

Combined Pretreatment for Enhancing Quality of Dried and Rehydrated Eggplant

Giuseppina Adiletta¹ · Paola Russo²  · Alessio Crescitelli³ · Marisa Di Matteo¹

Received: 28 January 2016 / Accepted: 20 July 2016 / Published online: 29 July 2016
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Abstract A combined pretreatment of trehalose (0.5 %) and NaCl (0.5 %) solution was applied prior to drying eggplant to reduce shrinkage, browning and loss of polyphenols. Drying behaviour of eggplant slabs was experimentally examined in a convective dryer at temperatures of 50, 60 and 70 °C and at 2.3 m/s air velocity. Then the effects of pretreatment and drying temperature on the quality of the eggplant slabs in terms of microstructure, porosity, colour, total phenolic content, rehydration ratio and texture were investigated. It was noted that the pretreated eggplants (TR) dried more rapidly than the untreated ones (UTR) with a reduction of up to 1/4 of drying time. After drying at 50 and 60 °C, they showed no significant differences ($p < 0.05$) in terms of White index compared with fresh eggplant (78.59 ± 0.63). They had higher total phenolic content (19.86 and 18.24 mg/g (db), respectively) than the UTR ones (11.91 and 12.89 mg/g (db)), but only for the TR samples at 50 °C the value is not statistically different ($p < 0.05$) from the fresh ones (20.00 mg/g (db)). The pretreatment can hold also a higher porosity (85, 86 % at 50 and 60 °C, respectively) than the UTR ones (78, 82 %), but scanning electron microscopy (SEM) images indicated a total damage structure of the UTR samples. On the contrary, after the pretreatment, the porous structure was more uniform with

more not lacerated cellular walls. Hence, the main effect of pretreatment was of protecting the microstructure of the eggplants by reinforcing the cell walls and to reduce the resistance of the water evaporation by avoiding the structural changes. After rehydration, the pretreated samples absorbed more water (rehydration ratio had almost doubled) than the untreated ones and showed lower firmness ($95,500 \text{ Nm}^{-1}$) compared with the untreated ones ($132,000 \text{ Nm}^{-1}$).

Keywords Drying · Phenolic content · Porosity · Rehydration · Texture · Trehalose

Introduction

The expansion of dehydrated food market demands high-quality products that maintain the nutritional and sensorial properties of the initial fresh product.

In particular, eggplant is a valuable ingredient in different kinds of meals (i.e. snacks, salads, soups and sauces). In addition to featuring a host of vitamins and minerals, eggplant also contains important phytonutrients, many of which have antioxidant activity. Phytonutrients contained in eggplant include phenolic compounds, such as caffeic and chlorogenic acid, and flavonoids, such as nasunin.

The eggplant in its dehydrated form, as well as all dehydrated foods, has a reduced cost for transport, due to the reduced mass, and possibility of transporting at room temperature, besides extending its shelf life.

But in dehydration processes, heat and mass transfer can modify physico-chemical properties of the material, such as chemical composition, mechanical properties (Lewicki & Lukaszuk, 2000), volume and porosity. These physico-chemical changes are of extreme importance in terms of

✉ Paola Russo
paola.russo@uniroma1.it

¹ Department of Industrial Engineering, University of Salerno, Via Giovanni Paolo II, 132, 84084 Fisciano, SA, Italy

² Department Chemical Engineering Materials Environment, Sapienza University of Rome, Via Eudossiana 18, 00184 Rome, Italy

³ Institute for Microelectronics and Microsystems (IMM) of the National Council of Research (CNR), Via Pietro Castellino 111, 80131 Naples, Italy

product quality. Therefore, a suitable scheme for drying food materials has to be determined to reduce various adverse changes.

Drying combined with some pretreatments appears to be a cost-effective method of preservation. Several methods of pretreatment have been widely utilized: such as immersion in chemical solutions (Vega-Galvez et al., 2008), hot-water blanching (Niamnuy et al., 2014) and physical pretreatments (Adiletta et al., 2015, 2016; Di Matteo et al., 2000).

Chemical pretreatments include sulfiting, immersion in sodium chloride, calcium chloride or sugars, use of surfactants and impregnation with biopolymers. Among these methods, sulfiting is one of the most common. The effects of sulfiting are well known. Immersion in solutions containing sulfites disinfects surface and reduces oxidation of liable food components (Negi & Roy, 2000), facilitates drying (Kaymak-Ertekin, 2002), reduces shrinkage (Lewicki, 2006) and improves rehydration (Kaymak-Ertekin, 2002). Moreover, sulfiting causes bleaching of anthocyanins and affects colour of some fruit subjected to dehydration (Sian & Soleha-Ishak, 1991).

Sulfites had been accepted as safe additive (generally recognized as safe) until their allergenic reaction was observed in sensitive people. If they are used more than the permitted levels, they can be allergenic (asthma) causing reactions like nettle rash, angio-neurotic edema and anaphylactic shock in ordinary individuals. For their allergenic effect, consumers tend to avoid sulfites (Aydin & Gocmen, 2015).

Dipping or soaking a product in organic acids such as citric acid (Pao & Petracek, 1997) or lactic acid (Uyttendaele et al., 2004) is an alternative pretreatment method that can reduce the number of normal flora and pathogenic organisms (Chiewchan et al., 2010), the action of enzymes responsible for browning and drying time (Doymaz, 2010).

Dipping of material in sodium chloride solution prior to drying inhibits the browning reaction and controls for microbial growth but causes some dehydration of the food tissue. Dehydrated material dries faster and preserves better the colour during drying; moreover, rehydration capacity is also increased (Lewicki, 2006; Kaymak-Ertekin, 2002). In particular, Vega-Galvez et al. (2008) studied the effect of NaCl chemical pretreatment on the microstructural changes of rehydrated dried red bell pepper. The results showed that the cell walls of the pretreated samples did not significantly collapse even after drying, indeed, a higher water holding capacity of the samples after rehydration was found (Niamnuy et al., 2014).

Non-reducing disaccharides such as trehalose can protect biological systems from the adverse effects of drying. Trehalose replaces water in membrane and prevents the phase transition. Moreover, trehalose does not react with amino acids or proteins to cause Maillard browning. Consequently, deterioration caused by Maillard reaction such as loss of nutrients can be avoided in addition to protection of flavour and colour (Aktas et al., 2007).

Upon the addition of trehalose prior to air drying, a wide variety of food products were protected from protein denaturation and the loss of aromatic volatiles. Superoxide dismutase (SOD)-like activity of vegetables was also maintained. A protective effect of trehalose in maintaining the SOD-like activity was observed for several vegetables, including cucumber, spinach and onion. Sucrose, on the contrary, was less effective in preserving the SOD-like activity upon drying: 28 % of predried activity was preserved with sucrose compared with 65 % for trehalose. Trehalose-dried food products were also found to contain less toxic by-products and higher nutritional content than conventionally processed foods (Ohtake and Wang, 2011).

In a previous paper (Albanese et al., 2007), the effect of an edible coating made by dipping the fruit in a solution containing trehalose at 0.8 %, sucrose at 1.0 % and sodium chloride at 0.1 % was investigated on the cold storage of minimally processed Annurca apples. The results showed that such a coating reduced the browning phenomena; moreover, a decrease in the weight loss and in the reduction of organic acids was observed for coated samples.

As regards to eggplants, only a few studies were focused on pretreatment of eggplant and they only referred to blanching pretreatment. Doymaz & Göl (2011) evaluated the effects of air temperature and the thickness of the sample on the drying kinetics of blanched/unblanched eggplant slices. They verified that blanched samples had shorter drying time than unblanched samples. Similar results were obtained by Ertekin & Yaldiz (2004).

In our previous papers (Adiletta et al., 2014; Russo et al., 2013), the effect of air temperature (40–70 °C) on microstructure of hot-air-dried eggplants was studied. We found that the porosity increased with the air temperature, but the structure was less damaged at intermediate temperature (60 °C), where the shrinkage was lower and the mean pore radius was higher. To take into account the shrinkage effect during drying, a mathematical model was also developed for eggplant slabs (Brasiello et al., 2013).

However, to our knowledge, the effects of pretreatment with trehalose and NaCl (in diluted solution) on drying/rehydration behaviour of vegetables and dried product qualities were not fully investigated.

Most of the studies reported in literature, instead, regard the use of trehalose and sodium chloride, in high-concentration solutions, as osmotic agents prior to conventional drying. For example, Xin et al. (2013) used trehalose in osmotic pretreatments for increasing the Tg of broccoli. In particular, broccoli were osmotically dehydrated for 2 h in 40 % (w/w) syrups of trehalose. NaCl (3 % w/w) and CaCl₂ (1 % w/w) were also added into the solution as texture-reinforcing chemicals. The Tg of broccoli was increased up to −25.34 °C, which is close to the commonly used freezing storage temperature (−25 °C).

Dermesonlouoglou et al. (2007) applied an osmotic step with carbohydrate/salt solutions prior to freezing tomato tissue to improve product quality characteristics (vitamin C, colour, texture) and sensory properties. Glucose, a high DE maltodextrin, oligofructose and trehalose were used in the osmotic solutions (56.5 %), combined with NaCl and CaCl₂. NaCl (3.5 %, wt/wt) and CaCl₂ (1.5 %, wt/wt) were also added for texture reinforcement purposes. The results showed that osmotic treatment of tomato slices at 35 °C caused substantial water loss and solid enrichment in tomato tissue. The obtained solid enrichment and partial water removal improves the sensory characteristics of treated tomatoes, when compared with untreated ones, which suffered from a detrimental texture and taste deterioration during the subsequent frozen storage. The protective effect of osmotic pretreatment on colour and vitamin C was also demonstrated.

Concerning eggplants, Bahmani et al. (2015) investigated water loss and solids gain during osmotic dehydration of eggplant in salt concentrations of 5, 10 and 15 %, sample/osmotic solutions ratios of 1:10, 1:15 and 1:20 and temperatures of 30, 45 and 60 °C and subsequent oven drying at 70 °C.

In this framework, the objective of this work was to evaluate the combined effect of trehalose (0.5 % in solution) and sodium chloride (0.5 % in solution) on the convective drying of eggplant slabs at 50, 60 and 70 °C. In addition to the use of diluted solutions, this pretreatment does not contain any substance (i.e. sulphites), which may cause allergenic reaction in sensitive people, in view of an industrial application. Therefore, the obtained dried eggplants are healthy products that may be consumed as snacks or ingredients for the preparation of soups, salads and sauces. Indeed, as consumers have become more aware of different diets and their impact on health, food industries and marketers have begun to dedicate more time and effort to develop healthier and more nutritive products.

Drying characteristics of eggplants with and without pretreatment and the quality of the dried vegetables in terms of microstructure, porosity, colour, total phenolic content, texture and rehydration ratio were evaluated, in order to optimize the process parameters (i.e. temperature).

Materials and Methods

Sample Preparation

Eggplants (*Solanum melongena* cv. Longo) were purchased from a local supermarket in Salerno, Italy, and stored in a refrigerator at +4 °C. Prior to drying, vegetables were washed and peeled. Cylindrical slabs with diameter of 30 mm and thickness of 6 mm were prepared, sampling the material from the whole vegetable using a suitable steel mould. One lot of eggplant slabs (TR) was pretreated by dipping in a solution of

0.5 % dihydrates trehalose (Acef, Italy) and 0.5 % anhydrous NaCl (Acef, Italy) at 25 °C for 5 min (Adiletta, 2011). The other lot was untreated (UTR).

The initial moisture content of eggplant was measured according to AOAC (1997) Method no. 934.01.

Drying Experiments

Drying experiments were conducted using a convective dryer (Zanussi FCV/E6L3, Italy) at three different temperatures (50, 60 and 70 °C). The air velocity was fixed at 2.3 m/s. The chosen air temperatures and velocity were used in our previous papers (Russo et al., 2013; Adiletta et al., 2014) and by many researchers (Yaldiz & Ertekin, 2001; Akpinar & Bicer, 2005). Each drying experiment was continued until the mass of the sample reached an equilibrium and constant value. The procedure is repeated until the weight remains constant for 30 min.

During the drying process, the weight loss of slabs was recorded every 15 min by using a digital electronic balance (mod. Gibertini E42, Italy). Moisture ratio (M_t/M_0) was calculated as the ratio between the actual (M_t) and the initial (M_0) moisture content on dry basis. Drying rate was expressed as the amount of moisture lost by the sample over time: $d(M_t/M_0)/dt$ (Doymaz, 2010).

Drying experiments were repeated for each temperature in three sets independently, each set having three replicates and the averages are reported with standard deviation (18 experiments totally).

Scanning Electron Microscopy Analyses

Samples for scanning electron microscopy (SEM) analysis were obtained by cutting the slabs along the thickness (longitudinal direction). Images of transversal surfaces of dried samples were captured at 250X magnification, using a scanning electron microscope (SIGMA ZEISS, featuring GEMINI® technology). Samples were prior coated with a thin layer of gold in a sputter coater (AGAR Auto Sputter Coater, mod.108A, England) for 150 s (Russo et al., 2013).

Porosimetric Analysis

The pore structure of eggplant samples was analysed by mercury intrusion porosimetry technique with the instruments Pascal 140 and Pascal 240 (Thermo Finnigan, Waltham, MA, USA) operating in the pressure range from sub ambient up to 200 MPa. Hg porosimetry measures the intruded volume in relation to the mass of the sample at a specific pressure; this pressure can then be converted to an equivalent pore diameter. The relation between the pore size and the applied pressure,

assuming the pore is cylindrical, is expressed by the Washburn equation (Washburn, 1921):

$$P \cdot r = -2\gamma \cos\theta \quad (1)$$

where r is the pore radius, γ the Hg surface tension, θ is the contact angle and P is the absolute applied pressure. Values of 141.3 and 0.0048 N/cm were used for the contact angle and mercury surface tension.

The Washburn equation provides a simple and convenient relationship between applied pressure and pore size. Monitoring the amount of non-wetting mercury intruded into pores as a function of increasing applied pressure, therefore, generates pore size distributions.

The pressure range investigated covers the pore diameter range from 0.0075 up to 100 μm . Thus, the pressure is sufficient to ensure intrusion of mercury in most of the mesopores (0.002–0.05 μm) and of the macropores (>0.05 μm). However, majority of the micropores would remain non-intruded.

Tests were carried out on fresh and dried eggplant samples. Mercury intrusion porosimetry tests were carried out in triplicate to ensure adequate accuracy of the results.

Colour

Colour measurements were carried out on surfaces of ten slabs for each fresh, dried and rehydrated sample. Colour was obtained through a colorimeter (Chroma Meter II Reflectance CR-300 triple flash mode aperture 10 mm Minolta, Japan). CIE standard illuminant D65 was used in all colorimetric calculations. In order to measure the colour changes of all samples (fresh and dried), CIE-Lab L^* , a^* and b^* colour coordinates were recorded using CIE L^* , a^* and b^* uniform colour space (CIE-Lab). The lightness value (L^*) indicates the darkness/lightness of the sample, a^* is a measure of the greenness/redness of the sample and b^* is the extent of blueness/yellowness. White index was calculated as follows (Hsua et al., 2003):

$$WI = 100 - \sqrt{[(100 - L^*)^2 + a^{*2} + b^{*2}]} \quad (2)$$

Whiteness index (WI) represents the overall whiteness of vegetable and the browning of the eggplant surface.

Water Activity

The water activity of each sample was determined using a water activity meter (Testo 650, Testo Inc., USA) at 25 °C. Approximately 3 g of each sample was put in sample holder.

After equilibration, a_w values were recorded. Each measurement was done in triplicate.

Total Phenolic Content

The total phenolics were extracted from fresh and dried samples with 80 % methanol (CHROMASOLV®, for HPLC, ≥ 99.9 , Sigma-Aldrich, USA). All extractions were performed in triplicate. The total phenolic content was determined using the Folin–Ciocalteu colorimetric method (Singleton et al., 1999), which was modified by Yang et al. (2004). The Folin–Ciocalteu reagent in sodium carbonate solution oxidized the eggplant extracts. The absorbance was measured at 760 nm after 90 min at room temperature by a spectrophotometer (Lambda Bio 40; Perkin Elmer, Waltham, MA, USA).

The results were expressed as milligrammes per gramme (db) of chlorogenic acid equivalent (Lo Scalzo et al., 2010). Chlorogenic acid was used because it is the main phenolic compound in eggplant. All values were expressed as the mean $\pm$ SD of three replications.

Rehydration Experiments

Rehydration kinetics for dried samples were carried out in distilled water bath at 25 °C. The approximate weight-volume ratio of dried fruits and water was kept 1:30 (Russo et al., 2013).

The samples were withdrawn from the liquid at fixed time intervals and excess water was carefully removed by blotting on a tissue paper, before weighing. Samples were weighted every 5 min in the initial phase of rehydration process (up to 30 min) and then every 20 min. The total rehydration time was 310 min. After this time, the UTR and TR samples did not gain weight.

Weights of dried and rehydrated samples were measured using an electronic digital balance.

The rehydration capacity, reported as rehydration ratio (RR), was calculated from the ratio of sample weight after and before the rehydration by using Eq. (3) (Doymaz, 2010):

$$RR = \frac{\text{weight of rehydrated sample}}{\text{weight of dried sample}} \quad (3)$$

The rehydration experiments were repeated in three sets independently, each set having three replicates, and the averages are reported with standard deviation.

Texture Analysis

Texture parameters of rehydrated eggplant were measured by compression tests using a texturometer (Ametek Lloyd Instruments LRX plus, UK), with specific software

(Nexygen batch 4.1). The values were obtained from load and strain curves recorded during the compression of samples up to 50 % of initial height using two horizontal parallel plates with the sample placed on the centre of the lower plate. The crosshead speed was 50 mm/min with a cell load of 50 N (Wu et al., 2009). During the tests, the parameters analysed were firmness and modulus of elasticity (Young's modulus). Firmness or rigidity is indicated by the slope of the initial straight line portion of the force–deformation curve. To express the elasticity of a material, Young's modulus is used in order to predict the elongation or compression of an object.

Statistical Analysis

The means and standard deviations of experimental results were calculated from three replicates.

Statistical analyses were performed by one-way ANOVA (at α level of 0.05) followed by a Tukey test: $p < 0.05$ was considered to be statistically significant.

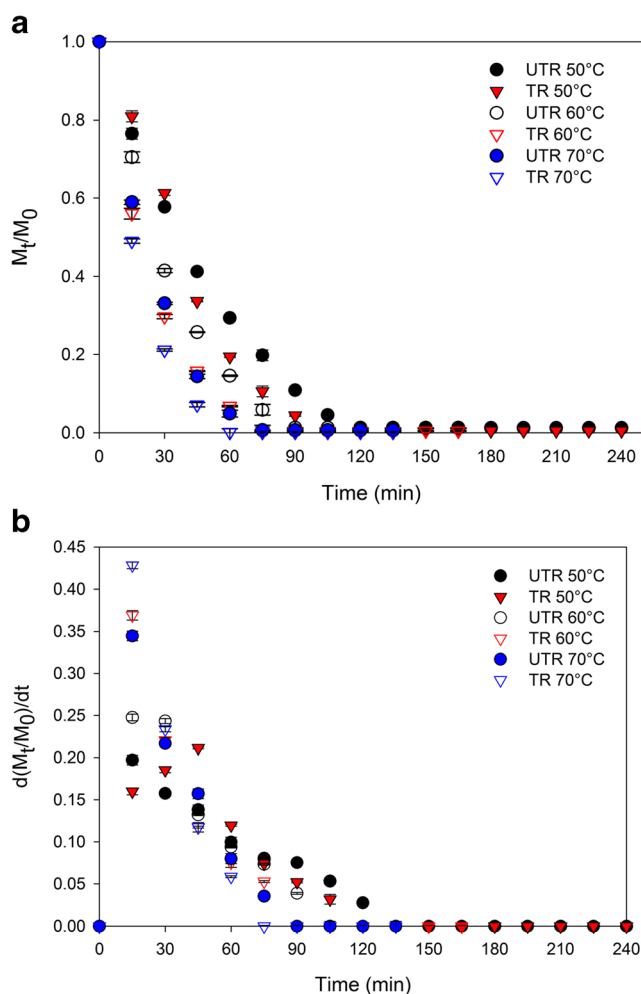


Fig. 1 Drying kinetics (a) and drying rate (b) of eggplants at 50, 60 and 70 °C

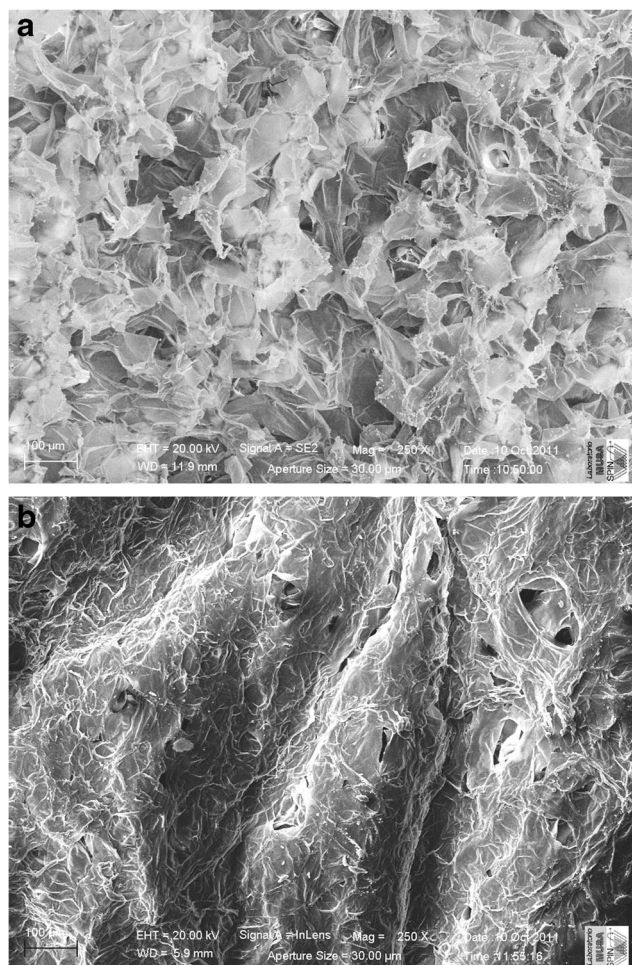


Fig. 2 SEM images of UTR (a) and TR (b) eggplants dried at 50 °C (magnification, 250X)

Results and Discussion

Drying Kinetics

The average moisture content of fresh samples was 12.58 ± 0.03 kg water/kg (db), and the average water activity was 0.92 ± 0.02 . Eggplant slabs were dried up to the final moisture of 0.06 ± 0.01 kg water/kg (db) and to the water activity of 0.41 ± 0.03 using different air temperatures (50, 60 and 70 °C) at 2.3 m/s.

The effect of air temperature and pretreatment on the drying kinetics (M_t/M_0 versus drying time) and the drying rate ($dM_t/M_0/dt$) of eggplant slabs is shown in Fig. 1a, b.

By analysing the Fig. 1, the plateau value of M_t/M_0 (<0.05) was obtained at the following times: 105, 75 and 60 min at the air drying temperatures of 50, 60 and 70 °C, respectively, for the UTR samples. Corresponding values for the TR samples were 90, 60 and 45 min at the same respective temperatures.

A constant-rate period was not detected in the drying experiments. Therefore, the entire drying process for eggplant slices at the investigated temperatures (50, 60 and 70 °C) occurs in the range of the falling-rate period. This shows that the diffusion is the dominant mechanism governing the moisture movement in the samples. These results are in agreement with previous literature results on the eggplant drying (Akpınar & Bicer, 2005; Ertekin & Yaldiz, 2004; Doymaz & Göl, 2011).

Drying temperatures affected the drying rates. As expected, the drying rates for both un-pretreated and pretreated slabs were higher at higher temperatures as can be seen in Fig. 1. But at fixed temperature, the drying rate of TR slabs was observed to be higher than that of UTR eggplants in the initial drying phase (30–60 min depending on temperature), then the two values approached.

The results show that the pretreatment with threalose and sodium chloride at low concentrations had a significant influence on eggplant drying process: at each temperature, the treat-

ed samples reached the plateau of M_t/M_0 in a shorter time and, hence, the drying rate was higher than the untreated ones.

The drying times (45–90 min) obtained in this work for the pretreated samples are significantly lower than those reported in previous literature studies on eggplant by using different pretreatments.

Indeed, Ertekin and Yaldiz (2004), analysing the effect of blanching pretreatment on eggplant slices in similar process conditions to present work (60 °C, air velocity of 2 m/s and slice thickness of 0.6 cm, final moisture content of 6 % (w.b.)), noted that the drying process took 6.11 h without pretreatment and 3.49 h with blanching.

Cruz and Menegalli (2004), using osmotic dehydration (10 % of NaCl solution for 20 min) as pretreatment before hot-air drying of eggplants at 60 and 70 °C, reported drying times of 255 and 150 min, respectively.

The observed increase in the drying rate may be due to the reduced resistance to moisture transport.

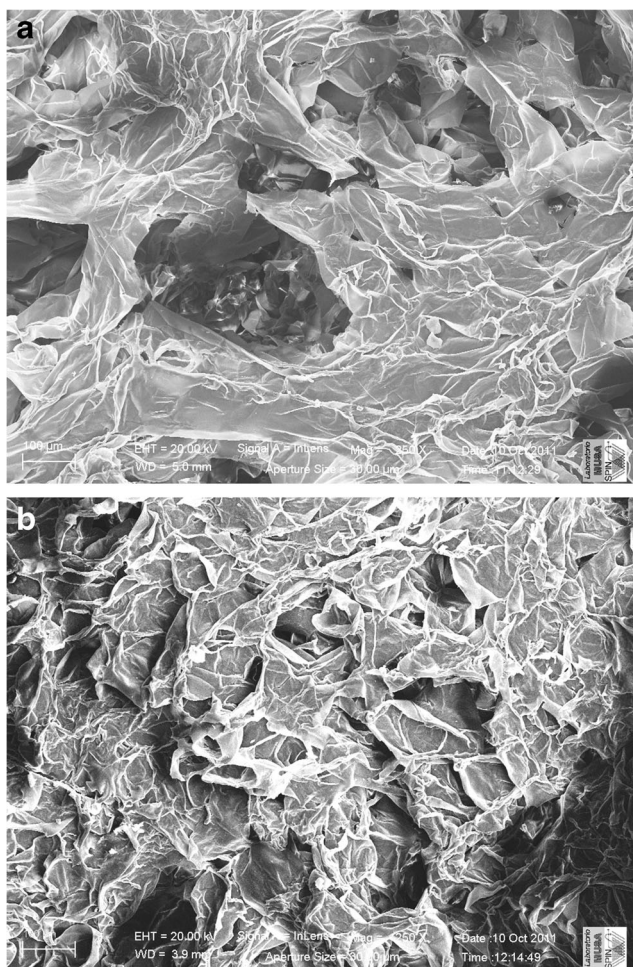


Fig. 3 SEM images of UTR (a) and TR (b) eggplants dried at 60 °C (magnification, 250X)

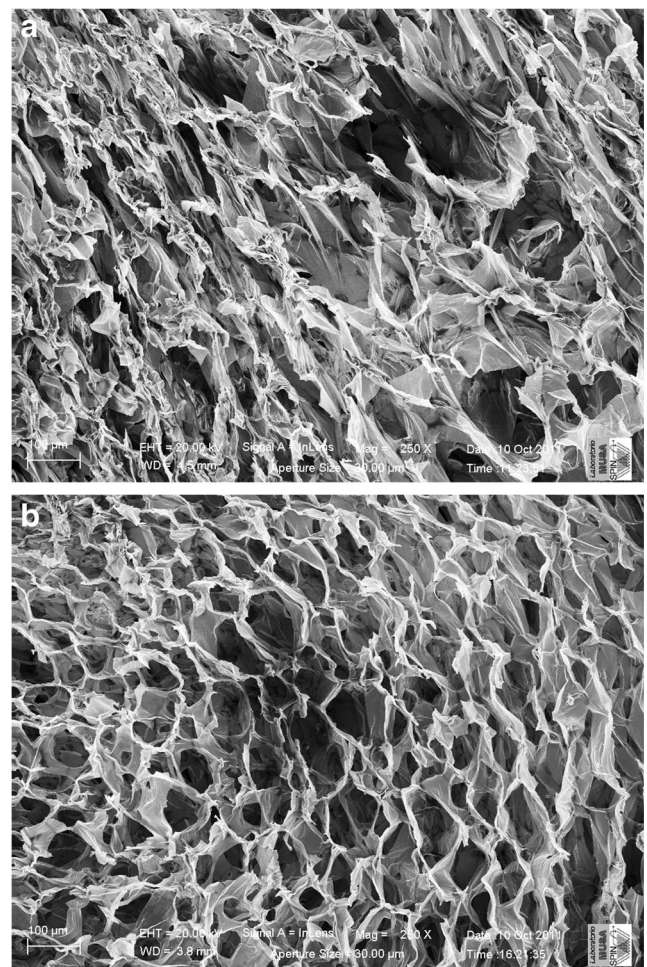


Fig. 4 SEM images of UTR (a) and TR (b) eggplants dried at 70 °C (magnification, 250X)

Table 1 Porosity parameters of fresh and dried eggplants

Sample	Bulk density (kg/m ³)	Porosity (%)	Average pore radius (μm)
Fresh	1.006 ± 0.100	42 ± 2	55 ± 3
UTR dried at 50 °C	0.285 ± 0.010	78 ± 1	20 ± 2
TR dried at 50 °C	0.144 ± 0.006	85 ± 1	45 ± 1
UTR dried at 60 °C	0.162 ± 0.005	83 ± 1	37 ± 1
TR dried at 60 °C	0.143 ± 0.003	86 ± 1	53 ± 2
UTR dried at 70 °C	0.173 ± 0.005	95 ± 1	32 ± 1
TR dried at 70 °C	0.141 ± 0.004	92 ± 1	55 ± 2

In order to elucidate this effect, the microstructure changes of samples dried at different temperatures were analysed by SEM and Hg porosimetry.

SEM Images and Porosity

Typical SEM images of both untreated and pretreated dried eggplants are reported in Figs. 2, 3 and 4 at 50, 60 and 70 °C, respectively. At 50 °C the wrinkled structure of the UTR dried eggplant disappeared as a consequence of pretreatment. Increasing the temperature (60 °C) the structure is more uniform and more porous, but larger pores were observed in the case of the UTR samples compared with the TR ones. At the highest temperature (70 °C), the UTR samples showed a totally damage structure. On the contrary, after pretreatment the porous structure was more uniform with more not lacerated cellular walls.

Table 1 shows the comparison between the porosity values of the fresh and dried eggplant slabs with and without pretreatment. The pretreatment had an evident impact on the porosity growth of the dried samples. Indeed, it was observed an increase in porosity from 42 % for the fresh slabs to 78, 82 and 95 % for the UTR samples and to 85, 86 and 92 % for the TR samples. The average pore radius was 20, 37 and 32 μm, for the UTR dried at 50, 60 and 70 °C, respectively, while higher values were found for the TR samples: 45, 53 and 55 μm at 50, 60 and 70 °C, respectively. In particular, with reference to the pore size distributions, reported in Fig. 5, the TR samples showed a higher fraction of pores with larger size and a peak in pore size distribution at 50 μm for 50 °C and 56 μm for 60 °C drying temperature.

The results for untreated eggplant are in agreement with those of Aydogdu et al. (2015): from SEM images for the conventionally dried eggplants they observed some areas where the cells appeared to be collapsed. This showed that the structure was non-uniform. This was also confirmed by pore size distribution in which both larger and smaller pores were observed.

The presence of smaller pores in the untreated dried eggplant evidenced the occurrence of phenomena to collapse along with shrinkage phenomena, as already observed in previous study (Adiletta et al., 2014). In

particular, the phenomena to collapse are due to the loss of the initial air present into the food matrix and it occurs when the solid matrix is not sufficiently strong to retain its structure. A harsh thermal treatment is able to modify the solid structure of the food matrix and cause phenomena to collapse (Khalloufi et al., 2015). In the solid structure so modified the resistance to moisture transport increases and, hence, the drying rate decreases as reported in Fig. 1.

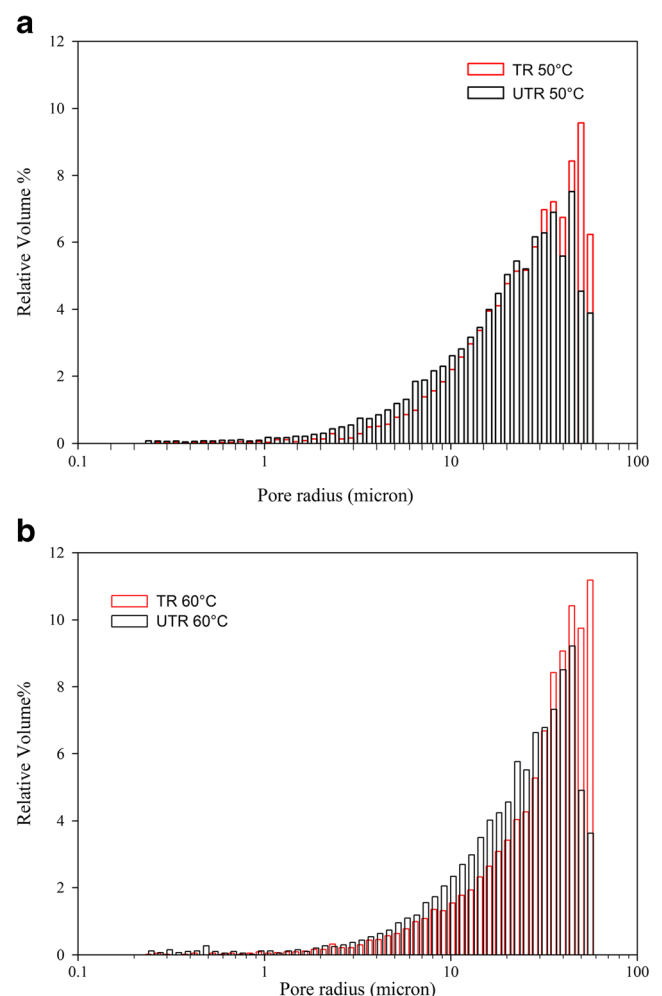


Fig. 5 Relative pore volume as function of pore radius for UTR and TR eggplants dried at (a) 50 and (b) 60 °C

Table 2 Colour changes in fresh, untreated and treated eggplants dried at 50, 60 and 70 °C

Sample	L^*	a^*	b^*	WI
Fresh	88.19 ^a ± 0.68	−6.32 ^b ± 0.31	16.70 ^c ± 0.41	78.59 ^a ± 0.63
Dried samples				
UTR 50 °C	78.33 ^d ± 4.37	1.36 ^d ± 0.29	25.58 ^a ± 1.67	67.14 ^d ± 5.29
TR 50 °C	84.95 ^a ± 0.78	−5.23 ^b ± 1.04	14.38 ^{bc} ± 1.02	77.45 ^a ± 1.15
UTR 60 °C	75.37 ^c ± 0.77	0.59 ^d ± 0.22	26.23 ^a ± 0.39	64.01 ^{cd} ± 0.99
TR 60 °C	85.20 ^a ± 1.72	−6.26 ^b ± 0.94	16.02 ^{bc} ± 1.04	77.30 ^a ± 1.00
UTR 70 °C	69.74 ^b ± 1.59	2.62 ^c ± 1.24	24.16 ^{ac} ± 2.14	61.19 ^{bc} ± 1.15
TR 70 °C	79.09 ^d ± 1.22	−1.73 ^c ± 0.23	20.38 ^d ± 1.36	70.75 ^c ± 1.15
Rehydrated samples				
Rehydrated UTR 50 °C	70.25 ^b ± 1.04	3.52 ^{ac} ± 0.24	22.29 ^{de} ± 0.48	62.66 ^{bc} ± 1.47
Rehydrated TR 50 °C	80.04 ^d ± 1.21	−1.14 ^c ± 0.14	13.84 ^b ± 1.26	75.68 ^a ± 1.19
Rehydrated UTR 60 °C	67.37 ^b ± 0.16	4.06 ^a ± 0.18	23.67 ^{ac} ± 0.15	59.48 ^b ± 0.28
Rehydrated TR 60 °C	80.95 ^d ± 1.62	−1.16 ^c ± 0.82	14.17 ^{bc} ± 1.25	76.23 ^a ± 1.77

Different superscript letters (a, b, c, etc.) in the same column mean significant differences ($p < 0.05$)

Therefore, it can be concluded that the observed effect of pretreatment on increasing the eggplant porosity and the average pore radius may be attributed to the ability of preserving the solid structure of the eggplants by protecting the cell walls, as observed by SEM images. The solid structure become sufficiently strong to keep intact the space initially filled with air, so that it does not collapse (Khalloufi et al., 2015).

Protective effect of trehalose and other sugars on carbohydrates, proteins (or enzymes) and cells during drying were observed in the literature (Aktas et al., 2007).

On the contrary, Aydogdu et al. (2015) comparing pore size distribution and SEM images of osmotically dehydrated eggplants (10 % NaCl solution) with those of untreated ones, found in the case of osmotically dehydrated eggplants both size and number of pores significantly lower. This was an indication that osmotically dehydrated eggplants had lower porosity than untreated ones. During osmotic dehydration, salt diffused into the cells of eggplants that led to less porous structure, without any protective effect.

Colour

Colour is one of the most important quality indexes of foods and agricultural products. Unsuitable changes in colour of agricultural products would make low quality food and marketing value (Krokida et al., 2000). The quality of a dried

product is also strongly affected by the colour surface. The consumers really like dried vegetables with visual appearance that looks like the colour of the fresh products.

The effects of drying process and temperatures on surface colour of fresh and dried samples were reported in Table 2. Hunter values L^* , a^* and b^* were collected and WI was determined.

Results showed that drying process has a significant effect on the colour parameters of the UTR samples. The L^* value decreases after drying for all the UTR slabs and for the TR slabs dried at 70 °C; on the contrary, no significant differences ($p < 0.05$) were observed between the fresh and the TR samples dried at 50 and 60 °C. The decrease of brightness indicates that all the UTR dried samples were darker than the fresh eggplants.

The parameters a^* and b^* increased after drying for all samples; in particular, for the UTR samples, a^* value became positive while for the TR samples was still negative. This behaviour denotes a deeper red-purple colour for the UTR dried samples, that is indicative of the browning reaction. That regards to b^* parameter, it increased (higher yellowness) for all the UTR-dried samples, with no significant differences between those samples.

As a consequence, a significant decrease of Whiteness index in all the UTR samples was observed which means that the final products are browner than the fresh ones.

Fig. 6 Eggplant fresh sample (right) and UTR and TR samples dried at 60 °C (left)

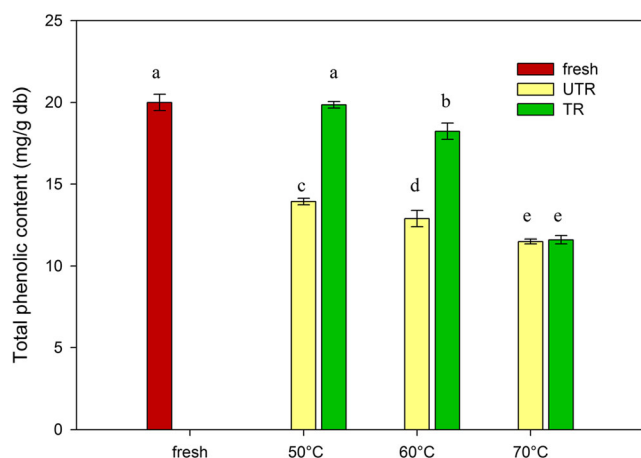


Fig. 7 Total phenolic content in fresh and UTR and TR eggplants dried at 50, 60 and 70 °C

On the contrary, no significant differences ($p < 0.05$) in L^* , a^* and b^* values were observed between the fresh and the TR samples dried at 50 and 60 °C. The same trend was observed for Whiteness index. But a significant colour change was found in the TR samples dried at 70 °C.

It can be concluded, that the pretreatment was capable to preserve the white colour of the eggplants during drying process up to 60 °C. The lowest WI and L^* values, found in the UTR dried samples, indicated that the UTR eggplants surfaces were darker when compared with the TR ones. This trend is shown in Fig. 6. At these low temperatures, the change of colour could be mainly attributed to the enzymatic browning reactions that took place during the eggplant drying process.

Total Phenolic Content

The experimental results showed that the higher the drying temperature, the lower the content of total phenols in the eggplant samples after the process (Fig. 7). In the fresh sample,

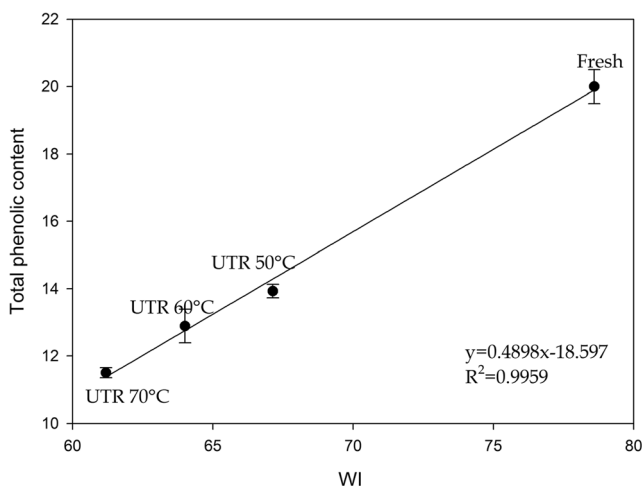


Fig. 8 Correlation between total phenolic content (mg/g db) and WI for UTR eggplants

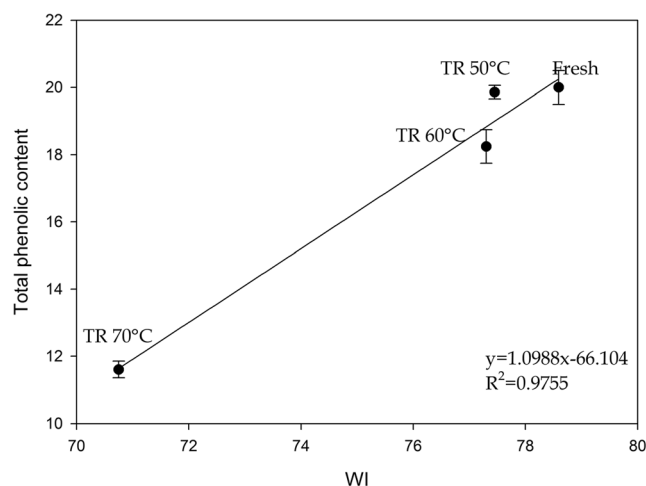


Fig. 9 Correlation between total phenolic content (mg/g db) and WI for TR eggplants

total phenolic content was measured and was found to be 20 mg/g (db). This value is according to the literature: 10–15 mg/g (db) (Hanson et al., 2006; Stommel et al., 2003).

Phenolic acids contribute to the taste and colour of the food and also offer nutritional benefits. There are many health benefits derived from eating foods that contain polyphenols. Polyphenols can act as an antioxidant and act as radical scavengers or chain breakers depending on their chemical structure (Mcsweeney & Seetharaman, 2015).

During hot-air drying, the evaporation of water at elevated temperatures can cause chemical, physical and biological changes in foods. In general, the hotter the air is, the faster the drying rate and similarly, the lower the humidity, the higher the drying rate is; however, both these factors also affect the total phenolic content of the product (Rahman, 2007).

The TR samples had higher total phenolic content than the UTR ones at 50 and 60 °C, but only the value of the TR samples at 50 °C is not statistically different ($p < 0.05$) from

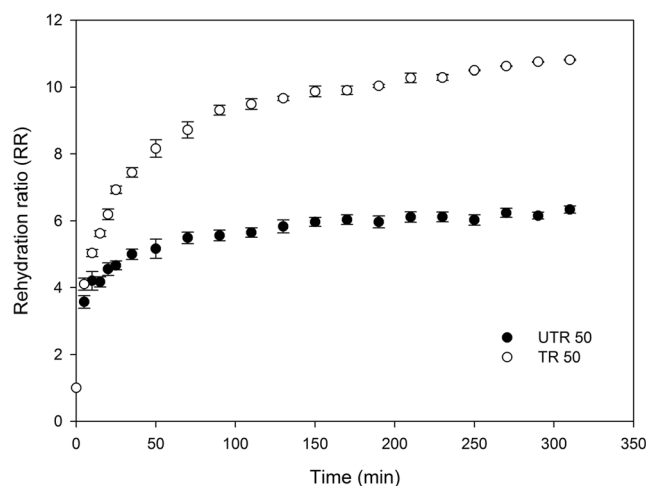


Fig. 10 Rehydration ratio of UTR and TR eggplants dried at 50 °C

the fresh ones. Furthermore, there was no statistical difference ($p < 0.05$) in total phenolic content between the UTR and the TR samples dried at 70 °C; this result indicates that the temperature of 70 °C has damaged the nutritional compositions of both samples with and without pretreatment.

The total phenolic content influences the Whiteness index of the eggplant. A linear relationship was found to correlate those parameters with a good agreement for the UTR ($R^2 = 0.9959$) and the TR samples ($R^2 = 0.9757$) (Figs. 8 and 9). Figure 9 highlights the strong change in total phenolic content and WI at 70 °C for the TR samples.

Rehydration and Texture Tests

Eggplant rehydration is a complex phenomenon affected by numerous factors (e.g. pretreatments, drying method and process, physical structure, chemical composition) (Russo et al., 2013). Since the samples dried at 70 °C (UTR and TR) showed the worst quality parameters (i.e. colour, total phenolic content) and a total damage structure, the rehydration tests were performed only on the samples dried at 50 and 60 °C.

The rehydration ratio at 25 °C is shown in Figs. 10 and 11, respectively, for samples dried at 50 and 60 °C. It was observed that the rehydration ratio of the TR samples, at each drying temperature, was higher than the untreated ones (10.8 for TR, 6.3 and 5.9 for the UTR at 50 and 60 °C). This behaviour was probably due to the fact that the structure of untreated samples was significantly modified by drying, as observed by the SEM images and porosity measurements described in the previous paragraphs and Fig. 12. On the contrary the better structure preservation of the pretreated ones, with higher porosity and average pore radius, determined a higher capability of rehydration.

In contrast, Ertekin & Yaldiz (2004) reported that the blanching pretreatment decreased the rehydration ratio.

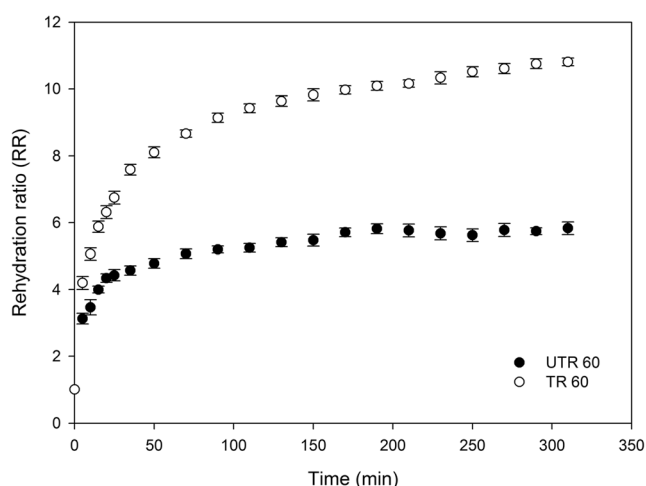


Fig. 11 Rehydration ratio of UTR and TR eggplants dried at 60 °C



Fig. 12 UTR (left) and TR (right) rehydrated eggplants at 25 °C

The colour parameters of the rehydrated samples dried at 50 and 60 °C are shown in Table 2. L^* and a^* values were changed in all rehydrated samples; in particular, L^* decreased while a^* increased with respect to the dried samples. On the contrary, b^* values and Whiteness index did not change significantly after rehydration. This indicates that the rehydration tests did not influence the white colour of the samples.

The effect of rehydration process on changes in texture was also evaluated for the eggplant slabs. Table 3 shows the main values of the textural properties for the eggplant samples obtained from the compression tests.

Many differences in firmness were found: after rehydration, the firmness had a huge increase for both the UTR and the TR samples (i.e. up to 67 and 56 %, respectively, for the UTR and the TR samples); the firmness of all rehydrated samples was significantly different ($p < 0.05$) from the fresh eggplants.

Among the rehydrated samples, the firmness of the TR samples was much lower than the UTR slabs, while Young's modulus was higher, indicating the higher elasticity of the pretreated ones. Finally, no differences were detected between the TR rehydrated samples dried at 50 and 60 °C.

Table 3 Firmness and Young's modulus of rehydrated eggplants

	Firmness (N m^{-1})	Young's modulus (MPa)
Fresh	$40,928^d \pm 250$	$1.5^e \pm 0.3$
UTR 50 °C	$141,657^a \pm 1232$	$6.2^d \pm 0.6$
TR 50 °C	$96,216^c \pm 1340$	$7.8^c \pm 0.1$
UTR 60 °C	$123,657^b \pm 421$	$8.2^b \pm 0.2$
TR 60 °C	$94,892^c \pm 1547$	$9.5^a \pm 0.8$

Parameter values followed by different superscript letters are significantly different ($p < 0.05$)

Conclusions

The effects of combined pretreatment of trehalose and NaCl and drying temperatures (50, 60 and 70 °C) on the quality of the eggplant slabs were studied in terms of several physical and chemical properties: microstructure, porosity, colour, total phenolic content and rehydration capacity.

The pretreatment was able to reduce the phenomena to collapse and to preserve the solid structure of the matrix also during harsh thermal treatments. In fact, at all drying temperatures (50–70 °C) the porous structure of pretreated eggplants was almost uniform and did not show neither lacerated cellular walls or phenomena to collapse as in the case of untreated ones. It was also observed an increase of porosity and higher average pore radius at lower temperatures. These results may be responsible of the increase of drying rate, due to the reduced resistance to heat and moisture transport. Moreover, the positive effect of the pretreatment on colour and phenolic content of the eggplant samples during drying process up to 60 °C could be seen. On the contrary, the change in colour of untreated samples could be mainly attributed to the enzymatic browning reactions that took place during the drying process.

Furthermore, the better structure preservation of the pretreated samples, with higher porosity and average pore radius, determined a higher capability of rehydration. After rehydration, the pretreated samples showed the same Whiteness index ($p < 0.05$) of the fresh and the dried eggplants and lower firmness compared with those untreated.

References

- Adiletta, G. (2011). *Hot air-drying and rehydration of fruits and vegetables: optimization and modelling*. PhD thesis, Mediterranean University of Reggio Calabria, Italy.
- Adiletta, G., Russo, P., Senadeera, W., & Di Matteo, M. (2016). Drying characteristics and quality of grape under physical pretreatment. *Journal of Food Engineering*, 172, 9–18.
- Adiletta, G., Senadeera, W., Liguori, L., Crescitelli, A., Albanese, D., & Russo, P. (2015). The influence of abrasive pretreatment on hot air drying of grape. *Food and Nutrition Sciences*, 6, 355–364. doi:10.4236/fns.2015.63036.
- Adiletta, G., Iannone, G., Russo, P., Patimo, G., De Pasquale, S., & Di Matteo, M. (2014). Moisture migration by magnetic resonance imaging during eggplant drying: a preliminary study. *International Journal of Food Science and Technology*, 49, 2602–2609.
- Aktas, T., Fujii, S., Kawano, Y., & Yamamoto, S. (2007). Effects of pretreatments of sliced vegetables with trehalose on drying characteristics and quality of dried products. *Food and Bioprocess Technology*, 85(C3), 178–183.
- Akpinar, E. K., & Bicer, Y. (2005). Modelling of the drying of eggplants in thin-layers. *International Journal of Food Science and Technology*, 40, 273–281.
- Albanese, D., Cinquanta, L., & Di Matteo, M. (2007). Effects of an innovative dipping treatment on the cold storage of minimally processed Annurca apples. *Food Chemistry*, 105, 1054–1060.
- AOAC (1997). *Official methods of analysis* (16th ed.). Arlington, Virginia, USA: Association of Official Analytical Chemist.
- Aydin, E., & Gocmen, D. (2015). The influences of drying method and metabisulfite pre-treatment on the color, functional properties and phenolic acids contents and bioaccessibility of pumpkin flour. *LWT-Food Science and Technology*, 60, 385–392.
- Aydogdu, A., Sumnu, G., & Sahin, S. (2015). Effects of microwave-infrared combination drying on quality of eggplants. *Food and Bioprocess Technology*, 8, 1198–1210.
- Bahmani, A., Jafari, S. M., Shahidi, S. A., & Dehnad, D. (2015). Mass transfer kinetics of eggplant during osmotic dehydration by Neural Networks. *Journal of Food Processing and Preservation*. ISSN 1745-4549.
- Brasiello, A., Adiletta, G., Russo, P., Crescitelli, S., Albanese, D., & Di Matteo, M. (2013). Mathematical modeling of eggplant drying: shrinkage effect. *Journal of Food Engineering*, 114, 99–105.
- Chiewchan, N., Prapthraiphetch, C., & Devahastin, S. (2010). Effect of pretreatment on surface topographical features of vegetables during drying. *Journal of Food Engineering*, 101, 41–48.
- Cruz, A. G., & Menegalli, F. C. (2004). Osmotic dehydration and drying of aubergine (*Solanum melongena*). *Proceedings of the 14th International Drying Symposium*, (pp. 2149–2156). São Paulo.
- Dermesonlouoglou, E. K., Giannakourou, M. C., & Taoukis, P. (2007). Stability of dehydrofrozen tomatoes pretreated with alternative osmotic solutes. *Journal of Food Engineering*, 78, 272–280.
- Di Matteo, M., Cinquanta, L., Galiero, G., & Crescitelli, S. (2000). Effect of a novel physical treatment process on the drying kinetics of seedless grapes. *Journal of Food Engineering*, 46, 83–89.
- Doymaz, I. (2010). Effect of citric acid and blanching pre-treatments on drying and rehydration of Amasya red apples. *Food and Bioprocess Technology*, 88(2–3), 124–132.
- Doymaz, I., & Göl, E. (2011). Convective drying characteristics of eggplant slices. *Journal of Food Process Engineering*, 34, 1234–1252.
- Ertekin, C., & Yaldiz, O. (2004). Drying of eggplant and selection of a suitable thin layer drying model. *Journal of Food Engineering*, 63, 349–359.
- Hanson, P. M., Yang, R.-Y., Tsou, S. C. S., et al. (2006). Diversity in eggplant (*Solanum melongena*) for superoxide scavenging activity, total phenolics, and ascorbic acid. *Journal of Food Composition and Analysis*, 19, 594–600.
- Hsua, C. L., Chen, W., Weng, Y. M., & Tseng, C. Y. (2003). Chemical composition, physical properties, and antioxidant activities of yam flours as affected by different drying methods. *Food Chemistry*, 83, 85–92.
- Kaymak-Ertekin, F. (2002). Drying and rehydrating kinetics of green and red peppers. *Journal of Food Science*, 67, 168–175.
- Khaloufi, S., Kharaghani, A., Almeida-Rivera, C., Nijssse, J., van Dalen, G., & Tsotsas, E. (2015). Monitoring of initial porosity and new pores formation during drying: a scientific debate and a technical challenge. *Trends in Food Science & Technology*, 45, 179–186.
- Krokida, M. K., Kiranoudis, C. T., Maroulis, Z. B., & Marinou-Kouris, D. (2000). Effect of pretreatment on color of dehydrated products. *Drying Technology*, 18(6), 1239–1250.
- Lewicki, P. P. (2006). Design of hot air drying for better foods. *Trends in Food Science & Technology*, 17, 153–163.
- Lewicki, P. P., & Lukaszuk, A. (2000). Changes of rheological properties of apple tissue undergoing convective drying. *Drying Technology*, 18, 707–722.
- Lo Scalzo, R., Fibiani, M., Mennella, G., Rotino, G. L., Dal Sasso, M., Culici, M., Spallino, A., & Brag, P. C. (2010). Thermal treatment of eggplant (*Solanum melongena* L.) increases the antioxidant content and the inhibitory effect on human neutrophil burst. *Journal of Agricultural and Food Chemistry*, 58, 3371–3379.
- McSweeney, M., & Seetharaman, K. (2015). State of polyphenols in the drying process of fruits and vegetables. *Critical Reviews in Food Science and Nutrition*, 55, 660–669.

- Negi, P. S., & Roy, S. K. (2000). Effect of blanching and drying methods on beta-carotene, ascorbic acid and chlorophyll retention of leafy vegetables. *Lebensmittel Wissenschaft und Technologie*, 33, 295–298.
- Niamnuy, C., Devahastin, S., & Soponronnarit, S. (2014). Some recent advances in microstructural modification and monitoring of foods during drying: a review. *Journal of Food Engineering*, 123, 148–156.
- Ohtake, S., & Wang, Y. J. (2011). Trehalose: current use and future applications. *Journal of Pharmaceutical Sciences*, 100(6), 2020–2053.
- Pao, S., & Petrcek, P. D. (1997). Shelf life extension of peeled oranges by citric acid treatment. *Food Microbiology*, 14, 485–491.
- Rahman, M.S. (2007). Handbook of food preservation, 2nd ed, pp. 403–432. CRC Press, Boca Raton, FL.
- Russo, P., Adiletta, G., & Di Matteo, M. (2013). The influence of drying air temperature on the physical properties of dried and rehydrated eggplant. *Food Bioproducts Processing*, 91, 249–256.
- Sian, N. K., & Ishak, S. (1991). Carotenoid and anthocyanin contents of papaya and pineapple: influence of blanching and predrying treatments. *Food Chemistry*, 39, 175–185.
- Singleton, V. L., Orthofer, R., & Lamuela-Raventos, R. M. (1999). Analysis of total phenols and other oxidation substrates and antioxidants by means of Folin-Ciocalteu reagent. *Methods in Enzymology*, 299, 152–178.
- Stommel, J. R., & Whitaker, B. D. (2003). Phenolic acid composition of eggplant fruit in a germplasm core subset. *Journal of the American Society for Horticultural Science*, 128, 704–710.
- Uyttendaele, M., Neyts, K., Vanderswalmen, H., Notebaert, E., & Debevere, J. (2004). Control of *Aeromonas* on minimally processed vegetables by decontamination with lactic acid, chlorinated water or thyme essential oil solution. *International Journal of Food Microbiology*, 90, 263–271.
- Vega-Galvez, A., Lemus-Mondaca, R., Bilbao-Sainz, C., Fito, P., & Andres, A. (2008). Effect of air drying temperature on the quality of rehydrated dried red bell pepper (var. Lamuyo). *Journal of Food Engineering*, 85, 42–50.
- Wu, L., Orikasa, T., Tokuyasu, K., Shiina, T., & Tagawa, A. (2009). Applicability of vacuum-dehydrofreezing technique for the long-term preservation of fresh-cut eggplant: effects of process conditions on the quality attributes of the samples. *Journal of Food Engineering*, 91(4), 560–565.
- Xin, Y., Zhang, M., & Adhikari, B. (2013). Effect of trehalose and ultrasound-assisted osmotic dehydration on the state of water and glass transition temperature of broccoli (*Brassica oleracea* L. Var. Botrytis L.). *Journal of Food Engineering*, 119, 640–647.
- Washburn, E. W. (1921). The dynamics of capillary flow. *Physical Review*, 17(3), 273–283.
- Yang, J., Meyers, K. J., Heide, J., & Liu, R. H. (2004). Varietal differences in phenolic content and antioxidant and antiproliferative activities of onions. *Journal of Agricultural and Food Chemistry*, 52, 6787–6793.
- Yaldiz, O., & Ertekin, C. (2001). Thin layer solar drying of some different vegetables. *Drying Technology*, 19(3), 583–596.