < 0.05$)

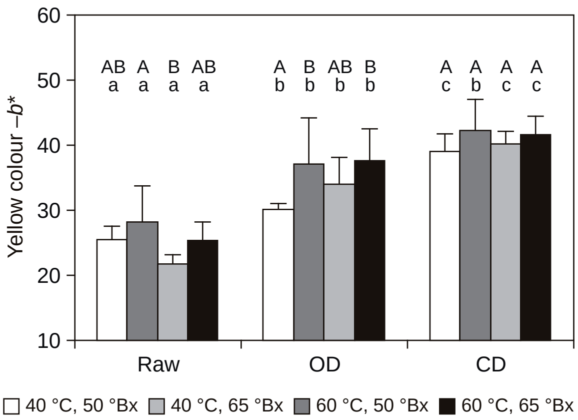

Fig. 10. Changes in the yellow parameter (–b^*) of quince samples

OD – after osmotic drying, CD – after convective drying. Different letters (small: different samples in the same treatment; capital: different treatment of the same case) indicate significant differences ($p < 0.05$).

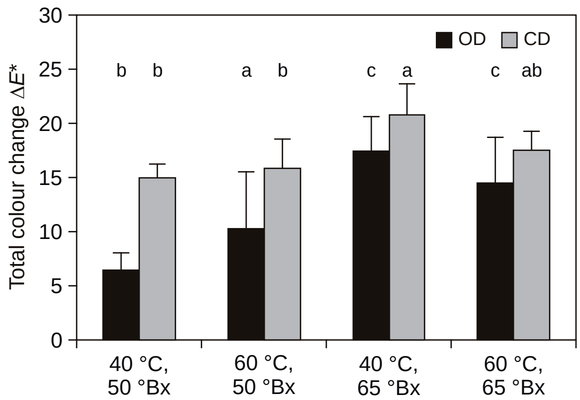

Fig. 11. Total colour change of quince samples.

OD – after osmotic drying, CD – after convective drying. Different letters indicate significant differences for the same treatment ($p < 0.05$).

in the third and the fourth treatments ($p < 0.05$). After convective drying, these values decreased and, therefore, it can be concluded that lightness of quinces did not change significantly after combined drying. Osmotically pre-treated papaya fruits had similar colour to fresh fruits as stated by RODRIGUES et al. [41].

The values of the parameter –a^*, indicating green colour, were within the range from 1 to 5 (Fig. 9). The increase in this parameter was recorded in all treatments after convective drying. The increase was small, so the differences in comparison with fresh (raw) samples were within the range from 2 to 4. Significant changes were recorded in –b^* parameter indicating yellow colour (Fig. 10). A significant increase in this value occurred after osmotic drying, and it was within the range from 5 to 13. More notable changes were determined for the third and the fourth treatments (65 °Bx). The increase in these changes followed the sequence of treatments (Fig. 10). The smallest increase was observed at the first treatment and the largest at the fourth. The trend of the increase in parameter –b^* continued after convective drying. The statistical analysis determined significant differences between the fresh samples and the samples after all treatments of osmotic and convective drying ($p < 0.05$). Moreover, all combinations of osmotic drying parameters had an effect on –b^* values during combined drying.

All treatments caused changes in the total colour ΔE^* (Fig. 11), which comprises all three colour parameters and is usually used for the measurement of colour change of food. More significant changes were recorded after osmotic drying at the third and the fourth treatment. Statistical analysis of the data confirmed that the concentration of a solution affected the total colour change ΔE^* during osmotic drying ($p < 0.05$). The changes of these values exceeded 10. Although no scale is available for assessing the quality of dried quinces according to colour, it can be stated that the determined changes were significant. For instance, the difference between two categories of meat quality based on the colour parameter L^* is 6. Based on the value change of some parameters, it was determined that the parameter $+b^*$ has the greatest effect on the total colour change. The parameter $+b^*$ also affects the change of chromaticity (chroma). Higher values of this parameter indicate "purer" and more intense colour. Therefore, the increase in b^* value, accompanied by slight changes in the a^* parameter, results in quince samples with purer and more intense colour. After convective drying, slightest differences in the change of the total colour (in comparison with the values after osmotic drying) were recorded at the solution temperature of 60 °C and a concentration of 65 °Bx. At higher temperatures and concentrations of the osmotic solution, greater amounts of solution are retained in the pores of fruit tissues, which may explain the total colour change after convective drying. RAHMAN and MUJUMDAR [42] stated that saccharose layers formed on the surface, prevented fruit tissue darkening, acting as a barrier between the fruit tissue and the surrounding air.

Quince fruits are very susceptible to intensive

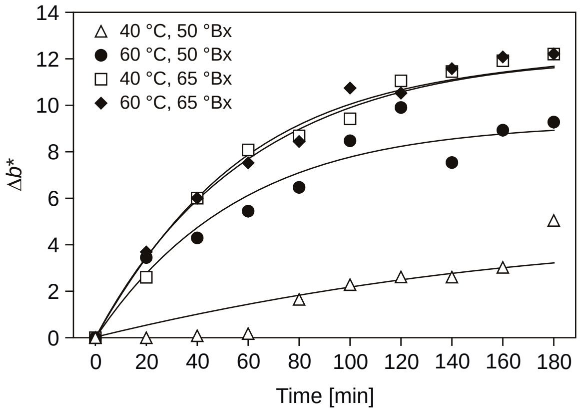

Fig. 12. Changes in paramater b^* during osmotic drying at different temperatures and concentrations of the osmotic solution.

Dots represent the values determined in the experiment, while the calculated data are shown as full lines.

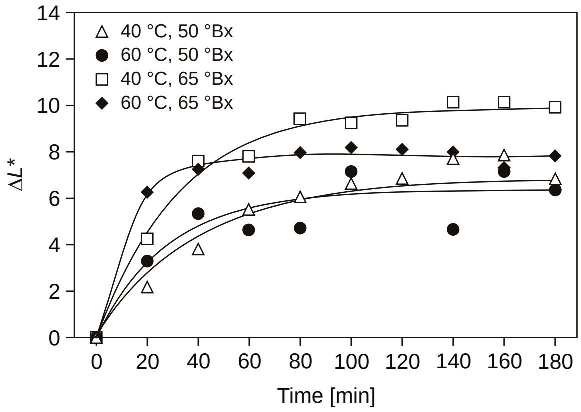

Fig. 13. Changes in paramater L^* during osmotic drying at different temperatures and concentrations of the osmotic solution.

Dots represent the values determined in the experiment, while the calculated data are shown as full lines.

and rapid browning [43]. Guiné and Barroca [43] found that the colour change of quince tissue exposed to air was faster in the first 30 min. After that period, it tended to reach an equilibrium value of total colour change ΔE^*. The total color change was $\Delta E^* = 30$. Due to the colour deterioration during processing, the samples treated with sulfur dioxide were used in the experiment, whereby change in colour parameters were considered in relation to the colour of the fresh fruit.

The values of colour change Δb^* and ΔL^* are shown in Fig. 12 and Fig. 13. The differences in colours are shown instead of the measured and calculated values of the b^* and L^* parameters. The effects of temperature and concentration of the osmotic solution on yellow colour (Δb^*) were evident. The value of Δb^* increased with the increase in temperature and concentration of the osmotic solution. The increase in Δb^* intensified at higher concentrations of the osmotic solution. The effects of the solution concentration on the yellow colour change were more significant than the effects of the solution temperature. The value of ΔL^* also increased with the increase in temperature and concentration of the osmotic solution. Extensive changes were recorded during the first 60 min of drying. Similar to the yellow colour change, the effects of the osmotic solution concentration were more evident in this instance as well.

A mathematical model (Eq. 4) used in this paper can be successfully used to describe the kinetics of quince colour change during osmotic drying. The model explicitly calculates the values of colour change parameters Δb^* and ΔL^*:

$$b^* - {b_0}^* = {b_e}^* + ({b_0}^* - {b_e}^*)\exp(-k_c t) - {b_0}^* \quad (8)$$

$$L^* - {L_0}^* = {L_e}^* + ({L_0}^* - {L_e}^*)\exp(-k_c t) - {L_0}^* \quad (9)$$

The values of a^* parameters did not change during osmotic drying. Therefore, only the values of Δb^* and ΔL^* parameters are shown in the charts.

The values of the function coefficient k_c were determined by fitting the function with the experimental data. The values of the function coefficient k_c are presented in Tab. 3.

Sensory analysis

The score attributes of the dried quinces are shown in Tab. 4. The samples were evaluated as having very low intensities of bitterness, astringency and off-taste. This is considered as very good since these sensory properties have impact on products acceptability. Sample 4 had the highest scores for astringency and this sample had also the highest content of total phenolics. The scores of sweetness were not related to the increase in

Tab. 3. Values of the coefficient k_c for colour parameters b^* and L^* for dried quinces.

Experimental parameters	b^*	L^*
40°C; 50°Bx	0.005658	0.025499
60°C; 50°Bx	0.018151	0.035265
40°C; 65°Bx	0.016905	0.030625
60°C; 65°Bx	0.017461	0.075101

Tab. 4. Sensory scores of dried quinces.

Treatment (samples)	Parameters	Sweetness	Bitterness	Astringency	Sourness	Off-taste	Flavour
1	40°C; 50°Bx	4.50	0.19	0.58	3.24	0.32	5.66
2	60°C; 50°Bx	5.04	0.15	0.24	2.46	0.00	6.04
3	40°C; 65°Bx	4.82	0.04	0.45	3.62	0.27	6.17
4	60°C; 65°Bx	4.68	0.17	0.66	3.43	0.29	5.56

solid gain. The highest solid gain was determined in sample 4, in which sweetness was not scored as the highest. Based on all scores, sample 2 had the best quality scores. Azoubel et al. [44] scored sweetness of osmotically pre-treated cashew apple, the fruit also characterized by astringency, with 6 on a scale from 0 to 9. Statistical analysis of the obtained data of sensory analysis showed no significant ($p < 0.05$) differences between the sensory properties of the samples of dried quinces.

CONCLUSION

The experiment of osmotic drying of quinces was conducted using parameters applicable in the production process and therefore the study has practical significance. Higher concentration of saccharose supported its retention on the surface of samples, thus preventing fruit tissue darkening during convective drying. The applied processes of sulfurization and osmotic drying had a positive effect on preservation of the colour of the dried quince. The solution temperature was found as a factor that affected the force ratio (f) and modulus of elasticity during osmotic drying. Different values of force ratio were determined for similar moisture contents. Using osmotic solution of increased temperature led to softening of osmo-convective dried quince, but without degradation of structure and shape. According to sensory analysis results, osmotic solution at temperature of 60 °C had a positive effect on quality of dried quinces. In general, osmotic pre-treatment had positive influence on physical properties and quality of dried quinces.

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